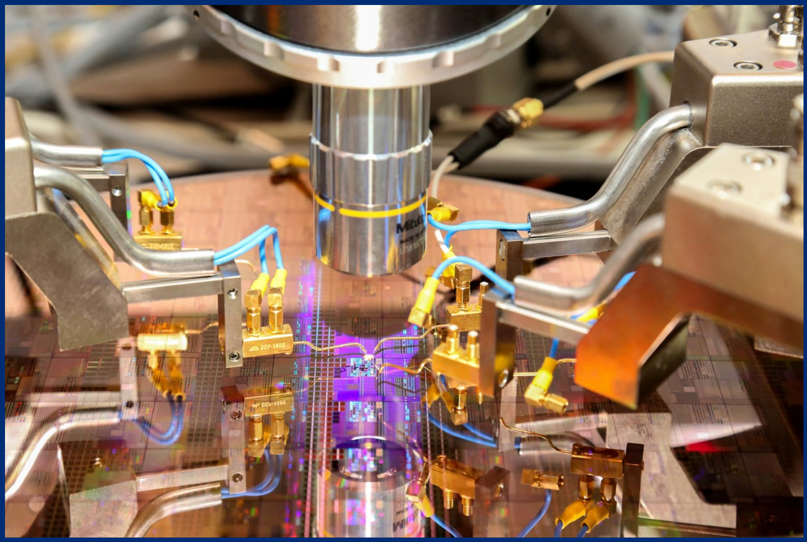
SUNY Polytechnic Institute 2018-2019 Faculty Research Report



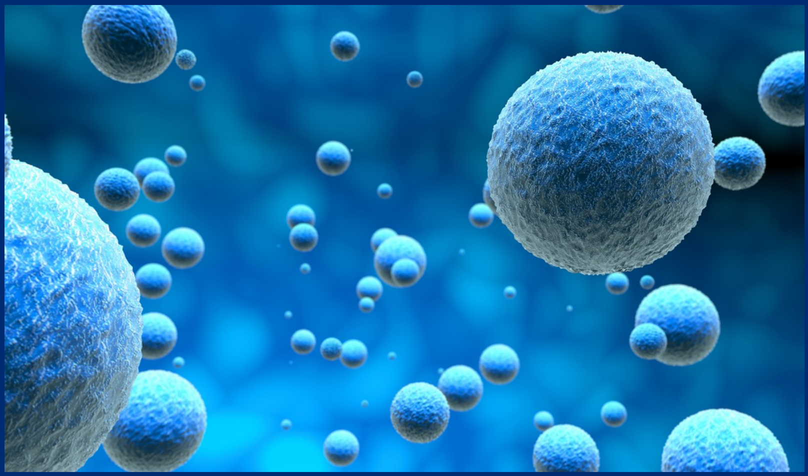


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Table of Contents

College of Arts and Sciences **3**

Intergenerational Transmission of Attachment in Cross-Cultural Context and Physiological Correlates of Attachment Phenomena, Kazuko Behrens 4

Information Theory, Quantum Theory, and Relativity, Carlo Cafaro 6

Topological Quantum Matter for Quantum Information Processing, Emilio Cobanera 7

Blood Flow Modeling in the Eye using Geometric Mechanics & Structure Preserving Discretizations, Andrea Dziubek & Dr. Edmond Rusjan 9

Translational Responses to Stress, Lauren Endres 12

Research in Low-Energy Quantum Chromodynamics (QCD), Amir Fariborz 14

Adaptive Behavior and Cognition, Andrew C Gallup 16

Data Mining and Image Analysis, Ana Jofre 18

Interactive Media and Game Design, Nick LeJeune 20

Intimate Partner Violence, Police Legitimacy, and Procedural Justice, Luye Li 22

Subjective Experiences of Interactive Nostalgia, Ryan Lizardi 23

Evolutionary Biology and Population Genetics, Adam T McLain 24

Organic and Supramolecular Chemistry, Vijay Ramalingam 26

Interdisciplinary Study of Technology Maintenance, Andrew Russell 28

Applications of Group Theoretical Methods to Differential and Difference Equations, Zora Thomova .. 30

Interactive Media and Game Design, Ibrahim Yucel 32

College of Engineering **34**

Climactic Effects on Transportation and Infrastructure, Asif Ahmed 35

Robust Model Predictive Control and Building Automation, Korkut Bekiroğlu 37

Chemical Sensors, Michael Carpenter 38

Quantum Algorithms, Computational Models and Complexity, Chen-Fu Chiang 42

Towards a Holistic Cybersecurity Framework, Hisham Kholidy 43

Graphics and Image Processing, Michael J Reale 46

Risk Assessment in Environmental Systems Management, Carolyn Rodak 48

Robot-Assist Microfluidic Devices & Data Clustering in HealthcareJiayue Shen 50

Operation Research and Data Mining in Transportation Planning and Management, Xie (Sarah) Yang 54

Blockchain, Machine Learning & Artificial Intelligence, and Post-Quantum Cryptography, X-Infinity Group 56

College of Health Sciences **61**

Adverse Childhood Experiences, Joanne Joseph 62

Sibling Abuse, Veronica Tichenor 64

College of Nanoscale Science and Engineering **66**

Nanobioscience & Engineering Nathaniel Cady 67
Materials Science, Characterization, And Metrology of Nanoscale Materials and Structures, Alain C Diebold 74
Chemical Mechanical Planarization and Additive Manufacturing, Kathy Dunn 80
Renewable Energy: Solar Cells and Li-Ion Batteries, Harry Efstathiadis 87
Genomic Profiling of Yeast Resistance to P450-Activatd Carcinogens, Michael Fasullo 95
Nanomaterials for Quantum, Optoelectronic and Sensing Applications, Spyros Gallis 102
Nanoscale Devices, Ji Ung Lee 105
Reliability Physics in Nanoscale Electronics, Jim Lloyd 108
Redox-Signaling & Biology, Andre Melendez 111
Compund Semiconductor Research, Serg Oktyabrsky 116
Neuroscience and Nanotechnology for Translational & Commercial Tissue Engineering, Janet Paluh 121
Novel Devices in Quantum, High Frequency RF and Nanobiology, Satyavolu S. Papa Rao 126
Wide Bandcap III-Nitride Device Research, F. Shadi Shahedipour-Sandvik 130
Power Semiconductor Devices, Woongje Sung 142
RNA-Based Nanotechnology, Scott Tenenbaum 150
Engineering Tissues and Stem-Cell Nanotechnology, Yubing Xie 155
Research Centers **160**
Robert Edgell, Joint Center for Creativity, Design and Venturing (JCCDV) 161
Naser Haghbin, Center for Global Advanced Manufacturing (CGAM) 164
Robert Geer, Northeast Advanced Technological Education Center (NEATEC) 167

College of Arts and Sciences

INTERGENERATIONAL TRANSMISSION OF ATTACHMENT IN CROSS-CULTURAL CONTEXT AND PHYSIOLOGICAL CORRELATES OF ATTACHMENT PHENOMENA

DR. KAZUKO BEHRENS

Scope: Children form attachments regardless of the manner in which their parents treat them. The mechanism for attachment is believed to be evolutionary based on children's natural propensity to seek proximity to their parents when they sense a natural clue to danger (Bowlby, 1969/1982). Too many children, however, learn very early in life that their signals for attachment needs are not always met with prompt and adequate responses (Ainsworth, Bell, & Stayton, 1974). Research has shown that attachment security consistently predicts developmental outcome and parental sensitivity predicts attachment security. However, cross-cultural studies of attachment are still limited in learning the possible cultural influences on some aspects of parent-child attachment relationships (Topic 1). Furthermore, genetic and neurological studies have begun to produce the findings of physiological correlations to better understand attachment phenomena from a different perspective (Topic 2).

TOPIC 1

Goals: With international collaborators, my goal is to contribute to the field of developmental science in general and attachment in particular by presenting and publishing cross-cultural data from diverse cultural contexts.

While a number of attachment studies with international collaborators are on-going, I have completed a few publications and a conference presentation for the year of 2018, as follows:

PUBLICATIONS AND PRESENTATIONS

[1] Kondo-Ikemura, K., **Behrens**, K. Y., Umemura, T., & Nakano, S. (2018). Japanese mothers' prebirth Adult Attachment Interview predicts their infants' response to the Strange Situation procedure: The Strange Situation in Japan revisited three decades later. Developmental Psychology, 54, 2007-2015.

[2] Verhage, M. L, Fearon, P. R. M., Schuengel, C, van IJzendoorn, M. H., Bakermans-Kranenburg, M. J., Madigan, S., Roisman, G. I., Oosterman, M., **Behrens**, K. Y., Wong, M. S., Mangelsdorf, S., Lynn E. Priddis, L., E., Brisch, K-H. (2018). Examining ecological constraints on the intergenerational transmission of attachment via individual participant data meta-analysis. Child Development, 89, 2023-2037.

[3] **Behrens**, K. Y. (2018). Wishes. In M. Bornstein (Ed.), The SAGE encyclopedia of lifespan human development (pp. 2322-2325). Thousand Oaks, CA: SAGE Publications, Inc.

[4] **Behrens**, K. Y. & Kondo-Ikemura, K. (2018, May). Crossover transmission of attachment: Qualitative analysis of Japanese attachment data. Poster presentation at the meeting of the World Association for Infant Mental Health, Rome, Italy.

TOPIC 2

Goals: My goal is to embark on the EEG study to understand neurological response to visual stimuli that are expected to invoke attachment system in comparison with non-attachment stimuli of different affect, and to investigate differences in hemispheric activations. The findings from such data will help us better understand the mechanism underlying parental behaviors toward their children.

PUBLICATIONS AND PRESENTATIONS

[1] **Behrens**, K. Y., & Umemura, T. (2017). Japan-US comparison of mothers' wishes for their children's futures in the context of attachment. Journal of Family Studies. Advance online publication.

[2] Granqvist, P., Sroufe, L. A., Dozier, M., Hesse, E., Steele, M., van IJzendoorn, M., Solomon, J., Schuengel, C., Fearon, P., Bakermans-Kranenburg, M., Steel, H., Cassidy, J., Carlson, E., Madian, S., Jacobvits, D., Foster, S., **Behrens**, K. Y, Rifkin-Graboi, A., Gribneau, N., Spangler, G., Ward, M. J., True, M., Spieker, S., Reijman, S., Reisz, S., Tharner, A., Nkara, F., Goldwyn, R., Sroufe, J., Pederson, Da., Pederson, De., Weigand, R., Siegel, D., Dazzi, N., Bernard, K., Fonagy , P., Waters, E., Toth, S., Cicchetti, D., Zeanah, C. H., Lyons-Ruth, K., Main, M., & Duschinsky, R. (2017). Disorganized attachment in infancy: A review of the phenomenon and its implications for clinicians and policy-makers. Attachment and Human Development, 19, 534-558.

[3] **Behrens**, K. Y. (2016). Reconsidering attachment in context of culture: Review of attachment studies in Japan. Online Readings in Psychology and Culture 6(1).

[4] **Behrens**, K. Y., Haltigan, J. D., & Gribneau Bahm, N. I. (2016). Infant attachment, adult attachment, and maternal sensitivity: Revisiting the intergenerational transmission gap. Attachment and Human Development, 18, 337-353.

RESEARCH ACTIVITY

DR. CARLO CAFARO

Scope: Dr. Cafaro's research focuses on the basic foundations of theoretical physics: information theory, quantum theory, and relativity. More specifically, Cafaro's recent research efforts involve: quantifying complexity with information geometry and statistical inference; applying geometric Clifford algebra techniques to classical electrodynamics and quantum computing; combatting quantum decoherence with quantum error correction schemes; employing statistical physics methods in complex network science.

PUBLICATIONS AND PRESENTATIONS

[1] D. Felice, **C. Cafaro,** and S. Mancini, Information geometric methods for complexity, CHAOS 28, (2018).

This paper was completed together with my collaborators Dr. Domenico Felice (Max Planck Institute for Mathematics in the Sciences, Germany) and Dr. Stefano Mancini (University of Camerino, Italy). This paper was selected as an Editor's Pick on CHAOS in March 2018.

[2] **C. Cafaro** and P. M. Alsing, Decrease of Fisher information and the information geometry of evolution equations for quantum mechanical probability amplitudes, Phys. Rev. E97, (2018).

This paper was coauthored together with my collaborator and supervisor at the United States Air Force Research Laboratory (AFRL) in Rome-NY, Dr. Paul Alsing, and appears in Physical Review E. This paper is one of the written outcomes of my research activity as an AFRL Summer Faculty Fellow.

[3] S. A. Ali, **C. Cafaro**, S. Gassner, and A. Giffin, An information geometric perspective on the complexity of macroscopic predictions arising from incomplete information, Adv. Math. Phys., Volume 2018, (2018).

This paper was coauthored with my two collaborators Dr. Adom Giffin (Clarkson University, USA) and Dr. Sean Alan Ali (Albany College of Pharmacy and Health Sciences, USA). The fourth co-author is Mr. Steven Gassner, an undergraduate student at SUNY Polytechnic Institute, College of Nanoscale Science and Engineering in Albany, NY. This paper was chosen as a Featured Article on Advances in Mathematical Physics in July 2018.

For more information on Dr. Cafaro's research, please visit: https://sunypoly.edu/faculty-and-staff/carlo-cafaro.html

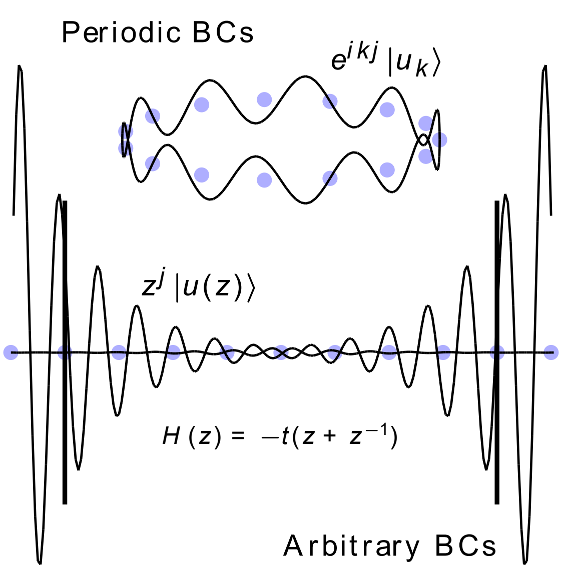
TOPOLOGICAL QUANTUM MATTER FOR QUANTUM INFORMATION PROCESSING

DR. EMILIO COBANERA

Scope: Topological Quantum Matter (TQM) is the name given to rigid states of many-body systems that cannot be characterized by any kind of low-energy local experimental probe. TQM is the best candidate class of materials for building passively fault-tolerant quantum hardware for large-scale quantum information processing devices. I investigate a variety of physical problems associated to TQM, from the mathematical theory of topological edge modes of insulators and superconductors to anyons in second quantization and the dynamics towards thermal equilibration of TQM.

Goal: Are scalable, self-correcting quantum memories possible in principle and technologically viable in low space dimensions and at finite temperature?

EXACT SOLVABILITY OF MEAN-FIELD, CLEAN ELECTRONIC MATTER WITH BOUNDARIES



Can one steer a material by its surface? A generalization of Bloch's theorem to arbitrary boundary conditions reveals actionable links going from surface physics towards changing overall electronic properties [2, 3, 4]. In addition, it predicts the existence, in short-range systems, of topological zero-energy modes with power-law corrections, and answers basic questions about system sizes for which bulk and surface properties merge. The generalized Bloch theorem yields inversion-free diagonalization algorithms, potentially of interest for large-scale band structure calculations, by relying on two new constructs: the analytic continuation of the Bloch Hamiltonian off the Brillouin zone (see figure on the right), and the boundary matrix that efficiently encodes the interplay between bulk and boundary conditions. The last chapter in this exciting story is Ref. [1], where the generalized Bloch theorem is extended to cover interfaces. One can now explore the possibility of interface zero modes displaying enhanced capabilities for storage of quantum information.

PUBLICATIONS AND PRESENTATIONS

[1] **E. Cobanera**, A. Alase, G. Ortiz, and L. Viola, Generalization of Bloch's theorem for arbitrary boundary conditions: topological surface band structure and mesoscopic applications, Phys. Rev.(2018).

[2] A. Alase, **E. Cobanera**, G. Ortiz, and L. Viola, Generalization of Bloch's theorem for arbitrary boundary conditions: theory, (2017). Editors' Suggestion and featured in Physics.

[3] **E. Cobanera**, A. Alase, G. Ortiz, and L. Viola, Exact solution of corner-modified banded block-Toeplitz eigensystems, J. Phys. A: Math. (2017).

[4] A. Alase, **E. Cobanera**, G. Ortiz, and L. Viola, Exact solution of quadratic fermionic Hamiltonians for arbitrary boundary conditions, Phys. Rev. (2016).

FRACTONIC MATTER IS THERMALLY FRAGILE

Topological quantum (TQ) matter offers a proof of principle that self-correcting quantum memories do exist, but only at strictly zero temperature. The failure of TQ memories at finite temperature, dubbed thermal fragility in the literature [1] (and references therein), is generic and is tied to the unique statistical-mechanical features of TQ matter [3]. At this point one can proceed in one of two ways. Either one modifies TQ matter so that it loses some if it characteristic features to yield better quantum memories, or one give up the idea that that a quantum memory should be built out of an equilibrium state of matter [2, 3]. The idea of fractonic matter falls within the first approach. Unfortunately, my collaborators and I established in 2018 that fractonic matter is also thermally fragile [1]. The quest for a quantum memory continues!

PUBLICATIONS AND PRESENTATIONS

[1] Z. Weinstein, **E. Cobanera**, G. Ortiz, and Z. Nussinov, Absence of finite-temperature phase transitions in the X-cube model, invited contribution to Annals of Physics: Special Issue on Fractons, (2019)

[2] **E. Cobanera**, P. Kristel, and C. Morais Smith, Quantum Brownian motion in a Landau level, Phys. Rev. B 93, 245422 (2016).

[3] Z. Nussinov, G. Ortiz and **E. Cobanera**, Effective and exact holographies from symmetries and dualities, Ann. Phys. 327, 2491 (2012).

BLOOD FLOW MODELING IN THE EYE USING GEOMETRIC MECHANICS & STRUCTURE PRESERVING DISCRETIZATIONS

DR. ANDREA DZIUBEK & DR. EDMOND RUSJAN

Scope: Drs. Dziubek and Rusjan explore the use of mathematical modeling in opthalmic science in order to provide quantitative representations of the biophysical processes in the eye. They have used this research to construct vascular tree networks of the eye and designing discretization schemes for shell elasticity.

GEOMETRIC RECONSTRUCTION OF VASCULAR TREE NETWORKS

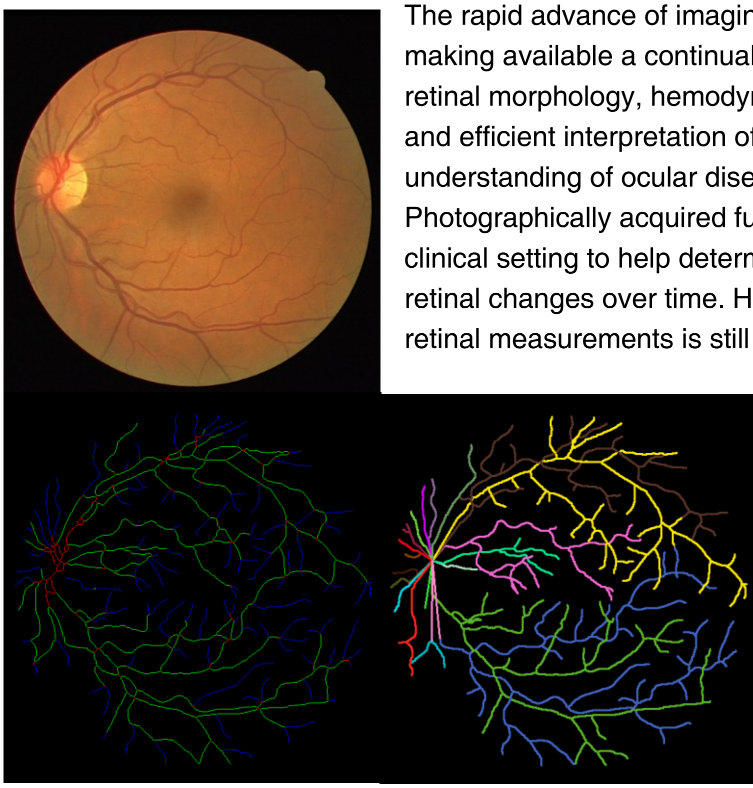
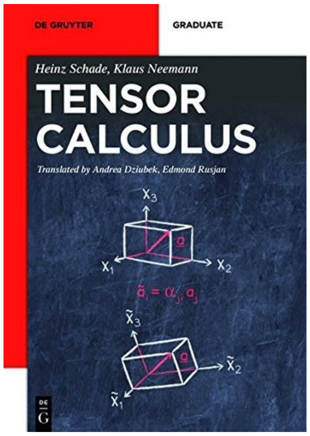


Figure 1: Vascular Tree Extraction (top) Original Fundus Image, (lower left) Vascular Graph (red = intersection points and root, green = segments, blue = terminals), (right) Labeled Unique

The rapid advance of imaging technologies in ophthalmology is making available a continually increasing amount of data regarding retinal morphology, hemodynamics, and metabolism. An accurate and efficient interpretation of such data is the key to advancing the understanding of ocular diseases and their treatment. Photographically acquired fundus images are widely used in the clinical setting to help determine the health of the retina, and to track retinal changes over time. However, the clinical interpretation of retinal measurements is still very challenging. Many systemic and ocular factors are combined in the observed data, and it is extremely difficult to single out their individual contributions during clinical and animal studies. Therefore, mathematical modeling is gaining more and more attention in the ophthalmic science, as it may help provide a quantitative representation of the biophysical processes in the eye and their interwoven physiology. More particularly, geometric reconstruction of vascular tree networks (VTNs) is a critical step in the development of physically based patient specific blood flow analysis framework.



Having said that, two critical problems remain. Firstly, to accurately extract these true vascular networks from patient data, advanced image segmentation and classification approaches are necessary. Secondly, there are key attributes of the vascular tree network missing from current mathematical models, in particular tortuosity and retinal curvature. Tortuosity of ocular blood vessels is a clinically-relevant parameter associated with various pathologies.

Goal: What is missing is a complete end-to-end system wherein the image segmentation and vascular tree extraction algorithm is verified by a descriptive mathematical model to determine the resulting tree's feasibility. We believe there is a synergy between image analysis and blood flow simulation and that this synergy presents an unexplored opportunity.

SHELL ELASTICITY AND STRUCTURE PRESERVING DISCRETIZATION METHODS

Many phenomena in physical, engineering, and biological systems are modeled by elastic shells; for example, the retina of the eye. From a mechanics perspective, elastic shells can be modeled as two-dimensional elastic bodies with a reference shape not necessarily flat that can withstand both membrane (in plane) and bending (out-of-plane) effects.

Structure preserving algorithms proved to be extremely useful in a variety of applications; for example, in classical field theory, plasma physics, or computer vision and graphics. However, similar discretization schemes for shell elasticity are yet to be designed. With their interconnection of differential geometry and continuum mechanics, shells are a natural place to study covariant discretization methods of metric dependent operators. Exterior calculus allows the definition of differential operators in a coordinate invariant manner, which can then be discretized by intrinsic computation of quantities in the finite elements approximating the shell surface. For computational purposes, exterior calculus has been discretized as finite element exterior calculus (FEEC) and discrete exterior calculus (DEC).

Goal: Our over-arching goal is to contribute to the development of structure preserving algorithms applicable to elastic continua described by partial differential equations. In particular, we focus on algorithms relevant to elastic shells.

PUBLICATIONS AND PRESENTATIONS

[1] “Tensor Analysis”, Heinz Schade, Klaus Neemann, De Gruyter Book, translated by **Andrea Dziubek and Edmond Rusjan**, 2018, ISBN 978-3-11-040426-5.

> All methods are explained in 3 dimensions, both in Cartesian & in curvilinear coordinates. The theory of surfaces & of the representation of tensor functions are introduced. A variety of problems with detailed solutions engage readers in learning.

Tensor calculus is a prerequisite for many tasks in physics and engineering. This book introduces the symbolic and the index notation side by side and offers easy access to techniques in the field by focusing on algorithms in index notation. It explains the required algebraic tools and contains numerous exercises with answers, making it suitable for self-study for students and researchers in areas such as solid mechanics, fluid mechanics, and electrodynamics.

[2] **Andrea Dziubek**, "Literature Review of Structure Preserving Discretizations for Shell Models", Canadian Mathematical Society (CMS) - Winter meeting, Advances and Applications in Geometric and Structure-Preserving Discretizations Session, Vancouver, Canada, 12/07-12/10/2018.

Research funded by: Slocum Dickson Foundation, and the SUNY Poly Seed Grant Program.

For more information, please visit: http://people.sunyit.edu/~dziubea/

TRANSLATIONAL RESPONSES TO STRESS

DR. LAUREN ENDRES

Scope: My research program aims to better understand translational defense mechanisms that protect against oxidative stress. This research has implications for diseases associated with the aberrant production of reactive oxygen species (ROS), such as aging and cancer. More specifically, I use eukaryote cells (S. cerevisiae and human cancer cell lines) as model systems to investigate tRNA methylating enzymes (methyltransferases ,or TRMs) that are ROS-responsive, and that have been linked to aging and cancer via deregulated gene expression.

Goals: 1) Shed new light on the role that non-coding RNA epigenetics plays in the stress response, 2) Use the combined approaches of bioinformatics and molecular profiling (of the translational machinery) to identify new tRNA methyltransferase (TRM) gene targets involved in the stress response, and 3) Determine how deregulated TRM activity contributes to cancer cell phenotypes.

TRM-DEPENDENT REGULATION OF THE OXIDATIVE STRESS RESPONSE

A proposal investigating the role of TRM7 in the oxidative stress response received funding from SUNY Poly's inaugural seed grant. With this funding, we are conducting experiments in budding yeast (Saccharomyces cerevisiae) to investigate the role of TRM7-dependent tRNA methylation in response to oxidative stress. The hypothesis is that TRM7 protects cells from oxidative stress by enhancing the translation of stress response transcripts with a codon bias. Overall, this seed grant will answer questions related to how cells respond to stress via tRNA methylation events that influence the translation of genes with a codon bias:

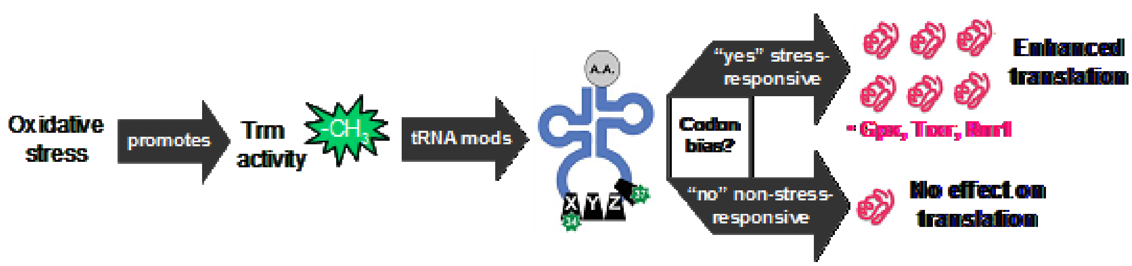


Figure 1. Concept model. tRNA methyltransferases (Trms) respond to exposure-induced oxidative stress by methylating their target tRNAs, which leads to the enhanced translation of mRNA transcripts with a codon bias.

Notably, the hypothesis for this seed grant stems from some exciting research data generated by Taylor Rahn and Bethany Lee (as summer research interns) showing that TRM7 is required for cells to recover from various toxicants that induce oxidative stress. An abstract will be presented at the 6th Annual RNA Symposium: The Language of RNA in Disease and Development" (U Albany, 03/21-03/22).

OXIDATIVE STRESS AND CANCER

Exposure to environmental toxicants and their metabolic derivatives put us at risk of being exposed to abnormally high levels of reactive oxygen species (ROS). This ROS stress can be mutagenic and initiate cancer development, thus understanding cellular anti-oxidant systems has human health impacts. Work in 2018 on this project, done in collaboration with Dr. Nadine Hempel (Penn State College of Medicine), furthered our understanding of detoxification systems in cancer. Specifically, we describe a new way in which the redox environment of tumor ascites influences the metastatic behavior of ovarian cancer, with implications for treatment strategies that stop the spread of this disease.

[1] Worley B.L., Kim Y.S., Mardini J., Zaman R., Leon K.E., Vallur P.G., Nduwumwami A., Warrick J.I., Timmins P.F., Kesterson J.P., Phaëton R., Lee N.Y., Walter V., **Endres L**., Mythreye K., Aird K.M., Hempel N. (2018) GPx3 supports ovarian cancer progression by manipulating the extracellular redox environment. Redox Biol. Nov 17. pii: S2213-2317(18)30891-7. [Epub ahead of print].

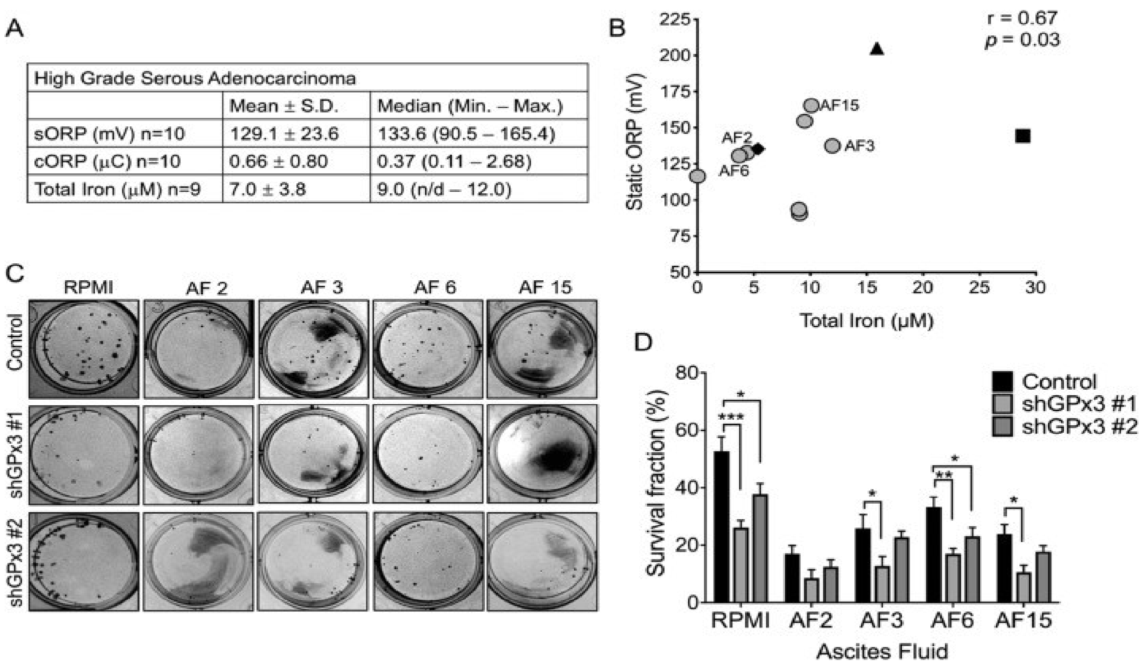


Figure 2. GPx3 is required for cell survival in ascites. A: Summary of static (sORP), capacity oxidation reduction potential (cORP) and iron content of HGSA derived ascites. Ascites were cleared of all cells by centrifugation and filtration and sORP and capacity cORP were measured using the RedoxSYS. Total iron was measured using a colorimetric assay. B: Positive correlation between ascites sORP and iron content. Ascites were derived from high grade serous ovarian adenocarcinomas (○) granulosa tumor (♦), endometrial ovarian cancer (▲), GI tumor (■; non-parametric Spearman correlation). C: Clonogenicity of OVCAR3 control or GPx3 shRNA knock-down cells (45 cells/well in 24 well plate) were seeded in ascites fluids with high (AF 15) and median sORP (AF 2, 3, 6). Clonogenicity was quantified after 10 days as in Fig. 3. Images are representative of at least 3 independent assays. Data expressed as mean ± SEM (n = 4/group, ANOVA, Tukey's post hoc $^{**}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$). D: Quantification of clonogenicity using ImageJ.

Research funded by: SUNY Poly Seed Grant

RESEARCH IN LOW-ENERGY QUANTUM CHROMODYNAMICS (QCD)

DR.AMIR FARIBORZ

Scope: My main area of research within theoretical particle physics, is related to the strong interaction through which protons and neutrons are bound together inside the atomic nucleus. Strong interaction is not just limited to inside the nucleus, as protons and neutrons belong to a large family of particles called hadrons, and all of these family members experience the strong interaction.

Goals: There are four fundamental forces in nature: gravitational, electromagnetic, weak, and strong forces. The last two are traditionally referred to as nuclear forces. It is the main objective of elementary particle physics to explore these forces and unify them into one fundamental theory.

QUANTUM CHROMODYNAMICS

It is known that hadrons can be best classified if they are to consist of elementary particles called quarks. The theory that describes the strong interaction of quarks is called Quantum Chromodynamics (QCD). This theory is very well established at high energies, and has successfully explained experiments at these energies. However, the strength of strong interaction at low energies becomes very large and the framework of fundamental QCD becomes non-perturbative (i.e. the perturbation methods in QCD that work so well at high energies no longer apply at low energies) and different methods need to be developed. Currently the complete answer is not known. In lack of a complete theoretical framework for low-energy QCD, model-building has been the main approach for this region of strong interaction. Of course, any model in this region is inspired and guided by the fundamental QCD, but the exact connections between the models and the fundamental QCD has remained an open problem which has challenged theoretical physics for at least half a century.

At the present time, understanding the low energy behavior of QCD is one of the main challenges in theoretical physics. The Clay Mathematics Institute http://www.claymath.org/millennium-problems has listed the complete solution of Yang-Mills theories (QCD falls in that category) as one of the seven remaining unsolved millennium problems in mathematics. More general information about this fundamental line of research can be found in Wikipedia, for example, (https://en.wikipedia.org/wiki/Mass_gap) which states: *“While lattice computations have suggested that Yang–Mills theory indeed has a mass gap and a tower of excitations, a theoretical proof is still missing. This is one of the Clay Institute Millennium problems and it remains an open problem. Such states for Yang–Mills theory should be physical states, named glueballs, and should be observable in the laboratory.”*

My main focus in low-energy QCD is on the lowest lying scalar mesons and their interactions with glueballs (the bound states of gluons). Understanding their status in general, and their quark substructure in particular, are topics of intense research activity in theoretical and experimental particle and nuclear physics. Two main low-energy QCD frameworks have been in development by myself and my collaborators over the past couple of decades. One of these frameworks is within the context of the linear realization of chiral symmetry (the generalized linear sigma model) and has given a coherent description of various low-energy processes.

Further details of my research can be accessed at INSPIRE High Energy Physics Literature Data Base,'' at: http://inspirehep.net/.

In collaboration with Dr. Renata Jora (of the National Institute of Physics and Nuclear Engineering, Bucharest-Magurele, Romania), several topics were investigated within the generalized linear sigma model. In Ref. [1] (below), the generalized linear sigma model of low-energy QCD was extended to include a scalar and a pseudoscalar glueball and the most general Lagrangian that can be used for studies of glueball-quarkonia interactions was derived. In Ref. [2], a decoupling limit was considered in which the glueballs, while remain in the classical vacuum of the model, at the level of quantum excitations become non-interacting and decouple from quarkonia. In this limit, the pure scalar glueball mass was estimated in the range of 1.6 – 1.9 GeV in a close agreement with lattice QCD simulations. In Ref. [3], the generalized linear sigma model with glueballs was used to probe the quark and gluon spectroscopy of light scalar and pseudoscalar mesons. It was shown that light pseudoscalars are mainly made of quark-antiquarks (also expected from conventional phenomenology) whereas the light scalars are made predominantly of diquark-antidiquark components. The numerical simulations showed that the scalar and pseudoscalar glueball masses are around 1.6 GeV and 2.1 GeV in agreement with lattice QCD simulations.

PUBLICATIONS AND PRESENTATIONS

[1] **A.H. Fariborz** and R. Jora, "Generalized linear sigma model with two glueballs," Physical Review (2018).

[2] **A.H. Fariborz** and R. Jora, "Comment on scalar glueball mass," Physics Letters (2019).

[3] **A.H. Fariborz,** R. Jora and M. Lyukova, "Quark and glue spectroscopy of scalars and pseudoscalars in SU(3) flavor limit,'' International Journal of Modern (2019).

RESEARCH ACTIVITY

DR. ANDREW C. GALLUP

Scope: Dr. Gallup is an evolutionary psychologist and the director of the Adaptive Behavior and Cognition (ABC) Lab at SUNY Poly. His research spans a variety of topics, including contagious behavior and comparative neuroanatomy, brain thermoregulation and vigilance, collective behavior and social cognition, aggression and sexual conflict, the evolution of cooperation, winner and loser effects, biomarkers of Darwinian fitness, and the effects of neuromodulation on adaptive responses.

Goals: The aim of my research is to uncover and characterize psychological adaptations.

PUBLICATIONS AND PRESENTATIONS

[1] **Gallup A.C.**, Vasilyev D.*, Anderson N.*, & Kingstone A. (in press). Contagious yawning in virtual reality is affected by actual, but not simulated, social preference. Nature Scientific Reports.

[2] Ripp J.*, Eldakar O.T., **Gallup A.C.,** & Arena P. (in press). The successful exploitation of urban environments by the spider Nephila clavipes (Araneae Nephilidae). Journal of Urban Ecology.

[3] Eldakar O.T., Kammeyer J.O., Nagabandi N.*, & **Gallup A.C.** (2018). Hypocrisy and corruption: how disparities in power shape the evolution of social control. Evolutionary Psychology 16, 1-12.

[4] **Gallup A.C.** & Fink B. (2018). Handgrip strength as a Darwinian fitness indicator in men. Frontiers in Evolutionary Psychology 9, 439.

[5] Bielert C.F., Costo N.*, & **Gallup A.C.** (2018). Tuskedness in African Elephants–An anatomical investigation of laterality. Journal of Zoology 304, 169-174.

[6] **Gallup A.C.,** Eldakar O.T.t Schonning M.*, & Yanchus M.* (2018). Winner and loser effects in collegiate baseball and softball doubleheaders. Adaptive Human Behavior and Physiology 4, 108-120.

[7] **Gallup A.C**., Ramirez V.*, Ryan C.P.*, & Eldakar O.T. Carotid artery temperature modulates the expression of contagious yawning. Psychonomic Society's 59th Annual Meeting, New Orleans, LA - November 2018.

[8] Pietruch K.*, Eldakar O.T., & **Gallup A.C**. The plasticity of male mating behavior in the water strider (Aquaris remigis). Summer Undergraduate Research Program Symposium, SUNY Polytechnic Institute, Utica and Albany Campuses, NY – August 2018.

[9] **Gallup A.C**. Handgrip strength as a fitness indicator in males: revisited. Northeastern Evolutionary Psychology Society Conference, SUNY New Paltz, New Paltz, NY – April 2018

[10] Eldakar O.T., & **Gallup A.C**. How disparities in power shape the evolution of social control. Northeastern Evolutionary Psychology Society Conference, SUNY New Paltz, New Paltz, NY – April 2018.

[11] **Gallup A.C**., Anderson N.C.*, Vasilyev D.*, & Kingstone A. Contagious yawning in virtual reality: the influence of social presence within and behind the scenes. Northeast Regional Conference on Complex Systems, Binghamton University, Binghamton, NY – April 2018.

[12] Pratt T.*, & **Gallup A.C**. Yawn duration in newborns and infants. Student Project Showcase, SUNY Polytechnic Institute, Utica, NY – April 2018.

[13] Clemishaw J.*, & **Gallup A.C.** Yawn duration predicts brain weight across domesticated dog breeds. Student Project Showcase, SUNY Polytechnic Institute, Utica, NY – April 2018.

[14] Peplinski W.*, & **Gallup A.C**. Thermographic imaging and contagious yawning in humans. Student Project Showcase, SUNY Polytechnic Institute, Utica, NY – April 2018.

* Student author

Research Funded by: The Leakey Foundation, SUNY Poly Visiting Scholar Seminar Series, and the SUNY Poly Seed Grant

RESEARCH ACTIVITY

DR. ANA JOFRE

Scope: Dr. Ana Jofre's research group is involved in the data-mining of the archives of Time magazine using image analysis. Additionally, she works in collaboration with historians to create web-based public resources. Dr. Jofre also has regularly publishes and shows her art and design work.

PUBLICATIONS AND PRESENTATIONS

[1] **Ana Jofre**. 2019. "Countering Patterns of Educationalization: Creating Digital Tools for Critical Evidence-based Thinking", pp.355-382. In Rosa Bruno-Jofré, ed. Educationalization and Its Complexities: Religion, Politics, and Technology. Toronto: University of Toronto Press.

Published with the help of a grant from the Federation for the Humanities and Social Sciences, through the Awards to Scholarly Publications Program, using funds provided by the Social Sciences and Humanities Research Council of Canada.

[2] **Jofre, Ana,** and Rosa Bruno-Jofré. "The Sisters of the Infant Jesus, St. Maur, in Spain: Their Transformation and the Mission in Bembibre in the Long 1960s. A Digital History Web Resource." Espacio, Tiempo y Educación 6, no. 2 (2019): 153-175.

[3] The Association for Computers and the Humanities (ACH) 2019 Conference, July 23 - 26, 2019, Pittsburgh, PA, USA. "What's in a Face? Examining Historical Trends Through the Faces of a Mass Media Publication" Kathleen Brennan, **Ana Jofre**, Vincent Berardi, Aisha Cornejo.

[4] Commemoration, Preservation, Celebration, Eleventh Triennial Conference on the History of Women Religious. Saint Mary's College, Notre Dame, Indiana. June 23–26, 2019. "Commemorating, Preserving, and Celebrating Women Religious in the Digital Domain" Rosa Bruno-Jofré and **Ana Jofre**.

[5] Popular Culture Association Annual meeting 2019 Washington DC, April 17-20, 2019. "A visual reading of Time Magazine through images of faces." **Ana Jofre**, Kathleen PJ Brennan, Vincent Berardi.

[6] International Symposium on Electronic Art (ISEA) 2019 Gwangju, Republic of Korea. June 22-19, 2019. "Deconstructing and reconstructing a periodical archive by tracking, tag-ging, and extracting images of faces" **Ana Jofre**, Kathleen Brennan, Vincent Berardi

CREATIVE WORK

Cover Design and Art: [1] Encounters in Theory and History of Education. Vol 19 (2018): Gendered Education in History, Theory and Practice. Cover design and cover artwork.

[2] The Theory and History of Education Monograph Series Volume 1: New Directions in Research on Education Reconstruction in Challenging Circumstances, edited by Tom O'Donoghue and Simon Clarke. Cover design and cover artwork.

Book Cover Art: [1] Rosa Bruno-Jofré. Forthcoming. The Sisters of Our Lady of the Missions: From Ultramontane Origins to a New Cosmology. Toronto: University of Toronto Press. Cover. Published with the help of a grant from the Federation for the Humanities and Social Sciences, through the Awards to Scholarly Publications Program, using funds provided by the Social Sciences and Humanities Research Council of Canada.

[2] Rosa Bruno-Jofré, ed. Educationalization and Its Complexities: Religion, Politics, and Technology. Toronto: University of Toronto Press. Published with the help of a grant from the Federation for the Humanities and Social Sciences, through the Awards to Scholarly Publications Program, using funds provided by the Social Sciences and Humanities Research Council of Canada.

Exhibitions [1] 2019 Big Ol' Steamroller Print Exhibition, August 2 - August 18, 2019. Participating artist.

[2] Gannett Gallery Faculty Show, Selected work by SUNY Poly faculty, September 10 - October 31, 2018. Participating artist.

Research funded by: SUNY Innovative Instruction Technology Grant (IITG), SUNY Poly Seed grant, ISCHE and University of Luxembourg.

Find more information at: https://onewomancaravan.net/

INTERACTIVE MEDIA AND GAME DESIGN

DR. NICK LEJEUNE

Scope: My current body of creative work involves sound converted video. Individual video frames are converted to sound files and back through algorithmic code. This conversion process involves concepts such as abundance, collection, organization, reconfiguration, juxtaposition and aesthetic elevation. With regards to my installation work, video and sound are recorded and processed in real time within the space. This video is processed with the result projected back onto the space. The resulting imagery is subject to change by viewer interaction and site specificity.

Goals: My main goals are to find a comprehensive definition of digital RAW sound file formats and to incorporate eye-tracking software into my process.

INVESTIGATIVE LOOK INTO RAW DIGITAL DATA FORMATS, RAW DATA INTERPRETERS AND THE CORRELATION BETWEEN SOUND AND COLOR

During the course of the 2018-2019 Academic year, my research lead into the investigation of how data is interpreted through my artistic process. Within this process, RAW data formats are used in ways that confuse the command-line software that interpret them (e.g. raw sound files are imported into graphic editing programs). When raw sounds transition into raw image through this process, the resulting imagery is represented by a basic, 16-color palette. I was primarily interested in what dictates this allocation and/or what assigns these color values. My hope was to determine more means of control and understanding of this converted data representation in the gallery. I was able to network with several visual artists as well as various computer scientists to investigate the relationship between RAW sound files and visual color information that results from my process.

At the conclusion of the academic year, I was able to determine that RAW sound files lack particular signatures or headers that other sound formats rely upon. This, in turn, makes determining specific factors of a RAW sound file difficult. Things such as compression, which is uncharacteristic of RAW formats generally, bit depth, amount of channels and their interleaving are left to be determined without the presence of a header.

For more information, please visit Dr. LeJeune's website: http://www.nicklejeune.com/

PUBLICATIONS AND PRESENTATIONS

[1] Faculty Showcase, Group Exhibition, 17 Sep.-Nov. 4, 2019, Gannett Gallery, SUNY Polytechnic Institute, Utica, NY

[2] **LeJeune, Nick**, "What is the correlation of sound and color in RAW digital data formats?" Thinking with Data and Information, SUNY Polytechnic Institute Seminar Series Spring 2019, Utica, NY, 29 Jan. 2019

[3] **LeJeune, Nick**, "What is the correlation of sound and color in RAW digital data formats?" PCA Annual Conference, Spring 2019 Washington, DC, 17 Apr. 2019

[4] **LeJeune**, Nick. "TRACKED by NICK LEJEUNE in collaboration with Evan Boggess and sponsored by Auxiliary Services Corporation." TRACKED, SUNY Polytechnic Institute, 03 Apr. 2019, http://people.sunyit.edu/~lejeunc/.

RESEARCH ACTIVITY

DR. LUYE LI

Scope: Dr. Li's research in criminology is focused in four areas: Intimate partner violence, police legitimacy and procedural justice, race, ethnicity and law enforcement and comparative criminal justice and data science.

PUBLICATIONS AND PRESENTATIONS

[1] Brandie Pugh, **Li, Luye**, & Sun, Ivan., (2018). Perception of Why Battered Women Stay in Physically Abusive Relationships: A Comparative Study of Chinese and U.S. College Students. Journal of Interpersonal Violence.

[2] Sun, Ivan, **Li, Luye**, Wu, Yuning, & Hu, Rong., (2018). Police Legitimacy and Citizen Cooperation in China: Testing an Alternative Model. Asian Journal of Criminology.

[3] **Li, Luye**. (2019) Race, Ethnicity, and Police Use of Force: An Examination of the Black-Civilian-and-White-Officer Combination. Academy of Criminal Justice Sciences (ACJS), Baltimore, MD

[4] **Li, Luye.** (2018). Procedural justice and police legitimacy: A comparison of racial/ethnic effect between Asian, White, African and Hispanic Americans. American Society of Criminology (ASC), Atlanta, GA.

[5] **Li, Luye.** (2018) Organizational Factors Matter: A Multilevel Test on Internal Procedural Justice and Public Perception of the Police. Academy of Criminal Justice Sciences (ACJS), New Orleans, LA.

Research funded by: National Institute of Justice and The International Project of Attitudes Toward Criminal Justice (IPACJ).

SUBJECTIVE EXPERIENCES OF INTERACTIVE NOSTALGIA

DR. RYAN LIZARDI

Scope: Dr. Lizardi's work tackles the subject of interactive nostalgia from historical, philosophical, rhetorical, sociological, and economic perspectives, all the while asking questions about what it means to be asked to be active participants in our own mediated histories.

Goal: Explore the subjectivities of interactive nostalgia.

There are as many varied experiences of nostalgic longing as there are varied approaches to studying nostalgia. From Johannes Hofer to Freud to Svetlana Boym to Stephanie Coontz, our understanding of what it means to long for the past has changed and morphed over time and, as such, our methodological approaches have morphed in kind. The encouragement of nostalgic impulses has only increased over time, with contemporary media seeking to make our past eternally relevant, but our experiences in reaction to this encouragement are varied.

We as consumers and researchers have different subjective experiences of longing for the past, especially in regards to our interactive media like video games, applications, and other digital content, and this collection seeks to honor those differences. In search of a more interdisciplinary understanding of the various forms and experiences of interactive nostalgic longing, this collection collects essays that explore these subjectivities of nostalgia from methodologically diverse perspectives (from the historical to the philosophical, from autoethnography to political economy).

The benefits of such an approach is not only that this book will appeal broadly within the already popular genre of media studies, but also that it will function as a text that can speak across academic borders.

RESEARCH ACTIVITY

DR. ADAM T. MCLAIN

Scope: My research is broadly concerned with evolutionary genetics, and more specifically the evolutionary history and patterns of speciation in non-human primates. To that end, my lab uses a combination of field, wet-bench, and computational techniques to better understand the evolutionary history of the primate radiation, as well as specific aspects of primate and other mammalian genomes. Lemurs, primates endemic to the African island of Madagascar, have been the main focus of my work since graduate school. The Lemuriform primates have been isolated on Madagascar for ~60 million years, and in that time have radiated into >100 species in five distinct taxonomic families. My research is particularly concerned with how distinct geographic environments across Madagascar have fueled speciation events, and the way in which new species are defined. I am also concerned with applying this research to the conservation of remaining lemur populations, as nearly every species of lemur is endangered or critically endangered in the wild. I am also interested in specific genomic aspects of aging, and have been exploring ways in which features of genomic architecture "protect" important parts of mammalian genomes from the deleterious impacts of aging.

Goals: The main goal of my research group is to better understand the mechanisms that drive speciation in non-human primates, while making an effort to apply this knowledge to the very pressing issue of primate conservation. I am also interested in better understanding the mechanisms that buffer or protect important sections of genomes from the impact of aging.

IDENTIFYING A NEW SPECIES OF DWARF LEMUR

Working with researchers from the Madagascar Biodiversity Partnership, the Henry Doorly Zoo and Aquarium, Conservation International, and the Australian National University my lab finalized identification of a new lemur species, the Groves's dwarf lemur (Cheirogaleus grovesi). This is a small-bodied primate from the mid-altitude rainforests of southeastern Madagascar, with populations identified in the national parks of Ranomafana and Andringitra as well as surrounding forest fragments. C. grovesi is a gregarious omnivore, primarily subsisting on fruits, flowers, and small insects. As a dwarf lemur, it is a member of the only genus of primates known to undergo seasonal hibernation (called torpor) during the Malagasy dry season, subsisting on fat stored in its long tail until the monsoons restore the forests to a more verdant state. This publication generated considerable publicity in the domestic and international press, including National Geographic, The Guardian, NY Daily News, and the Utica Observer-Dispatch. Many web-based journalists covered it as well, including the notable sites Mongabay and ScienceAlert. I was interviewed on local radio and by a television station in Buffalo, and recorded a segment for NPR's Academic Minute.

This identification is part of a broader research effort, ongoing since 2013, to better understand species diversity in the genus Cheirogaleus. This research will continue in coming years. In the spring of 2019 I gave a talk at the annual meeting of the American Association of Physical Anthropologists on another new species of dwarf lemur, this one from extreme southeastern Madagascar. In June of 2019 I was awarded a SUNY Seed Grant to do further fieldwork on the island of Nosy Hara, off the northwestern coast of Madagascar, where another cryptic dwarf lemur population has been spotted, but not studied. I suspect this to be another new species, and under the impact of island dwarfism. This proves to be an interesting opportunity to understand the impact of resource-depleted environments on an already-small bodied primate, with research implications related to island dwarfism, hibernation, and speciation.

Fig. 1: Cheirogaleus grovesi, the Groves's dwarf lemur

EXAMINING THE LINK BETWEEN CPG SITE DENSITY AND AGING IN 131 MAMMALIAN GENOMES

My lab has been working with a research group at the University of Minnesota to identify the impact of CpG density on the continued function of genes related to aging across multiple primate and non-primate mammalian species. CpG sites are locations in the genome where a phosphate group links a cytosine base and a guanine base. These regions are less prone to methylation. Our computational analysis indicates that CpG densities are greater in the promoter regions of genes important in longer life spans. I spent the fall of 2018 writing an NIH grant to further this research with a wet-bench component, which was submitted in the spring of 2019.

Research Funded by: SUNY Poly Seed Grant. For more information, please visit: http://www.thelemurguy.net/

PUBLICATIONS AND PRESENTATIONS

[1] **McLain, AT** and C Faulk. The evolution of CpG density and lifespan in conserved primate and mammalian promoters. 2018 Aging 10(4).

[2] **McLain, AT**, R Lei, CL Frasier, JM Taylor, CA Bailey, B Roberts, SD Nash, R Randriamampionona, RA Mittermeier, and EE Louis, Jr. A new Cheirogaleus (Cheirogaleidae: Cheirogaleus crossleyi Group) Species from Southeastern Madagascar. 2018 Primate Conservation (31).

ORGANIC AND SUPRAMOLECULAR CHEMISTRY

DR. VIJAY RAMALINGAM

Scope: My research focuses on two major divisions. First, in the design, syntheses, and characterization of mechanically interlocked molecules (MIMs) such as rotaxane and catenanes. Second, we investigate the selective functionalizations of aromatic rings using supramolecular non-covalent binding.

Goals: To synthesis a rotaxane and study the properties to utilize for catalysis and drug delivery.

Project background and significance: Mechanically interlocked organic molecules (MIMs) such as rotaxanes, catenanes, and Borromean rings are very interesting organic molecules with numerous potential applications from medicinal chemistry and drug delivery, to material chemistry. Rotaxanes (fig. 1) has been widely useful in many fields; for example, in the energy harvesting using Bodipy dye for solar power, building supramolecular polymer architecture, mimicking muscles by developing molecular muscles, and in asymmetric catalysis for chiral molecule synthesis and carbon nanotube encapsulated macrocycle, etc. The importance of this field was recently recognized with the Nobel Prize in chemistry 2016.

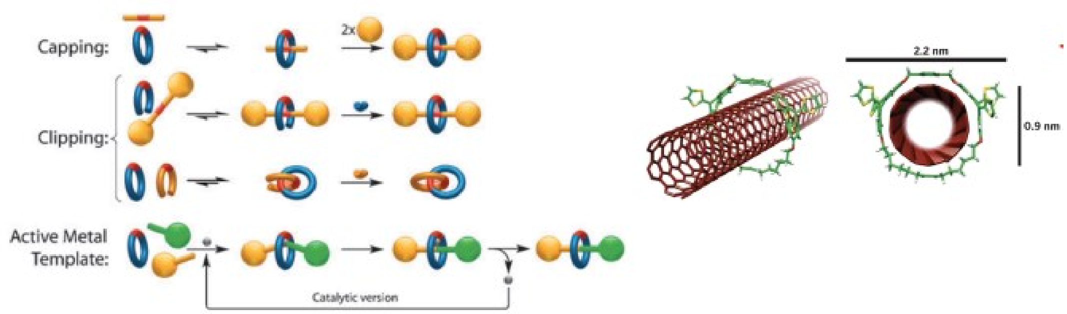
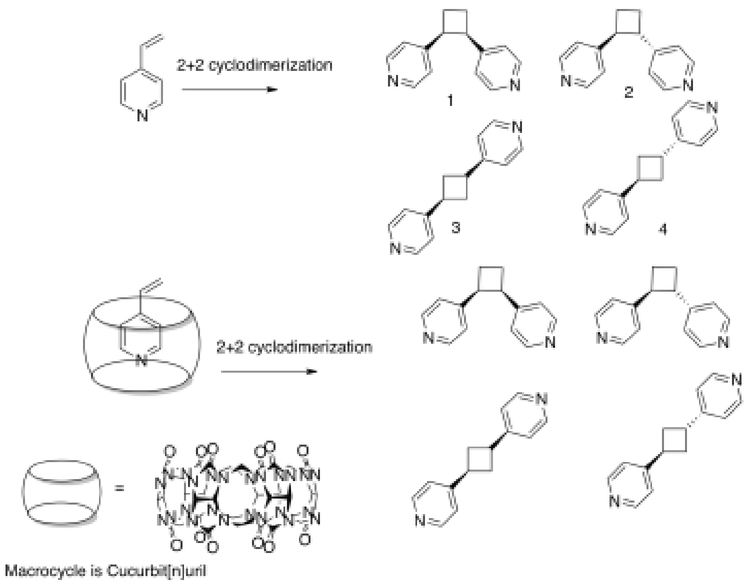


Figure 1: a.) Various methods to synthesize rotaxanes, b) Carbon nanotube Pseudorotaxane.

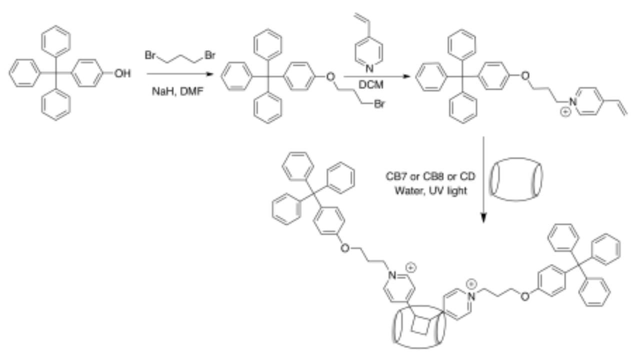
We are interested in the syntheses of rotaxanes using new methodology involving the effect ultraviolet light has as an energy source. This methodology is different from the conventional heat reaction. Most importantly we want to achieve this reaction in aqueous condition and in room temperature conditions for problem free, large-scale synthesis. Before the synthesis of these rotaxanes, the compatibility of the preliminary reaction using vinyl pyridine molecule will be conducted (Scheme 1). We also want to know the regioselectivity of the cyclobutane molecule with and without supramolecular complexes. Investigation of the cyclodimerization of the 4-vinyl pyridine under various solvents will be carried out. Upon stabilization this method will be tested for the synthesis cyclobutanes in reliable yield, a complete characterization of this material to understand which product (1,2 or 1,3) is formed as a major product and then same protocol will be used for with the macrocycle such as cucurbituril or cyclodextrin. In our theory this will improve the selectivity of the 1,2 product vs. 1,3 product in cyclophotodimerization. We will then use this methodology to build the mechanically interlocked molecules (MIM) and study the properties of these rotaxane for further binding of aromatic compound or drug molecule.

For the synthesis of rotaxane, tetraphenylmethane derivative will be used as the stopper group. Cucurbiturils are used as the large macrocyclic molecule (See Scheme 2). If the scheme 1 fails, an alternative routes for the synthesis of this rotaxane will be used (Scheme 3).

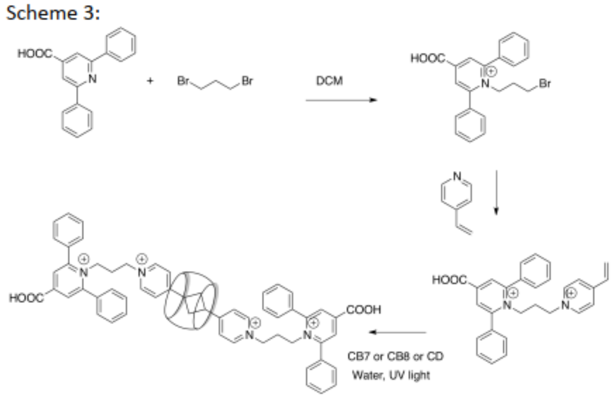
Scheme 1:



Scheme2: Cyclophotodimerization to synthesize rotaxanes.



Scheme 3:



PUBLICATIONS AND PRESENTATIONS

[1] Mahesh Pattabiraman, Maja Bajic, and **Vijayakumar Ramalingam**, Photochemical assisted synthesis of interlocked organic molecules. Poster presentation, 257th ACS National Meeting, Orlando, FL, USA, April 2, 2019.

[2] Maja Bajic and **Vijayakumar Ramalingam**, Synthesis of Mechanically Interlocked Molecules, SUNY Undergraduate Research Conference (SURC), April 26, 2019, SUNY Adirondack with SUNY Plattsburg, NY.

RESEARCH ACTIVITY

DR. ANDREW RUSSELL

Scope: In 2018 I worked with collaborators to advance a research and scholarly agenda in the fields of history, science and technology studies, and public communication. The principle area of my focus is the subject of maintenance, broadly defined, which includes upkeep and repair of technologies, technological infrastructure, and human and social services. Maintenance is a subject that cuts across any number of disciplines and professions, which is one reason why it draws interest from scholarly and popular audiences. My collaborators and I therefore take an interdisciplinary approach, drawing on methods from history, the social sciences, and journalism.

Goals: My goals are to provoke deeper scholarly and public engagement around the subjects of maintenance, infrastructure, and repair; to build and sustain networks of scholars and practitioners who share interests in maintenance, infrastructure, and repair; and to contribute to a public movement to recognize the importance of maintenance in modern society, and to reward maintainers through greater status and compensation.

PUBLIC OUTREACH

Together with my collaborators Lee Vinsel (Assistant Professor of Science & Technology Studies, Virginia Tech) and Jessica Meyerson (Research Program Officer, Educopia Institute) I am a co-Director of The Maintainers, a global research network interested in the concepts of maintenance, infrastructure, repair, and the myriad forms of labor and expertise that sustain our human-built world. Our members come from a variety of backgrounds, including engineers and business leaders, academic historians and social scientists, government and non-profit agencies, artists, activists, coders, and more. Our mailing list has nearly 600 members, and we have nearly 5000 followers on Twitter. As co-founders, Vinsel and I have spent a lot of time doing interviews with the media, writing for popular venues, and preparing a book manuscript for publication in 2020 by an imprint of Penguin Random House. Our publications for popular venues in 2018 included essays in the New York Times, Education Week's annual "Big Ideas" issue, and the online magazine The Conversation (the latter essay was republished in Fast Company magazine).

PUBLICATIONS AND PRESENTATIONS

[1] “The Maintenance Mindset,” After Design: Monitoring and Managing the Texas Landscape, Texas Tech University Department of Landscape Architecture, Lubbock, Texas, April 5, 2019.

[2] “Digital Maintenance,” APIdays, Paris, France, December 11, 2018.

[3] “After Innovation,” Department of Science & Technology Studies, Rensselaer Polytechnic Institute, Troy, New York, November 14, 2018

[4] Panel Commentary, “Digital History and History of Technology: A Critical Dialogue,” Society for the History of Technology, October 12, 2018.

[5] “The Innovation Delusion,” Decay, Maintenance, and Repair Symposium, Georgia Tech School of Architecture, Atlanta, Georgia, April 13, 2018.

[6] “Make Maintainers: Engineering Education and an Ethics of Care,” in Does America Need More Innovators? in Matthew Wisnioski, Eric S. Hintz, and Marie Stettler Kleine, eds. (Cambridge, MA: The MIT Press, 2019).

[7] “The Joy of Standards” (with Lee Vinsel), The New York Times, February 16, 2019.

[8] “How to Turn Maintenance into a Mindset” (with Lee Vinsel), Education Week, January 8, 2019.

[9] “Das Modulare und das Digitale,” Arch+ 233 (December 2018), 118-123.

[10]“Financial and Administrative Infrastructure for the Early Internet: Network Maintenance at the Defense Information Systems Agency,” Technology & Culture 59 (October 2018): 899-924 – co- authored with Bradley Fidler.

[11] “Silicon Valley, From ‘Heart’s Delight’ to Toxic Wasteland” (with Lee Vinsel), The Conversation, July 11, 2018.

[12]“After Innovation, Turn to Maintenance,” Technology & Culture Vol 29, no. 1 (January 2018), pp. 1-25 –co-authored with Lee Vinsel

Research funded by: Alfred P. Sloan Foundation

For more information on Dr. Russell’s research, please visit: https://sunypoly.edu/faculty-and-staff/andrew-russell.html

APPLICATIONS OF GROUP THEORETICAL METHODS TO DIFFERENTIAL AND DIFFERENCE EQUATIONS

ZORA THOMOVA

Scope: Application of Lie group theory and continuous symmetries to discrete equations, the aim of which is to make full use of the theory of Lie group to study the solution space of discrete equations, and in particular to solve difference equations. One of the approaches we use is to perform a symmetry preserving discretization. We also focus on the development of theory and tools for applications of Lie groups to the difference and differential-difference equations.

Goals: To solve the mathematical, physical, and engineering problems described by differential equations or discrete equations using the symmetry methods. The main goal is to obtain explicit solutions especially for nonlinear problems.

I continue the collaboration with Prof. Winternitz (U of Montreal, Canada), Prof. Levi (U Roma Tre, Italy) and Prof. Rodriguez (U Complutense, Spain). I am also active in the broader research community devoted to the topic of Lie symmetries and their applications: I have co-organized international meetings (SIDE 12 in 2017, QTS 11 in 2019) and have been a guest editor of the Special volumes of the journals (J. Phys A 2009, SIGMA 2018).

CONDITIONALLY INVARIANT EQUATIONS

One of the questions asked in the context of symmetry methods and differential equations is the construction of equations possessing a prescribed symmetry. Given a symmetry, one can construct differential invariants – quantities invariant under the symmetry group action. Further it allows us to ask the question “which equations of a given order/type possess the prescribed symmetry?”

The construction of equations with prescribed Lie point symmetries is known and has been used in many articles when one is looking for models that have properties related to prescribed symmetries. We have set out to apply this process to construct conditionally invariant nonlinear partial differential equations. The conditional symmetries of differential equations are important since if they exist they allow construction of additional solutions not obtainable from Lie point symmetries. We have considered the conditional symmetries of the Boussinesq equation: $u_{yy} + uu_{xx} + (u_x)^2 + u_{xxxx} = 0$

We then constructed nonlinear partial equations, such as non-autonomous KdV like equations among others, i.e. $u_y = \frac{1}{y}(u_{xxx} + uu_x) - 2y$

Note that it is known that the KdV equation does not have conditional symmetries.

See full results in [1], [2].

DISCRETIZATION THAT PRESERVES CONDITIONAL SYMMETRIES

The application of the Lie group theory to discrete equations is relatively new and has seen substantial development since the mid-1990s. There are several “types” of symmetries for differential equations: point symmetries, contact symmetries, generalized symmetries. In the 2011 and 2012 papers we (Levi, Scimiterna [2012], Thomova, Winternitz) defined the contact symmetries for difference equations.

The goal was to study conditional symmetries for discrete/difference equations – in particular to construct a discretization that preserves conditional symmetries. We presented few discretization of the Boussinesq equation on a lattice, each time preserving a chosen conditional symmetry. The lattice is also invariant under the prescribed symmetry. We have considered three different conditional symmetries and discretization were constructed for each one. Each case had a specific lattice: 1) nonorthogonal, Schwarzian with constant spacing or 2) nonorthogonal, non-Schawarzian and non-constant spacing or 3) orthogonal, Schwarzian and constant spacing. Symmetry based reductions were obtained and some numerical comparisons were performed. Understanding the relationship of the type of lattice on the solution is also an open question. Results were presented at 2 conferences [LTR4, LTR5] and are now presented in the submitted paper [LTR3].

PUBLICATIONS AND PRESENTATIONS

[1] D. Levi, M.A. Rodriguez, Z. **Thomova**: Differential equations invariant under conditional symmetries, J. Nonlin. Math. Phys. 26 281—293 (2019).

[2] D. Levi, M.A. Rodriguez, Z. **Thomova**: Construction of partial differential equations with conditional symmetries, accepted for publication in monographic issue "Integrability, Supersymmetry and Coherent States. A volume in honor of Professor Véronique Hussin" CRM series in Mathematical Physics – Springer (in print 2019).

[3] D. Levi, M.A. Rodriguez, Z. **Thomova**: The discretized Boussinesq equation and its conditional symmetry reduction; submitted to J. Phys. A: Math and Gen.

[4] V. Hussin, M. Ismail, D. Levi, Z. **Thomova**, P. Winternitz (Eds): Symmetries and Integrability of Difference Equations, Special Issue of SIGMA journal, March 2018

[5] D. Levi (presenter), M.A. Rodriguez, Z. **Thomova**: Conditional symmetry preserving discretization: the Boussinesq equation, presented during the SIDE 13 conference, November 2018, Fukukoa Japan.

[6] D. Levi, M.A.Rodriguez, Z.**Thomova** (presenter): Conditional symmetry preserving discretization of the Boussinesq equation, presented at Quantum Theory and Symmetry XI, July 1-5 2019, Montreal, Canada.

INTERACTIVE MEDIA AND GAME DESIGN (IMGD)

DR. IBRAHIM YUCEL

Scope: Dr. Yucel's group has focused on investigating the potential of Virtual Reality for education. At the Visualization and Interactive Media Center, Dr. Yucel tests the use of cutting-edge technology in the classroom.

HOSTED ROUNDTABLE AT GAME DEVELOPER'S CONFERENCE ON MONETIZATION EFFECT ON GAME DESIGN

Monetization and its Effect on Design

Below is a summary of discussion from the IGDA Game Design SIG roundtable on monetization at GDC2019, focusing on three different tiers of monetization integration.

The roundtable started with an invitation for those in the room to share their personal experiences designing or playing games with real money transactions within them. A few developers expressed their concerns about the ethics of the microtransaction model possibly putting their work in a bad light and one developer in particular expressed his wish to avoid microtransactions as a whole since he was not comfortable with it in the current environment. A few others pointed at the success they have had with microtransactions, and how the resources and capital it generated provided players with more content. That improved engagement and kept the game, and its player base, alive.

The roundtable then continued to set a framework for discussing the effect in game economies had on game design, highlighting three potential tiers of integration into a game. First, we identified games in which real money transactions only provide the player with additional cosmetic items for the player to use, with no mechanical impact on the game rules. It was pointed out that even though most found this form of monetization unobjectionable, it still prevents a player from self-expression and ownership, which can be detrimental to their experience. The next tier we identified was paying for access into new or additional content. This was not too problematic as developers acknowledge that much of this additional content could not be made without the additional capital the in-game purchase provided. The negative consequence of this, however, was a potential fracturing of one's player base due to limiting access via purchase. The third tier, and most problematic, was allowing the player to buy power and/or time via real money transactions. We acknowledged that good practice with monetization allowed players to accumulate currency through play in addition to real money transactions, but the roundtable did not come to a consensus on how valuable the players' time should be.

In addition to these tiers, developers also pointed out the difference in purchasing consumables versus purchasing “permanent” virtual items, and marketplace effects on these forms of monetization. The comparison eventually began a discussion on the game Magic: The Gathering (M:TG), which had traditionally been a physical collectable card game but was now fairly successful with the launch of the digital M:TG Arena game. Developers pointed out while the digital version no longer give player the chance to “cash out” via ordering physical copies of their cards like in a previous M:TG digital forms, The reduced cost and convenience of the digital version allowed players who had abandoned the game to return.

VISUALIZATION AND INTERACTIVE MEDIA CENTER OPENING

College of Engineering

CLIMATIC EFFECTS ON TRANSPORTATION INFRASTRUCTURE

DR. ASIF AHMED

Scope: Transportation Infrastructure, Climatic Loading, Freeze-Thaw Cycle, Pavement Performance, Real Time Subgrade Data.

Goals: To study the freeze/thaw cycle accurately based on real time soil moisture, temperature, and conductivity data in pavement subgrade. Currently, the freeze-thaw cycle is estimated based on average weather data, not real time soil moisture/temperature data.

DETERMINING THE FREEZE-THAW CYCLE OF PAVEMENT SUBGRADE BASED ON REAL TIME DATA

In New York State, distress in pavement arises due to the freezing and thawing of the subgrade beneath pavement. The most critical seasons for highways in this state are the winter and subsequent spring thaw. Pavements are strongest in the winter, but weakest in the spring.

Knowledge of the timing of the spring thaw allows highway agencies to reduce the damage caused during this season by enacting seasonal load restrictions. One primary reason for seasonality not being included in pavement design by highway departments is because it can be complicated to determine the timing of seasonal changes and determine the actual depth of frost and thaw in the pavement. There are models available to determine the depth of frost and the timing of the seasons, but many of the models can be difficult to use or understand.

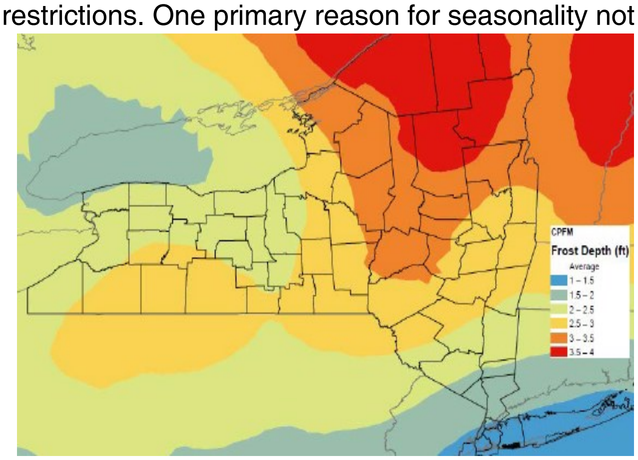


Fig. 1: Average Frost Depth of NY State (Duffy et al.2017)

Currently, the highway agency uses an average estimation for frost depth (Fig. 1) but it is not same each year. Obviously, the frost depth may be shallower in a warmer winter and deeper when winter is colder and longer.

Hence, a perfect real time frost model can allow determining the actual frost depth from moisture, temperature data.

METER group has recently agreed to accomplish a cost sharing project with SUNY Poly. The duration of the project will be two years (Spring 2019- Spring 2021). It is expected to have a complete freeze-thaw model of subgrade after the monitoring period.

PUBLICATIONS AND PRESENTATIONS

[1] **Ahmed, A**., Hossain, M.S., Khan, M.S., and Shishani A. (2018). Data Based Real Time Moisture Modeling in Unsaturated Expansive Subgrade in Texas. In Journal of the Transportation Research Record.

For more information on Dr. Ahmed's research, please visit: https://asifahmed3.wixsite.com/asif

RESEARCH ACTIVITY

DR.KORKUT BEKIROGLU

Scope: My research interests include the broad interface of system identification, optimization, longitudinal data analysis, robust control, robust model predictive control (rMPC), robust intervention design, adaptive treatment design, and building automation (HVAC control). I am particularly working on developing computationally efficient system identification algorithms for big, noisy, and incomplete datasets. I am also interested in MPC applications such as developing smart and adaptive personal treatment and distributed MPC for building HVAC systems for energy efficiency.

PUBLICATIONS

[1] **K. Bekiroglu**, O. Duru, E. Gulay, R. Su and C. Lagoa. “Predictive analytics of crude oil prices by utilizing the intelligent model search engine (IMSE).” In Applied Energy – Elsevier, 228, 2387-2397. 2018.

[2] C. Jiang, Z. Chen, L. C. Png, **K. Bekiroglu**, S. Srinivasan, and R. Su. “Building Occupancy Detection from Carbon-dioxide and Motion Sensors." IEEE The 15th International Conference on Control, Automation, Robotics and Vision ICARCV 2018.

[3] **K. Bekiroglu**, S. Srinivasan, R. Su, C. Lagoa, and K. Poolla. “Recursive Parsimonious System Identification Algorithm for Dynamical Systems." Accepted to IEEE Conference on Control Technology and Applications (CCTA) 2018.

CHEMICAL SENSORS

DR. MICHAEL CARPENTER

Scope: Study the optical, electrochemical and catalytic properties of nanocomposites comprised of plasmonically active metal nanoparticles in metal oxides as a function of temperature and gas exposure to enable development of multivariable sensing methods.

Goals: 1) Develop plasmonically active nanocomposites for use as novel functional nanomaterials within harsh environments. 2) Design and develop multivariable detection methods for non-condensable gases. 3) Design and develop highly sensitive and scalable pressure sensors.

ENHANCED UNDERSTANDING OF PLASMONIC SENSOR RESPONSE DYNAMICS

The sensing mechanism on active metal oxide sensors typically includes either the adsorption/desorption of oxygen ions on the surface of the metal oxide or reversible chemical reactions with the metal oxide or a combination thereof. In these studies a nanocomposite has been fabricated through patterning of the gold nanorod (AuNR) particles with electron beam lithography and the results from sensing experiments to H2, CO and NO2 were completed. More importantly, different reaction mechanisms between the tested gases and the nanocomposites have been studied and proposed as a function of the metal oxide thickness. Specifically, these studies have for the first time confirmed that the response of the sensor is a combination of charge transfer reactions occurring at the tri-phase boundary between gold nanoparticles and the metal oxide, as well as reactions occurring between the gas phase reagents and the metal oxide itself, through supporting ellipsometric studies. Such a combined response is a result of reactions likely occurring from the top of the film surface and then into the film as well as reactions occurring from the AuNR tri-phase boundary and progressing out of the film. The observed plasmonic response as a function of thickness indicated the presence of these multiple reactions as a convoluted optical response. A limiting factor for the response of these films is the overall thickness of the metal oxide itself when compared to the proximity of the plasmonically active nanoparticle and its associated LSPR field. Given this requirement, another outcome from this work is that nanocomposites with optimal thicknesses of the deposited films have been identified, which will enable predictive design of sensor arrays when such materials are used.

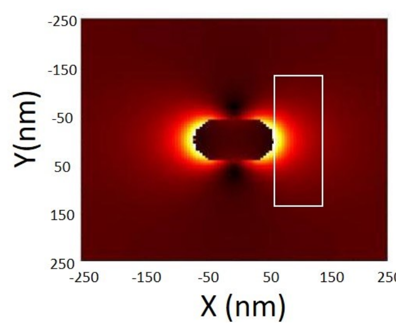


Figure 1: Plasmonic field intensity maps along x-y planes for a nanorod surrounded by YSZ

MULTIWAVELENGTH TUNABILITY: MULTIPOLAR PLASMONICS

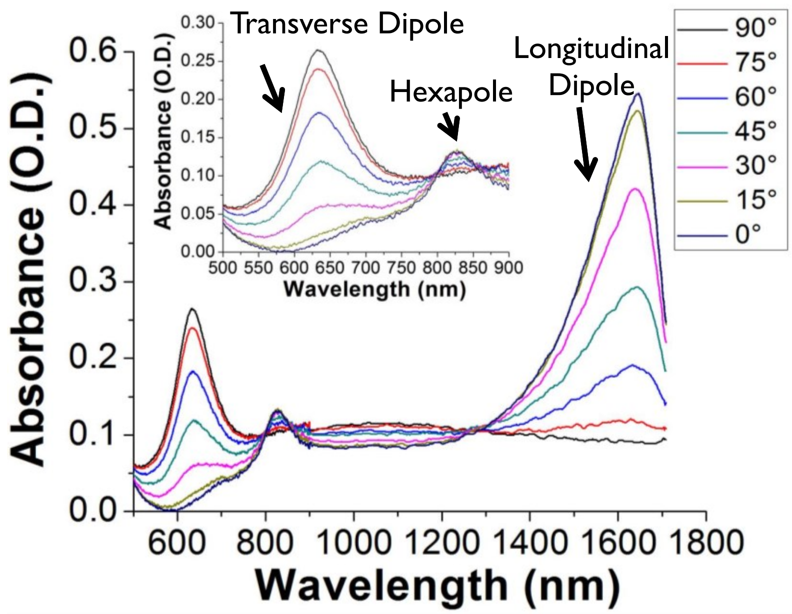


Figure 2: Plasmon spectra as a function of incident light polarization

The results detailed in this work illustrate a pathway to improved gas response in plasmonic sensors at high temperatures, which increases the number of plasmonic signatures that can be monitored and serve as beacons for chemical changes in harsh environments. Specifically, higher order plasmonic resonances in large nanoparticles have been exploited to achieve a narrow plasmonic response and for the first time, demonstrate high temperature gas sensing with these higher order modes. The hexapole mode has been identified both experimentally and modelled theoretically for 255nm x 60nm gold nanoparticles embedded in YSZ and is shown to follow the same polarization dependence as the longitudinal dipole mode. Due to the 36% decrease in linewidth of the hexapole peak compared to the transverse dipole, the figure of merit (FoM) of the multipolar resonance is calculated to be 22% higher than the longitudinal dipole resonance for the shown gas sensing results and is promising for high temperature gas sensing applications.

MULTIVARIABLE BIO-INSPIRED PHOTONIC SENSORS

Detection of diverse gas-phase chemical compounds such as condensable vapors and non-condensable gases over a wide range of concentrations is needed for numerous modern applications. Some examples include process control, industrial safety, urban pollution, environmental surveillance, medical diagnostics, and homeland protection. In these and many other applications, when detection selectivity is critical, high-resolution analytical instruments are preferred. These instruments are often inconvenient even with reduced carrier gas, vacuum, or

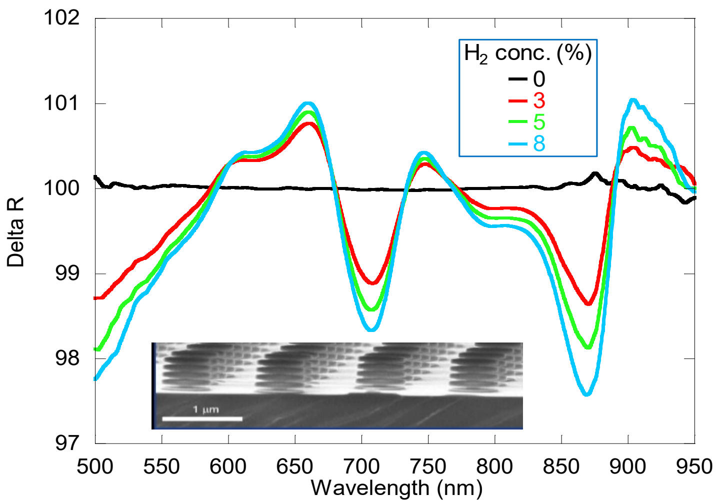


Figure 3: Differential reflectance ΔR spectra of the fabricated nanostructure upon exposures to a blank (0) and to different concentrations of H_2 gas (3, 5, and 8%). Inset shows microfabricated bio-inspired structures used in these studies

power demands, but are an unavoidable alternative to existing sensors. Our recent work is on a new generation of sensors, known as multivariable sensors, which has a fundamentally different perspective for sensing of gases and vapors to eliminate limitations of single-output sensors and their arrays. Fabrication of multivariable bio-inspired photonic sensors for diverse non-condensable gases is a key initiative undertaken in the last year. Such gas sensors are the critical next step in the development of new sensors with improved performance for practical applications.

SENSITIVE AND SCALABLE OPTICAL BASED PRESSURE SENSORS

Sensitive pressure sensors have a wide range of applications that can includes monitoring the dynamics of catalytic reactions to biocompatible sensors for glaucoma related research. Thin polydimethylsiloxane (PDMS) membranes have been employed as a highly sensitive optical reflectance based pressure sensor. A unique PDMS membrane transfer method was developed using a polystyrene coated silicon wafer which allows for multiple uses and ease of scalable manufacturing of the device structures. The device is produced through common PDMS preparation and bonding techniques and is sealed to a glass substrate. Light intensity reflected off of the membrane is recorded as pressure in the sensing environment changes, and a measurable reflectance intensity change is detected. The device performs well in both dry and humid environments achieving a sensitivity of 0.49 % reflectance per Torr and a 27 mTorr limit of detection.

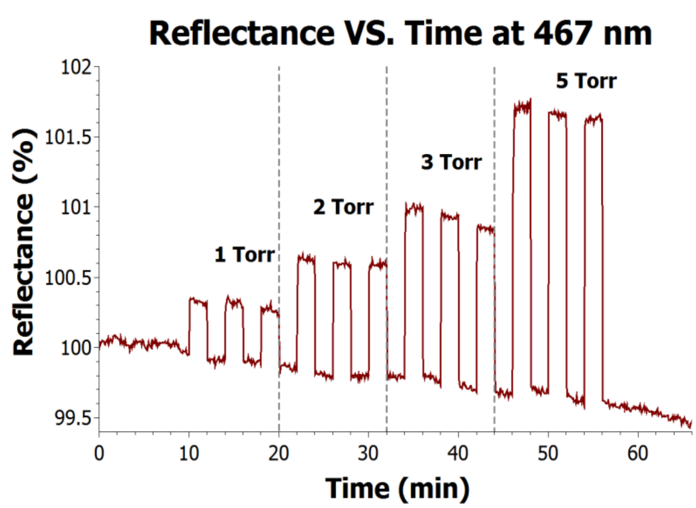


Figure 4: Sensing trace of a pressure sensing experiment in dry nitrogen with pressure set points of 1, 2, 3 and 5 Torr

PUBLICATIONS AND PRESENTATIONS

[1] G. Dharmalingam, **M. A. Carpenter**, “Chemical Sensing Dependence on Metal Oxide Chemistry and Thickness for High Temperature Plasmonics Based Sensors”, Sensors Actuators B., 251, 1104 - 11 (2017).

[2] N. Karker, **M. A. Carpenter**, “High Figure of Merit Hydrogen Sensor Using Multipolar Plasmon Resonance Modes”, Sensors Actuators B, 252, 385-90 (2017).

[3] R. A. Potyrailo, N. Karker, **M. A. Carpenter**, A. Minnick, “Multivariable bio-inspired photonic sensors for non-condensable gases: initial results, Journal Of Optics, Special Issue on Biomimetic Photonics, 20, 024006 (2018).

[4] N. Karker, G. Dharmalingam, **M. A. Carpenter**, “Survey of Optical Gas Sensors for Harsh Environments”, in Advances in Sensors: Reviews Volume 6, Chemical Sensors and Biosensors, Ed. S. Y. Yurish, International Frequency Sensor Association Publishing, (2018).

[5] **M. A. Carpenter**, “Oxygen anion and hydrogen reactions: experiments without lasers”, Farrar Symposium, University of Rochester, Department of Chemistry, June 2018, Invited.

[6] **M. A. Carpenter**, “Plasmonics: What is it and what is it good for?”, SUNY Geneseo, Chemistry Department, December 2017, Invited

[7] **M. A. Carpenter**, “Harsh Environment Compatible Plasmonics Based Chemical Sensors”, University of North Texas, Materials Science and Engineering Department, November 2017, Invited

[8] **M. A. Carpenter**, “Plasmonics Based Harsh Environment Chemical Sensors”, Army Research Laboratories, Adelphi, MD, September 2017, Invited

[9] **M. A. Carpenter**, “M. A. Carpenter, “Harsh Environment Compatible Plasmonics Based Chemical Sensors“ Optical Society of America, New Orleans (2017), Invited

[10] **M. A. Carpenter**, “Plasmonics: What is it and what is it Good For”, Knolls Atomic Power Laboratory, January 2017, Invited

Research funded by: Betchel Marine Propulsion Corporation, General Electric Global Research, and SUNY Poly Seed Grant

COMPUTER INFORMATION SCIENCE

DR. CHEN-FU CHIANG

Scope: Dr. Chiang's research is focused in three areas: Quantum algorithms, Quantum computation models and complexity and Classical algorithms. In quantum algorithms he focuses on design and analysis, implementation in the circuit level, approximate optimixation and optimization with limited quantum resources. In quantum computation models and complexity, he focuses in Adiabatic Quantum Computation (AQC), Quantum Walkers (QW), Resonant Transition (RT), Post-Quantum cryptograph and randomness. Finally, in classical algorithms his focus is in Constraint Satisfaction Problems (CSP) For additional information, please visit Dr. Chain's website: https://www.cs.sunyit.edu/~chiangc. Please also see the X-Infinity Group page in this report.

PUBLICATIONS AND PRESENTATIONS

[1] Noise Characterization: Keeping Reduction Based Perturbed Quantum Walk Search Optimal (short version). Chen-Fu Chiang, Chang-Yu Hsieh. To appear at European Physical Journal Quantum Technologies, SpringerOpen. 2018.

[2] Simulation of Quantum Walks via Hamiltonian Reduction. Aaron Gregory, Chen-Fu Chiang. IEEE Nanotechnology Symposium (ANTS), November 14-15, 2018. Albany, NY

[3] Dimensionality Reduction of the Complete Bipartite Graph with k Edges Removed for Quantum Walks. Viktoria Koscinski, Chen-Fu Chiang. IEEE Nanotechnology Symposium (ANTS), November 14-15, 2018 Albany, N.Y

[4] Optimal Dimensionality Reduced Quantum Walk and Noise Characterization. Chen-Fu Chiang. Proceedings of the Future Technologies Conference (FTC) 2018. Advances in Intelligent Systems and Computing, vol 880. pp 914-929, Springer.

[5] Optimal Dimensionality Reduced Quantum Walk and Noise Characterization. Future Technologies Conference (FTC) November 13-14, 2018, Vancouver, BC, Canada.

[6] Parameterized Pulsed Transaction Injection Computation Model And Performance Optimizer For IOTA-Tango. 13th International Conference on P2P, Parallel, Grid, Cloud and Internet Computing, Taiwan, Oct. 27-29, 2018, and The 55th NYSETA Fall 2018 Conference, Oct. 18 -19.

[7] Semi-synchronocity Enabling Protocol and Pulsed Injection Protocol For A Distributed Ledger System. 13th International Conference on P2P, Parallel, Grid, Cloud and Internet Computing, Taiwan, Oct. 27-29, 2018.

[8] A Semi-Synchronous Iota-Tangle Type Distributed Ledger with Periodic Pulsed Entries, The 55th NYSETA Fall 2018 Conference, Oct. 18 -19, 2018.

[9] Quantum Walk and Its Optimal Search on A Systematic Dimensioality Reduced Uniform Complete Multi-Partite Graph. Institute of Information Science, Academia Sinica, Taiwan, June 6, 2018.

TOWARDS A HOLISTIC CYBERSECURITY FRAMEWORK

DR. HISHAM KHOLIDY

Scope: My research focuses on cyber-security, service composition, and machine learning approaches. Most of this work is applied to cloud computing, SCADA, and 5G Systems. The scope of my research includes (1) enhancing the cybersecurity and protecting the information in IT industry and latest technologies like cloud computing, 5G systems, big data analytic, SCADA systems and critical information infrastructures which are essential to each nation's security, (2) Using machine learning approaches for solving service composition, resource scheduling, and other research problems related to the high performance systems such as the cloud computing environment.

Goals: This research is specifically geared toward the need for advanced security systems to identify, assess, and respond to attacks across a large system such as University Campus, Cypher Physical Systems, cloud computing environments, and 5G systems in a scalable and autonomous way with or without human intervention. To this end, the goals are to develop the following capabilities:

1. *A hierarchical distributed security framework*. This framework will be able to detect cyber-attacks and represent the geographically distributed nature of the real time systems where a large number of distributed nodes are serving users.
2. *A new risk assessment model*. This model quantitatively and accurately computes the entire security risk regardless of the IDSs alert granularity shortcomings. This model will be built on the fact that a complex or multi stage attacks are a sequence, e.g. a chain, of elementary attacks where a threat agent acquires the privileges to implement each attack through the previous attacks in the chain.
3. *An autonomous risk mitigation system*. This system may or may not include human in-the-loop based on the criticality of the system's assets that can be protected. This system yields high classification accuracy and low false positive rate. It selects the most proper set of response actions to protect the system assets against a particular attack.

A second direction of my research work studies the developing of machine learning approaches to solve several research problems related to high performance systems. To this end, we develop a new prediction approach to predict with higher accuracy the resource needs of a cloud consumer in terms of CPU, memory, and disk storage utilization. This approach is also able to predict the response time and throughput which in turn enables the cloud consumers to make a better scaling decision. It also takes into account the dynamic behavior of consumer requests in a long term period and the seasonal or/and trend patterns in time series.

ATTACKS DETECTION IN SCADA SYSTEMS USING AN IMPROVED NON-NESTED GENERALIZED EXEMPLARS ALGORITHM

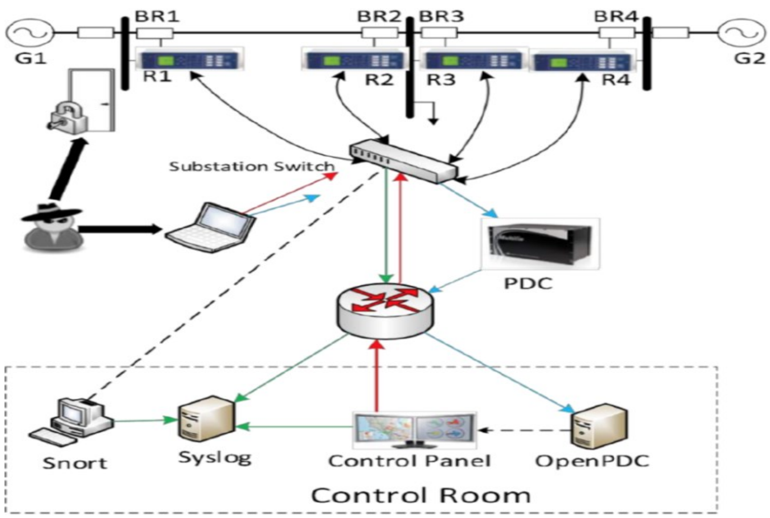


Fig.1: The CPPS testbed.

Supervisory Control and Data Acquisition (SCADA) systems became vital targets for intruders because of the large volume of its sensitive data. The Cyber Physical Power Systems (CPPS) is an example of these systems in which the deregulation and multipoint communication between consumers and utilities involve large volume of high speed heterogeneous data. The Non-Nested Generalized Exemplars (NNGE) algorithm is one of the most accurate classification techniques that can work with such data of CPPS. However, NNGE algorithm tends to produce rules that test a large number of input features. This poses some problems for the large volume data and hinders the scalability of any detection system.

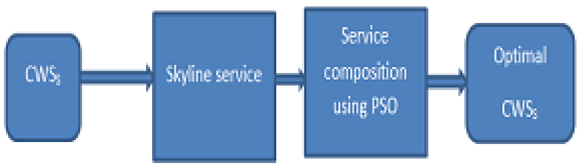
In this paper, we introduce our new Feature Selection and Data Reduction Method (FSDRM) to improve the classification accuracy and speed of the NNGE algorithm and to reduce the computational resource consumption. FSDRM provides the following functionalities: (1) it reduces the dataset features by selecting the most significant ones, (2) it reduces the NNGE's hyperrectangles classifiers. The experiments show that the FSDRM reduces the NNGE hyperrectangles by 29.06%, 37.34%, and 26.76% and improves the classification accuracy of the NNGE by 8.57%, 4.19%, and 3.78% using the Multi, Binary, and Triple class datasets respectively. Figure 1 shows the CPPS testbed that we used to test the FSDRM.

PUBLICATIONS AND PRESENTATIONS

[1] The 12th IEEE International Conference on Computer Engineering and Systems, date published on IEEE Explore: 01 February 2018.

ICSD: INTEGRATED CLOUD SERVICES DATASET

The service composition problem in cloud computing is formulated as a multiple criteria decision making problem. Due to the extensive search space, cloud service composition is addressed as an NP-hard problem. Using a proper dataset is considered one of the main challenges to evaluate the efficiency of the developed service composition algorithms. According to the work in this paper, a new dataset has been introduced, called Integrated Cloud Services Dataset (ICSD). This dataset is constructed by amalgamating the Google cluster-usage traces, and a real QoS dataset. To evaluate the efficiency of the ICSD dataset, a proof of concept has been done by implementing and evaluating an existing cloud service compositing approach; PSO algorithm with skyline operator using ICSD dataset. The experimental results show that the ICSD dataset has achieved a high degree of optimality with low time complexity, which significantly increases the ICSD dataset accuracy in cloud services composition environment. Figure 2 and 3 show the steps of the composition approach and the ICSD schema respectively.



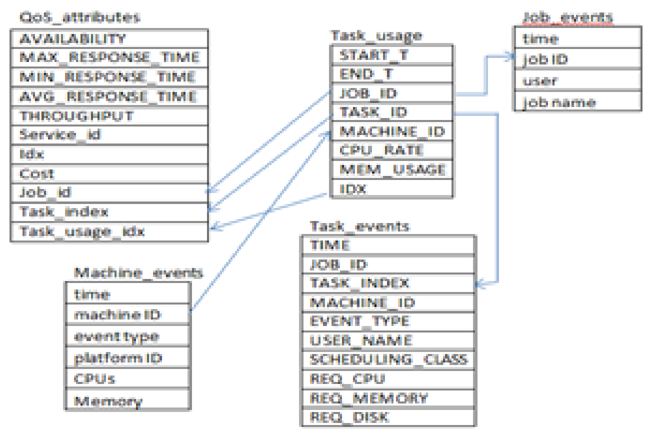


Fig.: 2 The PSO-skyline service composition approach

Fig.:3 ICSD Schema

PUBLICATIONS AND PRESENTATIONS

This paper was published in the Springer Lecture Note in Computer Science, ISBN 978-3-319-94471-5, https://doi.org/10.1007/978-3-319-94472-2. 14th World Congress on Services, June 25 – June 30, pp. 18-30. Held as Part of the Services Conference Federation, SCF 2018, Seattle, WA, USA.

For more information on Dr. Kholidy’s research please visit: http://acrlab.info/#/Director

Research funded by: SUNY Poly Seed Grant

GRAPHICS AND IMAGE PROCESSING RESEARCH LAB (GIPR)

DR. MICHAEL J. REALE

Scope: Research in Computer Vision, Computer Graphics, and Machine Learning, with an emphasis on Facial Expression Analysis and Deep Learning.

Goals: (1) Propose and develop new algorithms/architectures/approaches to detect and recognize facial activity (such as facial expression, eye gaze behavior, and gestures) in different data modalities, and integrate approaches into a unified, real-time recognition system. (2) Perform research to address challenging computer vision and computer graphics problems.

FACIAL EXPRESSION ANALYSIS AND DEEP LEARNING

The primary focus of this project is to correctly analyze facial expression behavior with deep learning approaches. This includes recognizing whole expressions (e.g., happiness, pain, confusion, etc.) and/or detecting FACS Action Units (which correspond roughly to muscle movements on the face). In recent years, deep learning has become a very popular tool for a variety of computer vision and image analysis tasks, including facial expression analysis. Specifically, convolutional neural networks (CNNs) have proven to be particularly effective, both in static 2D forms and dynamic 3D forms. Thus, we are concentrating on utilizing deep learning approaches.

In terms of data, we are focusing on analyzing 3D dynamic data. Dynamic information has been found to be critical for correctly identifying expression behavior, especially with subtle or short-lived expressions (i.e., “micro-expressions”). Three-dimensional data offer significant advantages over 2D data. For example, it is very challenging to correct for non-frontal head pose with only 2D information, whereas 3D information allows for the model to be rotated directly. Moreover, assuming the model has been captured correctly, illumination issues are non-existent with 3D information.

During the spring and fall 2018 semesters, I have had three graduate assistants working on problems related to this: one on Generative Adversarial Networks and the other two on 3D point cloud data extraction.

During the summer, I had two of my three Summer Undergraduate Research Program students working on the problem of 3D point cloud networks applied to facial expression analysis, and their poster was presented at both the Utica and Albany campuses.

Two other graduate students will also be working on these matters as part of their graduate project and thesis, respectively.

FUNDUS IMAGE SEGMENTATION AND ANALYSIS PROJECT

I have been collaborating with Dr. Andrea Dziubek and Dr. Edmond Rusjan from the mathematics department on a computer vision project they have been working on. The goals of the project are to perform image segmentation on the arteries and veins from fundus (back of the eye) images, build a 3D mesh of aforementioned arteries and veins, and perform analyses as well as simulations on this information.

Research funded by: Slocum-Dickson Foundation, SUNY Poly Seed Grant

For more information on Dr. Reale's research, please visit: https://web.cs.sunyit.edu/~realemj/

ENVIRONMENTAL ENGINEERING/SCIENCE

DR. CAROLYN RODAK

Scope: Exploration, management, and protection of environmental systems primarily though the quantification of risk.

Goals: Development of probabilistic risk assessment tools and methods to quantify risks to environmental systems. Field-based validation and use of novel contaminant detection methods.

MOHAWK RIVER WATER QUALITY

The Mohawk River supplies drinking water to several communities in upstate New York and provides a location for recreational activities throughout the region. Previous sampling campaigns of the Mohawk River have documented high levels of biological and chemical contaminants from combined sewer overflow (CSO) events and urban and agricultural runoff.

In the summers of 2016 and 2017, Dr. Rodak and several SUNY Poly students collected "high frequency" water quality data on the Mohawk River in Utica and Rome, NY in parallel with monthly citizen science sampling efforts throughout the Mohawk. These studies focused on the detection of two fecal indicator bacteria (FIB), E.coli and Enterococci, which are used to identify potential fecal contamination. The USEPA established the 2012 recreational water quality criteria (RWQC) as guidelines on FIB concentration thresholds for recreational water use based on illness rates at beaches with known human-sourced fecal contamination. When compared to recreational thresholds, the citizen science efforts demonstrated frequent FIB detection while the targeted sampling in Utica and Rome, NY highlighted spatial and temporal trends in bacterial counts such as increasing FIB counts as the water flows through the CSO dense infrastructure of Utica.

Figure 1: Mohawk River @ Barnes Ave sampling site following a major rain event in Utica, NY.

In 2016, Oneida county and the city of Utica began a $270 million expansion to increase capacity and reduce CSO events in the city of Utica. August 2018 marked the start of a DEC-funded SUNY Poly sampling effort in the Utica and Rome NY area to identify baseline conditions within the upper reach of the Mohawk River. The project, which also spans the summer of 2019, focuses on the collection of in-situ water quality metrics, such as pH, temperature, dissolved oxygen, and conductivity, as well as ELAP-certified laboratory measurement of total organic carbon, Nitrates and Nitrites, E.coli, and Enterococci. At the completion of the study, the data will be evaluated via standard statistical methods for field analysis as well as performance indicators of reliability, resilience, and vulnerability which provide a quantitative metric for communication of the frequency, duration, and severity of contamination events. Initial analysis of the data suggests sampling locations in Rome had high reliability and resilience indicating infrequent, short-term elevated microbial counts compared to those in Utica which had frequent, long-term, contamination events well above the recreational thresholds.

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[3] **Rodak C**., Abend T., and X. Wei. 2018. Mohawk River water quality: Trends and observations of bacterial indicators during the summer of 2017. In: Proceedings of the 2018 Mohawk Watershed Symposium, Union College, Schenectady, NY. Extended abstract Pg 54-59. https://www.researchgate.net/publication/323779749_Proceedings_of_the_2018_Mohawk_Watershed_Symposium_Union_College_Schenectady_NY_4_Mb

[4] Sweeney, Wanits, Townsend, Brabetz, Law, **Rodak**, Epstein, Liscomb, Shapley. 2018. A Series of Snap-shots: Data and observations from the Riverkeeper, SUNY Cobleskill, and SUNY Poly Mohawk River water quality project as it enters Year Four. In: Proceedings of the 2018 Mohawk Watershed Symposium, Union College, Schenectady, NY. Poster abstract Pg 76. https://www.researchgate.net/publication/323779749_Proceedings_of_the_2018_Mohawk_Watershed_Symposium_Union_College_Schenectady_NY_4_Mb

Research funded by: SUNY Poly Seed Grant, NYS Dept of Environmental Conservation (DEC)

ROBOT-ASSIST MICROFLUIDIC DEVICES & DATA CLUSTERING IN HEALTHCARE

DR. JIAYUE SHEN

Scope: Development of microfluidic sensors for robotic-assisted minimally invasive surgery (RMIS) applications, flexible electronics, wearable sensors, heterogeneous viscoelastic materials and data clustering in healthcare.

Goal: (1) Development of microfluidic tactile sensors for exploring Robotic-assisted Minimally Invasive Surgery (RMIS) applications (pathology study of costal cartilages, tumor diagnoses, cardiorespiratory monitoring), and conducting the analytical, and experimental study of micromechanics critical for the performance of the microfluidic tactile sensors and biomechanical properties of biologics. (2) To explore the application of data clustering in healthcare.

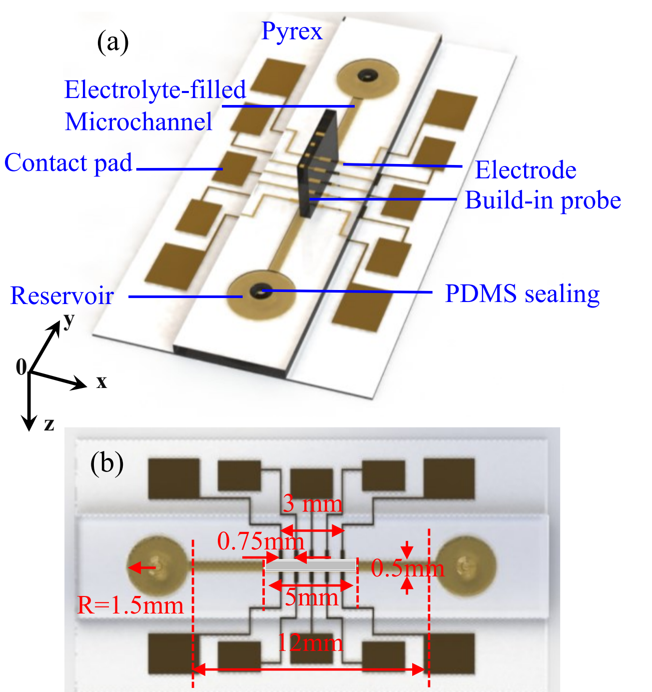

Fig.1 Schematics of a distributed-deflection sensor with a built-in probe: (a) 3D configuration; (b) Top view with key dimensions.

ROBOT-ASSIST MICROFLUIDIC TACTILE SENSOR ON PATHOLOGY STUDY OF COSTAL CARTILAGES

Collaborators: Zhili Hao, Ph.D., Michael Stacey, Ph.D., Yichao Yang, Ph.D., and Xavier-lewis Palmer, Old Dominion University

Goal: (1) To design a simple tactile sensor for measuring curved surface of chest cavity (CC) exterior; (2) To characterize and compare mechanical properties of healthy porcine CC exterior and cross-section; (3) To characterize the mechanical properties and structure-function relation of PE/PC CC and discover the pathogenesis of PE/PC.

This research is funded by an NSF grant. To obtain the true mechanical properties of costal cartilages (CC) with curved surfaces, the CC exterior needs to remain intact and thus retains a curved surface in most cases. To date, with the advancement of micro/nano-fabrication technology, although flexible tactile sensors have also been explored for mechanical measurement of objectives with curved surfaces, they require new materials and complex fabrication technology for achieving higher conformity to a curved surface, which increase the cost and prevent the wildly implement. Thus, as shown in Fig.1, I designed a distributed- deflection sensor with a built-in probe by conventional fabrication protocols and common materials for accommodating the curved surface of CC exterior and extracting its true mechanical properties. A theoretical analysis of the key design parameters of the sensor and the built-in probe is carried out, with costal cartilage tissues as the example of a soft tissue with curved surface.

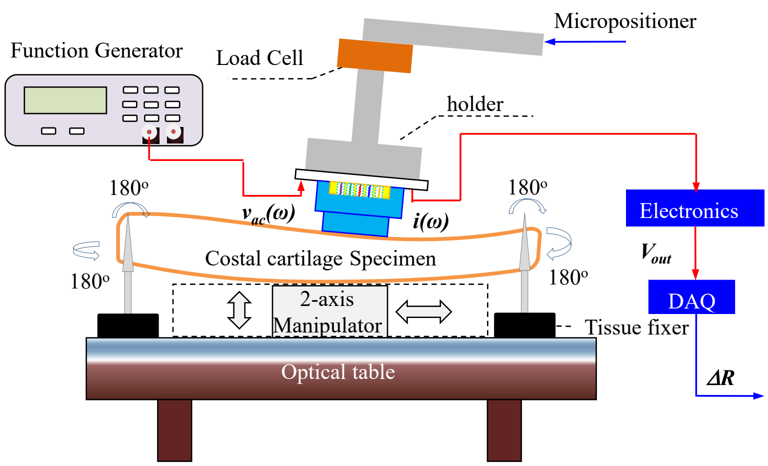

Fig. 2. Schematic of experimental setup

Most tests focus on characterizing the mechanical properties of CC cross-section and require deconstructing the CC specimens into disks in the literature. So it is interesting to test the mechanical properties of healthy porcine CC exterior without deconstruction. In this research, the designed tactile sensor is integrated with a robotic system to mimic the working condition when it is assembled with microsurgery tools as depicted in Fig.2 and allow measuring the specimens with their whole thickness which is a critical feature for in field applications. Since most results in the literature are from the cross-section of CC, the corresponding porcine CC cross-sections are also examined by the tactile sensor for correlating the measured mechanical properties with those of CC exterior and providing a comparison with the results in the literature. The measured results of porcine CC exterior serve as a guideline.

Currently, the two most common types of chest wall deformity, sunken chest (pectus excavatum, PE) and pigeon chest (pectus carinatum, PC), an incidence of 1/300~1/1000 live births, are known to arise from the disorder of CC. The biological composition and structure of human healthy and PE/PC costal cartilage are now well known, but the structural analyses at all scale-level have failed to identify a significant difference between healthy and diseased CC. Although currently one study examined the mechanical behavior of human PE CC and found weakened mechanical stability of PE CC as compared with healthy CC, the exact cause of PE/PC still has not been well understood. Basically, the main leading hypotheses for the pathogenesis of PE: a biomechanical weakness caused by developmental disorder which may be induced by insufficient collagen and proteoglycans (PG). Therefore, by characterizing the mechanical properties of PE/PC CC exteriors and comparing the measured results with the CC biological compositions and structures, the same tactile sensor integrated robotic system is used for revealing the pathogenesis of PE/PC.

PUBLICATIONS AND PRESENTATIONS

[1] **Jiayue Shen**, Michael Stacey, and Zhili Hao. "A Distributed-Deflection Sensor With a Built-In Probe for Conformal Mechanical Measurements of Costal Cartilage at Its Exterior Surface." IEEE Sensors Journal 18.2 (2018): 822-829.

WEARABLE DEVICES ON CARDIORESPIRATORY MONITORING USING ARTERIAL PULSE SIGNALS

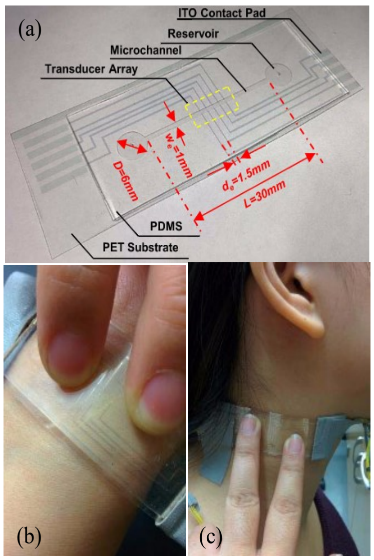

Fig. 3. (a) Sensor configuration (b) sensor measurement on radial and (c) carotid pulse.

Collaborators: Zhili Hao, PhD, and Dan Wang, Old Dominion University

Arterial pulse waveforms are intimately associated with the physiological conditions of the whole cardiovascular system for early diagnosis and optimized treatment of patients with cardiovascular diseases (CVDs). To date, although quite a few arterial tonometric devices have been developed for arterial pulse waveform measurement, these tonometric devices are unsuitable for wearing with relative comfort and for an untrained individual to use at home.

To address this issue, we have developed a wearable flexible distributed-deflection sensor for an untrained individual to measure his arterial pulse waveforms as illustrated in Fig. 3. Built on a flexible plastic substrate, the low-cost sensor incorporates a Polydimethylsiloxane (PDMS) microstructure embedded with an electrolyte-enabled transducer array, which allows an untrained individual to easily align the sensor above an artery for its pulse measurement. The measured tonometric parameters of measured radial and carotid pulse waveforms on the subjects are consistent with the related findings in the literature. The measured PWV and radial and carotid AI of the subjects show good agreement with how they should vary with age, gender, and hypertension.

PUBLICATIONS AND PRESENTATIONS

[1] Wang, Dan, **Jiayue Shen**, Lanju Mei, Shizhi Qian, Jiang Li, and Zhili Hao. "Performance Investigation of a Wearable Distributed-Deflection Sensor in Arterial Pulse Waveform Measurement." IEEE Sensors Journal 17, no. 13 (2017): 3994-4004.

APPLICATION OF DATA CLUSTERING METHODS AND ALGORITHMS IN HEALTHCARE

Collaborators: Weiru Chen, Jared Oliverio, Jin Ho Kim, and Yufei Xing, Old Dominion University

Data clustering is one of the most important steps in data mining. With data clustering, mining on the reduced data set should be more efficient yet produce quality analytical results. Data clustering could play a critical role in the healthcare area, which could benefit the hospitals, doctors, pharmacists, and patients. However, there is little research and analysis by using data clustering methods and algorithms in the healthcare industry. Thus, data clustering and knowledge discovery can generate various applications in healthcare. To improve the efficiency and accuracy of data mining, modeling and simulation of different data clustering methods for data mining with big data are studied and compared first. Then these methods and algorithms are extended to the healthcare application. Centroid-based Clustering, Distribution-based Clustering, and Density-based Clustering are discussed, mainly, k-means, EM, and DBSCAN are utilized to conduct modeling and simulation for the data set of healthcare. The results illustrate and indicate the notable usage of data clustering in healthcare. Fig. 4 shows the trend of cancer deaths from 2000 to 2015.

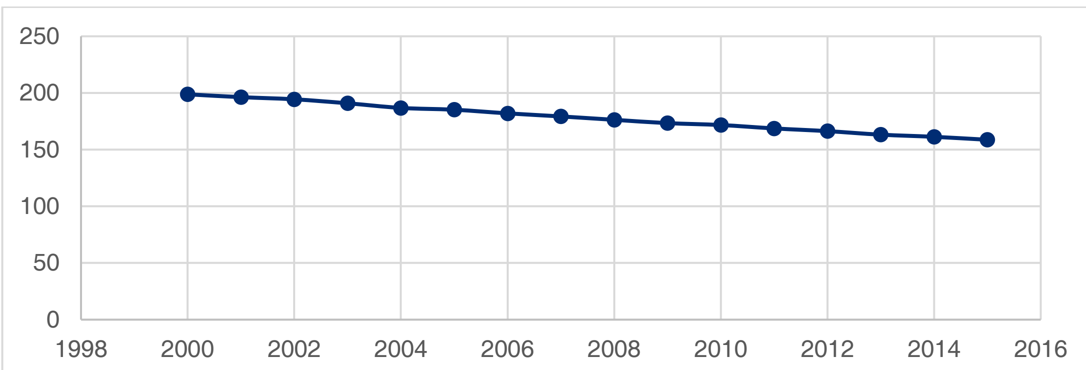

Fig 4. Trend of Cancer Deaths from 2000 to 2015

PUBLICATIONS AND PRESENTATIONS

[1] Weiru Chen, Jared Oliverio, Jin Ho Kim, and **Jiayue Shen**. "The Modeling and Simulation of Data Clustering Algorithms in Data Mining with Big Data." Journal of Industrial Integration and Management. Accepted September 2018.

OPERATION RESEARCH AND DATA MINING IN TRANSPORTATION PLANNING AND MANAGEMENT

XIA (SARAH) YANG, PH.D.

Scope: To analytically model multimodal transportation network evacuation for the purposes of planning and improving efficiency for noticed emergencies; to apply advanced data mining technology to assist transportation operation and management by identifying transportation patterns or behaviors.

Goals: The effectiveness and efficiency of traffic and transportation operations, management, planning, and policy decisions can be significantly guided and improved, if we can better model the traffic flow dynamics and discover the underlying patterns and interactions of the transportation system. My research interests and expertise have been mainly focused on transportation network modeling and optimization, data mining and machine learning, urban freight transportation, and connected/autonomous vehicles. My short term research goals include: (1) developing a systematic framework on intelligent evacuation planning and management, access restoration, and emergency recovery; (2) identifying the hidden behaviors, patterns, and theories in transportation and urban development using cutting-edge technology such as deep learning; (3) developing models or theories to promote smart urban freight transportation. All these areas will target the interface of mobility, safety, land use, sustainability, and resilience in multimodal transportation systems.

DYNAMIC BUS SCHEDULE OPTIMIZATION FOR MULTIMODAL EMERGENCY EVACUATION

In the era of connected and autonomous vehicles, all vehicles could be systematically guided for the system benefits during emergency evacuations. While currently practitioners adopt the peak-hour bus schedules in major cities such as NYC, we can dynamically optimize the bus schedules to improve evacuation efficiency. In this research, I have formulated the dynamic system optimum (DSO) model as an integer problem with linear constraints and will further test the model with numerical experiments.

PUBLICATIONS AND PRESENTATIONS

[1] **Yang X**., Ban J. and J. Mitchell, 2018. Modeling multi-modal transportation network evacuation considering users' cooperative behavior. Transportation Research Part A: Policy and Practice 114B, 380-397

[2] **Yang X.** (speaker), He X.Z., and J. Ban, 2018. Bus Schedule Optimization for Multimodal Emergency Evacuation. The 7th International Symposium on Dynamic Traffic Assignment (DTA): Smart Transportation, Hongkong.

[3] **Yang X.,** Hwang F.J., He X.Z., and J. Ban, 2018. Dynamic bus schedule optimization for multimodal emergency evacuation, working paper to be submitted to Transportation Research Part E.

OVERSIZE DETECTION IN RAIL FREIGHT TRANSPORTATION

As oversize loading could lead to severe consequences in rail freight transportation, oversize detection is a critical step in rail freight transportation. While traditional manual oversize detection is inefficient, the state-of-the-art technology laser detection is highly expensive. In this research, we propose a new method based the cutting-edge computer vision technology Mask-RCNN to identify different oversize levels in rail freight transportation, which would be far more efficient than manual detection and much cheaper compared with laser detection.

PUBLICATIONS AND PRESENTATIONS

[1] **Yang X**., Sun Z.B., Ban J. and J. Holguín-Veras, 2014. Urban Freight Delivery Stop Identification Using GPS Data. Transportation Research Record: Journal of the Transportation Research Board, Transportation Research Board of the National Academics, Washington, D.C.

[2] Liu S., Luo Y., **Yang X**.* (speaker), and L. Du. Oversize Load Detection in Rail Freight Transportation: a Method Based on Mask R-CNN, 2018 INFORMS Annual Meeting, Phoenix.

[3] Liu S., Luo Y., **Yang X**.*, and L. Du. Oversize Detection in Rail Freight Transportation: a Method Based on Mask R-CNN, working paper to be submitted to IEEE Transactions on Intelligent Transportation.

ALTERNATIVE TRAVEL MODE TO AIRPORTS FROM THE UTICA AREA

Motived by the inconvenience of residents traveling from the remote Utica area to nearby airports, proposing an alternative mode, which is more convenient and cost effective, will significantly help the local residents including faculties, staff, and students. In this research, we first study the travel behaviors and preferences to airports of residents from the Utica area using survey data, and then propose an alternative travel mode. The study results could be transferred to other similar remote cities and pilot study could be conducted in future study.

For more information on Dr. Yang's research, please visit: https://sunypoly.edu/faculty-and-staff/xia-sarah-yang.html

X-INFINITY RESEARCH GROUP

XInfinity

DR. BRUNO ANDRIAMANALIMANANA
DR. CHEN-FU CHIANG
DR. SAM SENGUPTA
DR. JORGE NOVILLO
DR. ALI TEKEOĞLU
DR. KORKUT BEKIROĞLU
DR. MICHAEL REALE

Scope: Our team consists of researchers with diverse backgrounds including; computer science, mathematical modeling, quantum computing, cryptography, computer vision and cybersecurity. Scope of our interdisciplinary research encompasses three main fields; (I) Blockchain Research, (II) Machine Learning and Artificial Intelligence, (III) Post-Quantum Cryptography. In each of these areas, we are developing and implementing novel and innovative approaches to improve state-of-art. Particularly, the scope of Blockchain research so far has been on improving performance of transactions in Distributed Ledger systems, by investigating and exploring efficiently operational architectures. Machine Learning/AI Research started off with developing methods for intrusion/anomaly detection in cloud hyper-visors. Quantum Cryptography research is focusing on review and improvement of post-quantum cryptographic algorithms and methods that would replace the current cryptographic algorithms in presence of super-fast quantum computers.

Goals: Our research goals for these three areas can be summarized as follows: (I) Identify a normative semi-synchronous delivery architecture model with performance better than IOTA-Tangle. Implementation of the proposed model and deployment on SUNY campuses for purposes such as secure and safe student information archival, secure voting for school related surveys, automation of school processes with smart-contracts on blockchain. (II) To explore and investigate the process of Anomaly Detection, and Intrusion Detection using new Information Theoretic frameworks. (III) To explore and investigate Lattice based cryptography deemed to be quantum resistant.

Four papers introducing and outlining a new model architecture were presented at two international conferences both sponsored by IEEE. Student member presented his Master’s project [5]. One ML workshop paper submitted to an IEEE conference, pending review.

BLOCKCHAIN RESEARCH

To keep a distributed ledger system at its optimal performance, it is necessary to utilize the resources and avoid latency in its network. To achieve this goal, dynamically and efficiently injecting the unverified transactions to enable synchronicity based on the current system configuration and the traffic of the network is crucial. To reduce latency and provide optimization, we offer [1, 2, 3, 4] a distributed ledger architecture, Tango, that is based on the Iota-Tangle distributed system. We model periodic pulsed injections into the evaluation layer from the entry layer, as shown in Figure 1. To meet this need, we introduced four protocols: Decentralized Semi-synchronous Pulse Diffusion (DSPD) protocol [4], Pulsed Injection of Transactions into the Evaluation Corridor (PITEC) protocol [3], Pulsed Transaction Injection Parameterization (PTIP) protocol and Verification Performance Optimizer (VPO) protocol [1]. The DSPD Protocol lays out the roles of the participants in the network and introduces the diffusion mechanism for the controllers to provide semi-synchronicity to the system. The diffusion speed is dependent on the p2p network performance. The PITEC Protocol simulates the inventory system by estimating the optimal pulse injection size to be released for the verifiers at each periodic cycle in order to keep the system's performance. The PTIP protocol regulates the injection volume based on the performance from previous verification cycle. The VPO takes the capacity of the verifiers pool as a constraint to optimize for various house policies. We observed that under property construction of the system, we can refine the parameters to integers such that dynamic programming to offer us a pseudo-polynomial complexity to solve this NP-hard optimization problem.

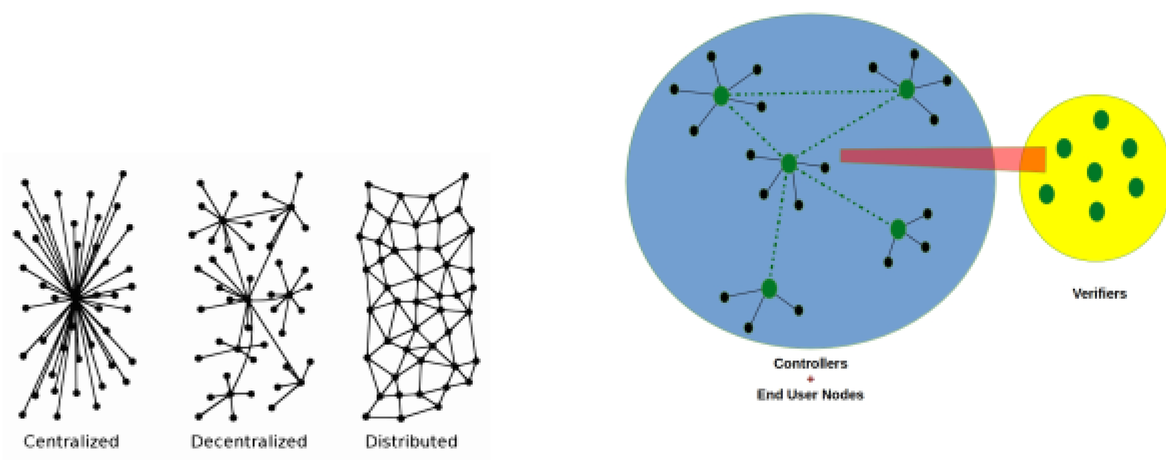

Figure 1: (left) Centralized, Decentralized vs Distributed Computing. (right) Proposed model of verifiers, controllers and end-user nodes.

Future work: Further latency reduction, Tango system simulation, optimization

MACHINE LEARNING/AI RESEARCH

Intrusion Detection systems for Cloud Hypervisors are vital due to the amount of Virtual Machines that would be affected in a possible compromise. A Cloud Hypervisor orchestrates, manages many Virtual Machines, and their central role in cloud computing made them a target for the attackers. Intrusion detection has been mostly relied on signature-based detection of malicious behavior. However, when a new type of attack occurs it will not have a signature in the Intrusion Detection system's database. In those cases, behavior based anomaly detection produces better results in detection. In this work, we have started with a data-set provided by University of Victoria's ISOT lab, which includes 2 weeks of logs, including network packet captures; memory dumps; disk, memory, CPU usage statistics; and more. The proposed method of anomaly detection only used vmstat and iostat command output generated on the cloud hypervisor, and developed algorithms to detect anomalies, which indicates attacks. For anomaly detection, we have evaluated values in the data set in a sliding time window, where for each window a KL value is calculated and compared to the three previous windows, as shown in Figure 2. Our team open-sources the developed and implemented methods for anomaly detection [6] [7].

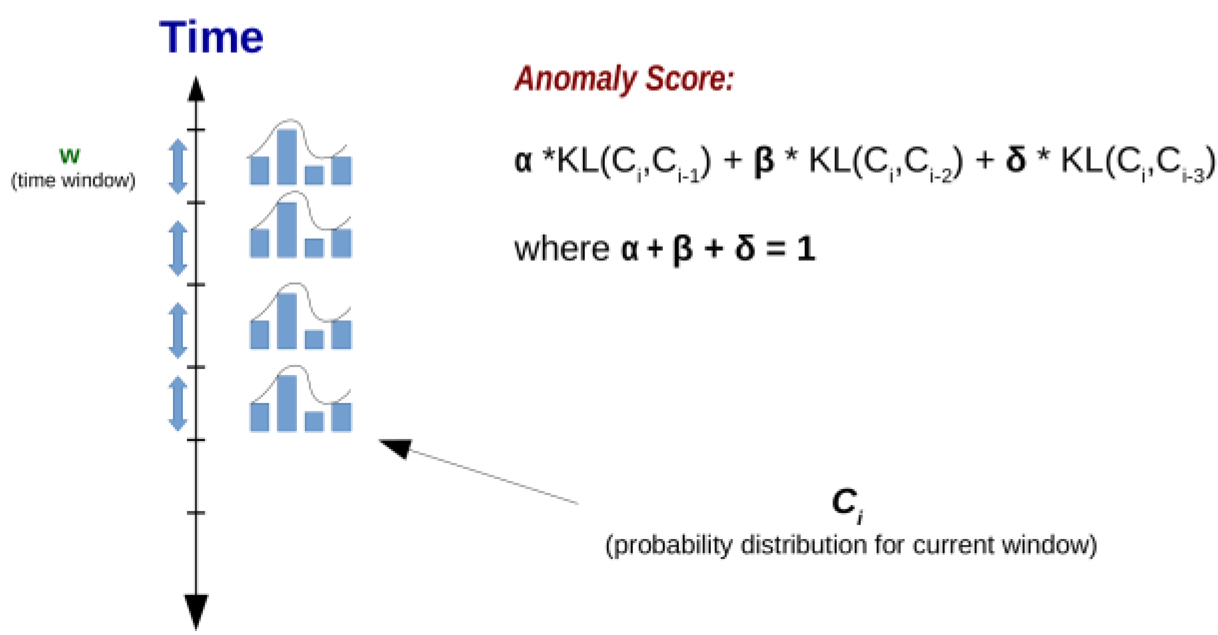

Figure 2: Proposed method of anomaly score calculation

POST-QUANTUM CRYPTOGRAPHY RESEARCH

Cybersecurity has become a necessity for today's digital world. Cryptography has played an extremely critical role in cybersecurity for defending the privacy and integrity of the data. However, with recent advances in quantum technologies, it is likely quantum computers will break many existing commonly used cryptosystems. Post-quantum cryptography is cryptography under the assumption that the attacker has a large quantum computer; post-quantum cryptosystems strive to remain secure even in this scenario. It is known that hard instances of NP-complete problems cannot be solved "exactly" and "efficiently" by quantum computers. There are many candidate problems, such as shortest vector problem and closest vector problem in a lattice system that can be further designed and used for post-quantum cryptography. This relatively young research area has seen some successes in identifying mathematical operations for which quantum algorithms offer little advantage in speed, and then building cryptographic systems around those. The central challenge in post-quantum cryptography is to meet demands for cryptographic usability and flexibility without sacrificing confidence. We are exploring and investigating Lattice (Figure 3) based cryptography, which is deemed to be quantum resistant. Research continues in this area.

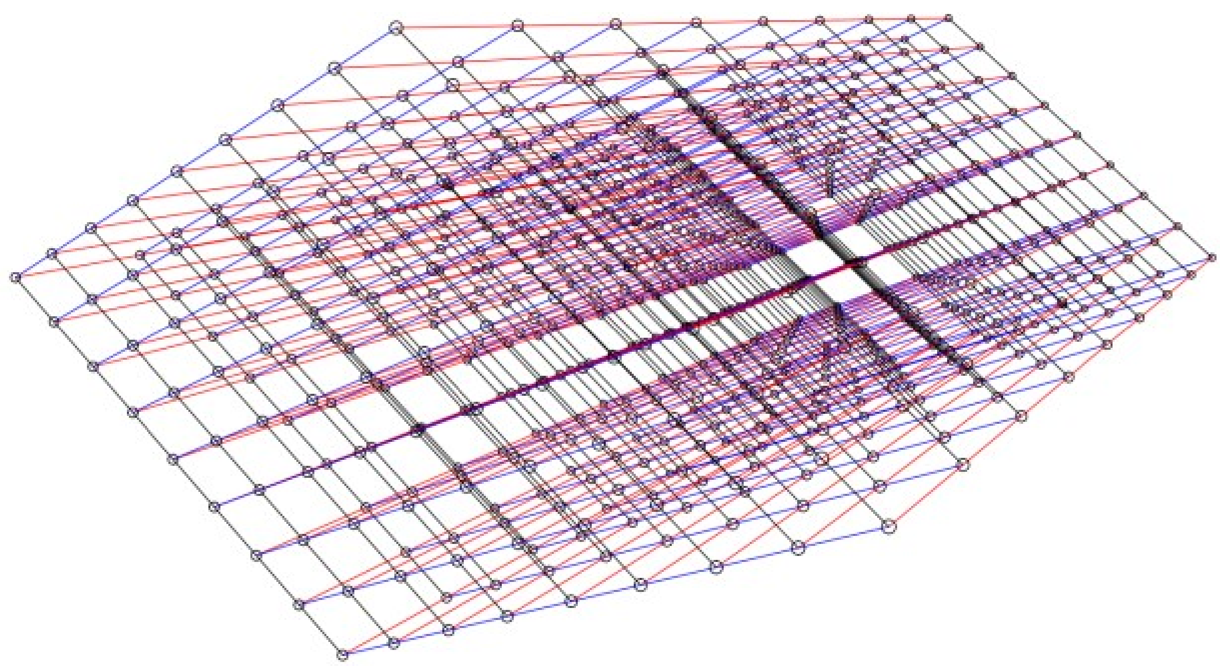

Figure 3: Perspective view of a 9_9_9 subset of a non-orthogonal three-dimensional lattice. Lattice-based cryptography hides a point in a high-dimensional lattice mod q by making small changes to all coordinates. Code-based cryptography hides a point in a very-high-dimensional lattice mod 2 by changing some coordinates.

PUBLICATIONS AND CONFERENCES

[1] Bruno Andriamanalimanana, Chen-Fu Chiang, Saumendra Sengupta, Jorge Novillo and Ali Tekeoglu, \Parameterized Pulsed Transaction Injection Computation Model And Performance Optimizer For IOTA-Tango" 13th Int.Conf.on P2P, Parallel, Grid, Cloud and Internet Computing. Taiwan, October 27-29, 2018.

[2] Bruno Andriamanalimanana, Chen-Fu Chiang, Saumendra Sengupta, Jorge Novillo and Ali Tekeoglu, \Semi-Synchronocity Enabling Protocol and Pulsed Injection Protocol For A Distributed Ledger System" 13th Int.Conf.on P2P, Parallel, Grid, Cloud and Internet Computing(3PGCIC). Taiwan, October 27-29, 2018.

[3] Bruno Andriamanalimanana, Chen-Fu Chiang, Saumendra Sengupta, Jorge Novillo and Ali Tekeoglu, \A Probabilistic Model of Periodic Pulsed Transaction Injection", The 2nd Cyber Security In Networking Conference (CSNet'18), Paris, France, October 24-26, 2018.

[4] Bruno Andriamanalimanana, Chen-Fu Chiang, Saumendra Sengupta, Jorge Novillo and Ali Tekeoglu, \Tango: The Beginning - A Semi-Synchronous Iota-Tangle Type Distributed Ledger with Periodic Pulsed Entries", The 2nd Cyber Security In Networking Conference (CSNet'18), Paris, France, October 24-26, 2018.

[5] Ibraheem Aljamal, Master of Science in Computer Science Final Project, \Hybrid Intrusion Detection System Using Machine Learning Techniques in Cloud Computing Environments", presented December 2018.

For more information, please visit, X-Infinity Research Group Website
http://www.cs.sunyit.edu/~chiangc/xinfinity/

Machine Learning Methods for Anomaly Detection in Cloud Hypervisors:
https://github.com/aliteke/mlintrusiondetection

College of Health Sciences

ADVERSE CHILDHOOD EXPERIENCES

DR. JOANNE JOSEPH
(RESEARCH PARTNER: DR. RONNI TICHENOR)

Scope: Dr. Joseph's research focuses on the areas of Family (Power/Abuse) Dynamics, Early Childhood Trauma, Resiliency and Physical and Mental Health Outcomes

Goals: The goals of Dr. Joseph's research are two-fold. (1) Examine links between Adverse Childhood Experiences (ACEs) and bullying as well as pregnancy complications/outcomes, and (2) Recommend new interventions/policy initiatives to: Reduce bullying behavior, and ameliorate the negative effects of ACEs on physical and mental health.

ACES AND BULLYING

Researchers Partners: Ronni Tichenor, Joseph and Robert Yeh

This project utilizes three waves of data from the TAP (Teen Assessment Project) Survey, distributed to youth in Oneida and Herkimer County to examine the links between ACEs in the home and bullying behavior at school. We also examine family, school, and community factors as potential moderators of the impact of ACEs on bullying. In 2018 we refined the theoretical model and recruited a faculty partner to assist with additional statistical analyses.

ACES AND PREGNANCY COMPLICATIONS

Researchers Partners: Ronni Tichenor, Joseph and James R. Tichenor, Jr.

This project examines the impact of ACEs on pregnancy complications and outcomes, working with a local physician as our research partner. We also examine the impact of social support as a potential moderating factor. In 2018 we sought a site for data collection and recruited medical students as research assistants. Data will be collected at the Hobart Street Clinic in Utica, NY.

R4K (READY FOR KINDERGARTEN) PARTNERSHIP: SPEARED HEADED BY UNITED WAY

Research Partners: Joanne Joseph, Ronni Tichenor, and Dan White, Siena College

Scope: Kindergarten Readiness/Academic Success; Physical and Mental Health; Family Well Being

Goals: Expand the Family-School Navigator (FSN) Model in Central New York, to (1) improve school readiness; (2) improve academic performance; (3) improve mental, physical, and behavioral health outcomes for children; (4) improve family functioning.

EXPANSION OF FSN MODEL IN CENTRAL NEW YORK UNDER THE HEALTH HOMES INITIATIVE

The FSN model seeks to connect families and children to early screening and intervention for mental, physical, and behavioral health services for children, working through the local school districts and partnering with BOCES and Central New York Health homes. The R4K initiative has targeted a number of state and federal grants in the last few years to bring this partnership to additional school districts. Drs. Joseph, White, and I provided expertise in conceptualizing the model and designing the evaluation plan.

SERVICE BASED LEARNING, MULTIDISCIPLINARY COLLABORATION AND HEALTH

Research Partners: Joanne Joseph, Daniel Jones and Lorin Williams

Goals: Develop an ecosystem to promote multidisciplinary minors and research designed to promote technological interventions for health care issues.

Poster Presentation: Using Service Based Learning and Interdisciplinary Collaboration to Create and Assess the Impact of Technology APA's Technology, Mind & Society Conference American Psychological Association, April 4 2018.

- Poster presentation at the American Psychological Association's Technology, Mind & Society Conference in Washington, D.C.
- Presenting on a pilot course that integrated service based learning, social humanitarian engineering, and interdisciplinary collaboration.
- Community & Behavioral Health and Mechanical Engineering and Technology majors worked together to create assistive technology for a local not-for-profit organization.

Research funded by: Central NY Care Collaborative, US Dept of Education, and US Dept of Health and Human Services

SIBLING ABUSE

DR. VERONICA TICHENOR

Scope: Dr. Tichenor's research focuses primarily on the dynamics of abuse and power in the family.

ADVERSE CHILDHOOD EXPERIENCES

Scope: Dr. Tichenors research focuses on how Adverse Childhood Experiences (ACES) affect the family dynmaics concerning power and abuse, as well as patient physical and mental health outcomes.

Goals: The goals of this research are two-fold. First, examine links between Adverse Childhood Experiences (ACEs) and bullying as well as pregnancy complications/outcomes, and (2) Recommend new interventions/policy initiatives to: Reduce bullying behavior, and ameliorate the negative effects of ACEs on physical and mental health.

ACES AND BULLYING

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Research funded by: Central NY Care Collaborative, US Dept of Education, and US Dept of Health and Human Services

College of Nanoscale Science and Engineering

NANOBIOSCIENCE & ENGINEERING

DR. NATHANIEL CADY

Scope: My research group focuses on the unique interface between nanotechnology and biology. Our research falls into the following two general categories. In our first approach, we draw knowledge from biological systems to enable unique nanotechnologies, and to improve our abilities in engineering, processing and manufacturing. In our second approach, nanoscale phenomena, technologies or processes are used to study biology at its fundamental level – the nanometer length scale and below. In this approach, nanoscale devices, materials, or phenomena can be harnessed for therapeutics, diagnostics, medicine, pharmaceuticals, and many other biological applications.

Goals: Our over-arching goals are to develop cutting-edge nanotechnologies for biological research and employ biological principles for developing novel nano-devices.

RESISTIVE MEMORY FOR NEUROMORPHIC AND RAD-HARD APPLICATIONS

We have established a long-term research program focused on resistive memory devices (aka: memristors or ReRAM). These metal-insulator-metal (MIM) devices can function like neural synapses, as their "memory state" depends on the current and voltage history of the device. This is a good example of bioinspired/ biomimetic research, since the biological process of synapse formation is mimicked by a physical, electronic device. We have previously developed ReRAM as both non-volatile memory (NVM) elements, as well as devices to control the reconfigurability of CMOS circuits (for encryption applications). Our work supported by the Air Force Research Laboratory (AFRL) is focused on integrating memristors with CMOS circuits for neuromorphic computing applications, in collaboration with faculty at the University of Tennessee – Knoxville (Profs. Garrett Rose, James Plank, and Mark Dean - http://neuromorphic.eecs.utk.edu/). In this work, memristors serve as "synapses", literally encoding the synaptic weight between neural connections in the circuits. To date we have developed a hybrid 65nm CMOS/memristor hybrid chip design and have fully developed a process flow in the SUNY Poly 300mm fabrication facility. This work has greatly expanded our ability to demonstrate fully hybrid CMOS/memristor circuits, and is a launching pad for follow-on projects. We are also working on an NSF-sponsored program with Prof. Sumit Kumar Jha (University of Central Florida - https://sumitkumarjha.com/) to utilize arrays of ReRAM for non-Von Neumann computing approaches. This work uses ReRAM arrays to do so-called "flow computing" in which computations are performed as data flows through the processing architecture.

For our ReRAM fabrication efforts, we have been able to achieve close to 100% yield 1T1R cells with significantly lower cell-to-cell variability by optimizing deposition conditions for the HfO2 switching layer of ReRAM cells. These 1T1R cells were also investigated for high temperature retention up to 100 °C and long-term endurance, exhibiting excellent endurance of up to 1 billion switching cycles with an average Roff/Ron ratio of 10:1. We have also performed full wafer measurements of ReRAM cells showing excellent consistency for threshold voltages and resistance values across full 300 mm wafer. We are currently working on developing theoretical models for understanding switching and conduction mechanisms in depth for RRAM wafers with different process splits which would eventually allow us reducing inherent stochasticity of memristor device performance. This will improve reliability of these devices and make the amenable to larger scale integration with complex CMOS circuits and processors.

In addition to developing memristors for neuromorphic applications, we are also working on memristors for radiation hardened (rad hard) applications, with a specific focus on tantalum oxide-based devices. This work has been supported by NASA, through their graduate research fellowship program (which funds my graduate student, Joshua Holt). Our work in this area has enabled partnerships with the Jet Propulsion Laboratory and Sandia National Labs. It also represents a novel area of research for my group, particularly in the realm of radiation testing/exposure for nanoelectronic devices. As part of this effort, we have developed resistive memory devices that are resistant to all but the most extreme radiation environments, which should be of interest for space exploration and other rad-hard applications.

Beyond the projects mentioned above, we have ongoing efforts to characterize the switching mechanism of our devices, to better enable modeling and simulation of memristors in complex circuits. We are also investigating methods (both fabrication methods and testing methods) that reduce the stochastic nature of memristor device performance. This will improve reliability of these devices and make the amenable to larger scale integration with complex CMOS circuits, processors, etc.

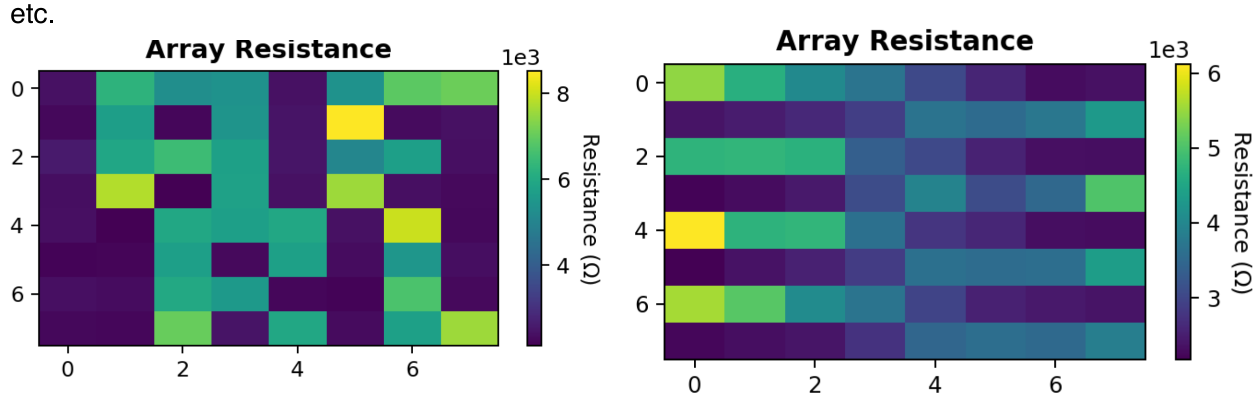

Fig 1: Example of an 8x8 one-transistor/one-ReRAM (1T1R) array designed by the Cady group and fabricated in a hybrid 65 nm CMOS process at the SUNY Poly 300mm foundry. The array was programmed (set) with two different current compliance levels to form the AFRL logo (left). The array was then programmed (set) with a gradient of current compliance levels, according to the intensity of each pixel in a greyscale image (right). This image demonstrates the multi-level / analog capabilities of our 1T1R cells.

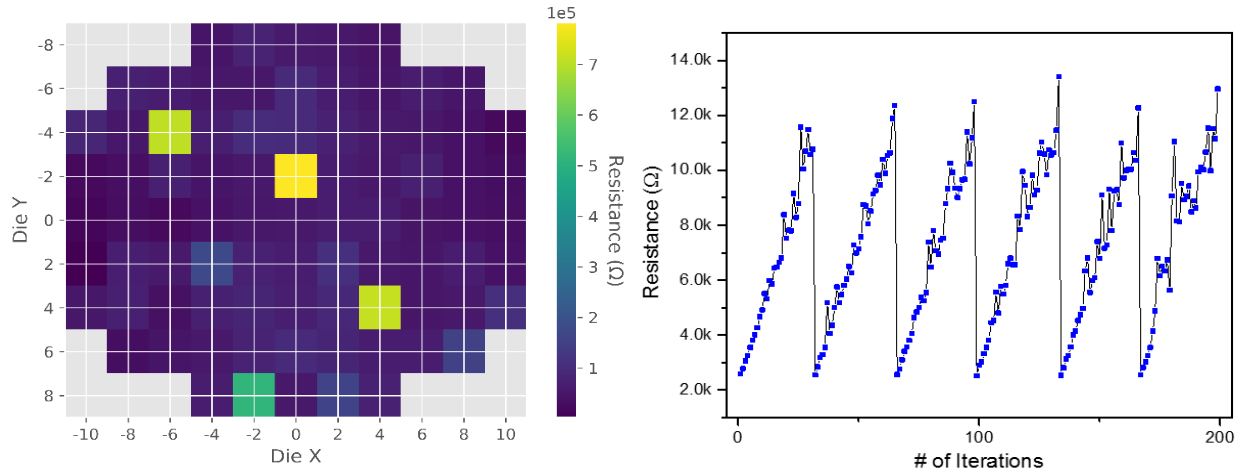

Fig 2: Full 300 mm wafer map of 1T1R ReRAM performance is shown on the left (fabricated in the SUNY Poly 300 mm foundry). The map shows the range of high resistance state (HRS) values measured for devices across the entire 300 mm wafer. The image on the right shows pulse-based setting of incremental resistance values for 1T1R cells. These data were obtained using ultra-short 1.5 ns pulses at -1.3 V.

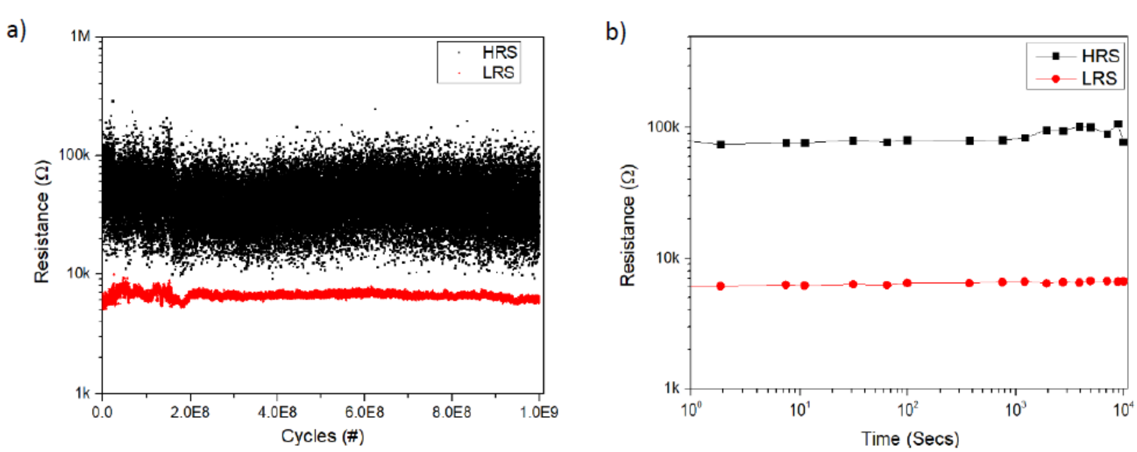

Fig 3: a) Endurance measurement for 1T1R cell for up to 1 billion switching cycles, and b) HRS and LRS retention up to 10^4 seconds at 100°C.

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[1] J. Hazra, M. Liehr, K. Beckmann, C. Hobbs, M. Rodgers, **N.C. Cady**. Impact of Organic and Chlorine Based ALD Precursors on Hafnium Dioxide Based Nanoscale RRAM Devices. The 61st Electronic Materials Conference (EMC), Michigan, USA, 2019.

[2] K. Beckmann, N. Suguitan, J. Van Nostrand, **N.C. Cady**. Interface Modification of HfO2-based ReRAM via Low Temperature Anneal. Submitted to Semiconductor Science & Technology, April 2019. Reviewed, under revision.

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BIOSENSORS & MICROFLUIDICS

In 2019 we have expanded our work on biosensors, primarily for the diagnosis of Lyme disease, which is caused by bites from ticks infected with the bacterium Borrelia burgdorferi. Diagnosis of this infection is currently expensive, time consuming, and non-quantitative. Working with our partners at Ciencia Inc. and the NYS Dept. of Health, we are developing a Lyme disease assay and platform that is based on grating coupled surface fluorescent plasmonics (GC-FP). We have been able to positively detect Lyme infection in human serum samples (as compared to gold-standard testing methods, such as ELISA and Western blot analysis). We have also shown that our assay (and assay platform) can be used in a prognostic manner, to monitor the response to antibiotic treatment for Lyme disease. An example of how the system operates, and some sample results are shown in Figure 4, below.

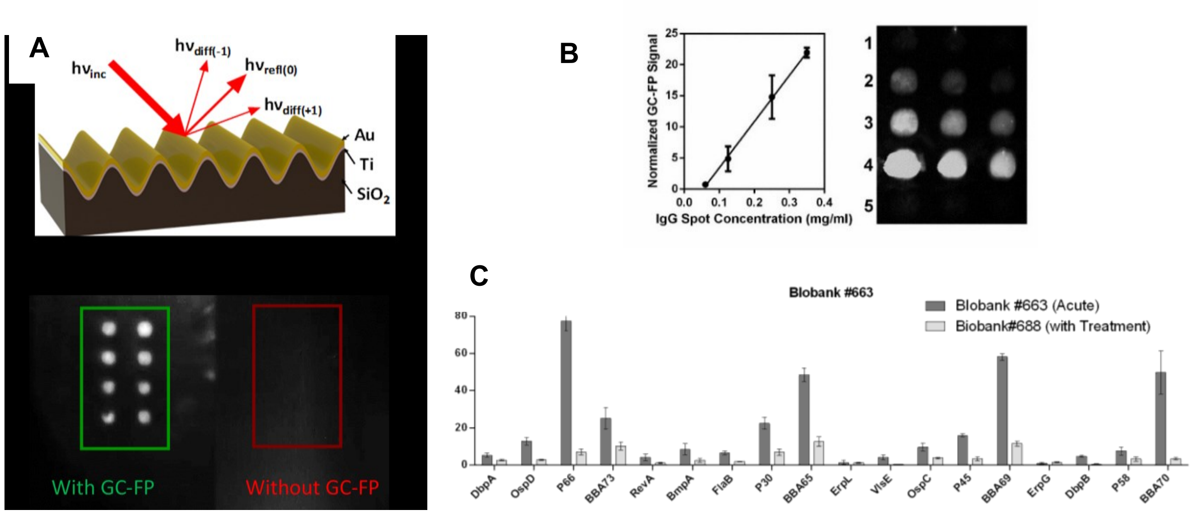

Figure 4: A) The principle of grating-coupled fluorescent plasmonics (GC-FP) for biosensing. Sensor chips have a periodic grating structure coated with a thin layer of gold that enables plasmonic coupling and fluorescent enhancement at the chip surface. The bottom panel shows that only grating-based surfaces enable fluorescence enhancement. **B)** An example of determining protein (in this case IgG) concentration on a chip surface using GC-FP. **C)** GC-FP detection of antibodies in human blood samples, showing the ability to quantify an acute response to Lyme disease, vs. reduction of antibody titer after treatment of Lyme disease (samples from the Lyme Disease Biobank).

In 2019 we expanded our work on microfluidics under the AIM Photonics program, in collaboration with University of Rochester and Ortho Clinical Diagnostics (OCD). Our goal is to develop a manufacturable approach to fabricate microfluidic chips and integrate these chips with photonic biosensor elements. In 2018 year we used a high volume manufacturing compatible process (hot embossing) to fabricate microfluidic chips from cyclic olefin based polymer (TOPAS™). We have successfully integrated these microfluidic chips with silicon-based photonic sensor chips via a chip stacking and bonding process. In addition to working with microfluidic chips that require active component such as pumps, we also worked on passive microfluidics where fluid is transported through the chips via capillary forces. Since capillary flow requires the surface of the microfluidic chips to be hydrophilic, we investigated effect of different treatments and their longevity of hydrophilicity. Examples of work from this effort are shown in Figure 5.

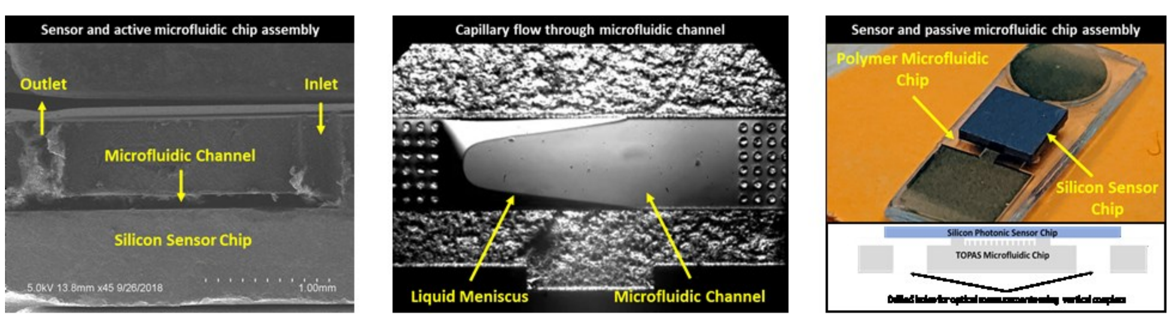

Fig 5: Microfluidic components for silicon-photonic biosensor chips. These components were fabricated using a hot embossing method, using cyclic olefin based polymers (eg. TOPAS). Embossed components can be stacked and bonded together for multi-level fluidics. In addition, we are exploring passive microfluidics, including micropillar-filled channels that can transport fluids to optical detector components without using pressure-driven flow.

This year we also began working on a collaborative project with Albert Einstein College of Medicine (AECOM), in which we are developing an microfluidic intravital window (MFIW) that will be used to deliver drugs, biomolecules, and other fluids to tumors in vivo, while performing microscopic imaging studies. The key challenges in this project are maintaining fluidic integrity of the devices, controlling fluid flow / fluid delivery, and understanding the diffusion / delivery profile on the interior of the organism being studied. We have utilized a lithographic approach to fabricate SU-8 based microfluidic components on ultra-thin glass substrates. Examples of the devices and simulations of the fluid diffusion profile are shown in Figure 6.

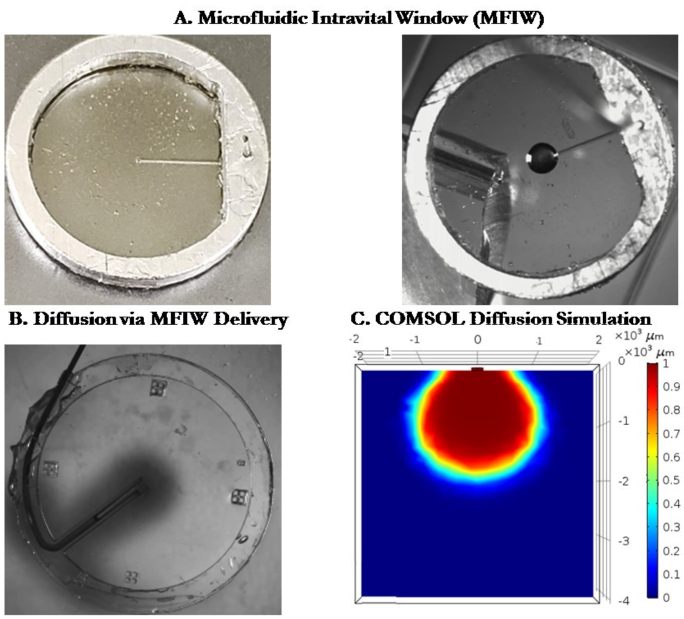

Fig 6. A) An example of a microfluidic intravital window (MFIW) for extended observation of drug delivery in vivo. B) Diffusion of dye through an 1% agarose gel informs early modeling of drug delivery in vivo, using COMSOL multi-physics simulations (C).

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Research funded by: AFRL, NASA, Albany Nutraceuticals, NSF, NYSTAR

For more information on Dr. Cady's research, please visit: https://sunypoly.edu/research/nano-bio.html

MATERIALS SCIENCE, CHARACTERIZATION, AND METROLOGY OF NANOSCALE MATERIALS AND STRUCTURES

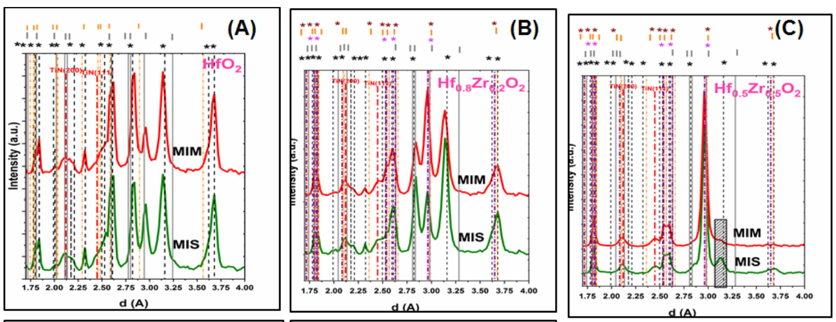
DR. ALAIN C. DIEBOLD

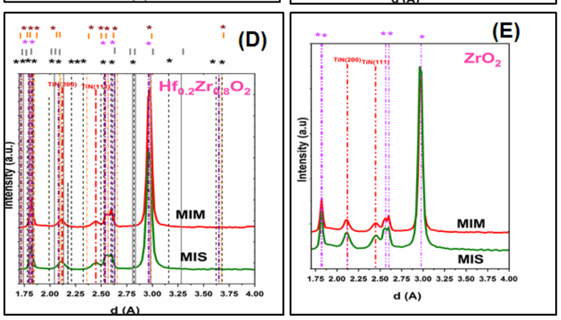
Scope: The Diebold group works in all areas of characterization, metrology, and materials science of nanoscale materials and structures. Through collaboration with CNSE partners, measurement is used to advance R&D into new device materials and structures. Example topical areas associated with integrated circuits include lithography, transistor, and interconnect metrology. The group also works on 2D materials such as graphene and transition metal dichalcogenides and materials with topologically protected properties such as Bi2Se3. Measurement methods frequently used by the group include spectroscopic ellipsometry, scatterometry, photoluminescence, second harmonic generation, high resolution X-Ray diffraction, X-Ray reflectivity, transmission electron microscopy, X-Ray photoelectron spectroscopy, and ion beam analysis.

Goals: Measure and understand the properties of materials and structures at the Nanoscale.

MULTI-METHOD APPROACH TO DETERMINING THE PHASE AND TEXTURE OF CRYSTALIZED HF-OXIDE BASED HIGH K

Collaborative research covering the characterization of high K – metal gate stacks with TEL Technology Center America continued in 2018. In the last decade, Hafnia based high dielectric constant materials have been in use in the advanced CMOS technology. To continue the device scaling and enhance gate dielectric performance beyond the 10nm technology node, crystal engineering and mixing of Hafnia based dielectrics with ZrO2, SiO2 and alumina are attracting significant attention due to their higher K-value, lower leakage current and reduced equivalent oxide thickness. Discovery of ferroelectric behavior in this material have led to attractive applications such as negative capacitance field effect transistors and memory devices. The phase of the thin films changes with the concentration of Zr, overall thickness of the hafnia-zirconia films, annealing and the presence of metal layers above the film as shown in Figure 1. The crystal phases of ultra-thin films are difficult to measure as there are mixtures of different structures in these films. Synchrotron based grazing incidence in-plane X-ray diffraction (GIIXRD) and X-Ray texture studies provided key results in 2018. As the composition changes from 0% to 100% ZrO2, it is found that stack's properties changes from ferroelectric to anti-ferroelectric as shown in Figure 2. Emergence of ferroelectricity in these stacks is attributed to the non-centrosymmetric orthorhombic phase. Currently we are using a combination of extended x-ray absorption fine structure spectroscopy (EXAFS) as shown in Figure 3 and GIIXRD to estimate the percentage content of the dominant phases present in these stacks. A couple of manuscripts are in preparation based on these results. Complementarily, we use the Titan TEM and piezo-response force microscopy (using the AFM) at CNSE for studying the interface structures and ferroelectric signatures. This work is based on experiments done at CHESS supported by NSF and NIH/NIGMS under the NSF award DMR-1332208 and used 6-BM, of the NSLS II, a U.S. DOE Office of Science User Facility operated for the DOE Office of Science by BNL under Contract No. DE-SC0012704.





(F)

Compos.	Stack Type	M %	Non-m %
HfO2	MIM	0.73	0.27
	MIS	0.81	0.19
Hf0.8Zr0.2O2	MIM	0.57	0.43
	MIS	0.75	0.25
Hf0.5Zr0.5O2	MIM	0.07	0.93
	MIS	0.14	0.86

Fig 1. : Summary of the GIIXD comparison data of MIM and MIS samples of the same compositions. Green plots are MIS stack while red plots correspond to MIM stacks. (A) HfO2 (B) Hf0.8Zr0.2O2 (C) Hf0.5Zr0.5O2 (D) Hf0.2Zr0.8O2 (E) ZrO2. The symbols on top of each plots corresponds to the different structural phases identified in these stacks. Black star (*) corresponds to P21/c; m-phase; Grey letter (I) – Orthorhombic Pnma; Magenta star (*) corresponds to P42/nmc; t-phase; Orange letter (I) – Orthorhombic Pbca; Purple star (*) corresponds to Pca21. One symbol may indicate one or a host (multiplicity) of peaks. Figure from https://doi.org/10.1557/adv.2019.148

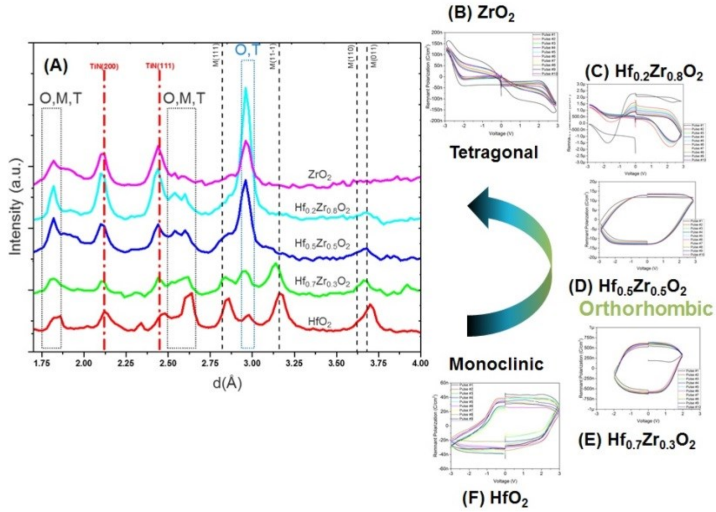


Fig 2: Summary of the GIIXD and PUND measurements of HZO samples as MIM stacks. (A) GIIXD overlay of pure hafnia, Hf0.7Zr0.3O2, Hf0.5Zr0.5O2, Hf0.2Zr0.8O2 and pure Zirconia. Here the symbols on top correspond to different structural phases as explained in Figure 2 caption. PUND measurements shown in (B) pure Zirconia (C) Hf0.2Zr0.8O2 (D) Hf0.5Zr0.5O2 (E) Hf0.7Zr0.3O2 (F) pure hafnia.

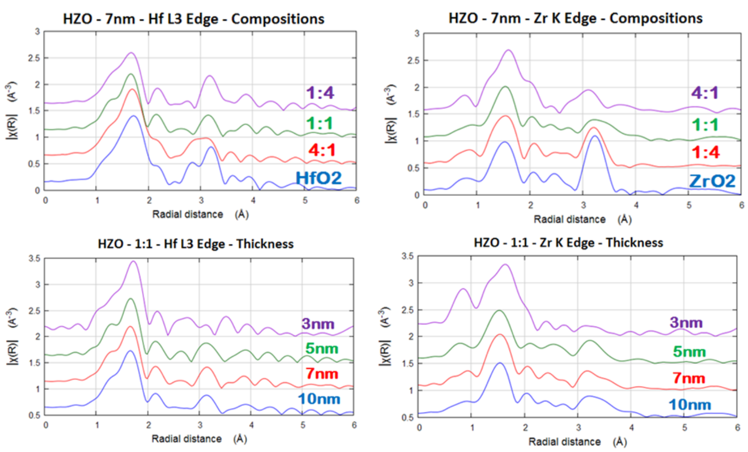


Figure 3. : Summary of the EXAFS comparison data of MIM of different compositions and thicknesses. Here 4:1, 1:1 and 1:4 corresponds to Hf0.8Zr0.2O2, Hf0.5Zr0.5O2, and Hf0.2Zr0.8O2 respectively.

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[1] Structural correlation of ferroelectric behavior in mixed hafnia-zirconia high-k dielectrics for FeRAM and NCFET applications, V. Mukundan, K. Beckmann, K. Tapily, S. Consiglio, R. Clark, G. Leusink, N. Cady, **A.C. Diebold**, MRS Advances (2019), pp 1-17. https://doi.org/10.1557/adv.2019.148

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MEASUREMENT OF 3D NANOWIRE FET STRUCTURES USING MUELLER MATRIX SPECTROSCOPIC ELLIPSOMETRY AND CD-SMALL ANGLE X-RAY SCATTERING

New Gate-All-Around (GAA) transistors especially Nanosheet (NS) FETs and Nanowire (NW) FETs are being considered for end of the roadmap semiconductor devices by the semiconductor industry due to their superior electrical performance and unique channel properties. However, characterization of nanoscale materials properties, 3D structure shape, and 3D critical dimensions remains an open challenge that requires path finding. This project is researching and developing the ability of two advanced characterization methods: Mueller Matrix Spectroscopic Ellipsometry (MMSE-Satterometry) and CD-SAXS (Critical Dimension Small Angle X-Ray Scattering) for this challenge.

Scatterometry can be applied to measurement of the 3D shape and dimensions of periodic arrays of non-crystalline materials (e.g., polymers) polycrystalline, and crystalline materials such as semiconductor fin arrays. The most typical form of scatterometry uses traditional spectroscopic ellipsometry. Here we use a more capable Mueller Matrix ellipsometer. In that way, cross-polarized light scattering can be used to measure feature shapes.

CDSAXS uses a high energy X-Ray beam to diffract from a period sample or grating structure. Two modes of operation are possible: reflection and transmission. CDSAXS can be applied to periodic arrays of non-crystalline polymers such as photoresist or crystalline semiconductor fin arrays.

These methods have been applied to state of the art nanowire structures used to fabricate Nanowire FETs. In 2018, graduate student Madhulika Korde simulated the characterization of Nanowire Test Structures (NWTS) advancing new optical models and assessing their capability for measuring three-dimensional changes in these structures. Using a Nanowire Test Structure (NWTS) shown in Figure 4, an optical model was developed and using the Rigorous Coupled Wave Approximation to simulate MMSE-scatterometry data. In 2019, experimental measurement of these structures will be reported and published. A critical and previously unmet challenge for these structures was measurement of sub-surface etching of the SixGe1-x layers. The progression of the SixGe1-x cavity etch as well the shape of the hole and the nanosheet thicknesses were successfully simulated as demonstrated through the Mueller matrix elements that showed high sensitivity to changes in the amount of etch and the shape of holes. Additionally, preliminary CD-SAXS (Critical Dimension Small Angle X-Ray Scattering) results were obtained. A schematic diagram of the CD-SAXS measurement is shown in Figure 5. We compare CD-SAX data for samples having varying amounts of etch. As observed from the experimental data collected at the APS at the Argonne National Laboratory, diffraction fringes from the etched and unetched samples are significantly different, showing a clear change in peak intensities, peak positions and peak spacing vs selective etch of SixGe1-x. This is shown in Figure 6. The preliminary simulations show that the shape predicted for these structures along the X and Y cross-sections, represents a simplified version of the actual shape and this model will be further refined with more detailed simulations. Hence, we can conclude that CD-SAXS measurements can be effectively used to predict the amount of undercut in NWTS structures. Consequently, the capability of both techniques: MMSE scatterometry and CDSAXS to measure the dimensions of subsurface features of NWTS has been demonstrated.

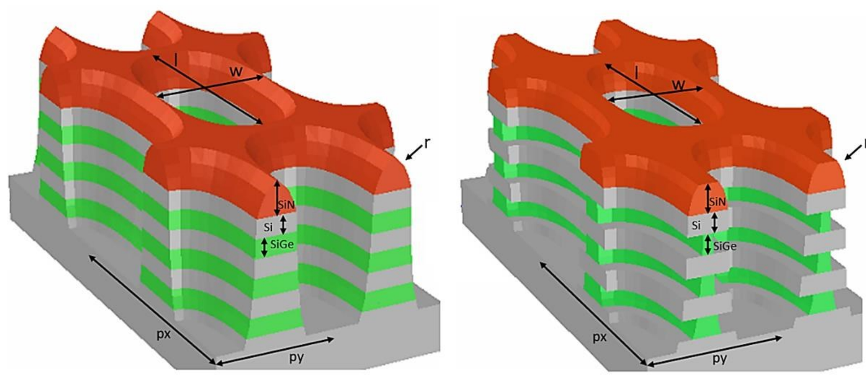

Figure 4. A 3D rendering of the optical model for NWTS before and after selective etching of the SiGe layers is shown before and after etch.

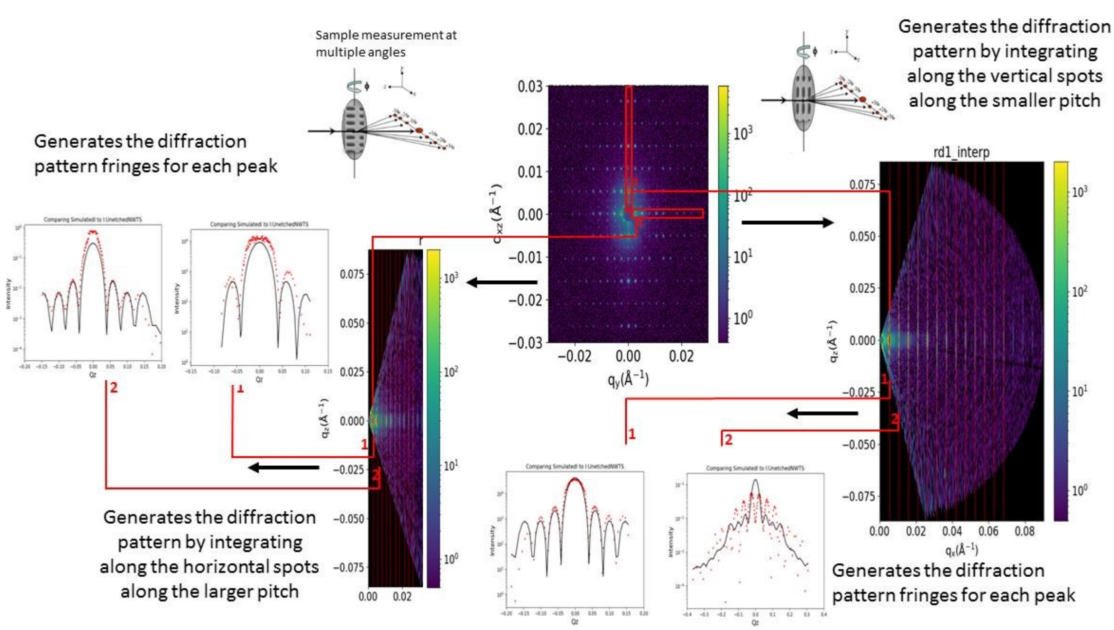

Figure 5. Diagram of the CD-SAXS measurement showing the origin of the reciprocal space scattering data. Figure from M. Korde.

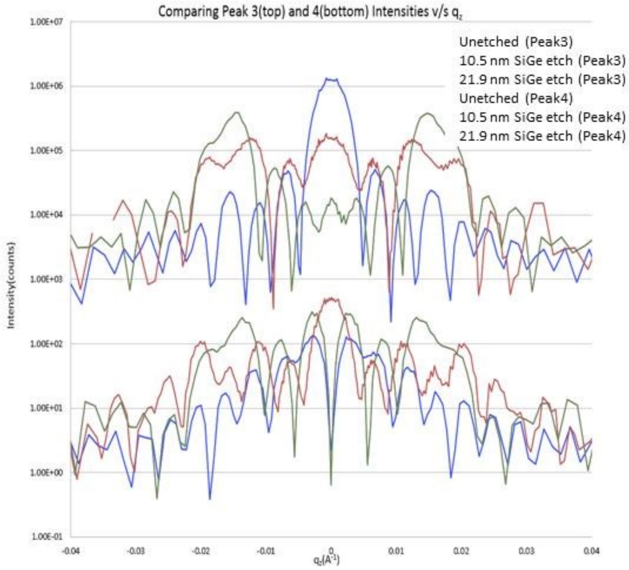

Figure 6. CD-SAXS data demonstrating the ability to observe subsurface etching of SiGe.

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OPTICAL AND ELECTRICAL PROPERTIES OF 2D MATERIALS

Research into the optical and electrical properties of 2D materials continued in 2018. Interpretation of spectroscopic ellipsometry data from optically uniaxial materials is relevant to measurement of transition metal dichalcogenides and many other materials that display topological properties. Publications should be available in 2020.

Research Funded by: Semiconductor Research Corporation, Nanoelectronics Research Corporation, TEL.

For more information on Dr. Diebold's research, please visit: https://sunypoly.edu/research/optical-physics.html

DUNN RESEARCH GROUP

DR. KATHY DUNN

Scope: Uncovering relationships between crystalline defects and chemical inhomogeneities in advanced materials using photons, electrons and ions.

Goals: Manipulate crystalline defects to improve performance and tailor functionality in ceramics, alloys, and composites.

NANOMATERIALS ENGINEERING FOR CHEMICAL MECHANICAL PLANARIZATION

The Chemical Mechanical Planarization (CMP) process in the semiconductor manufacturing flow is important for avoiding defects of the final products. Furthermore, the particles in the CMP slurry are the most important sub-material for maintaining wafer surface quality through both chemical and mechanical effects in polishing. The Dunn group explores how nanoparticle size, size distribution and surface chemistry change with use conditions, and how these changes impact the removal rate and surface quality of the polished wafer. New metrics for gauging the overall 'health' of the slurry have been developed, and are being exploited to design new slurries for better performance and longer usable life, to reduce the cost of consumables in the CMP process.

Manipulating valence states of particle cations

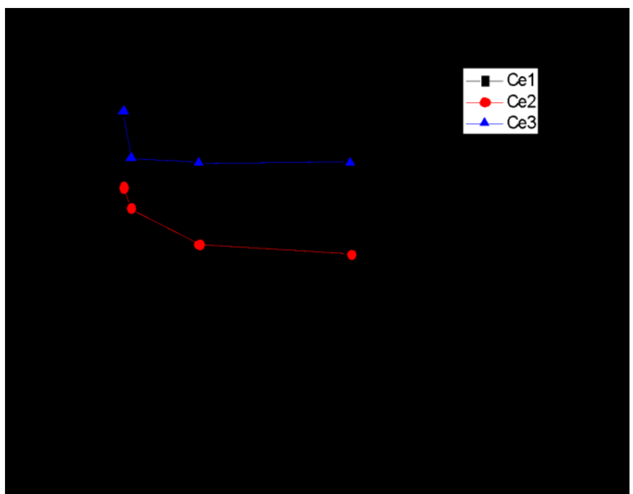

Figure 1. The presence of an oxidizer in the slurry does not always result in high Ce4+ concentrations.

Ceria nanoparticles have been used for polishing glass lenses since the 1930's. Since the introduction of the 65 nm node in 2006, ceria has been embraced by the semiconductor industry as the abrasive of choice for CMP of thermal silicon oxides after shallow trench isolation. This choice was driven by ceria's high removal rate of oxides and its high selectivity for polishing oxides over nitrides. The origin of these properties was detailed by Cook in 1990, where he describes how ceria participates in both chemical and mechanical removal of silica. In this model, the normal bulk cation state Ce4+ may be replaced, at the particle surface, by a certain percentage of Ce3+ cations which can bind oxygen.

This oxygen undergoes a condensation reaction with oxygen on the substrate surface leading to removal of silicates as the particle leaves. While physical properties such as particle size or synthesis method can change the ratio of Ce3+ to Ce4+ on the surface of the particle, we are pursuing chemical means including oxidative environment and the use of surfactants to control the 3+/4+ ratio (see Figure 1). Recent results demonstrated that optimizing this ratio leads to high removal rates of silicon oxide while simultaneously decreasing wafer surface roughness, two features which do not usually co-occur. These results were presented at the spring meeting of the Materials Research Society and have been submitted for peer to review in *the ECS Journal of Solid State Science and Technology.*

Reuse of silica slurry

The success of CMP operations is defined not only as an improvement in the removal rate and surface roughness, but also the minimization of the variation in these quantities across a wafer surface and among different batches. In most cases, these quality variations arise from deterioration of CMP consumables (pads, conditioner, and slurry). In particular, the slurry is typically exchanged after only 106 seconds of use, to forestall the creation of scratches and other asperities on the surface. The particles' behavior is typically investigated by Dynamic Light Scattering (DLS), Scanning Electron Microscopy (SEM) or Transmission Electron Microscopy (TEM). DLS can analyze the size of scattering centers in solution, but these may be agglomerates of multiple particles and may not accurately reflect the individual particle size diameter and the size distribution because agglomeration is affected by the concentration of solvent and surfactants. In contrast, measuring particles in solution is difficult in either SEM or TEM because of the vacuum conditions required for these instruments; even with specialized encapsulated liquid cells, imaging is still difficult due to the Brownian motion of the particles in liquid. Dried samples for EM do offer unparalleled visualization of individual particle sizes, but cannot offer information about their behavior in the liquid. Hence, DLS and EM each offer only a limited understanding of the slurry particles, if used in isolation.

On the other hand, using these techniques in tandem (see Fig. 2, below), offers a clearer picture of both the individual particle shapes and sizes (SEM) as well as their agglomeration behavior in the liquid (DLS). In particular, for the slurry seen in Fig. 2, the particles display two distinct populations, a fact which is not obvious from the DLS results. The difference between the population averages from DLS and SEM, and how that number changes with reuse, offers more insight than any one technique alone. In particular, we find that this new metric, the Agglomeration Level (AGL) is strongly correlated with both the removal rate and the surface roughness (Fig. 3), which are only weakly correlated to average particle size in a bimodal population such as this slurry contains. These results have recently been submitted for peer review to the *Journal of the Electrochemical Society.*

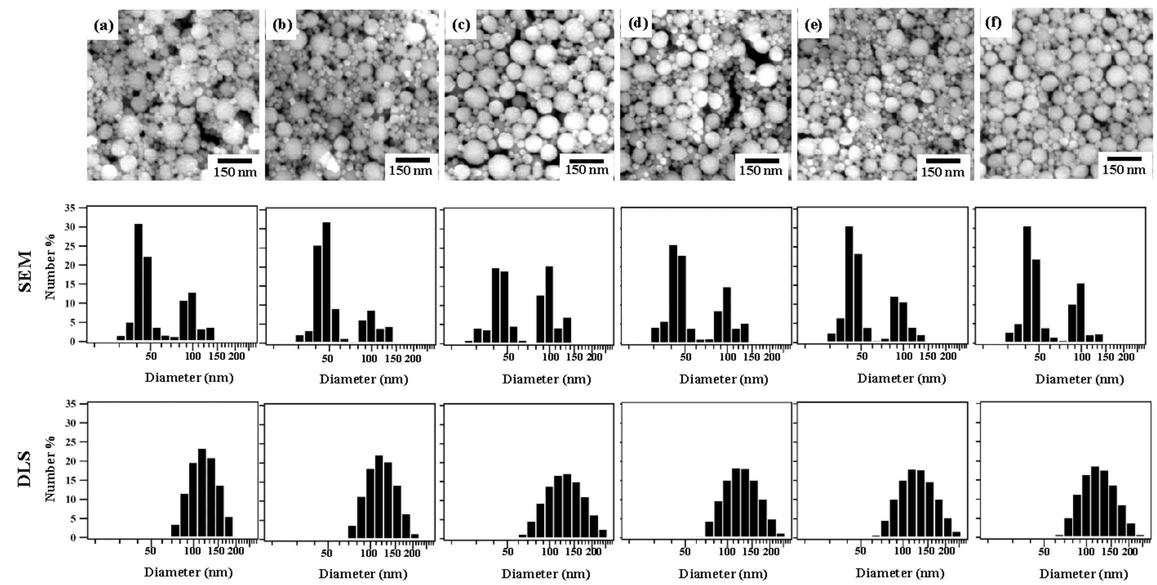

Figure 2: SEM micrographs, size distributions analyzed by SEM image, and size distributions analyzed by DLS at (a) 0 H, (b) 0.5 H, (c) 5H, (d) 8H, (e) 10 H, (f) 12 H.

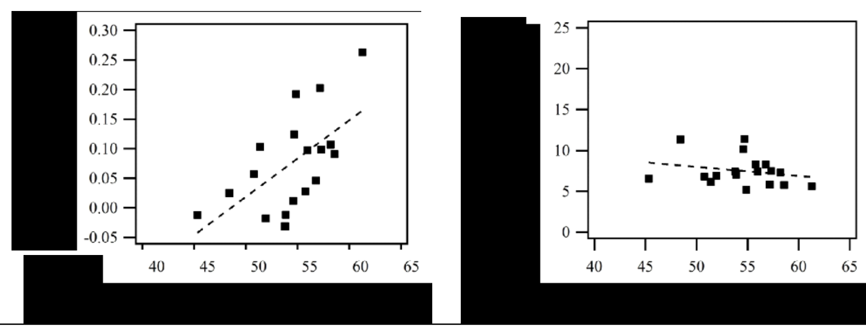

Figure 3. Removal rate and surface roughness are both strongly correlated with agglomeration level.

ADDITIVE NANOMANUFACTURING USING A CHARGED PARTICLE BEAM

The ability to manipulate and alter matter at length scales approaching atomic is critical for enabling many high-risk, high-payoff nanotechnology applications in Additive Nanomanufacturing, Plasmonics and Biomedicine. Focused Electron Beam Induced Deposition (FEBID) is a direct-write technique capable of producing three-dimensional structures with high spatial resolution, high placement fidelity, and the flexibility to deposit on non-planar surfaces. The Dunn group is pursuing two remaining Achilles' heels of FEBID: low growth rates and low purity of the deposited material.

Cryogenically assisted FEBID

Traditional FEBID employs a gaseous precursor adsorbing onto a surface, such that growth occurs in a material-starved regime limited by the arrival of fresh precursor gas. The Dunn group employs a unique custom-built cryogenic stage for FEBID, and previously demonstrated the growth in this case is reaction-rate limited, yielding growth rates 4-5 orders of magnitude higher than conventional FEBID. The exposure process was modeled by Monte Carlo simulations of electron-condensate interactions, which were used to develop fabrication schemes for three-dimensional self-supporting structures with incorporated gaps, for example. Recently, we have been collaborating with the Spolenak group at ETH Zürich to determine the mechanical properties of cryo-EBID structures using nano-indentation and compression testing; a high-aspect ratio pillar for the latter test is shown in Fig. 4. A manuscript is in preparation for submission to the journal Small.

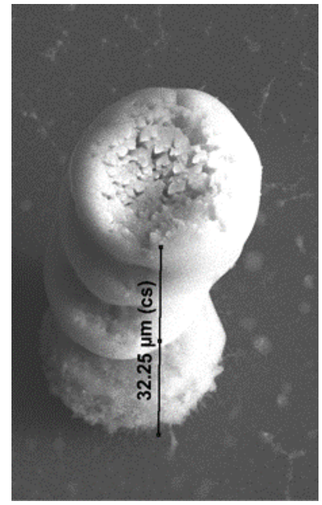

Fig. 4. High aspect-ratio pillar for nanocompression testing, made in four cryo-EBID cycles.

Athermal purification of deposits

While FEBID offers superb resolution and design flexibility, the deposited material is not pure metal, instead retaining fragments of the precursor molecule. Previous work by the Dunn group has shown that the typical precursor MeCpPtMe3, when used in ALD or CVD chambers result in films which are 98% pure Pt, but only 20% Pt when grown by FEBID. The Pt is concentrated in small nanoparticles embedded in a carbonaceous matrix, as shown in Fig. 5. Purification of the "platinum" deposits is necessary to enable applications such as site-specific direct-write of electrical contacts to nanostructures, high resolution photomask repairs, and the creation of tips for field emission and conductive atomic force microscopy. The prevailing composite microstructure limits the conductivity of FEBID structures to a percolation-type conduction, rather than the more desirable metallic behavior. Metal content as high as 85% has been achieved using ex situ annealing in oxidizing atmospheres, for example, but this often leads to loss of shape fidelity because a significant proportion of the mass is removed and the features distort.

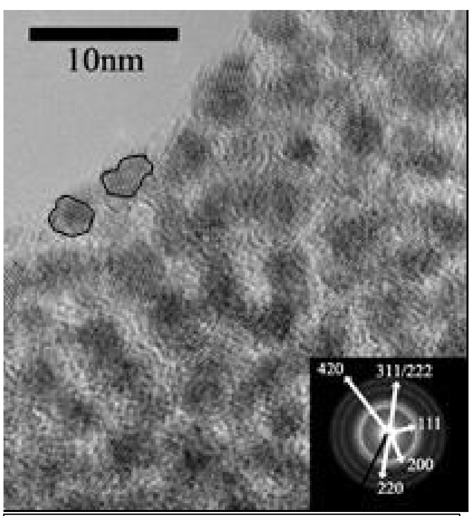

Fig.5. HRTEM of FEBID structure showing Pt nanoparticles embedded in an amorphous carbonaceous matrix.

The Dunn group is developing an athermal process for carbon removal in situ, by depositing the material in an environmental SEM capable of tolerating a small pressure of water vapor in the chamber with the electron beam. The combination of electron beam and water vapor has been shown, in principle, to etch carbonaceous material; it also offers the possibility of creating functional metal oxides such as WOx by judicious selection of precursor gas and microscope conditions. Proof-of-principle experiments have already demonstrated that oxide particle size can be controlled; the Dunn group is currently upgrading their system to enable more sophisticated control over the deposition and oxidation processes.

ENGINEERING SUPERIOR COPPER ALLOY BEHAVIOR

This National Science Foundation-funded project started July 1, 2018, building on the Dunn group's 15 years' of experience uncovering the mechanisms and driving forces for recrystallization in electroplated copper and Cu(Co) alloys. The overarching goal of this work is to establish the fundamental principles and methodology for deliberately manipulating the electronic band structure of 2D interfacial/grain boundary phases in order to tailor the electro-mechanical performance of select copper alloys. Grain boundaries (GBs) strongly impact a range of properties and behavior of polycrystalline metals (Fig. 6) including conductivity, diffusivity, brittleness, adhesion, corrosion resistance, fracture toughness and tensile strength. The influence of GBs in nanostructured metals can be even more dramatic because the number of atoms participating in GBs constitutes an appreciable fraction of the total atoms in the sample. As a result, observable properties are often dominated by GB, not bulk, material properties.

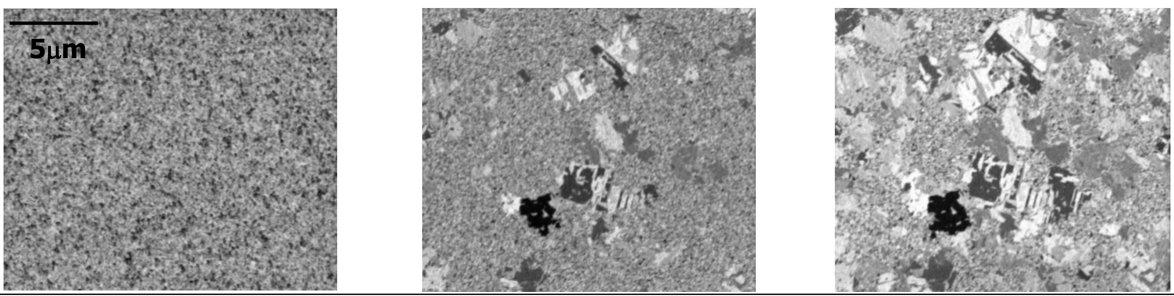

Figure 6. Focused ion beam (FIB) images of an electroplated copper film during room temperature self-annealing. In these images, grains can be distinguished from each other based on image contrast. The initially fine-grained microstructure (left), produces several large grains within 30 minutes (center). After an hour (right), more large grains have emerged, but the initial 'early bloomers' have paused. Both the abnormally fast grain growth and its cessation have been speculatively attributed to GB mobility being impacted by both GB orientation and by impurities segregating to GBs.

Solute segregating to some or all of these GBs offers a key opportunity for materials-by-design since segregants can change the energy, mobility, structure and cohesion of boundaries (Fig. 7). In this context, solute decoration need not be viewed as merely an unintended or undesirable phenomenon but can be exploited for manipulating microstructure, composition, atomic bonding and energy of GBs. Furthermore, since the composition of those boundaries may differ significantly from the overall composition at equilibrium, relatively small changes in bulk composition of an alloy may have an outsized impact on material properties, offering excellent sensitivity in the design of beneficial behavior through engineering of specific GB structures, composition and properties.

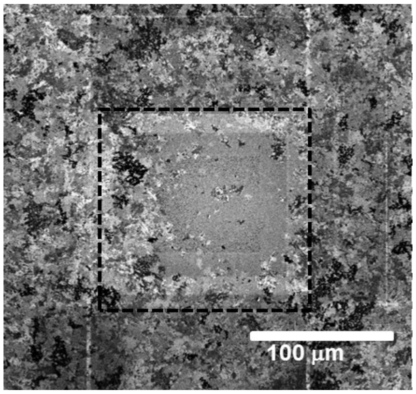

Figure 7. FIB image of Bi-implanted copper film after several days at room temperature. A Cs+ ion beam has been used to remove a native oxide, enabling imaging of the grain structure (contrast arising from orientation-based channeling effects). The black dashed box indicates the Bi exposure region (8.4×10^{14} ion/cm^2, 25keV at 45° incidence in a Secondary Ion Mass Spectrometer). Within the black square, the grain growth has not progressed as rapidly as in the surrounding matrix.

Structural relaxation, solute segregation, and changes to the atomic nearest-neighbor environment that occur at surfaces and interfaces naturally result in the local reorganization of the hybridized d-like and s-like valence states that characterize metallic bonding. It follows that the commensurate local physical properties are unique to grain boundary structure and composition, and frequently are the limiting factors determining alloy performance. We intend to use analytical transmission electron microscopy and density functional theory to elucidate the correlations between the atomic and electronic structures at grain boundaries and observed electro-mechanical properties. As the experimental and simulation approaches proposed here mature, they could form a powerful set of predictive tools for designing grain boundary phases in order to manipulate the engineering properties of alloy systems.

The merit of our approach lies in the unprecedented opportunity offered by applying atomic-resolution electron energy loss spectroscopy (EELS) and elementally sensitive imaging (high angle annular dark field imaging, HAADF) in an aberration-corrected STEM at individual grain boundaries. The interpretation of the electronic band structure changes revealed by comparing EELS of ‘clean’ vs. ‘decorated’ boundaries will be aided by Density Function Theory (DFT) modeling to understand the impact of segregation on the observed changes. Alloying elements were selected based on experimental evidence of macroscopic behaviors which are substantially influenced by GB segregation, and encompass a broad range of solute-matrix interactions. Establishing the link between electronic band structure and macroscopic behavior will enable the articulation of selection rules for choosing solutes which would, for example, restrict diffusion or increase adhesion.

The success of this project will advance nanostructured alloy design and enable superior performance by providing an electronic band-structure foundational strategy for grain boundary segregation engineering in polycrystalline Cu alloys. In particular, selection of effective solutes for desired outcomes such as improved diffusion barrier performance, enhanced cohesiveness, or resistance to electromigration voiding could be predicated on atomic EELS experiments with concurrent DFT modeling. Additionally, the principles developed here and the techniques used to uncover them will be broadly applicable to the study and design of other nanostructured metal alloy systems used in additive manufacturing, fuel cells and battery electrodes.

In the first year of this project, we have focused on the initial fabrication of copper alloys, including Cu(Co) and Cu(Ag) as our negative control. We are also upgrading our electron microscopy facilities to enable faster, automated analysis of grain orientation and texture. DFT modeling efforts have also begun using Ultrasoft Vanderbilt pseudopotentials for perfect crystal Cu, a clean bicrystal Cu, and a decorated bicrystal.

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[2] Tsurumaru, L. Prestowitz, B. O'Brien and **K. Dunn**, "The impact of solute segregation on grain boundaries in dilute copper alloys," to appear in the Proceedings of the 2017 Advanced Metallization Conference.

Research funded by: SUMCO Corporation, NSF, Fluor Marine Propulsion LLC, Bechtel Marine Propulsion Corporation

For more information on Dr. Dunn's research, please visit: https://sunypoly.edu/faculty-and-staff/kathleen-dunn.html

NANOENGINEEING

DR. HARRY EFSTATHIADIS

Scope: My research group focuses on renewable energy. My Research falls under Material deposition and characterization for thin film CuInGaSe2-, and Si-based solar cells, development and evaluation of Si-based nanostructured anodes and solid for Li-ion battery applications

Goals: 1) Optimize the properties of Li-ion batteries through the integration of silicon-nickel nanowires with controlled interfaces and desired physical and chemical properties and develop and test novel solid electrolytes.

2) Develop and characterize the absorber layer, buffer, transparent conducting layers of CuInGaSe. Replace CdS with graphene and study graphene n-type doping.

3) Optimize the antireflection properties of SiO_2 nanostructures for IR detectors.

4) Develop a hybrid photoelectrochemical (PEC) water splitting system that dissociates heated water recycling the residual thermal energy produced by a phosphoric acid fuel cell and demonstrate photoanode structures of Diamond/InGaN/Silicon with indium fractions $x < 30\%$ that produce hydrogen through water splitting under AM1.5 solar illumination for at least 240 hours

5) Perform fundamental understanding of materials and processing.

6) Perform materials composition and device fabrication

BROADBAND ANTIREFLECTION COATINGS FOR ADVANCED SENSING AND IMAGING APPLICATIONS

Prof. Harry Efstathiadis and Magnolia Optical Technologies, Inc. are involved in an ongoing research program to develop broadband nanostructured antireflection (AR) coatings for advanced sensing and imaging applications. Sensors and systems operating from ultraviolet (UV) to long-wave infrared (LWIR) spectrum are being developed for various defense and commercial security applications [1-5]. This work is being performed under a U.S. Army Phase II SBIR Program.

Reflection loss of incident signals due high refractive index of sensor substrates and optical components limits the sensitivity of image sensing systems. Reducing optical reflections from surfaces, which is important to many optical applications including optical lenses, windows, photovoltaic devices, and photodetectors, has commonly been achieved through coating, or texturing, the surfaces of interest. Nanostructured AR coatings that have optimal index profiles can minimize and nearly eliminate the reflection loss over broad spectral bands and wide ranges of incidence angles, thus enhancing the sensitivity and performance of imaging systems.

As part of this novel research effort, we are developing a new class of nanostructured thin films enabling the realization of ultralow refractive index materials. These nanostructured AR coatings are fabricated using a tunable self-assembly process on substrates that are transparent for a given spectrum of interest ranging from the UV to LWIR. The nanostructured multilayer structures are being designed, developed, and optimized for various optoelectronic and imaging applications. The optical properties of AR-coated optical components and sensor substrates have been measured and the coating structure fine-tuned to achieve high levels of optical performance.

The nanostructured optical layers are fabricated using a scalable physical vapor deposition (PVD) self-assembly process, which allows them to be processed on virtually any type of substrate. The deposition angle, the angle between the normal to the sample surface and the incident vapor flux, governs the formation of nanorod structures that are tilted relative to the sample surface. Because the gaps between the nanorods are typically much smaller than the wavelengths of visible and infrared (IR) light, the nanostructured layers act as a single homogenous film.

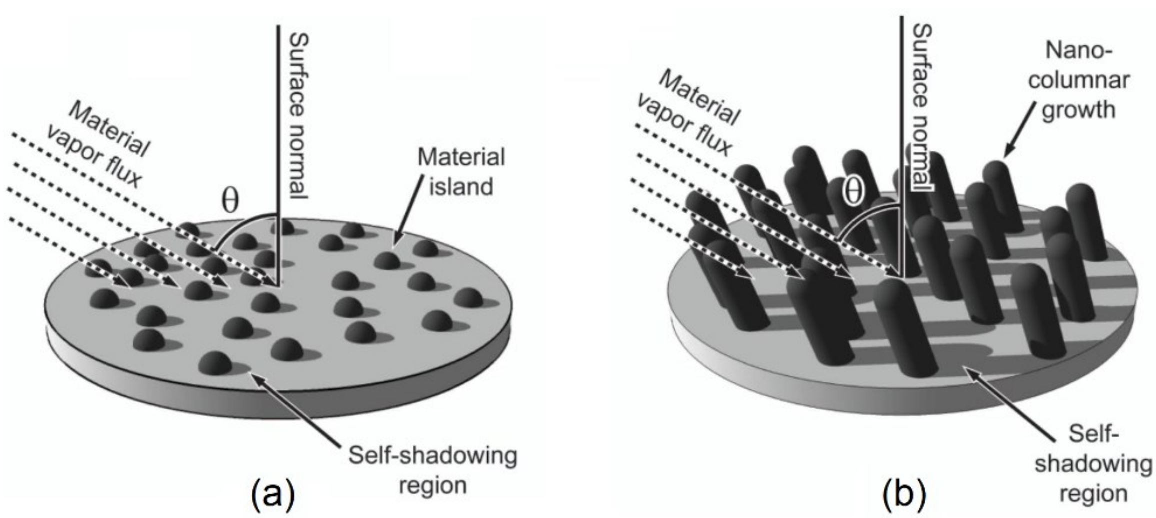


Figure 1. (a) Schematic of self-assembly process for synthesis of nanostructured films, showing (a) initial formation of material islands at random locations across the substrate, followed by (b) formation of self-shadowed regions and nanocolumnar growth when the material vapor flux arrives at a non-normal deposition angle θ to the substrate [1].

We have fabricated and tested many various step-graded AR structures on glass substrates. Figure 2 compares the measured broadband performance of an uncoated glass slide to one coated on both sides with a multilayered, nanostructured SiO2 coating, where the transmittance is characterized as a function of wavelength and incident angle. The inset in Figure 2 shows a representative cross-sectional scanning electron micrograph of the two-layer structure interface. It can be seen that the transmittance through the nanostructured SiO2 coated glass is significantly higher than that through the uncoated glass across a wide range of incident angles. While the transmittance of the uncoated glass slide falls below 80% at an incident angle of 65°, the glass slide with the double-sided coating still maintains a transmittance above 95%.

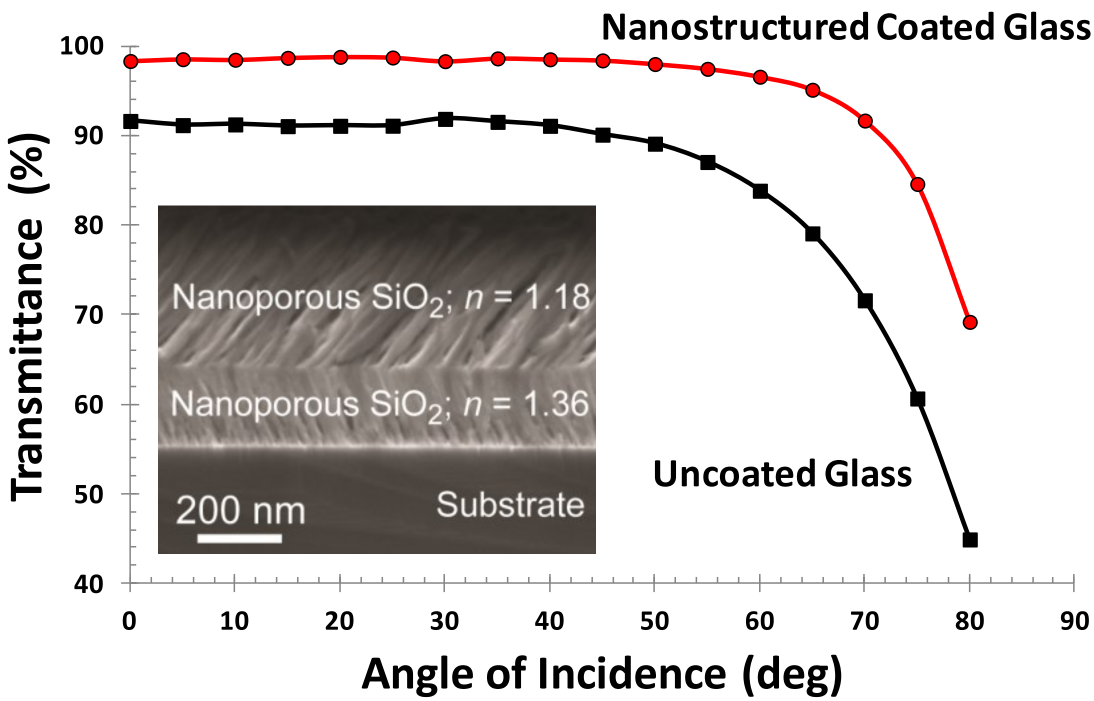
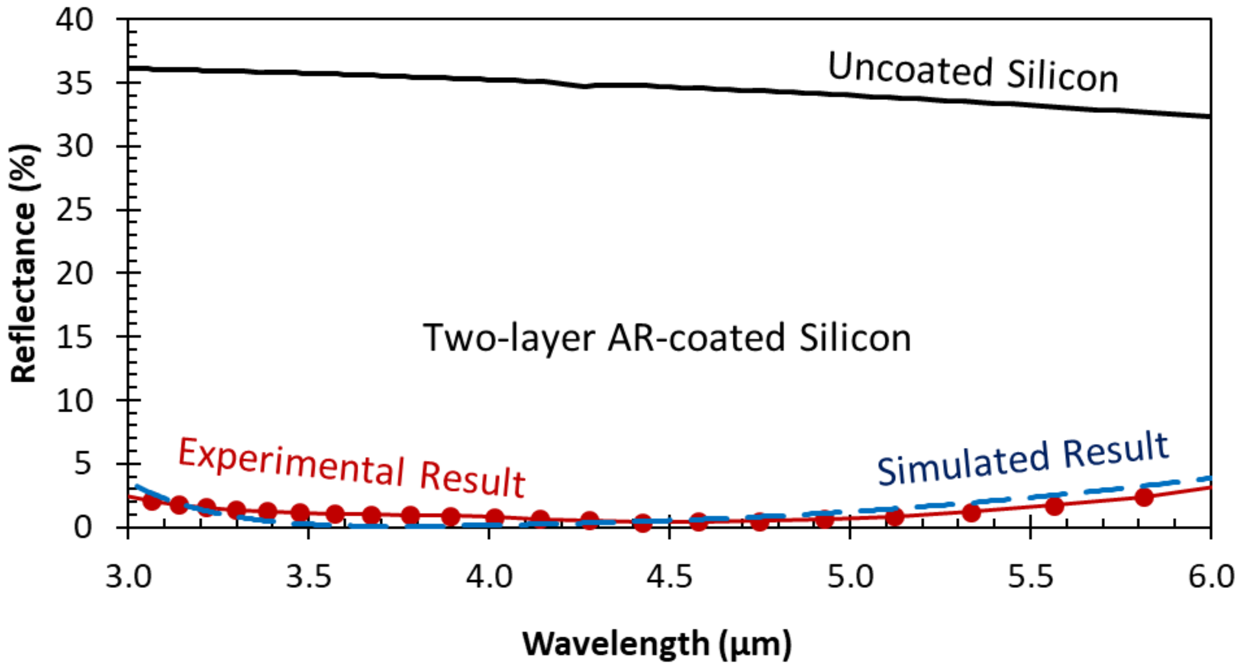


Figure 2. Incident angle-dependent broadband transmittance measurement through a glass slide coated on both sides with step-graded, nanostructured SiO2 AR structure. Also shown is the measured broadband transmittance of an uncoated glass slide, along with a cross-sectional scanning electron micrograph of the two-layer nanostructured coating.

In order to extend the application of the nanostructure AR coatings to the IR spectral bands, nanostructured AR coatings on silicon wafers have been fabricated and successfully demonstrated ultrahigh AR performance over the 3-5 μm and 10-12 μm spectral bands. Measured wavelength-dependent reflectance of multilayer AR-coated and uncoated Si substrates are shown in Figure 3. The multilayer AR coating has been synthesized by sequentially growing multiple layers of nanostructured Si and SiO2 layers with desired graded-index profiles for the 3-5 μm mid-wave infrared (MWIR) band. The average measured reflectance for the multilayer AR-coated Si wafer is less than 1.5%, while the average measured reflectance for the uncoated silicon <211> wafer is approximately 30% over the 3-5 μm MWIR spectral band.



θMeasured wavelength-dependent reflectance of multilayer AR-coated and uncoated Si<211> wafers. The multilayer AR coating on Si<211> shows an average reflectance of 1.43% over the 3-5 µm spectral band [1].

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[1] Gopal G. Pethuraja, Adam W. Sood, John W. Zeller, Roger E. Welser, Ashok K. Sood, **Harry Efstathiadis**, and Priyalal S. Wijewarnasuriya. “Broadband antireflection coatings for advanced sensing and imaging applications.” In Image Sensing Technologies: Materials, Devices, Systems, and Applications VI, vol. 10980, p. 109800U. SPIE, 2019.

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[3] Gopal G. Pethuraja, John W. Zeller, Roger E. Welser, Ashok K. Sood, **Harry Efstathiadis**, Pradeep Haldar, Priyalal S. Wijewarnasuriya, and Nibir K. Dhar. “Development of Nanostructured Antireflection Coatings for Infrared and Electro-Optical Systems.” Sensors & Transducers 214, no. 7 (2017): 46.

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[5] Gopal G. Pethuraja, John W. Zeller, Roger E. Welser, **Harry Efstathiadis**, Pradeep Haldar, Priyalal S. Wijewarnasuriya, Nibir K. Dhar, and Ashok K. Sood. “Development of nanostructured antireflection coatings for infrared technologies and applications.” In Infrared Sensors, Devices, and Applications VII, vol. 10404, p. 104040S. SPIE, 2017.

SOLID ELECTROLYTE LI-ION BATTERIES

In 2018 our group has expanded its work on Li-ion batteries to include work solid state electrolytes. Several alloys have been investigated as possible electrolytes with high ionic conductivity. Battery cells were designed, fabricated and were tested. The motivation for this work is that the rapid adoption of Li-ion batteries with liquid organic electrolytes created many safety issues, due to gas production and leakage of the flammable liquid organic electrolytes when operating at high voltages of ~6V and/or elevated temperatures of ~150°C. A possible solution to this problem is to use solid state electrolytes instead of liquid electrolytes. It has been demonstrated that some solid electrolytes can perform as well as their liquid electrolyte counterparts during battery operation. One such promising solid-state electrolyte is Lithium Aluminum Titanium Phosphate (LATP). Thick LATP films (several micrometers) have shown ionic conductivity of ~3x10-3 S cm-1, which is similar to that of a typical liquid electrolyte’s conductivity. It has excellent long-term stability in contact with the lithium anode and has been evaluated as a solid electrolyte for Li-ion batteries, as well as for electrochromics and deep neural networks. This study is therefore aimed at in-depth exploration of the LATP electrolyte for both the lithium ion battery and neuromorphic devices applications. Our work is focused on studying the influence of sputtering deposition parameters on the composition and the ionic conductivity of LATP that is not well understood. A systematic study to optimize sputtering target power, substrate heating, sputtering vacuum pressure, annealing temperature, atmospheric composition during annealing, and sputtering atmospheric composition was performed. Compositional uniformity of LATP films were analyzed via dynamic secondary ion mass spectroscopy (D-SIMS), nuclear reaction analysis (NRA), and Rutherford backscattered electron spectroscopy (RBS). Results from the aforementioned techniques have shown that deposition of compositionally uniform LATP films can be achieved by co-sputtering of Ti, Al and Li3PO4 on a Si or Si/SiO2 substrate. However, annealing of these films at > 400oC is required to enhance their performance. Microscale batteries (~ 100 µm x 100 µm) created with the annealed LATP films show promising electrolyte behavior. Charging of the batteries with a constant current of 200pA to 4.2V displayed charging and discharging characteristics of a typical battery with no measurable leakage.

Solid electrolyte films were deposited by Plasma Vapor Deposition. To test the charging and discharging capabilities of the electrolyte, specialized devices were fabricated. In these devices, a blanket layer of Ti (~200nm) was deposited on the silicon substrate. A “liftoff” process was utilized to pattern the devices, due to the nonexistence of an LATP etchant. A LiCoO2 cathode (~200nm) and a Ti top contact (~150nm) were also deposited (Fig. 1). This structure was utilized for both the annealed and the unannealed microbatteries, where the annealed samples were subjected to an Ar anneal.

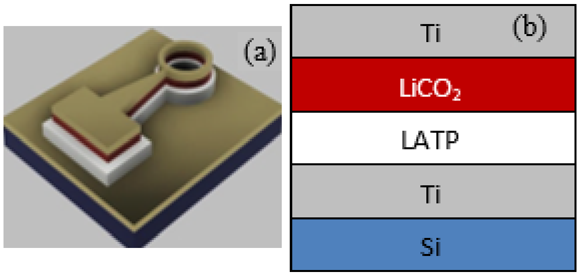


Fig. 1. Three-dimensional illustration of (a) the micro battery and (b) the associated cross-sectional diagram.

The compositions of the electrolyte thin films were characterized by dynamic secondary ion mass spectroscopy (SIMS, Physical Electronics 6650), nuclear reaction analysis (NRA, Dynamitron accelerator at SUNY University at Albany's Ion Beam Laboratory (IBL)) and Rutherford backscattering spectrometry (RBS, UAlbany's IBL). Scanning electron microscopy (SEM, LEO 1550) was used to determine the film surface morphology and thickness. Batteries were charged using a microprobe station with an attached Agilent 4156C semiconductor parameter analyzer with constant current source. Any decrease of voltage indicates internal leaking, likely due to electrolyte failure. Voltage vs. time and charge current vs. time were collected for each sample at an applied constant current of 200pA.

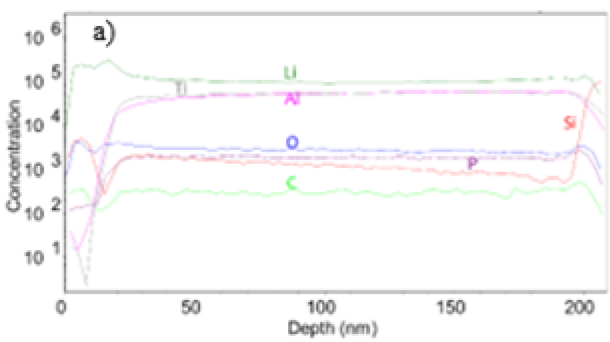


Fig. 2. D-SIMS depth profile of the ambient temperature LATP sample, monitoring both positive and negative Cs-cluster ions and normalized to a Cs-Cs cluster ion baseline.

To characterize the electrolyte composition, secondary ion mass spectroscopy was utilized to determine the compositional uniformity of the LATP samples as a function of depth into the film. The Physical Electronics SIMS tool uses a cesium source to bombard the sample with a ray of cesium ions, physically digging a crater in the film while simultaneously creating cesium cluster ions with atoms in the film. A quadrupole mass spectrometer periodically analyzes the quantity of particles matching each atomic mass and matches the data to user provided information on the sample's expected composition. Fig. 2 displays the SIMS depth profiles of the LATP sample deposited at ambient temperature of approximately 170C.

The final compositional characterization method employed was Rutherford backscatter spectrometry, a method which is sometimes referred to as referred to as high-energy ion scattering (HEIS) spectrometry. RBS involves measuring the backscattering of a high-energy beam (typically consisting of alpha particles), which allows the user to gather information about the exact composition of the sample being analyzed. The energy range of the RBS tool, however,

TABLE 1. ATOMIC PERCENTAGES OF LATP THIN FILMS

Element	Compositional Results	
	Original RBS At. Percent	*Corrected At. % with NRA*
Li	N/A	0.032
Al	0.10047	0.098
Ti	0.30727	0.297
P	0.07399	0.072
O	0.51826	0.502

cannot detect lithium, and thus RBS could only yield measurements for the remaining elements. These results were analyzed in conjunction with nuclear reaction analysis of the same films in order to determine lithium concentration. Compositional results from RBS analysis of an unheated electrolyte sample are shown in Table 1. Both the annealed and unannealed samples yielded nearly identical compositions; only one set of data is reported. The yield vs. energy/channel graph with fit curve is displayed below in Fig. 3.

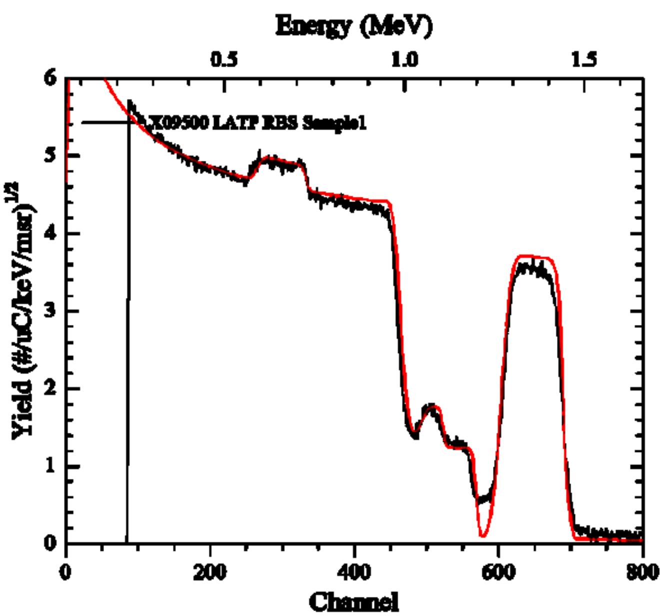
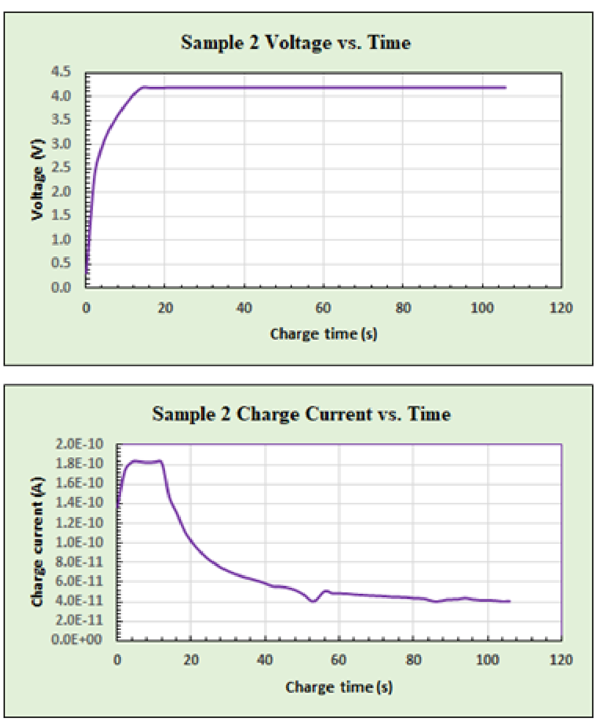


Fig. 3. RBS yield vs. energy/channel graph with fit curve. Compositional data is calculated based on the intensity of peaks/troughs and their respective location on the energy scale.



MICROBATTERY CHARGING AND DISCHARGING

Microbattery samples were fabricated using both annealed and unannealed electrolyte films. Batteries were charged using a microprobe station with an attached Agilent 4156C semiconductor parameter analyzer with constant current source. Several fabricated devices presented the best isolation, displaying charging characteristics Vxt and Ixt proper of a functioning battery, storing charge until the compliance voltage of 4.2 volts

Fig. 4. Sample 2 voltage vs. time and charge current vs. time at an applied constant current of 200pA.

was reached. The charging results are displayed in Fig. 4.

In a novel experiment, NASICON-like lithium aluminum titanium phosphate (LATP) electrolyte thin films have been successfully deposited via magnetron co-sputtering process. SEM imaging shows an electrolyte film that has a smooth surface structure, free of cracks and abnormalities, which is important for creating an electrolyte which will avoid short-circuiting in battery applications. D-SIMS depth profiles of the deposited films show an electrolyte with compositional consistency throughout the entire thickness of the films, necessary for having a consistent, stable electrolyte. RBS and NRA compositional analysis indicates a compound that is stoichiometrically correct. Microscale batteries created with an annealed LATP thin film presented charging characteristics proper of a functioning battery, storing charge to a compliance voltage of 4.2V, showing that cosputtered LATP thin films have the possibility to be a competitive solid electrolyte in all-solid-state LIBs. More research is required to understand the potential of a cosputtered LATP thin film electrolyte, but preliminary testing shows that cosputtering may be a possible alternative to typical electrolytes used in all-solid-state LIBs.

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Research funded by: SAVD Solar Incorporated, Magnolia Optical Technologies Incorporated, Landauer Incorporated, Lux Semiconductors, NYSTAR.

GENOMIC PROFILING OF YEAST RESISTANCE TO P450-ACITIVATED CARCINOGENS

DR. MICHAEL FASULLO

Scope: The main focus of my laboratory is to determine human response to pharmaceuticals, environmental chemicals and carcinogens, also referred to as xenobiotics. The rationale is that human susceptibility to carcinogens is highly variable; individual differences may result from both genetics and lifestyle factors. Since many environmental chemicals are metabolized and detoxified within the body, we postulate that xenobiotic susceptibility results from bioactivation that produces genotoxic metabolites. Additionally, xenobiotics could affect gene expression by causing epigenetic changes. Differences in genetic susceptibility could then result from variability in activation of the xenobiotics or deficiencies in repairing xenobiotic-associated DNA damage. We individually characterize polymorphic human P450 enzymes that metabolize compounds and eukaryotic genes that confer resistance to the activated compounds. For model chemicals, we use aflatoxin B_1 (AFB_1), a highly potent liver carcinogen, and heterocyclic aromatic amines (HAAs), which are potent colon cancer carcinogens found in charred meats. As a model eukaryote, we use *Saccharomyces cerevisiae* (budding yeast), which although does not contain any endogenous P450 enzymes that can activate carcinogens, can express human P450 genes. We have constructed expression vectors for P450 genes and created a library of 5,000 yeast strains that express CYP1A2 and NAT2, where each yeast strain is deleted for a non-essential gene. This research employs state-of-the art next generation sequencing (NGS), high throughput screening, molecular biology and bioinformatics to identify genes that confer chemical resistance. This approach can be expanded to include P450-metabolized pharmaceuticals, pollutants, and nanoparticles.

Goals: 1). Developing biosensors to detect genotoxic and epigenetic effects of xenobiotics; 2). Engineering expression of both human phase I (P450) and phase II (NAT2) enzymes in model organisms; 3). Genome profiling of food carcinogen resistance in budding yeast expressing P450 enzymes.

DEVELOPING BIOSENSORS TO DETECT GENOTOXIC AND EPIGENETIC EFFECTS OF XENOBIOTICS.

Many chemicals, including nanoparticles, affect gene expression by non-genotoxic mechanisms that alter chromatin or RNA structure. Such alterations include tRNA modifications, DNA methylation, and chromatin modifications. Chromatin modifications include histone acetylation and methylation, or inhibition of histone deacetylase, such as *SIR2*, an evolutionarily conserved histone deacetylase found in the eukaryotic kingdom**.** Resistance to reactive oxygen species (ROS) may also require tRNA or other mRNA modifications to accurately translate DNA repair genes. We have collaborated with Lauren Endres (SUNY Polytechnic, Utica) to determine the phenotypes of mutants in two different genes encoding tRNA methyl transferases, *TRM7* and *TRM9*. We observed that *trm7* mutants are hypersensitive to hydrogen peroxide while *trm9* mutants are hypersensitive to a variety of oxidative agents and carcinogens, including AFB_1.

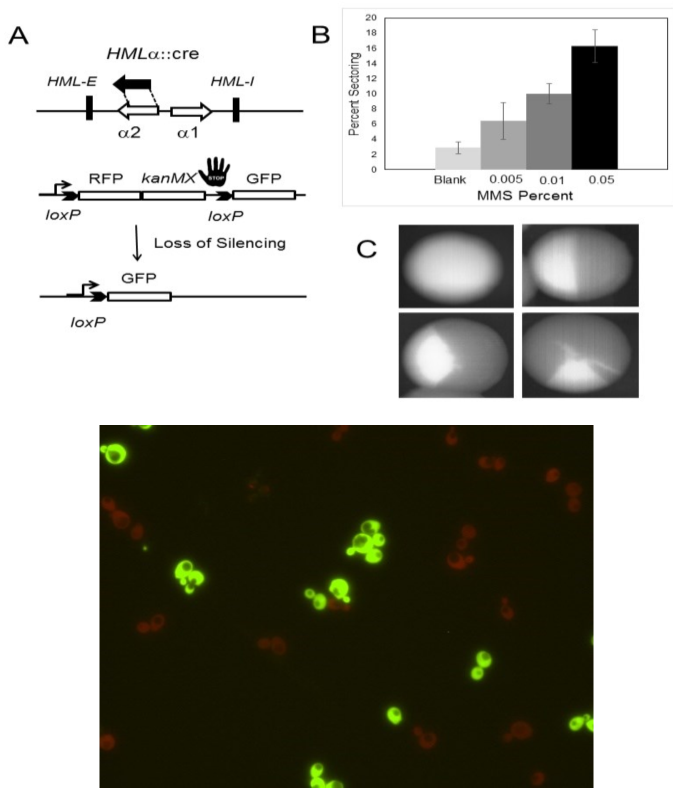

Fig 1: (Left, A) Strain construction used to monitor epigenetic effects of alkylating agents. HML expression was monitored by the expression of *HML*::cre. Cre catalyzes intrachromosomal recombination of the loxP sites and deletes the intervening stop signal, allowing for GFP expression. *HML*-E and *HML*-I are effective silencers of the HML locus. The direction of gene transcription is shown by the arrow of *HML*α1 and *HML*α2. *HML*::cre is inserted into *HML*α2. The feathers represent loxP sites that are recombined upon expression of Cre. **(Right, B)** Percent colonies exhibiting sectoring phenotypes after three day exposure to methyl methane sulfonate. (**Right, C**) Below is shown an example of sectoring colonies; clockwise, a fully sector colony, a half-sector colony, a quarter sector colony and a multi-sector colony are shown. The figure was published in Derevensky and Fasullo (2018). (**Bottom, D**)Image of cells expressing wither RFP or GFP after exposure to a genotoxic agent.

To determine whether environmental carcinogens cause changes in chromatin modifications that allow for gene expression we used a clever yeast strain construction that detects expression of silent mating type locus, *HML* (Figure 1), which was first designed by J. Rine (University of California Berkeley). The assay consists of a green fluorescent protein (GFP) reporter gene whose promoter is interrupted by an intervening sequence containing the red fluorescent protein (RFP) reporter gene flanked by the bacteriophage Cre recombinase recognition sequences. The gene encoding Cre recombinase is inserted in the silent mating type cassette *HML* and under growth conditions in rich medium is not expressed. However, if the *HML* chromatin structure is perturbed that allows for gene transcription, the Cre recombinase is expressed, resulting in excision of the RFP reporter gene and expression of the GFP reporter gene (Figure 1). The expression of the reporter gene thus renders cells fluorescent for GFP (Figure 1D); colonies derived from these cells are also fluorescent (Figure 1C). This erturbation can result from transient inhibition of multiple factors that function to repress *HML*, including the Sirtuin histone deacetylase Sir2.

We determined that cells exposed to several potent alkylating agents, such as methyl methanesulfonate (MMS), exhibited higher frequencies of epigenetic changes that can lead to transient expression of the yeast silent mating type locus *HML*. This was determined by analyzing both single cell fluorescence and colony sector phenotype (Figure 1). On the other hand, cells exposed to environmental agents that directly caused double-strand breaks, such as zeocin, did not exhibit increase frequencies of GFP-expressing cells. Future experiments will determine whether exposure to nanoparticles and P450-activated chemicals trigger epigenetic effects. These studies thus reveal an aspect of chemical toxins, which has not been previously described. A similar design could also be designed for mammalian cell lines.

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[2] Endres, L., **Fasullo, M.,** and Rose R. tRNA modification and cancer: potential for therapeutic prevention and intervention. Future Med Chem. 2019 11:885-900, 2019

[3] **Fasullo, M**. Cellular responses to aflatoxin-associated DNA adducts. In Advances in DNA Repair, Intech Open, **2018.**

ENGINEERING EXPRESSION OF BOTH HUMAN PHASE I (P450) AND PHASE II (NAT2) ENZYMES IN MODEL ORGANISMS

Cytochrome P450 enzymes are critically important enzymes that convert multiple pharmaceuticals into hydrophilic compounds that are subsequently excreted. However, many xenobiotics, such as AFB1 and heterocyclic aromatic amines are converted into highly reactive electrophiles that form genotoxic DNA adducts. Budding yeast do not express endogenous P450 enzymes that can metabolically activate carcinogens. This enables one to express individual human P450 genes into yeast strains and measure genotoxic effects resulting from the metabolic activation of carcinogenic compounds. These compounds include polyaromatic hydrocarbons, such as AFB1 and benzopyrene, which are found in both food products and in tobacco products, respectively.

We have previously constructed expression vectors that express human CYP1A2, CYP1A1, and CYP3A4 in budding yeast. We also expressed particular CYP1A1 alleles in yeast, which have been previously been ascribed as risk factors for lung, breast, or kidney cancer. We showed that genotoxic effects resulting from CYP-mediated metabolic activation of compounds could be observed in yeast strains that were defective in DNA repair. Additional genotoxic effects that could be monitored included mutation, recombination, and induction of DNA damage-inducible genes.

We successfully constructed expression vectors containing CYP1A2 and NAT2 that can activate both polyaromatic hydrocarbons, such as AFB_1, and heterocyclic aromatic amines, such as 2-amino-3-methylimidazo [4,5-f]quinoline (IQ). To determine that IQ was activated into a potent genotoxic agent, we expressed both CYP1A2 and NAT2 in a *rad55 rad4* strain, defective in DNA repair, and exposed this strain to varying concentrations of IQ. We then measured growth over a period of twenty-four hours (Figure 2). The data show that IQ is a more potent genotoxic agent when the strain is expressing both CYP1A2 and NAT2, compared to expressing only CYP1A2, NAT2, or no P450 gene. This assay will allow us to phenotype individual NAT2 alleles that have been correlated to higher incidence of colon cancer and determine whether these alleles confer higher levels of genotoxicity when cells are exposed to colon cancer-associated carcinogens.

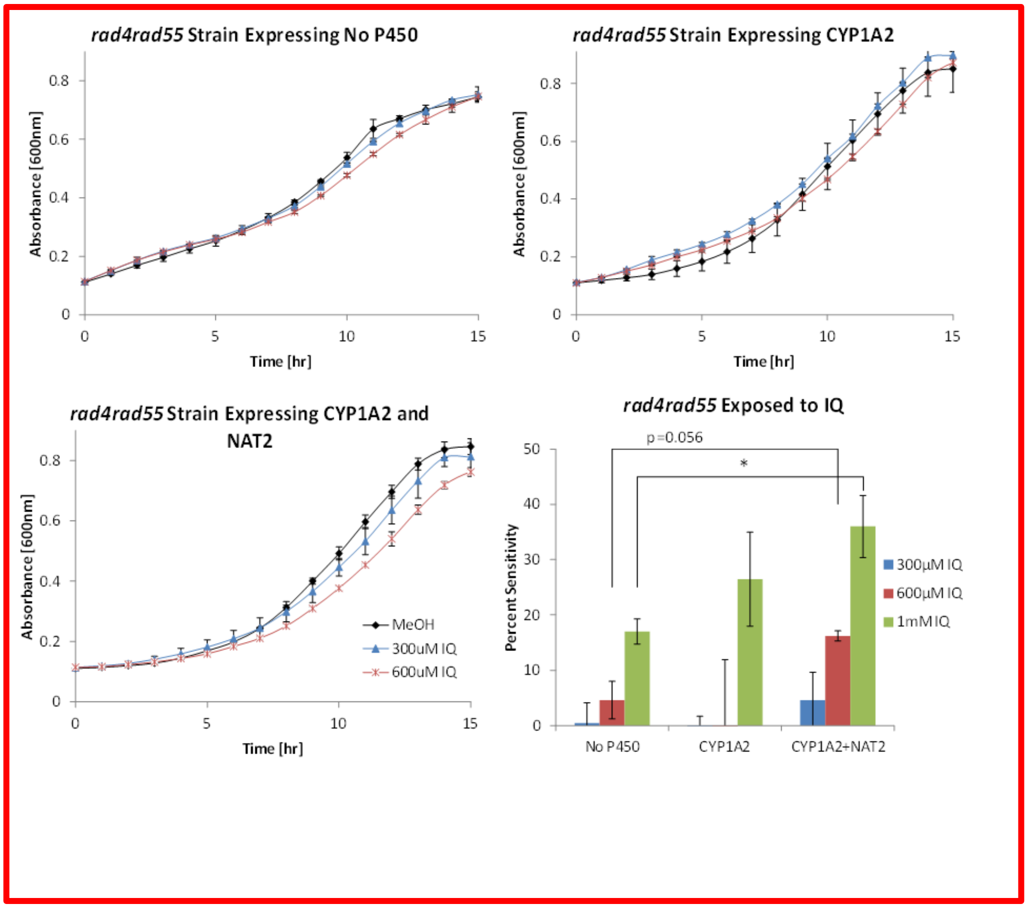

Figure 2.A – Growth curve of *rad4rad55* with no P450 expressed. **B** – Growth curve of *rad4rad55* expressing CYP1A2. **C** - Growth curve of *rad4rad55* expressing CYP1A2 and NAT2. **D** – Bar graph depicting sensitivity calculations for growth curves **A-C.** Statistical analysis was performed using a 1-tailed t-test (excel) with 2 samples of unequal variance.

PUBLICATIONS AND PRESENTATIONS

[1] **M Fasullo**, N St John, J Freedland, F Doyle, C Cera, H Baldino High-throughput screening for Food Carcinogen Resistance Genes in Budding Yeast Identifies Mechanisms in DNA damage Tolerance of Carcinogen-associated DNA adducts Environ and Mol Mutagen. 59, 68-68, 2018

Fasullo M, Freedland J, St John N, Cera C, Egner P, Hartog M, Ding X. An invitro system for measuring genotoxicity mediated by human CYP3A4 in Saccharomyces cerevisiae. Environ Mol Mutagen. 58(4):217-227. 2017

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GENOME PROFILING OF FOOD CARCINOGEN RESISTANCE IN BUDDING YEAST EXPRESSING P450 ENZYMES.

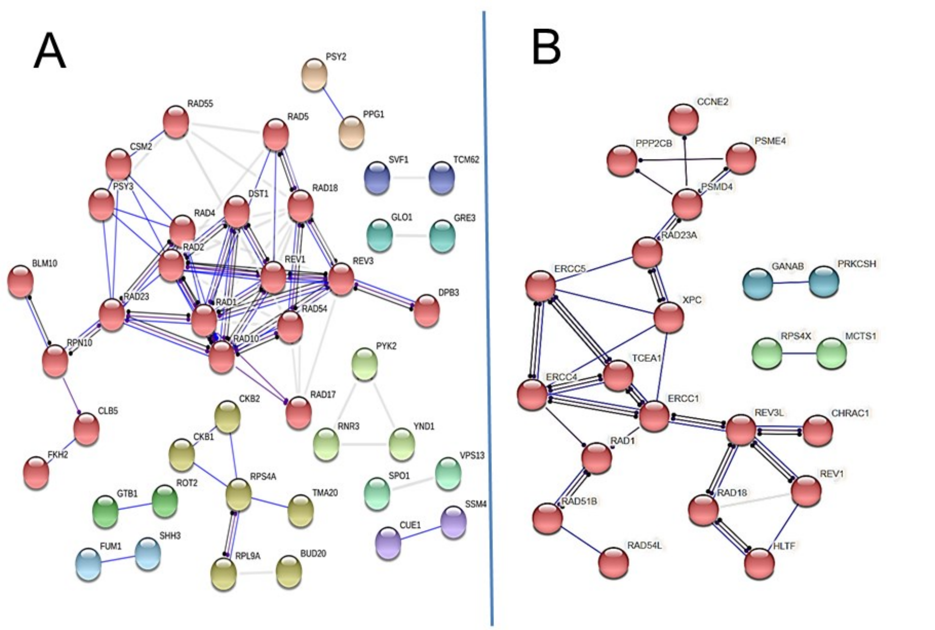

Figure 3. The protein interactome encoded by AFB_1 resistance genes in budding yeast (left, A) and protein interactome encoded by their associated human homologs (right, B). The interactome was curated using String V11 (https://string-db.org), using a high confidence level of .8 and MCL cluster factor of 1.1. Proteins are represented by colored circles (nodes); different colors represent distinct interacting clusters. A core group, in red seen in both images, includes proteins that function in DNA repair pathways, and interact with proteases, transcription and cell cycle factors. Lines represent the edges; a solid blue line indicates a binding event, a dark line indicates a reaction, and a purple line indicates catalysis. The lighter lines indicate a strong connection, as deduced from the literature. Lines that terminate with a dot indicate an unspecified interaction, whether positive or negative.

The purpose of this study is to identify genes that confer resistance to P450-activated food carcinogens, such as AFB1 and IQ. Epidemiological studies have revealed some genes linked to colon and liver cancer; however, it is unknown whether these genes confer higher levels of food carcinogen-associated genotoxicity. Since ~30% of the yeast genes are orthologous to human genes, we reason that identifying yeast genes would also aid in identifying the corresponding human genes. In order to identify the wide range of gene functions, we scanned the 5,000 non-essential yeast strain collection expressing CYP1A2 and CYP1A2 and NAT2. This yeast strains contain molecular barcodes, which identify each strain. The yeast strains are pooled and divided into triplicates which either are exposed to carcinogen or exposed to solvent. The DNA barcodes are then counted using the Illumina high-throughput sequencing platform. With the aid of Frank Doyle, we set up a bioinformatics platform to identify both sensitive and resistant strains. Once genes are identified, we used freely-available bioinformatics software to identify gene ontology groups and human homologs.

Using this method we identified 86 genes that conferred resistance to AFB1. These genes over-represent pathways involved in DNA damage tolerance and their products can be shown to interact, as indicated by direct protein-protein interaction, cellular location, or function (Figure 3).

Nick St. John (Master's student) identified over one hundred genes, and those highlighted in red (Table 1), indicate genes that have appeared twice in the screen and therefore likely to be significant. Of particular interest are *NTG1* and *RAD18*, which are DNA repair genes that have been previously linked to a higher incidence of colon cancer. Our future studies will focus on identifying DNA repair pathways for IQ resistance and whether particular DNA repair mutants exhibit higher frequencies of IQ-associated DNA adducts. Such studies will indicate that one reason why these genes are associated with colon cancer is that they are important in repairing DNA damage caused food carcinogens. Patients containing such susceptibility alleles may then choose to make lifestyle or dietary changes to decrease their risk to cancer.

5-6G IQ Results			
gene_Id	Gene	m.value	q.value
YMR020W	FSM1	-6.44104	0.017213
YBR044C	TCM62	-4.80094	0.039437
YGR204W	ADE3	-2.62456	0.041407
YLL045C	RPL8B	-1.87136	0.022324
YOR093C	CMR2	-1.83953	0.000211
YOL027C	MDM38	-1.81571	0.006669
YGL084C	GUP1	-1.78172	0.050047
YER111C	SWI4	-1.63783	0.006669
YNL145W	MFA2	-1.37706	0.044867
YAR002W	NUP60	-1.29838	0.017213
YGL071W	AFT1	-1.22975	0.002619
YBL103C	RTG3	-1.22496	0.075982
YLR192C	HCR1	-1.18197	0.030044
YOR085W	OST3	-1.17503	0.039437
YDR202C	RAV2	-1.09672	0.086138
YOL051W	GAL11	-1.0842	0.030044
YJL139C	YUR1	-1.07576	0.030555
YDR508C	GNP1	-1.04609	0.006669
YMR118C	SHH3	-1.04283	0.017213
YBR191W	RPL21A	-1.03768	0.033715
YIL056W	VHR1	0.848557	0.078663
YLR455W	PDP3	0.912949	0.058136
YOR005C	DNL4	0.919988	0.078791
YOR315W	SFG1	0.929419	0.089705
YML072C	TCB3	0.95752	0.058854
YJR091C	JSN1	0.958108	0.04927
YER167W	BCK2	0.972593	0.0735
YOR334W	MSR2	1.031057	0.072917
YLR011W	LOT6	1.056317	0.056793
YOR288C	MPD1	1.058127	0.028434
YLR461W	PAU4	1.077505	0.044867
YKR010C	TOF2	1.12907	0.068733
YKL168C	KKQ8	1.149231	0.037425
YKR103W	NFT1	1.189503	0.028434
YPR160W	GPH1	1.246872	0.006669
YOL062C	APM4	1.261643	0.052467
YML086C	ALO1	1.288648	0.039437
YOR013W	IRC11	1.339199	0.007666
YER060W	FCY21	1.672707	0.068664
YOR003W	YSP3	2.113875	0.028434

10G IQ Results			
gene_Id	Gene	m.value	q.value
YMR189W	GCV2	-7.62747	0.001833
YJL145W	SFH5	-6.94407	0.052335
YMR157C	AIM36	-6.68999	0.078906
YMR242C	RPL20A	-6.63906	0.073979
YLR401C	DUS3	-6.44345	0.060074
YML030W	RCF1	-6.20677	0.066373
YIR038C	GTT1	-5.98644	0.034888
YOL103W	ITR2	-5.72335	0.068088
YMR063W	RIM9	-4.69757	0.010099
YHR108W	GGA2	-4.52304	0.007062
YJL181W	RBH1	-3.98538	0.055921
YLR331C	JIP3	-3.69341	0.052335
YOL121C	RPS19A	-3.07329	0.089963
YBL090W	MRP21	-2.94628	0.07571
YBL038W	MRPL16	-2.52764	0.025386
YOR093C	CMR2	-2.38847	5.87E-07
YGR150C	CCM1	-2.35705	0.000917
YOR270C	VPH1	-2.19156	0.025386
YGL084C	GUP1	-2.16501	0.012466
YIL135C	VHS2	-1.99354	0.089926
YOR246C	ENV9	-1.80701	0.02453
YLR447C	VMA6	-1.72663	0.025386
YCR008W	SAT4	-1.70158	0.055921
YOR187W	TUF1	-1.64596	0.015399
YOR221C	MCT1	-1.64171	5.14E-06
YHR073W	OSH3	-1.63726	0.084057
YBR036C	CSG2	-1.60654	0.014285
YHR067W	HTD2	-1.56273	1.21E-05
YGL071W	AFT1	-1.56262	5.14E-06
YDR202C	RAV2	-1.53582	2.00E-05
YER111C	SWI4	-1.53025	1.21E-05
YOR085W	OST3	-1.50846	0.004579
YJL046W	AIM22	-1.49638	0.000842
YML088W	UFO1	-1.4894	0.000363
YKL110C	KTI12	-1.43138	0.080846
YDR351W	SBE2	-1.43058	0.073979
YBR048W	RPS11B	-1.43056	0.097534
YNL322C	KRE1	-1.42956	0.073979
YER161C	SPT2	-1.41881	0.000517
YAR020C	PAU7	-1.40958	0.000843
YFL018C	LPD1	-1.40354	0.001203
YDR518W	EUG1	-1.39727	0.025386
YEL009C	GCN4	-1.36778	0.015403
YAR015W	ADE1	-1.35265	0.000363
YAR028W	DUP240	-1.33763	0.000929
YKL007W	CAP1	-1.32876	0.019485
YMR214W	SCJ1	-1.31366	0.035839
YOL051W	GAL11	-1.30736	0.001826
YPL145C	KES1	-1.28984	0.075965

10G IQ - Continued			
gene_Id	Gene	m.value	q.value
YJR145C	RPS4A	-1.25212	0.003604
YOR067C	ALG8	-1.25146	0.001826
YNL077W	APJ1	-1.24853	0.054765
YDR027C	VPS54	-1.24462	0.083215
YML036W	CGI121	-1.22355	0.003348
YIL093C	RSM25	-1.22258	0.072851
YNL183C	NPR1	-1.22242	0.001672
YJL134W	LCB3	-1.19607	0.060074
YER164W	CHD1	-1.18284	0.003645
YOR371C	GPB1	-1.17632	0.00628
YIL099W	SGA1	-1.16859	0.078052
YIL087C	AIM19	-1.16298	0.010898
YDR260C	SWM1	-1.15616	0.05207
YDR295C	HDA2	-1.12551	0.02966
YAL042W	ERV46	-1.11777	0.023872
YAL056W	GPB2	-1.1175	0.073979
YOR233W	KIN4	-1.09334	0.060489
YJL024C	APS3	-1.08464	0.011014
YGR193C	PDX1	-1.07858	0.010099
YDL167C	NRP1	-1.0646	0.021526
YBR026C	ETR1	-1.06322	0.015403
YGL147C	RPL9A	-1.04993	0.054765
YMR118C	SHH3	-1.04171	0.005591
YNL053W	MSG5	-1.03751	0.007062
YJL139C	YUR1	-1.02461	0.036679
YCR066W	RAD18	-1.01749	0.030866
YIL114C	POR2	-1.01496	0.074872
YKL040C	NFU1	-1.00866	0.017019
YAL015C	NTG1	-1.00047	0.02453
YKR007W	MEH1	-0.99398	0.054765
YJL172W	CPS1	-0.97224	0.072284
YLR191W	PEX12	-0.94213	0.063847
YNL071W	LAT1	-0.94093	0.097532
YOR006C	TSR3	-0.93294	0.036109
YLR426W	TDA5	-0.92821	0.083473
YDR508C	GNP1	-0.92306	0.025386
YLR239C	LIP2	-0.91953	0.044627
YFL001W	DEG1	-0.90718	0.054765
YCR028C-A	RIM1	-0.90398	0.080846
YOR008C	SLG1	-0.87237	0.0886
YAR002W	NUP60	-0.85795	0.073979
YNR010W	CSE2	-0.84947	0.073979
YDR161W	ACL4	-0.8416	0.06429
YAR014C	BUD14	-0.83474	0.090475
YFL042C	LAM5	-0.83028	0.090475
YAR003W	SWD1	-0.79676	0.090475
YGL133W	ITC1	-0.79366	0.06429
YGR063C	SPT4	-0.79296	0.079953

Table 1. Results of 800 µM IQ exposure of diploid library expressing CYP1A2+NAT2. Expected results are highlighted in yellow, whereas common mutants between the 5-6 generation (G) and 10G exposures are highlighted in red. This study was performed in fulfillment of the Master's degree research requirement for Nick St. John.

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[1] De La Rosa, V. Y., Asfaha, J., **Fasullo, M.**, Loguinov A., Li, P.,Nakamura J., Swenberg, J.; Smith M. T., Vulpe, C.; Scelo D. G. Functional profiling in yeast reveals genotoxicity mechanisms and candidate susceptibility genes associated with trichloroethylene exposure and renal cell carcinoma. Toxicol Sci. 2017 Nov 1;160(1):111-120 Editor's Choice

Research funded by: National Institute of Health, National Institute of Environmental Health Sciences.

For more information on Dr. Fasullo's research, please visit: https://sunypoly.edu/faculty-and-staff/michael-fasullo.html

SGNANO RESEARCH GROUP

DR. SPYROS GALLIS

Scope: Quantum and materials sciences form the scientific foundation for perceiving and controlling the properties of matter with the goal of developing new and superior technologies. The most urgent challenges we face come from the limits of materials and how we use them. Approaching these challenges from the unique viewpoint of nanoscale science and engineering can open new pathways to fundamentally revolutionizing the current and potential future of quantum and materials science. To this end, our research group focuses on the fabrication and characterization of nanostructured materials for quantum, optoelectronic and sensing applications.

Single photons and photonic qubits are critical building blocks in many quantum secure communication protocols. Non-classical (single-photon) light sources emitting in the near-infrared region of the electromagnetic spectrum around 1540 nm, where signal transmission losses in optical fibers are small, are essential for the development of fiber-based quantum networks and communications. Our research program aims to accelerate research and development in such quantum sources for telecom quantum network technologies deeply impacting our lives as we are moving towards the Fourth Industrial Revolution.

ON-DEMAND CMOS-COMPATIBLE FABRICATION OF ULTRATHIN SELF-ALIGNED SIC NANOWIRE ARRAYS

The field of semiconductor nanowires (NWs) has become one of the most active and mature research areas. However, progress in this field has been limited, due to the difficulty in controlling the density, orientation, and placement of the individual NWs, parameters important for mass-producing nanodevices. Our group is focused on creating a novel CMOS-compatible synthesis route for silicon carbide (SiC) NW arrays (Fig. 1). This synthesis route overcomes the drawbacks of the typical bottom-up approaches that inhibit the desired deterministic positioning, while also not limiting the optical, electrical, and geometric properties of the NWs. This holistic approach can enable the development of new scalable SiC nanostructured materials for use in a plethora of emerging applications, such as NW-based sensing, quantum sources, and quantum photonics.

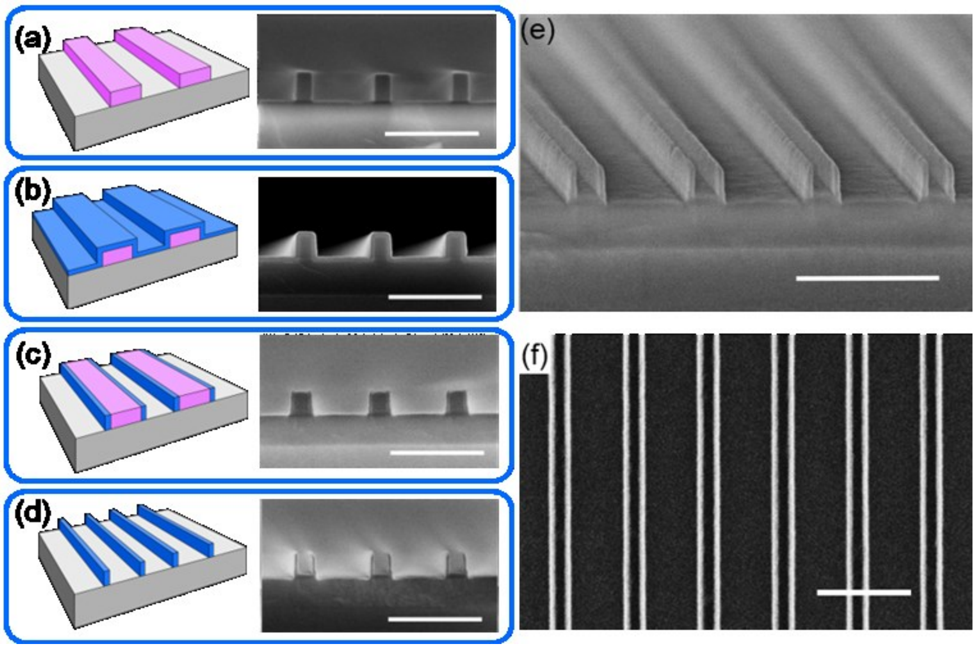

Figure 1. Nanofabrication of ultrathin self-aligned nanowires (NW) array. (a) Si wafer (gray) was spin-coated with hydrogen silsequioxane (HSQ) followed by exposure and development yielding a ribbon array (pink) with width and pitch ranging from 50 nm to 150 nm and from 200 nm to 600 nm, respectively; (b) ultrathin conformal silicon carbide (SiC) layer (blue) was deposited using thermal CVD; (c) ultrathin conformal SiC layer was etched open to expose the HSQ ribbon array using inductively coupled plasma reactive ion etching (ICP-RIE); (d) removal of the HSQ ribbon array was done by wet etch in buffered hydrofluoric acid (BHF), yielding SiC NW arrays with 20 nm critical dimension (width) NWs. Cross-section SEM images are shown after corresponding steps; (e) tilted cross-section and (f) top-down SEM image of the SiC NW array. Scale bar in all SEM images is 500 nm.

PUBLICATIONS AND PRESENTATIONS

[1] Tabassum N., Kotha M., Kaushik V., Ford B., Dey S., Crawford E., Nikas V., and **Gallis S.**, "On-demand CMOS-Compatible Fabrication of Ultrathin Self-Aligned SiC Nanowire Arrays", *Nanomaterials*, 8, 906, (2018). https://www.mdpi.com/2079-4991/8/11/906

SCALABLE NANOPHOTONIC STRUCTURES FOR LONG-DISTANCE QUANTUM COMMUNICATIONS

(*Work presented in the Quantum Information Science 1st International Workshop; see Figure 2*)

Quantum devices, such as single-photon sources and optical quantum memories at telecom wavelengths, are critical building blocks for the development of long-distance quantum communications and optical quantum networks. Recent attempts at developing material-platforms for these devices have been hindered by their unsuitable emission wavelength, random placement of emitters, and stringent fabrication and operational temperature requirements. Rare-earth-doped materials are one of the most promising candidates towards the implementation of such quantum devices, because of their near-radiative-limited intra-4f transitions, and exclusively true for erbium ions with emission at the low-loss telecom 1540 nm wavelength. Our research work, supported by NSF, has been aimed at developing critical optical properties of erbium ions, enabled by a new class of silicon carbide nanophotonic structures, which provide high design adaptability, tunability, and integration capabilities with silicon nanophotonics. The underlying hypothesis is that erbium integrated into the proposed nanophotonic structures can experience modification of its spontaneous light emission rate and emission angular distribution. Both simulations and photoluminescence measurements revealed that the photostable and polarized erbium emission was enhanced by engineering the geometry of the nanophotonic structure. Benefits from this holistic approach with the fundamental understanding of erbium emission in such scalable nanophotonic structures can expedite the advances towards long-distance optical quantum networks (Figure 2).

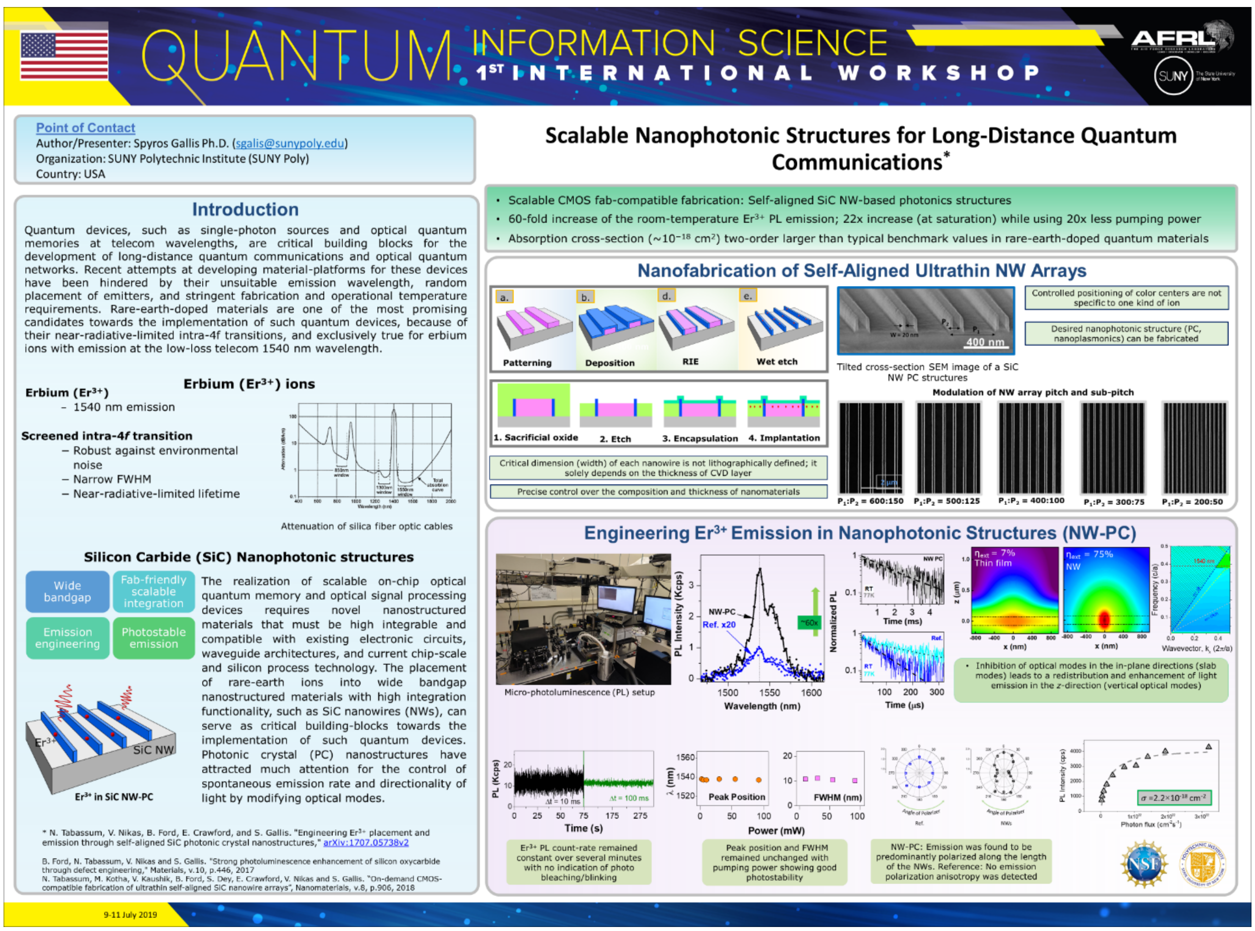

Figure 2

Research funded by: NSF, Gelest Incorporated.

For more information on Dr. Gallis's research, please visit: https://sites.google.com/sunypoly.edu/galisresearch/home

NANOSCALE ELECTRONICS

DR. JI UNG LEE

Scope: We explore fundamental devices in nanoscaled materials, including carbon nanotubes, graphene, and transition metal dichalcogenides. We fabricate devices such as p-n junction diodes to examine the linkages between materials properties and device performance.

Goals: Develop reconfigurable devices and novel transport phenomena.

GATE TUNABLE GRAPHENE-WSE2 HETEROJUNCTIONS AT THE SCHOTTKY-MOTT LIMIT

Metal-semiconductor interfaces, known as Schottky junctions, have long been hindered by defects and impurities. Such imperfections dominate the electrical characteristics of the junction by pinning the metal Fermi energy. Here, a graphene-WSe2 p-type Schottky junction which exhibits a lack of Fermi level pinning is studied. The Schottky junction displays near-ideal diode characteristics with large gate tunability and small leakage currents. Using a gate electrostatically coupled to the WSe2 channel to tune the Schottky barrier height, the Schottky-Mott limit is probed in a single device. As a special manifestation of the tunable Schottky barrier, a diode with a dynamically controlled ideality factor is demonstrated.

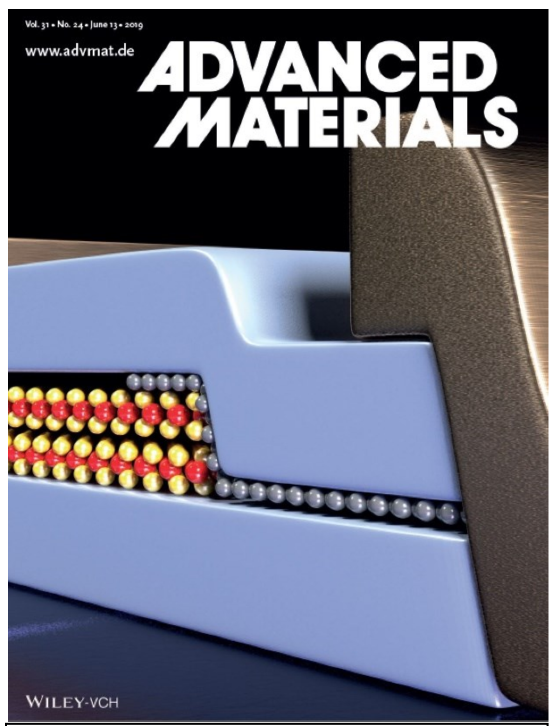

Figure 1: Cover figure from our publication: Gate Tunable Graphene-WSe2 Heterojunctions at the Schottky-Mott Limit

DIRECT MEASUREMENT OF THE ELECTRON BEAM SPATIAL INTENSITY PROFILE VIA CARBON NANOTUBE TOMOGRAPHY

Electron microscopes are ubiquitous across the scientific landscape and have been improved to achieve ever smaller beam spots, a key parameter that determines the instrument's resolution. However, the traditional techniques to characterize the electron beam have limited effectiveness for today's instruments. Consequently, there is an on-going need to develop detection technologies that can potentially measure the smallest electron beam, which is valuable for the continual advancement of microscope performance. We report on a new electron beam detector based on a single-wall carbon nanotube. The nanotubes are atomically smooth, have a well-defined diameter that is similar in size to the finest electron probes and can be used to directly measure the beam profile. Additionally, by rotating the nanotube in a plane perpendicular to the beam path and scanning the beam at different angles, we can apply tomographic reconstruction techniques to determine the spatial intensity profile of an electron beam accurately.

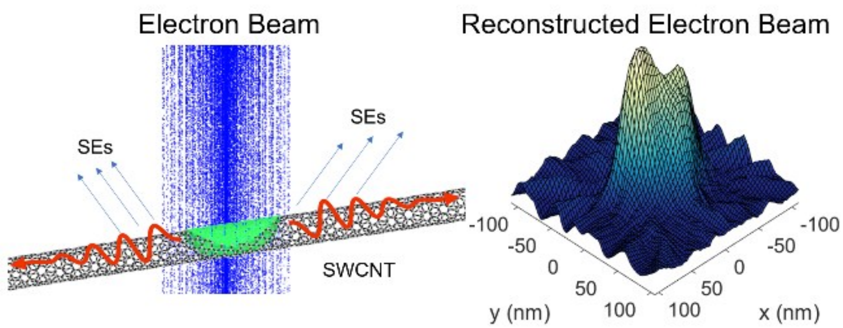

Figure 2: Generation of plasmons in nanotubes by an electron beam and the reconstructed image of an aberrated beam.

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[1] Direct Measurement of the Electron Beam Intensity Profile via Carbon Nanotube Tomography, Authors: Matthew Zotta, Sharadh Jois, Prathamesh Dhakras, Miguel Rodriguez, **Ji Ung Lee**, Nano Letters, (Featured as Articles ASAP).

[2] Gate Tunable Graphene-WSe2 Heterojunctions at the Schottky-Mott Limit, S. W. LaGasse, P. Dhakras, K. Watanabe, T. Taniguchi, **J. U. Lee**, Adv. Materials. (2019), DOI, (Cover Article, Featured in Adv. Sci. News)

[3] Atomic-Scale Characterization of Graphene p–n Junctions for Electron-Optical Applic Xiaodong Zhou, Alexander Kerelsky, Mirza M. Elahi, Dennis Wang†, K. M. Masum Habib, Redwan N. Sajjad, Pratik Agnihotri∥, **Ji Ung Lee**, Avik W. Ghosh, Frances M. Ross, and Abhay N. Pasupathy, ACS Nano January 28, 2019.

[4] Two-Parameter Quasi-Ballistic Transport Model for Nanoscale Transistors, **Ji Ung Lee**, Ramya Cuduvally, Prathamesh Dhakras, Phung Nguyen, and Harold L. Hughes, Scientific Reports, 9, 525 (2019).

[5] Tunneling Spectroscopy of Quantum Hall States in Bilayer Graphene p-n Junctions K. Wang, A. Harzheim, T. Taniguchi, K. Watanabe, **Ji Ung Lee**, P. Kim, (2019).

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Research funded by: The Dormitory Authority of the State of NY, NRL, NSF

For more information on Dr. Lee's research, please visit: https://sunypoly.edu/research/ji-ung-lee.html

RELIABILITY PHYSICS IN NANOSCALE ELECTRONICS

DR. JIM LLOYD

Scope: My group focuses on the fundamental science behind reliability issues in nanoelectronics. Semiconductor devices have entered a regime where our understanding of the behavior of materials at the dimensions now employed is not well understood. This is occurring at the same time that the challenges to the materials is growing. Higher current densities, higher temperatures and higher electric fields are imposed upon intrinsically less reliable materials chosen for their electrical properties and not for durability. In order to test devices for contemporary applications require a precise understanding of the physics of degradation in order to know how to test and predict reliability at almost inconceivable levels of complexity. Knowledge of the reliability must be obtained under "accelerated conditions" where information must be gathered in realistic time frames and be able to extrapolate the results of testing to realistic use conditions. Here we study these degradation phenomena and apply them to engineering solutions.

Goals: To provide understanding of the physics of failure in nanostructures semiconductor materials, create physical models for degradation and apply that knowledge for predicting lifetime of semiconductor devices

TDDB IN LOW-K DIELECTRICS

In recent years, the practice of "materials scaling" has been embraced to achieve performance. For instance, a limiting factor in circuit speed is the RC time constant. R is resistance and C is capacitance. As a result, the benign metal Al was replaced by the much trickier metal, Cu, due to its lower resistivity and the "bullet proof" silica based interlevel dielectrics were replaced by low dielectric constant materials like SiCOH which is much less robust to dielectric breakdown and is much more susceptible to Time Dependent Dielectric Breakdown (TDDB) where electric fields are imposed that are lower than the ultimate breakdown strength, but eventually wear out causing catastrophic breakdown and device failure.

At the present time there have been at least 7 physical models proposed to account for TDDB in low-k dielectrics. The challenge comes the fact that at accelerated conditions, all the models fery narrow it the data well, but the projections to use conditions differ by many orders of magnitude. This is obviously an unacceptable situation for reliability engineering.

This past year my student (Niaz Mahmud) has investigated the behavior of very small structures with respect to the various models. He was working with intralevel spacing as little as 11 nm to determine which of the models was valid in this regime. He found that two of the models survived detailed statistical investigation, a power law model of uncertain physics and what has become called the “lucky electron” model(LEM) where breakdown is due to defects generated by scattered electrons that have gained energy and momentum through the electric field.

An additional experiment was conducted with the help of Prof. Pat Lenahan of Penn State where SiCOH dielectrics were obtained with the hydrogen supplanted by deuterium. In the LEM, hydrogen is the only component of the dielectric that can be ejected by an electron, the probability that an electron would be able to gain enough momentum to eject a deuterium atom is vanishingly small. Preliminary experiments here showed that deuterated SiCOH was at least 2 orders of magnitude more robust to TDDB than standard SiCOH.

The work was presented at the 2018 IIRW (International Integrated Reliability Workshop and the 2019 IRPS (International Reliability Physics Symposium), the two most important venues for semiconductor reliability studies. Both are IEEE events.

ELECTROMIGRATION IN PULSED POWER APPLICATIONS

My student (Jennifer Passage) investigated a number of electromigration issues in nanostructured semiconductors. Electromigration has been an important wearout failure mode for the life of the semiconductor industry. It is due to high current densities in metal wires causing the conductor metal to move in the direction of current flow. This can cause open circuits or extrusions in the presence of flux divergences which are ample in the structure of a device.

Her work looked at 3 particular issues. 1) The limits of current density that can be imposed in accelerated testing and still be extrapolated to use conditions 2) The behavior of conductors under high current density stress following a “stress voiding” anneal and 3) The lifetime of low frequency pulsed power as compared to DC powering.

Her findings were significant. She found that for 40 nm wide and smaller line widths, the current density could safely be increased to more than 20,000,000 A/cm2 and still be able to be used for reliability predictions at lower operational use conditions. This is about an order of magnitude higher current than is generally used in industry. This realization enables testing that will take significantly less time than present testing protocols.

The stress voiding experiments were surprising in that there was little effect on the lifetime from a “stress anneal” which has been shown to cause failures in itself, without current flowing. It just appeared trhat there may have been a few early fails attributed to the thermal exposure

The most interesting observation in this study was that in the pulsed power investigation, considerable relaxation occurred at modest (2 MA/cm2) current densities, increasing lifetime by a factor of about 3 at 10% duty cycle (Percent time on as compared to DC). However, at high current density (more than 10MA/cm2) damage continued even when the current was off.

This latter result was attributed to the fact that damage in the form of a void must first nucleate, which has a 1/j2 dependence on lifetime and then grow to fatal dimensions that has a 1/j dependence. Thus at higher current densities, the nucleation time is shortened considerably more than the growth time, and even when the void is nucleated, the extra stress that was built up during testing is “dumped” into the void, which of course is stress free. This is very good evidence that electromigration needs to be treated as a nucleation and growth process.

This work was also presented at IIRW and IRPS.

The senescence associated (SA) production of mitochondrial H2O2 governs the amplitude of SASP through phosphatase inhibition enhancing mTOR-signaling, SASP post-transcriptional processing and promoting renal fibrosis.

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Research Funded by: Boeing Company

For more information on Dr. Lloyd’s research, please visit: https://sunypoly.edu/faculty-and-staff/james-lloyd.html

REDOX-SIGNALING & BIOLOGY

DR. ANDRE MELENDEZ

Scope: Our studies revolve around a key central paradigm, that oxidant signaling is precise, compartmentalized and amenable to targeted-antioxidant based therapies. Reactive oxygen and nitrogen species (ROS/RNS), in addition to their ability to damage biomolecules, have also emerged as key mediators in regulation of signaling networks by modulating phosphatase activity, kinase cascades and transcription factor binding. Thus, ROS/RNS serve a dual role, at low concentrations they are secondary signaling molecules that regulate the expression of a wide array of signaling networks, and at high concentrations damage lipids, protein and DNA. The principle mediator of ROS-dependent signaling is the 2e- reduction product of oxygen, H2O2, which is produced in response to numerous physiologic stimuli. Recent work from my lab and others indicate that superoxide (O2-•) may also play an important role in cellular signal regulation.

Our work is focused on defining how ROS/RNS drive cellular signaling events that control cellular senescence, metastatic disease, matrix destruction and the virulence of infectious bacteria. We have developed many cutting-edge tools to monitor oxidant production from cells in real time. Our studies indicate that that augmented free radical production initiate or drive age-associated disease. CNSE is unique and provides the scientific infrastructure for the development of innovative therapeutic and diagnostic technologies to limit degenerative disease.

Goals: Provide R&D for the development of targeted antioxidant based therapies for the treatment of metastatic cancer, aging and infection disease.

TOPIC 1

Fifteen percent of American adults (>30 million) suffer from some degree of chronic kidney disease (CKD). Medicare costs for patients aged 65 years or older with CKD were about $45 billion in 2012. Globally from 8-16% of the population worldwide is affected by CKD and in 2014 kidney disease was

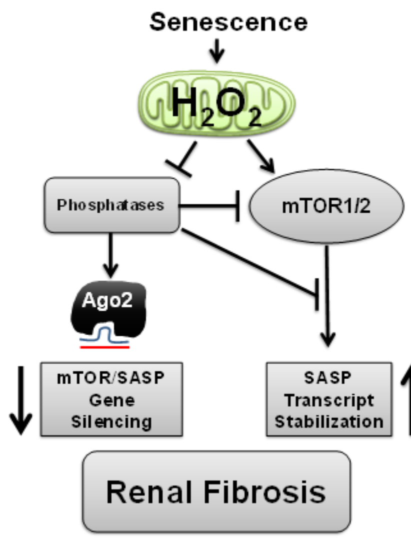


Figure 1: The senescence associated (SA) production of mitochondrial H2O2 governs the amplitude of SASP through phosphatase inhibition enhancing mTOR-signaling, SASP post-transcriptional processing and promoting renal fibrosis.

the 9th ranked cause of death nationally. Strategies to reduce burden and medical costs related to renal disease are critically needed. Senescence cells have recently emerged as contributors to age-related renal pathology. While cellular senescence has evolved as a protective mechanism to arrest cells exposed to oncogenic insult, chronic senescence activation promotes loss of renal function. The harmful effects of senescence are attributed to high secretory activity, commonly referred to as the Senescence Associated Secretory Phenotype (SASP).

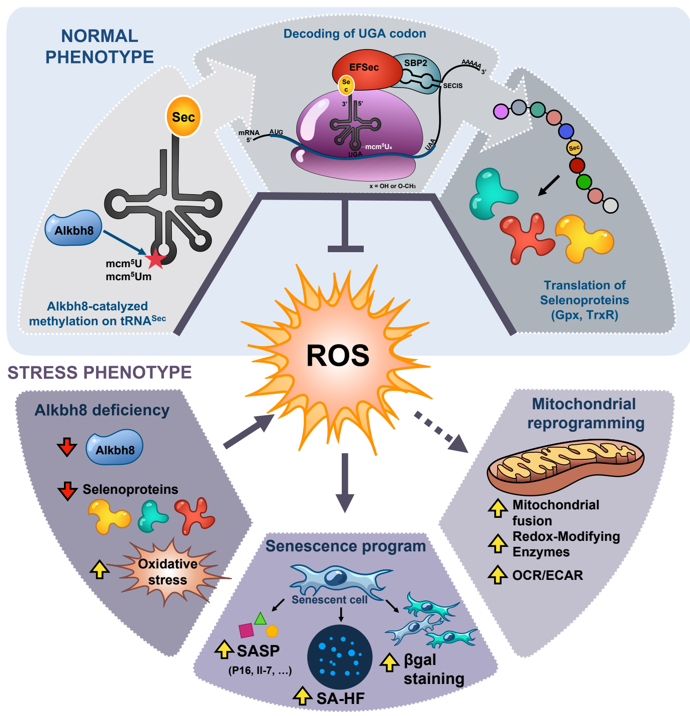
Strategies which limit the amplitude and duration of SASP will serve to delay age related renal decline. SASP activation is reliant on production of interleukin-1 alpha (IL-1α) and we have shown that H2O2, likely of mitochondrial origin, regulates IL-1α transcription and processing in this process. H2O2 signals, in part, through oxidative inactivation of specific protein tyrosine phosphatases (PTPs) that coordinate a broad array of signaling networks. Conversely, IL-1α mRNA stabilization and translation in SASP is also regulated by mTOR. Hence, we have been defining the interplay between H2O2 and PTPs that govern mTOR signaling and how this contributes to gene silencing and post-transcriptional processing of the SASP. Fibrotic insult is a precursor to loss of renal function and we are developing targeted strategies which restrict mitochondrial H2O2, mTOR or SASP and can limit renal fibrosis.

PUBLICATIONS AND PRESENTATIONS

Chandrasekaran, A, Zhang, X, Lee, MY, Desta, H, Trebak, M and **Melendez, JA**. Redox and mTOR-dependent regulation of TRPC channels controls the SASP. Manuscript in Submission, Cell Calcium.

TOPIC 2

Maintenance of the GSH redox cycle is reliant on the activities of selenocysteine-containing GSH metabolizing enzymes. Selenocysteine is the 21st amino acid and does not contain a dedicated codon. Selenocysteine incorporation during translation requires UGA-stop-codon recoding, which uses specifically modified tRNA for accurate decoding. Dynamic changes in tRNA modification are an epitranscriptomic signal because they regulate gene expression post-transcriptionally. The Begley lab has shown that the stress-induced translation of many selenocysteine containing ROS detoxifying enzymes is dependent on the Alkbh8 tRNA methyltransferase. Alkbh8 enzymatically



methylates the uridine wobble base on tRNASelenocysteine to promote UGA-stop codon decoding. Surprisingly the Alkbh8-deficient (Alkbh8-/-) mice reproduce, thrive normally and live past 15 months, suggesting they adapt to the selenoprotein deficiency, high ROS and increased DNA damage levels. In collaboration with the Begley lab we have been investigating a potential adaption mechanism, we have used molecular, biochemical and genomic approaches to demonstrate that Alkbh8-/- mouse embryonic fibroblasts (MEFs) and some organs display markers of senescence and a senescence gene signature. Using theAlkbh8-/- mice we are testing the hypothesis that senescence occurs in vivo as a result of defective epitranscriptomic signals that controls selenocysteine utilization and prevents tumor emergence.

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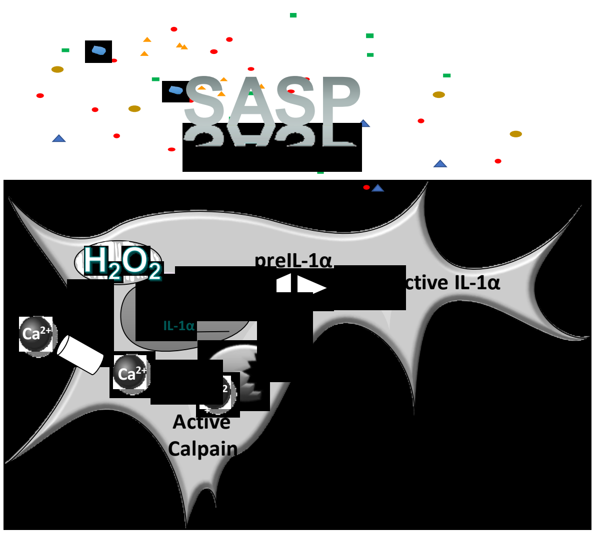
Andrea Leonardi, A, Sara Evke, S, May Lee, **M, Melendez**, JA, and Begley, TJ. Epitranscriptomic Systems Regulate the Translation of Reactive Oxygen Species Detoxifying and Disease Linked Selenoproteins. Free Radical Biology & Medicine (2019).

Lee MY, Leonardi, A, Begley, TJ and **Melendez, JA**. Epitranscriptomic defects responsible for selenocysteine utilization engage senescence and metabolic reprogramming. Redox Biology, (2019).

TOPIC 3

Cellular senescence has evolved as a protective mechanism to arrest growth of cells with oncogenic potential. While senescent cells have lost the ability to divide, they remain metabolically active and adapt a deleterious senescence associated secretory phenotype (SASP) central to the progression of several ageassociated disease pathologies. The SASP is mechanistically regulated by the pro-inflammatory cytokine interleukin-1 alpha (IL-1α) whose expression and activity is responsive to the senescence associated (SA) oxidant production and the accompanying disruption of calcium (Ca2+) homeostasis. Using primary IMR-90 human fetal lung fibroblasts as a model of replicative senescence, we explored the molecular underpinnings facilitating increased Ca2+ entry in senescent cells. We establish that the redox-responsive Transient Receptor Potential TRPC6 channel is compromised due to desensitization owing to SA increases in steady state hydrogen peroxide (H2O2) production. SA dysregulation of Ca2+ is also accompanied by loss of response to H2O2-induced Ca2+ influx that can be rescued with catalase pre-treatments. Senescent cells are also insensitive to Ca2+ entry induced by hyperforin, a specific activator of TRPC6, that can be restored by catalase pre-treatments, further suggesting redox regulation of TRPC6 in senescence. Inhibition of TRPC6 channel activity restores ability of senescent cells to respond to peroxide-induced Ca2+ in addition to suppressing SASP gene expression. Furthermore, mammalian target of rapamycin (mTOR) signaling regulates SASP by means of modulating TRPC6 channel expression. Together, our findings provide compelling evidence that redox and mTORmediated regulation of TRPC6 channel modulates SASP gene expression. As TRP channels emerge as targets of pharmacologic intervention for numerous disease pathologies, it is exciting to speculate that effects of TRP interventions may be attributed in part to inhibition of senescence and the SASP.



Senescence associated redox/Ca2+-deregulation promotes Senescence Associated Secretory Phenotype SASP

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Research funded by: Albany Medical College, National Institute of General Medical Sciences

For more information on Dr. Melendez's research, please visit: https://sunypoly.edu/faculty-and-staff/j-andres-melendez.html

COMPOUND SEMICONDUCTOR RESEARCH

DR. SERGE OKTYABRSKY

Scope: The Oktyabrsky Group research focuses on physics, materials and technologies of quantum confined structures, photonic/optoelectronic devices, group III-V MOSFETs.

Goals: 1. Demonstrate a novel approach to ultrafast and efficient scintillation detector based on quantum dots imbedded into semiconductor waveguide. 2. Develop integrated laser-modulator module for microwave photonics with the same gain/electro-absorption medium for both laser section of the device and modulator section.

INTEGRATED SEMICONDUCTOR QUANTUM DOT SCINTILLATION DETECTOR

The goal of this project is to develop and test a novel scientific approach and technology of a scintillation nano-material with unsurpassed speed and light yield, and to provide a path for scintillator integration with a waveguide and photodetector in order to prove the material's performance benefits. This project opens a possibility of single x-ray photon timing in picosecond range, reduction of radiation doses in medical 3D imaging/tomography applications, improvement of spectroscopic accuracy in nuclear security and enhances particle identification capabilities in high-energy physics.

Highlights

In 2018 the major accomplishments included:

- Design and fabrication of thick epitaxial waveguiding (WG) structures with nano-engineered InAs quantum dots (QDs) where the reduced InAs wetting layer (Fig. 1) resulted in low self-absorption of about 1 cm-1 ; multilayer modulation doping for electrostatic potential engineering that resulted in fast and efficient collection of carriers into QDs that resulted in 60% luminescence efficiency at room temperature
- Waveguide attenuation was measured, modeled and quantified against various propagation models (Fig. 2). The role of surface scattering was identified as the major contributor to attenuation over the first few mm of light propagation. This outcome requires additional focus on surface preparation technologies.
- An Integrated photodiode on multimode WG was modeled, fabricated and tested. It was further used to characterize scintillation response of α-particles with rise time jitter of 70 ps (Fig. 3). This proves that although the scintillator properties are significantly impaired by the surface scattering, its yield of 17,000 photoelectrons per 1 MeV of incident energy (Fig. 4) and 0.3-0.4 ns decay makes it the fastest scintillator. It is likely that further technology development will provide even better results.

In 2018 we secured funding from DOE, and continued funding from NSF; they both will further support our ongoing program on quantum dot waveguiding scintillation detectors.

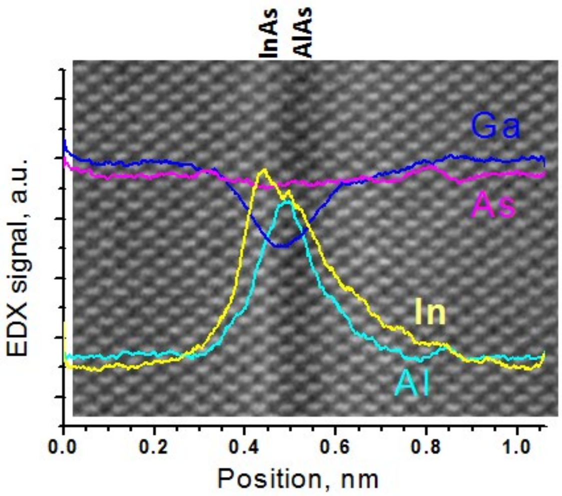


Fig. 1. High-angle annular dark-field (HAADF) cross-sectional micrograph along <110> direction of a wetting layer (WL) between the dot, and the overlapped characteristic x-ray intensity profile of the constituent elements across the WL Bright contrast corresponds to atomic columns, higher-Z elements appear brighter. Al elemental peak is just 1ML displaced from the In peak that raises the transition energy in the InAs WL.

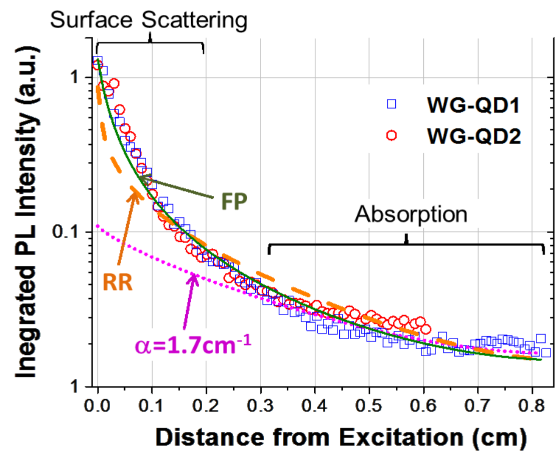


Fig. 2. Integrated PL intensity of two waveguiding samples (symbols) along with the fitting curves (lines). Each symbol is the result of integrating a single PL spectrum attenuated in the waveguide. Dotted line is a single exponent Beer–Lambert law modified with waveguide mode propagation with material absorption 1.7cm^{-1}; 'RR' dash line is a Rayleigh-Rice roughness scattering fit with Gaussian roughness of 60nm and □=2cm^{-1}; and 'FP' solid line is an angle-independent fixed probability photon scattering fit with □=0.14 and □=0.7cm^{-1}.

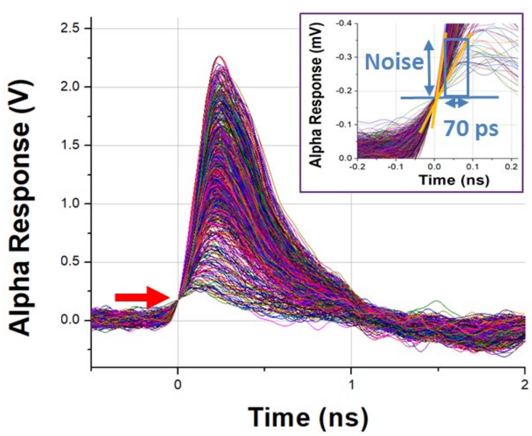


Fig. 3. Alpha particle response of integrated GaAs/InAs QD scintillation. The signal was amplified by ~50 dB and recorded by a 4 GHz oscilloscope; triggering level is indicated with arrows The insets are the leading edges of the pulses illustrating the measurable time resolution (jitter) of about 70ps.

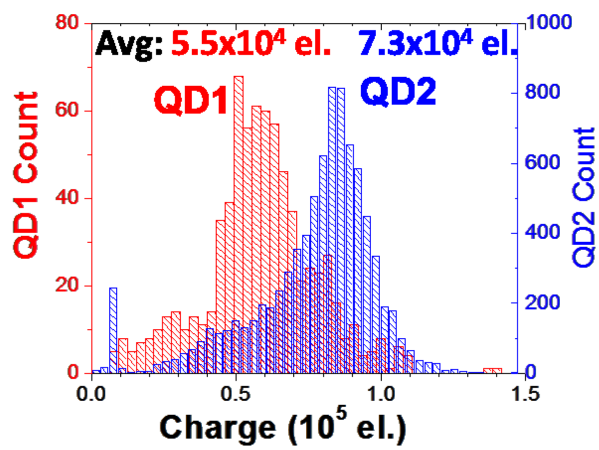


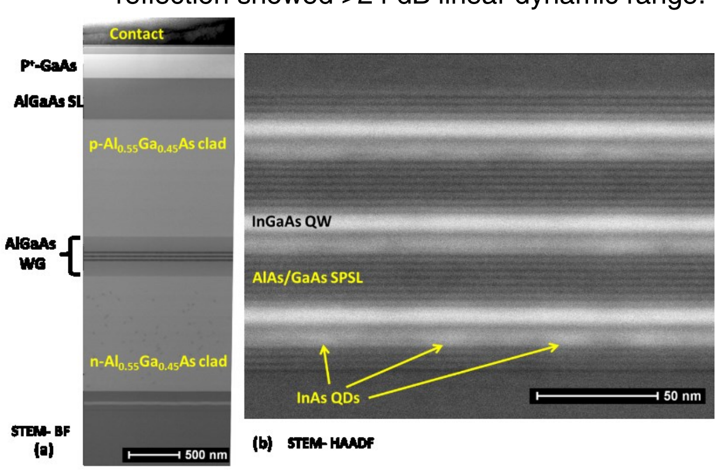
Fig. 4. Histograms of collected charge from alpha-particles by integrated scintillation detectors on QD1 and QD2 WGs. The average collected charge is 40% higher in the QD2 sample due to its larger area.

INTEGRATED MICROWAVE OPTICAL SOURCE

The scope of this DOE SBIR Phase II subcontract was design, fabrication and bench-testing of the first-generation prototype of a diode waveguide laser with integrated modulator with a quantum well on dots (QW-on-QDs) medium providing both gain at forward bias and electro-absorption modulation at reverse bias. The device with adequately designed inter-section reflector and travelling mode modulator will be capable of microwave operation. The main original idea of the current project is to utilize the same medium for both gain laser section of the device and integrated modulator section.

Highlights

- For the first time a monolithic laser-modulator device is demonstrated with the same tunnel coupled QW-on-QDs medium, where the quantum well acts as a tunnel injector into QDs in the laser diode section and as a quantum Stark effect electro-absorber in the modulator section (Fig.1).
- Ground state energy matching in the QW-on-QDs active medium was demonstrated for lasing with tunnel QW-to-QD injection (at ~1090 nm) and modulation by the same active medium in directly and inversely biased sections, respectively.
- For the first time, a wave-function engineered double tapered QW-on-QDs structure was used for in-plane integrated laser-modulator with improved linearity.
- Multiple engineering approaches were developed and applied to demonstrate a device performance and extract basic characteristics: developed and implemented process flows for two-section laser-modulator with implant and junction isolation, low threshold current density, required DC modulation characteristics
- Developed a FIB-fabricated intermediate distributed Bragg reflector (DBR) with low electrical leakage and required optical mode reflection (Fig.2).
- Demonstrated laser-modulator performance at CW and low frequencies (Figs. 3,4).
- Developed, implemented/packaged (Fig. 5) and tested laser-modulator device with FIB-fabricated intermediate DBR reflector of low electrical leakage and optical mode reflection showed >24 dB linear dynamic range.



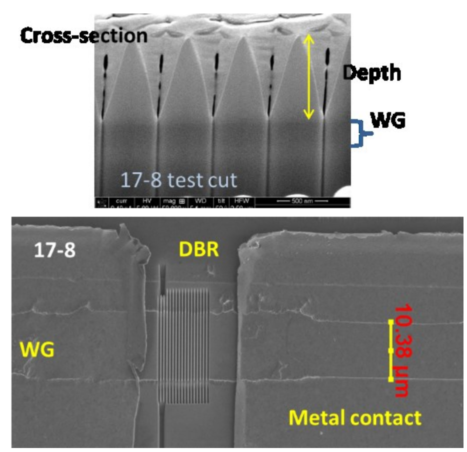


Fig. 2. Top view and cross-sectional SEM images of FIB-prepared with 10 µm wide

Fig. 1. Scanning TEM cross-sectional images of the laser-modulator structure (a) bright field (BF) STEM image. Darker contrast corresponds to higher-Z material in BF. (b) Magnified high-angle annular dark field (HAADF) STEM image of the QW-on-QDs medium. Brighter contrast corresponds to higher-Z material in HAADF.

waveguide . DBR parameters: 0.24 □m nominal (Si) depth; 0.27 □m trench width; 0.55□□m period; 17 periods. A longer and wider trench is a cut for electrical insulation.

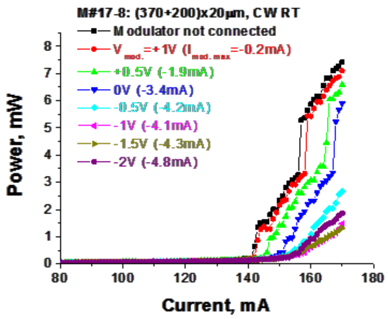


Fig. 3. CW power-current characteristics with modulation bias as a parameter lasing at 1085 nm: shows low threshold current change with modulator voltage bias. Modulator current is given in brackets.

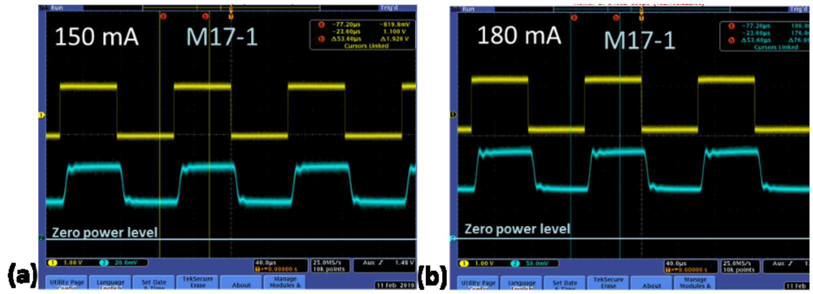


Fig. 4. Low frequency (10 kHz) optical signal from chip M#17-1 (15x550 nm DBR periods). (a) at 150 mA, 50% and (b) 180 mA laser section current, 43% modulation, respectively Modulation bias is yelow trace +1/-1V, and optical signal collected by multimode fiber is a blue trace. Zero power level of the device is indicated.

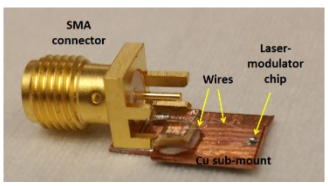


Fig. 5. Laser-modulator chip mounted with an SMA connector for modulation measurements.

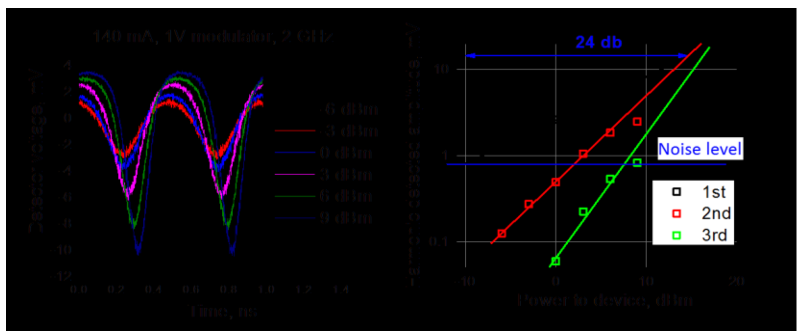


Fig. 6. Linearity test of a laser-modulator chip at 2GHz. (a) Traces of the fiber-connected PD signal at different power levels to the modulator section. (b) Plots of amplitudes of the first three harmonics showing maximum RF driver linear power level of 14 dbm corresponding to equal first and second harmonics of the PD signal.The linear dynamic range is higher than 24dB, given the estimated 0.8 mV noise level of the PD signal.

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Research funded by: NSF, DOE, Physical Optics Corporation, Intellisense Systems Incorporated

NEUROSCIENCE NANOTECHNOLOGY FOR TRANSLATIONAL & COMMERCIAL TISSUE ENGINEERING

DR. JANET L. PALUH

Scope: Dr. Paluh's research is focused on human stem cell biology with applications to multicellular tissue microarchitectures, neural circuitry and neurodegeneration as well as research on multi-scale biological processes including subcellular self-assembling nanomachines relevant to mitosis and neural plasticity. Recent contributions include a framework for nanoscale and molecular communication networks described in the IEEE Standard 1906.1 and computational neuroscience modeling of neuron-neuron communication and neuron subsystems. Biomedical research includes identification and patent of a new cancer therapy target published in Nature Communications and collaborations in multiple disease areas with biomedical applications facilitated by nanotechnology.

Goals: Translational and commercial biomedical applications. Current research collaborations include neural circuitry restoration of spinal cord injury, traumatic brain injury neural cell-cell interaction microchip, neural degeneration and axonopathies; human stem cell derived bionetwork for airborne opioid detection; and biomanufacturing of human stem cell derived pancreatic ß-islets.

BIOMEDICAL APPLICATIONS IN NEUROSCIENCE: SPINAL CORD INJURY AND TRAUMATIC BRAIN INJURY

We have established multi-university collaborations for advancing therapeutic cell delivery, retention, integration and regeneration of spinal cord function using a rat hemicontusion model of SCI and a microribbon platform containing therapeutic spinal motor neurons and oligodendrocye cells + injury microenvironment modulators. This customized shippable platform provides high cell retention at the injury site and is being validated by functional behavioral recovery studies in animal models that are ongoing. Towards traumatic brain injury (TBI) we collaborate on a cell-cell interaction microchip capable of multifunctional parameter analysis of the interaction of neurons and immune system microglia cells. This biomimetic platform is capable of reproducing cell mechanotransduction responses to stretch injury as a new approach to identify potential new biomarkers of cell-cell communication changes that can be applied translationally to monitor TBI generation and recovery or exacerbation. In addition, the microchip is being used to better define subpopulations during differentiation of therapeutic central nervous system neurons by evolving cell-signaling capabilities to assist cell choice in therapeutic interventions. These are examples of human neural stem cell studies that bridge the bench to clinic gap through animal models or via biomimetic lab on a chip strategies. Both strategies as we use them establish and evaluate neural circuitry formation in vitro and for the SCI studies (Figure 1) the transplantation of neural circuits in vivo to interconnect with native circuits in xenographs. These studies are supported by the New York State Department of Health initiatives by the spinal cord injury review board (NYSCIRB, C44278GG) and stem cell research (NYSTEM, C32574GG) organization through ~$1million PART and $275K IDEA research awards. The SCI research involves collaborators at Houston Methodist Neurosurgery, Prof. Philip Horner; Michigan State University Cellular Reprogramming, Prof. Jose Cibelli; SUNY Albany Electrophysiology; Prof. Annalisa Scimemi; and Rensselaer Polytechnic Institute Biocatalysis and Metabolic Engineering, Prof. Robert J. Linhardt. The NYSTEM award is led by PI Prof Jun Wang, SUNY Albany/Stony Brook University, Biochemical Engineering. These are spearhead research projects at the cutting edge of human stem cell applications with the goals of near future achievable therapeutic interventions.

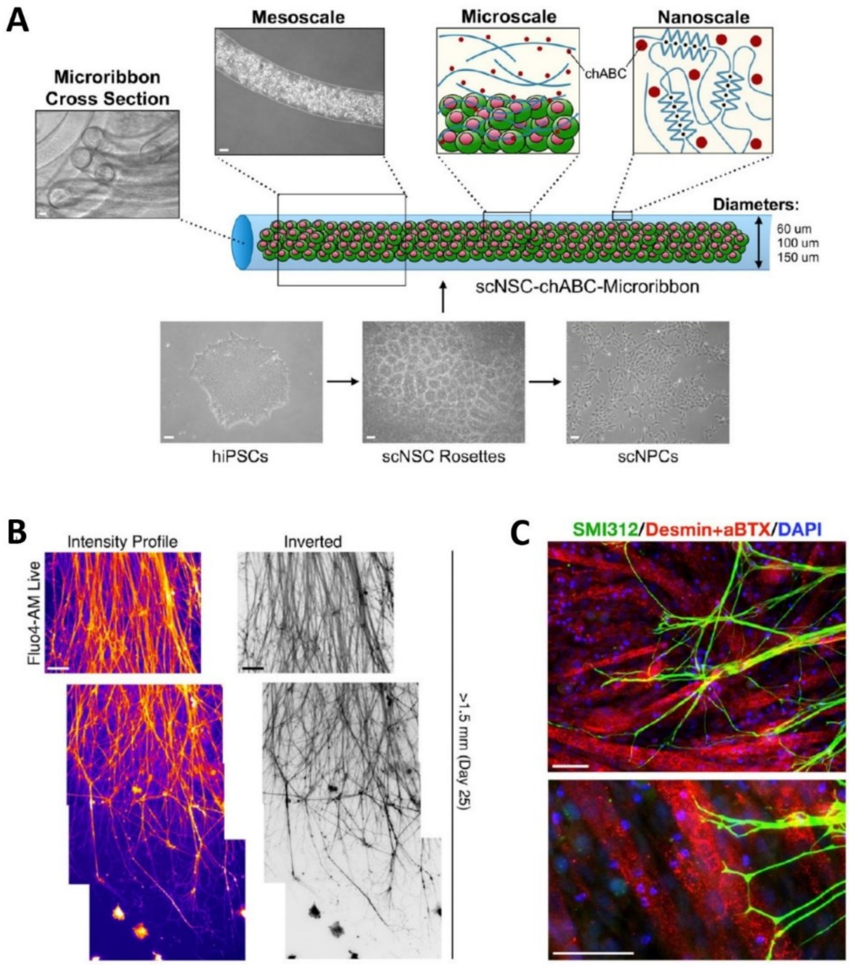

Figure 1: Transplantable Neural Circuitry. Alginate microribbon platforms offer an FDA approved material that can be customized for encapsulation of multipotent neural stem cells or differentiated neural cells, such as spinal motor neurons and oligodendrocytes. A. Human stem cell technology coupled with nanotechnology and chemical regulators provide a means for neural network formation in vitro and delivery in vivo with injury site modifiers and cell tracking capabilities. B. Neurites. C. Spinal motor neuron-skeletal muscle junctions. The current work is supported by the NYSCIRB award (C33278GG) to translate research into therapies to improve the quality of life of those affected with spinal cord injury by advancing treatment and recovery strategies.

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BIOMEDICAL APPLICATIONS IN COMPUTATIONAL NEUROSCIENCE AND BIOSENSORS APPLIED TO AXONOPATHIES AND NEURAL PLASTICITY

In addition to immediately approachable neural stem cell based therapies of Topic 1, we are applying mathematical modeling to computationally dissect complex subcellular neuronal signaling network elements for integration with multiscale computational neuroscience modeling platforms. Such detailed models incorporate compartmentalization of neurons into dendrites and axons and regional specializations of the microarchitecture of the cytoskeletal networks, ion channels, synapses and so forth. The detailed modeling in Figure 2 applies a mathematical framework first discussed in the IEEE Standard 1906.1 publication. In addition to modeling transport we have additional projects underway to model pre- and post-synapse communication networks to facilitate future work with artificial neural networks. The computational neuroscience research involves the collaboration with Dr. Amitava Mukherjee, formerly with IBM International and a leader in the area of modeling multiscale network communications. The increasing complexity of the subcellular neural anatomy being realized through superresolution microscopy necessitates high end modeling such as those we are developing and will advance our understanding of normal versus neurodegenerative disease mechanisms and development of neuromorphic platforms and artificial neural networks.

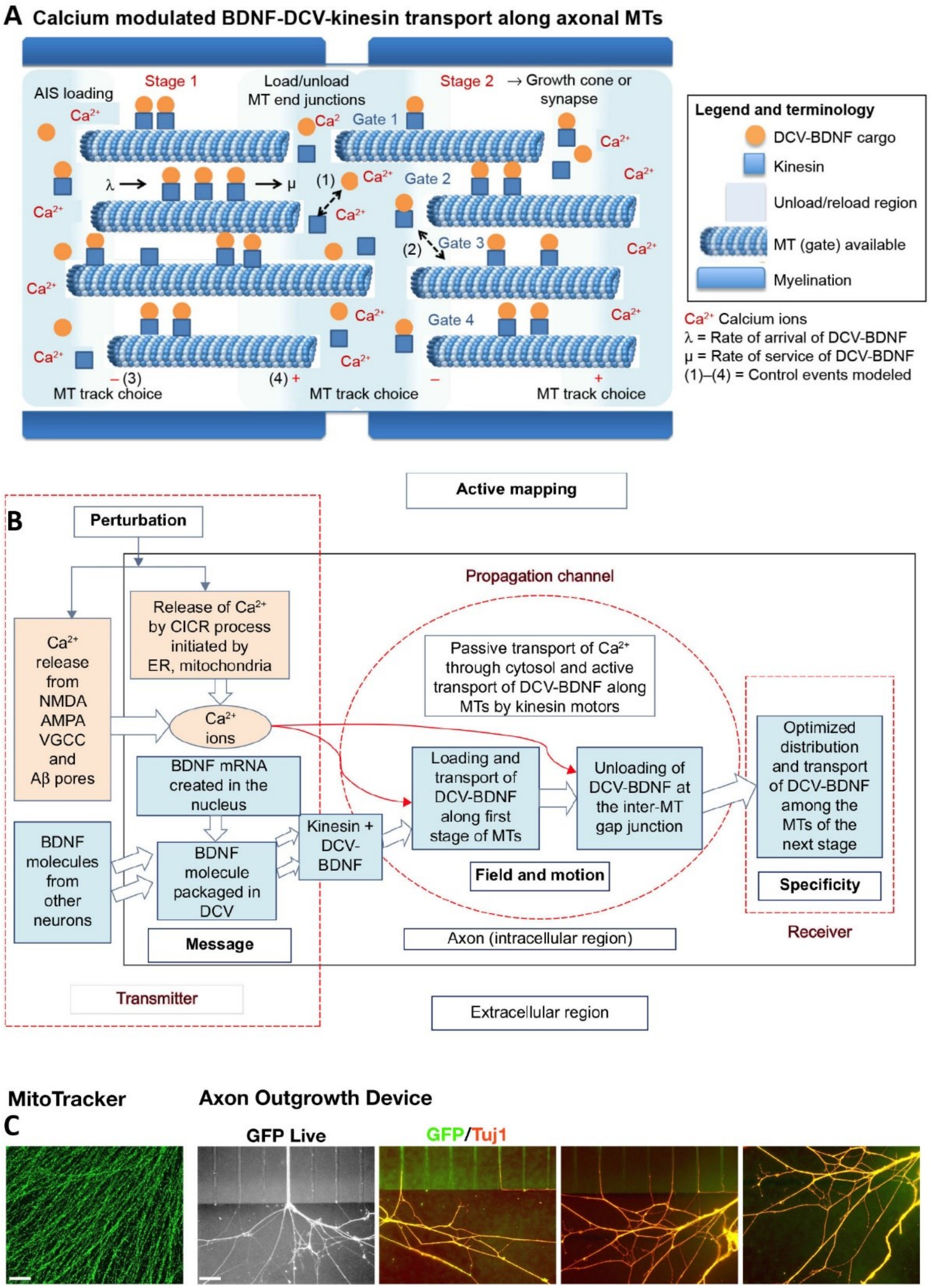

Figure 2: Computational Neuroscience. A. The complex infrastructure of a neuronal axon has yet to be modeled in sufficient detail that evaluates cargo-kinesin transport machinery along with the complex cytoskeleton networks that are discontinuous, branched and include subcompartments. B. Framework model for nano-microscale communication impact of amyloid beta on neurodegenerative Alzheimer's disease. C. Integrating mathematical modeling with axon outgrowth chambers provides a platform for experimental confirmation of computational models and discoveries.

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Research funded by: SUNY Poly Seed Grant, NYS Department of Health

For more information on Dr. Paluh's research, please visit: https://sunypoly.edu/faculty-and-staff/janet-paluh.html

NANOSCALE SCIENCE & ENGINEERING

DR. SATYAVOLU S. PAPA RAO

Scope: My team and I focus on enabling higher performance with novel devices in areas ranging from quantum technologies, through high frequency RF devices, to nano-biology. In the area of quantum technologies, we seek to exploit synergies in process technology development with applications in superconducting qubits, superconducting digital electronics, photonic qubits, neuromorphic computing, etc. Nano-biology research efforts are in collaboration with other faculty members at SUNY Poly, again seeking to identify novel applications of processes previously applied to semiconductor fabrication, with necessary modifications.

Goals: The broad goal is to demonstrate novel structures and devices capable of achieving significantly better performance in a variety of technologies, by inventing and developing tailored processes on advanced state-of-the-art tools.

QUANTUM FAB PLATFORM USING 300MM WAFER PROCESSES

We are continuing an ongoing research program to establish processes for the fabrication of devices for quantum computing/communications and sensing. This work is done in collaboration with researchers at University of Maryland, College Park, and the Laboratory for Physical Sciences (LPS), College Park, MD. The 2018-2019 period saw the first publication to report the fabrication of transmon qubits patterned using 193 nm optical lithography. 300mm wafers carrying Dolan bridges patterned using 193nm lithography (Figure 1a) were diced into coupons for shadow evaporation of aluminum-based Josephson junctions. Room temperature measurements of arrays of Josephson junctions showed that the room temperature normal resistance of the junctions varied by < 5% across multiple lithography runs. The variation in normal resistance of the Josephson junction is indicative of the variation in qubit frequency at cryogenic operating temperatures. Characterization (at LPS) of the qubits at millikelvin temperatures (Figure 1b) indicated that the promise of improved control of the qubit 0 → 1 transition frequency could indeed be realized through advanced optical lithography, with frequencies that were only ~1.5% apart. Additionally, two qubits analyzed both showed energy relaxation times of 25 microseconds. Further work is ongoing to move to a fully-300mm compatible transmon qubit fabrication process, utilizing damascene structures as shown in Figure 1c.

Scaling of trapped ion qubits needs ultra-low loss waveguides based on wide bandgap materials that are transparent to UV wavelengths. Over the past year, we have embarked on the process development of AlN-based waveguides. We have demonstrated world-class levels of surface roughness in Atomic Layer Deposited AlN films (through a partnership with Tokyo Electron Ltd.), utilizing chemical-mechanical planarization processes that had hitherto never been employed in AlN waveguide fabrication (Figure 2a). The ability to modify the fiber texture of the deposited AlN film as a function of process conditions was also studied (Figure 2b) – this can be exploited to the fullest by designing structures where the crystallographic axes of the film are oriented along the direction of the electric field to be applied, in a manner consistent with scaling the circuit to smaller footprints.

Starting in March 2019, we started work (along with Prof. Cady) on a 3-year AFRL-funded research program to develop some of the important devices and associated process technologies for superconducting optoelectronics for neuromorphic computing. The devices include fab-friendly Josephson junctions that utilize alpha-tantalum films generated at SUNY Poly, for which a superconducting transition was confirmed (by partners at Auburn University) to be just below 4K. In addition to Josephson junctions, Ta-based nanowire patterning processes are to be developed for building superconducting nanowire single photon detectors. The third device technology that is required is a silicon-based infrared photon emitter that operates at cryogenic temperatures. For all these devices, it is necessary to develop processes that achieve tight across-wafer and wafer-to-wafer uniformity in device characteristics. We have obtained preliminary results through micro-photoluminescence testing (by our partners at NIST Boulder) showing that 300mm wafer processes can successfully give rise to narrow bandwidth emission of 1.22 um light at cryogenic temperatures (Figure 3)

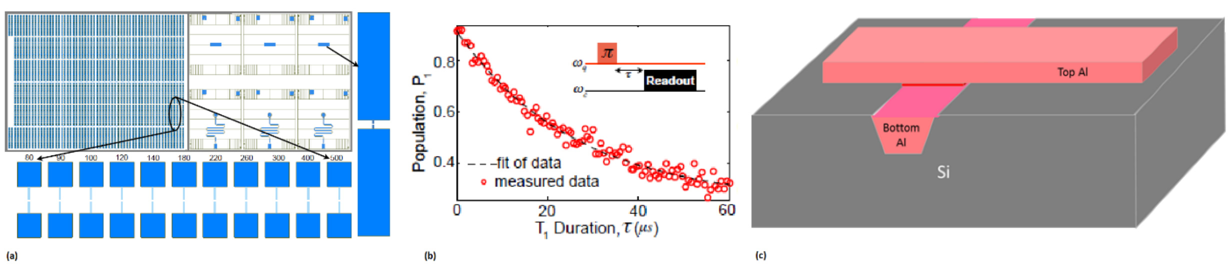

Figure 1: (a) Layout of 193 nm mask with Josephson junction (JJ) arrays and transmons (b) Measurements of energy relaxation time of a SUNY Poly fabricated qubit fabricated by shadow evaporation using 193nm patterned Dolan bridgesat LPS. (c) Schematic of 300mm processing compatible Josephson junction.

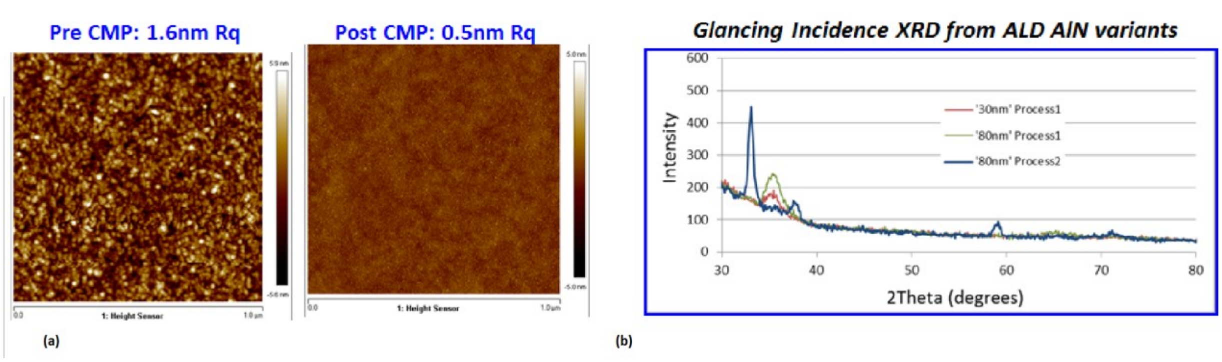

Figure 2: (a) Atomic Force Microscopy imaging of AlN films before and after chemical mechanical planarization (CMP) to improve roughness. (c) AlN process conditions can be used to tailor film texture.

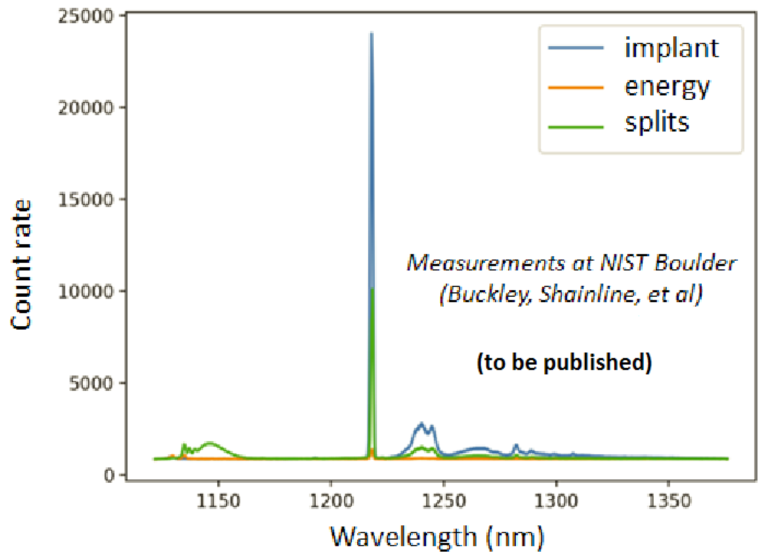

Figure 3: Micro-photoluminescence characterization of W-centers formed on a 300mm SOI wafer confirming modulation of 1.22um emission through choice of Si ion-implantation energies.

SEMICONDUCTOR FABRICATION PROCESSES APPLIED IN NANOBIOLOGY

Accelerated Neutral Atom Beam (ANAB) technology has shown significant promise in achieving sub-nanometer-scale surface modification of crystalline Si surfaces, and of metallic films. This technology was applied to cast polyurethane films where the surface roughness modification caused a statistically significant improvement in cell viability (Figure 4). Other applications of ANAB to biologically-relevant problems are under study.

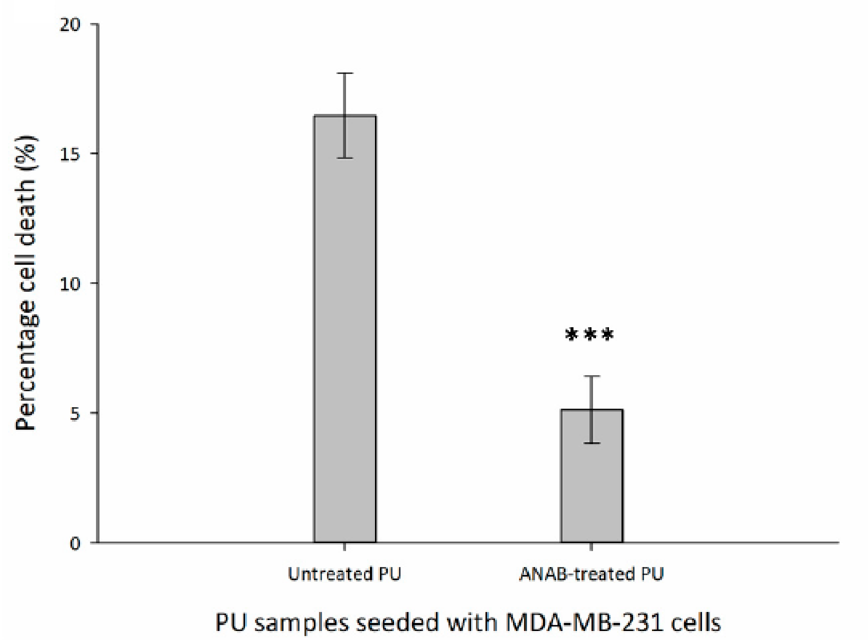

Figure 4: Improvement in cell viability on cast polyurethane films through ANAB treatment of the surface.

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Research funded by: AFRL

WIDE BANDGAP III-NITRIDE DEVICE RESEARCH

DR. F. SHADI SHAHEDIPOUR-SANDVIK

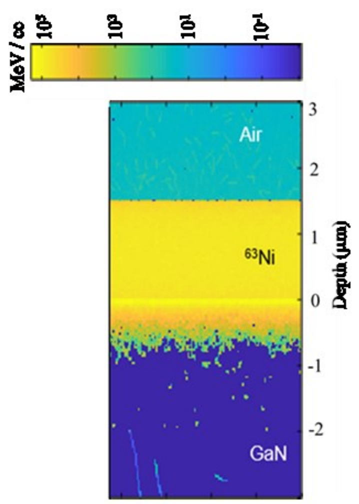
Goals: Our research is to explore and exploit the properties of wide bandgap and ultra wide bandgap III-Nitride materials and developing electronic and optoelectronic devices with novel structures and characteristics, better efficiencies and/or greater functionalities, based on them. Our current focus is on long lifetime beta(photo)voltaic batteries, high power/high frequency electronics with improved reliability, and high efficiency solar-blind photocathodes for single photon detection. Understanding the fundamental properties of the material including dopant incorporation (via in-situ, or implantation) and role of defects in material/device characteristics are of high importance.

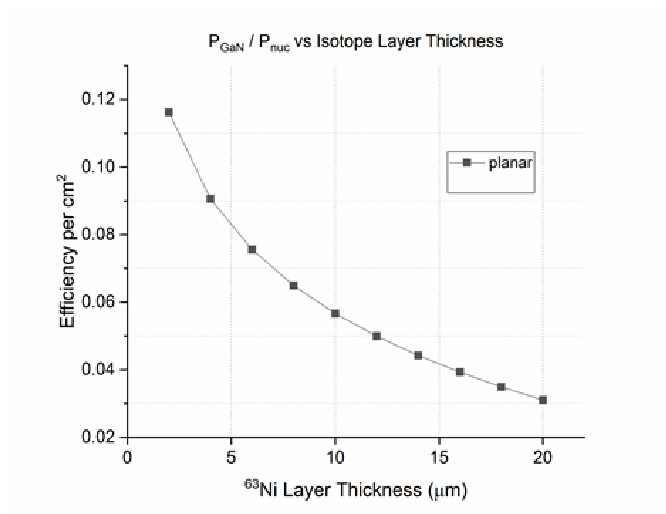
(AL)GAN-BASED BETAVOLTAIC MICROBATTERIES

In ongoing collaboration with the Army Research Lab (ARL), our research group is working to develop the next generation in high efficiency, radiation hard betavoltaic (BV) batteries. Conventional lithium batteries, although low in cost, expel energy relatively quickly and require replacement. BV batteries show promise as a replacement in low power (nW-µW) applications due to high energy density, relatively low weight and long lifetime. A BV device is analogous to a solar cell, where electron hole pairs (EHPs) are created by incident radiation. The radiation source in a BV device are high energy electrons, or β-particles, emitted from a coupled radioactive isotope. The kinetic energy of these β-particles dissipates throughout a semiconductor material through creation of EHPs by impact ionization and losses due to numerous scattering mechanisms.

The (Al)GaN material system shows promise for use in BV configuration due to its diverse properties; wide bandgap, radiation hard, chemically inert, and physically hard nature. Under electron beam induced current (EBIC) we have previously reported GaN planar n-i-p devices with output powers of 70 nW and 640nW with quantum efficiencies of 1.2% and 4.0% at electron energy of 5.6 keV and 17 keV, respectively. Subsequent fabrication improvement has led to an increased efficiency of 6.96% at 16 keV beam energy. Fabrication improvements include a thin transparent p-contact to improve generated carrier collection across full mesa area with minimum energy attenuation of incident electrons, and KOH-based wet chemical treatment for plasma damaged mesa sidewalls. Planar device active area diameter/width from 200 µm to 2000 µm have been tested.

There are many inherent challenges with using a planar GaN device in a betavoltaic configuration such as limitation in surface area to maximize power, and excitation of carriers outside of the depletion region that are lost to various types of recombination processes. By moving to a 3D device design, a lower average defect density can be achieved, along with optimal absorption and recombination regions. We are currently working towards achieving higher efficiency BV devices using a hybrid 3D+2D III-Nitride device. A feedback loop between theory, epitaxial growth, and characterization is ongoing to achieve such efficiencies. Physics-based TCAD and Monte Carlo simulations have been employed to optimize 3D structure dimensions by simulating energy absorption for a realistic source with full emission spectrum. When coupled with a novel $^{63}NiCl_2$ radioactive source, Monte Carlo N-particle Extended (MCNPX) simulations show the efficiency of energy transfer from the source material to GaN (η_{src}) to be at 2.75x that of planar device for optimized dimensions.





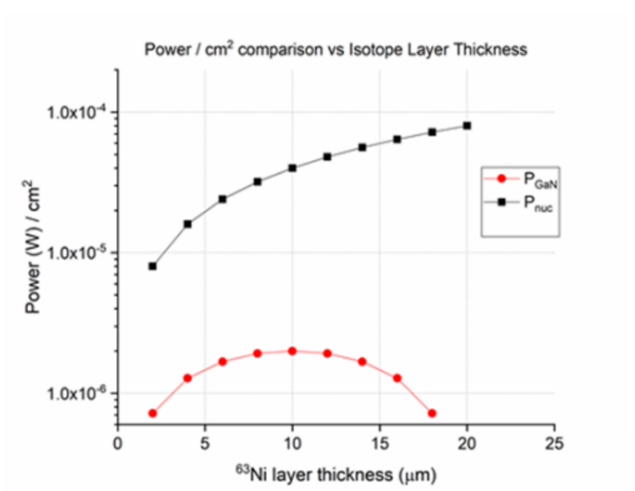


Figure 1. MCNPX simulations of planar GaN device coupled with the $^{63}NiCl_2$ isotope source. The efficiency of energy transfer (P_{GaN}/P_{nuc}) is plotted as a function of the isotope thickness, along with power density (P_{nuc}, P_{GaN}) as a function of isotope thickness. The maximum generated power within GaN occurs at an isotope layer thickness of ~10 µm.

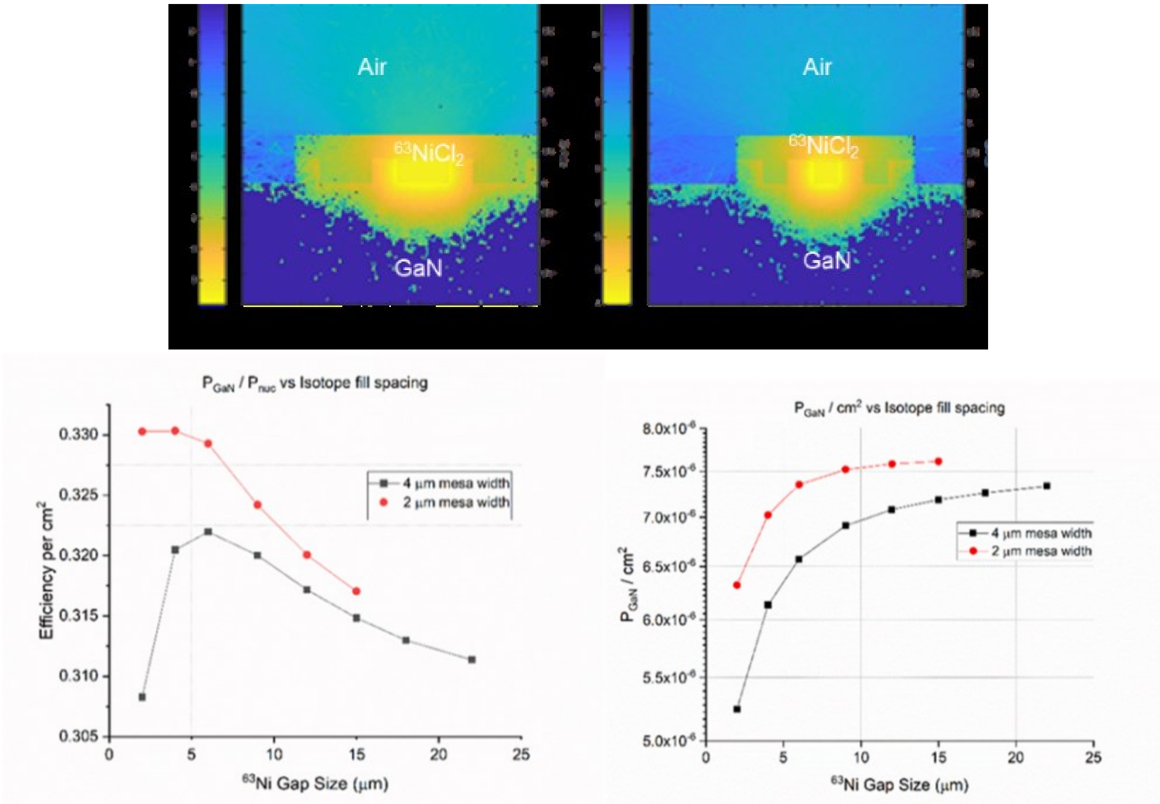


Figure 2. MCNPX simulation of 3D GaN pillars, with mesa width/mesa gap varied. Optimum condition of 2 µm width/gap is achieved, both power and efficiency of energy transfer are higher for all mesa gap (63Ni Gap Size) for the 2 µm mesa compared to 4 µm mesa. Self-absorption within isotope source forms a trade-off better power and transfer efficiency.

Metal organic chemical vapor deposition (MOCVD) is utilized to form GaN 3D core-shell structures for use in a betavoltaic configuration. Both top-down (etch and regrowth) and bottom-up (selective area growth (SAG)) are employed. Through optimization of growth conditions, high aspect ratio structures have been achieved. Continued studies of lower dimensional structures and core-shell PiN overgrowth are underway.

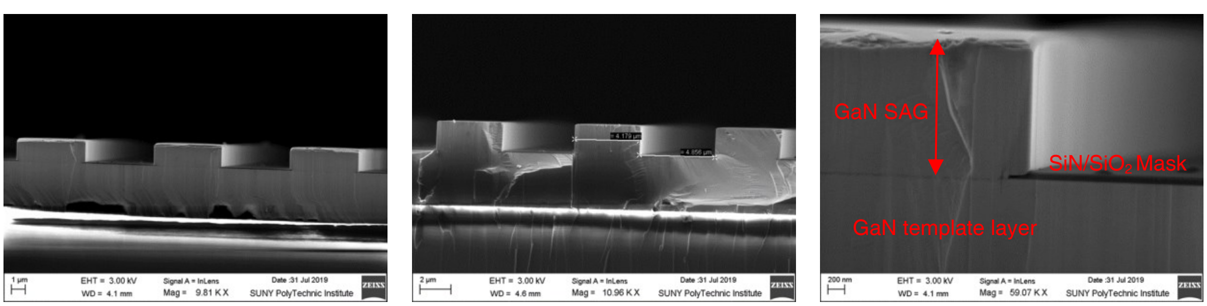


Figure 3. High aspect ratio SAG GaN structures grown using bottom-up methodology. A 9:1 (vertical:lateral) growth rate is achieved under optimal V/III precursor ratio.

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PHOTOCATHODE DETECTOR

High-performance ultraviolet photocathodes for low signal photon detection are critical in astronomy for investigation of some of the most fundamental questions regarding the origin and expansion of the universe. Spectrograph instruments currently employed by NASA utilize microchannel plates with alkali halide (KBr, CsI) or Cs_2Te photocathodes which achieve efficiencies of 60% and 20% respectively. These materials face challenges for use as photocathodes due to instability in air and moisture, requiring the devices be fabricated and packaged in vacuum, increasing size and cost. A UV photocathode material with high stability to air, moisture and radiation is necessary to overcome the challenges of traditional photocathodes.

The (Al)GaN material system is an ideal candidate for use in UV photocathodes as it has a wide and tunable bandgap through alloying, is chemically inert and radiation hard. Along with collaborators at NASA's Jet Propulsion Laboratory (L. Doug Bell), our group's work has pioneered the development of Cs-free III-Nitride photocathodes. This work has included the use of delta doping to increase downward surface band bending, as well as the use of the nitrogen polar orientation of GaN to increase the electric field within the device.

In 2019, we have extended our work on nitrogen polar GaN photocathodes, achieving a record efficiency for Cs-free GaN photocathodes of 26.6% in the near-UV range. Our studies on the enhancement of p-type conductivity in N-polar GaN films allowed the realization of these high efficiency photocathode devices. Through MOCVD growth of GaN:Mg films on N-polar GaN template layers with a high density of hexagonal pyramidal hillock structures we have shown a 2x increase in the hole concentration by capacitance-voltage measurements. The increased hole concentration is attributed to an increased incorporation efficiency of the Mg-dopant into energetically favorable semi-polar facets of the hillock structures. Increased Mg incorporation efficiency was observed through atom probe tomography (APT) performed in collaboration with The University at Buffalo (B. Mazumder). This work demonstrates photocathodes devices in a lab-based set up that are comparable to state-of-the-art photocathode devices, and shows promise for extending these devices into the UV range.

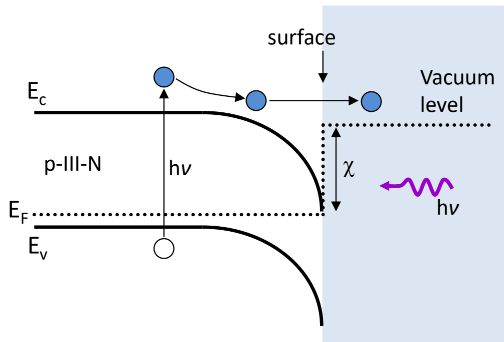

Figure 3. Schematic band diagram of III-Nitride photocathode with photon incident on the semiconductor surface. The photodetector absorbs photons with sufficient energy, creating photoexcited carriers which transport to the surface aided by an intern electric field, and are emitted into vacuum and counted.

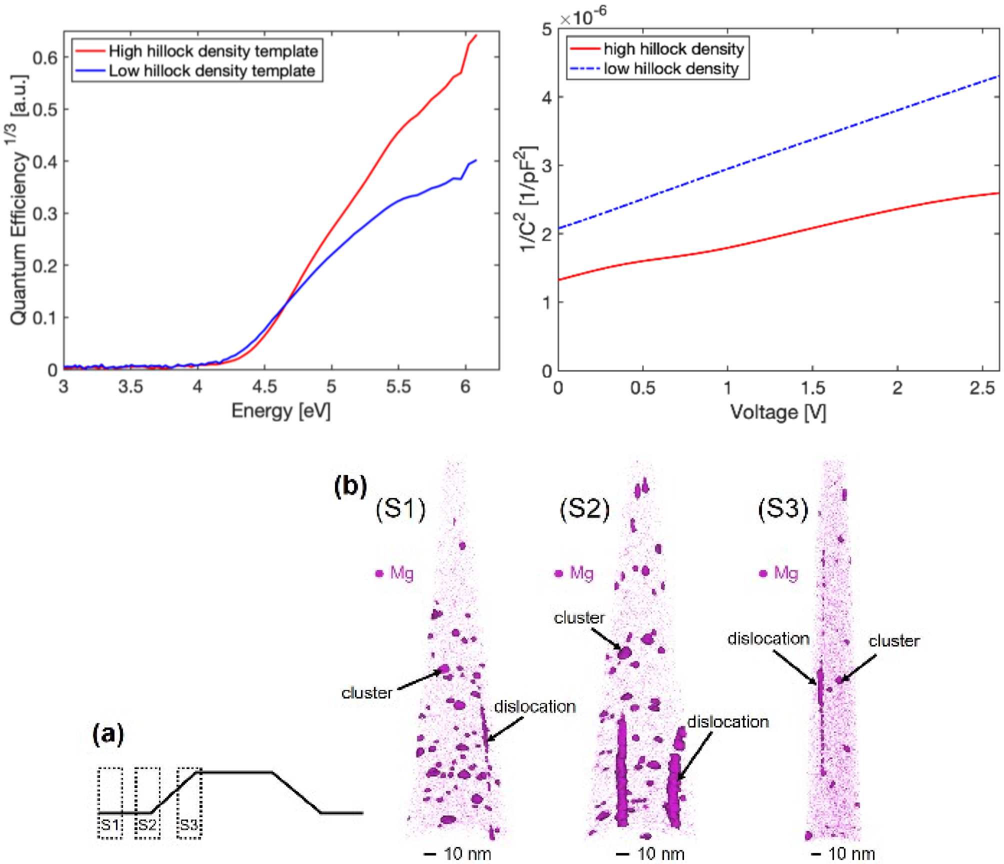

Figure 4. (left) Photoemission spectroscopy shows the highest quantum efficiency for photocathode structures grown on a high hillock density film. (Middle) The improved efficiency is attributed to an enhancement in p-type conductivity observed by capacitance-voltage measurement. (Right) Atom probe tomography (APT) reconstructions showing a decrease in Mg-clustering within hillock structures which allows for a greater probability for Mg-atoms to act as acceptors within the film.

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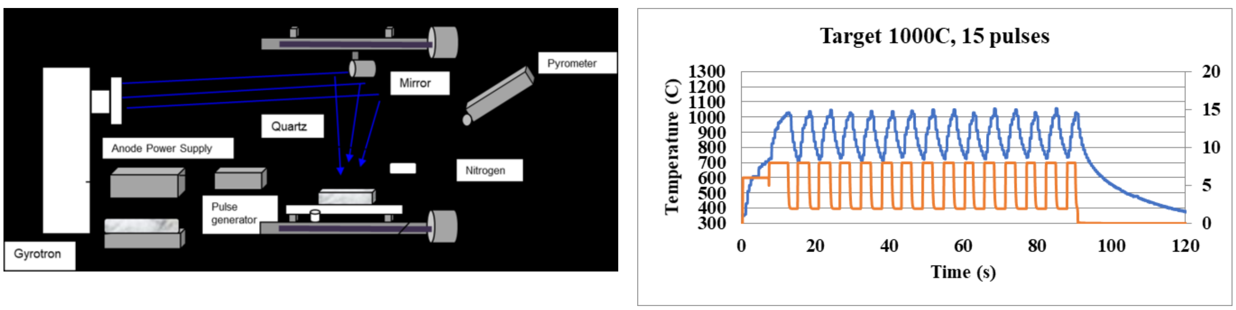
PN-JUNCTIONS BY ION IMPLANTATION

Selective-area doping is often required to obtain figure-of-merit performance in semiconductor devices. While selective-area ion implantation has been used to enable high-performance devices in Si, GaAs, and SiC, using it to obtain p-type III-nitrides remains challenging due to the temperature required to repair defects and locate the p-type dopant, Mg, in substitutional sites. Achieving selective-area p-doping through Mg implantation requires an activation anneal at temperatures above 1300 °C, beyond the region of thermodynamic stability in GaN. This requires nonequilibrium annealing conditions to activate the material without inducing degradation.

Our current work (supported by the Department of Energy's ARPA-E) is in collaboration with researchers at the Army Research Lab, Drexel University, Gyrotron Technology Inc. and Woongje Sung group at SUNY Poly. This project is one of eight selected under ARPA-E PNDIODES program for funding with the goal of developing selective area doping methodologies for the formation of embedded pn diode structures. Selective doping is required in a number of device designs including current aperture vertical electron transistors (CAVET), vertical junction FETs, and junction barrier Schottky (JBS) diodes to form junction termination extension structures, shaping the high electric fields in a diode device to prevent breakdown and permit high voltage operation. This will enable high voltage, high power, and high frequency GaN power devices for applications in radar, vehicle drivetrain, power grid, and other power electronics.

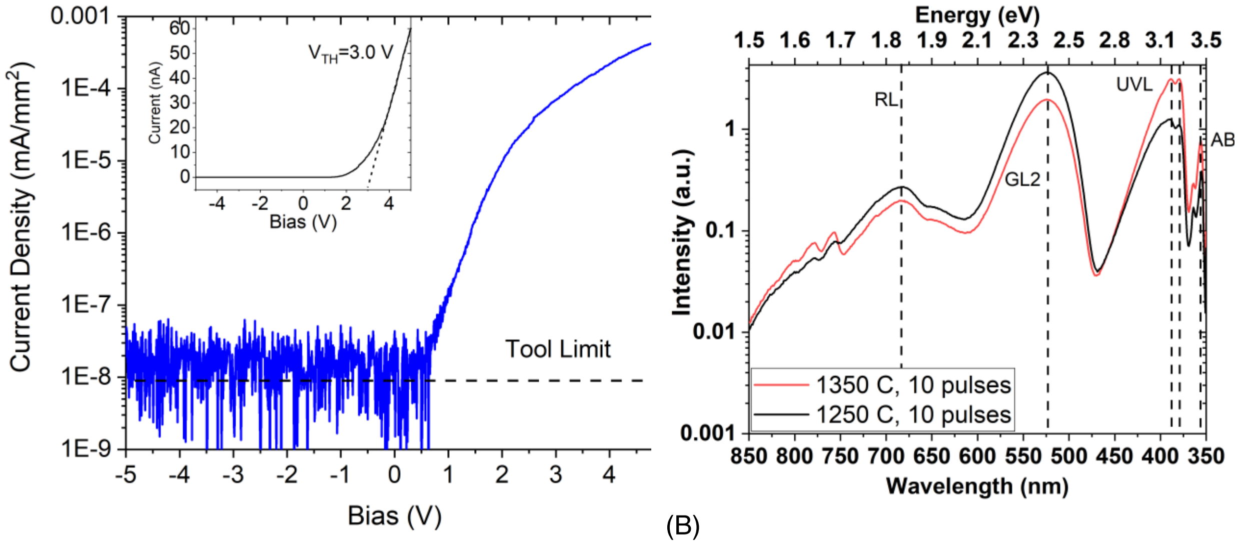
This project aims to achieve and demonstrate GaN p-n diodes with breakdown voltage of 1200 V using selective area doping. We are developing a process to activate acceptor dopant and anneal-activation by using two annealing techniques: annealing by rapid, high temperature pulsing using a novel application of a gyrotron microwave beam at temperatures of greater than 1300 °C (Fig. 5) and thermal annealing at temperatures as high as 1300 °C for durations of >2 minutes. In both cases a protective AlN capping layer is used to prevent the preferential evaporation of nitrogen while creating locally doped p-type regions. We aim at achieving high acceptor activation of greater than 10% by this novel gyrotron beam technology (conventional annealing is limited to acceptor activation efficiency of around 1%).

At temperatures of >1300 °C for duration of ~22 s, p-type activation by gyrotron of Mg-implanted GaN has been observed by optical and electrical characterization. Photoluminescence measurements show 1.6X higher emission intensity in the Mg related UVL over V_N related GL2 band, representing a regime that anneal-activated Mg acceptor concentration is beyond compensating donor defects. Measurement of device shows characterstics of p-n diode witha turn-on voltage of 3.0 V. Gyrotron annealing also proves effective at recovering implant-induced lattice damage, increasing in effectiveness with annealing temperatures from 1150 °C to 1350 °C, as measured by XRD 2θ-ω symmetric and asymmetric scans (Fig. 7). Annealing at 1350 °C results in decreased 2θ-ω position and intensity of the satellite peaks in both the c- and a-directions. (These structural, optical, and electrical measurements point to the promise of the gyrotron annealing technique for selective p-doping for its implementation in power devices such as in JTE structures.



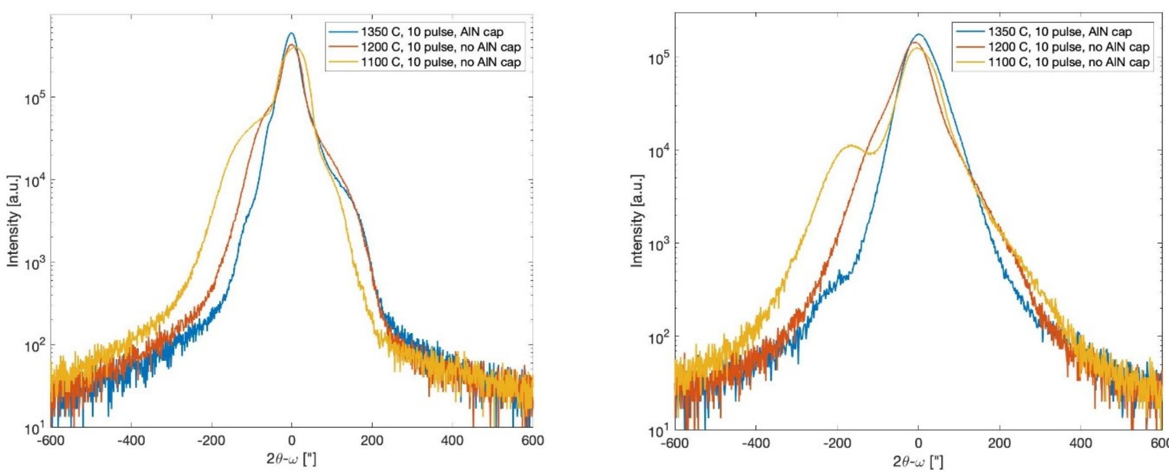
(A) (B)

Figure 5. (A) Schematic diagram of novel gyrotron annealing system used for high temperature annealing above 1300 °C for activation of the Mg-dopant (B) experimental heating diagram (blue) of annealing with pulsed gyrotron microwave source (orange).



(A) (B)

Figure 6: (A) Diode I-V from Mg-implanted GaN annealed by gyrotron at 1350 °C showing p-n diode characteristics and (B) low-temperature (20 K) photoluminescence spectra of gyrotron annealed samples. Sample annealed at 1350 °C shows 1.6X stronger Mg related UVL over V_N related GL2 band, representing a regime that anneal-activated Mg acceptor concentration is beyond compensating donor defects.



(A) (B)

Figure 7: Symmetric (0004) (A) and asymmetric ($10\bar{1}5$) (B) 2θ-ωXRD measurement of gyrotron annealed Mg-implanted GaN films. Improved lattice dilation with increasing annealing temperature are clearly observed.

2019 PUBLICATIONS

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Gyrotron Beam Annealing Method for Mg-Implanted Bulk GaN." *2019 IEEE International Reliability Physics Symposium (IRPS)* (2019): 1-6.

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[3] K. Hogan, S. Tozier, E. Rocco, I. Mahaboob, V. Meyers, B. McEwen, **F. Shahedipour-Sandvik**, R. Tompkins, M. Derenge, K. Jones, M. Shevelev, V. Sklyar, A. Lang, J. Hart, M. Taheri and M. Reshchikov. (2019, April). High Power GaN Devices: Novel Gyrotron Beam Annealing Method for Mg-Implanted Bulk GaN as an Enabling Technology. Poster presentation at the International Reliability Physics Symposium, Monterey, CA.

[4] S. Tozier, M. Reshchikov, K. Hogan, E. Rocco, V. Meyers, B. McEwen, I. Mahaboob, M. Shevelev, V. Sklyar, R. Tompkins, M. Derenge, A. Lang, K. Jones, M. Taheri, W. Sung and **F.Shahedipour-Sandvik** (June, 2019) Photoluminescence characterization of high temperature microwave annealed homoepitaxially grown Mg-implanted GaN. Oral presentation at the MRS Electronic Materials Conference, Ann Arbor, MI.

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ENHANCED RELIABILITY AND PERFORMANCE OF HIGH ELECTRON MOBILITY TRANSISTORS FOR BIOLOGICAL SENSORS AND POWER SYSTEMS

AlGaN/GaN heterostructures possess a two-dimensional electron gas (2DEG) formed due to the presence of spontaneous and piezoelectric polarization. This two-dimensional channel can be modulated, either with charged molecules in the case of sensing applications or with a gate to form transistors.

In a novel design, we have implemented dynamic body-bias technique to improve the performance of AlGaN/GaN HEMTs with the successful integration of a body-diode. We have experimentally demonstrated enhanced effect of body-diode-based back-gate control in shifting the threshold voltage of a normally-ON HEMT toward normally-OFF mode.

In this configuration, p-GaN body-diode-based back-gate control is used to shift the threshold voltage and dynamically modulate the ON/OFF characteristics of a normally-ON AlGaN/GaN HEMT. A fourth back-gate terminal is connected to the p-GaN layer to control the depletion width of the body-diode, which in turn modulates the 2DEG density, as shown in Figs. 8 and 9. A positive/negative shift in the threshold voltage is measured by increasing/decreasing the depletion width below the channel. A positive back-gate bias application in the ON-state is shown to increase the 2DEG current density resulting in higher ON-current (Fig. 10). The application of a negative back-gate bias is shown to be effective in the positive shift of the threshold voltage, in reducing the 2DEG channel current, and in increasing the OFF-state break-down voltage.

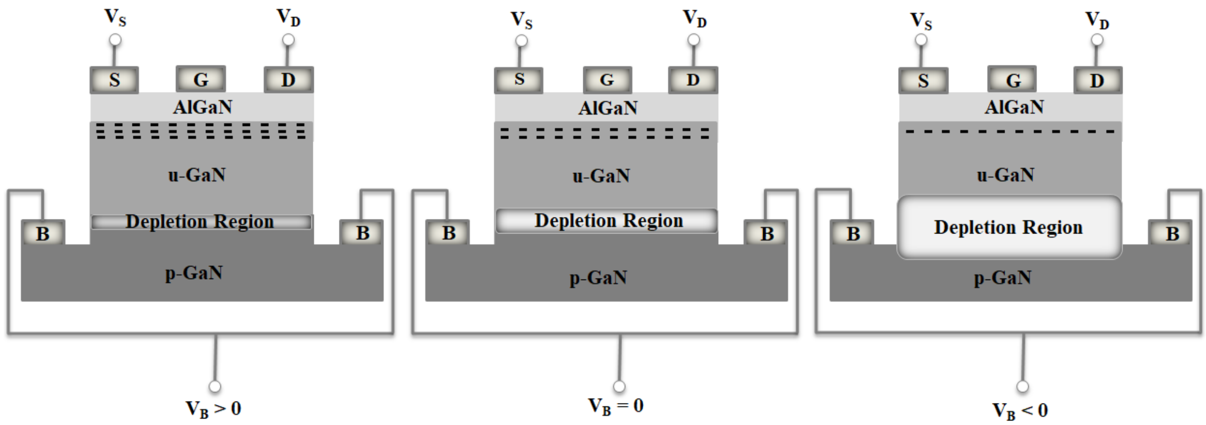


Figure 8. Variation of charge distribution in depletion and 2DEG channel region with the application of positive, negative, and zero bias to the back-gate terminal.

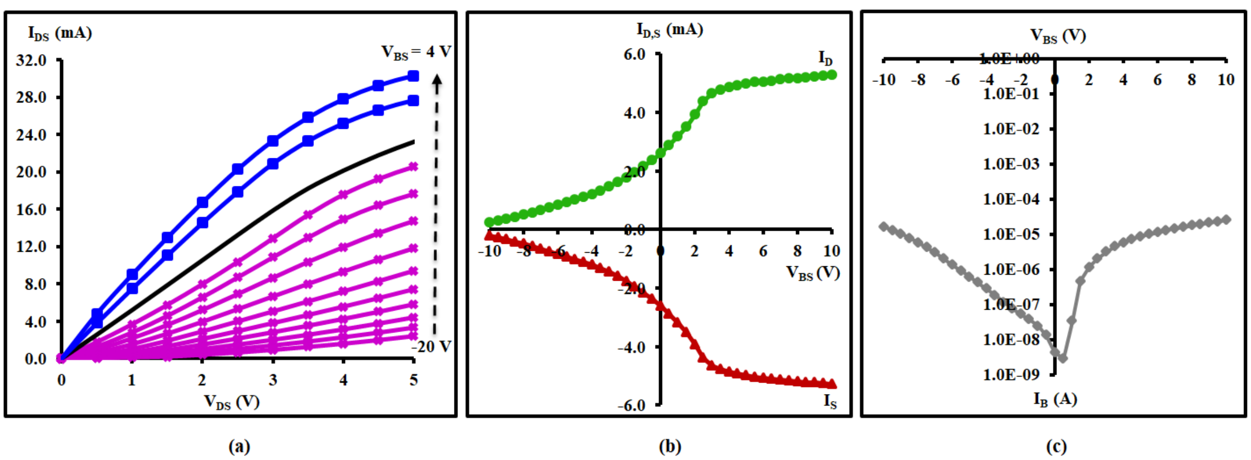
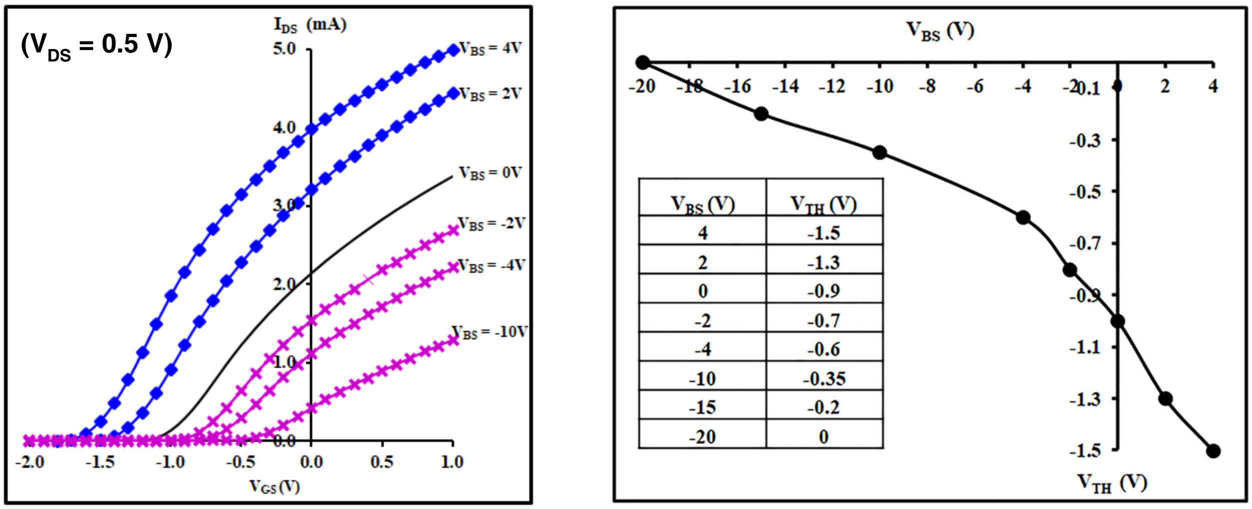


Figure 9. Three terminal (a) output (b) transfer and (c) back-gate current characteristics of an AlGaN/GaN HEMT showing 2DEG modulation with back-gate control under floating top-gate conditions. The transfer and back-gate current, plotted as a function of V_{BS} at V_{DS}=0.5 V, show minimal contribution of back-gate current in the 2DEG channel current modulation.



V_{BS} (V)	V_{TH} (V)
4	-1.5
2	-1.3
0	-0.9
-2	-0.7
-4	-0.6
-10	-0.35
-15	-0.2
-20	0

(a) (b)

Figure 10. (a) Four terminal transfer characteristics at V_{DS}=0.5 showing the shift in the top-gate threshold voltage with the application of different back-gate voltages and (b) variation of the top-gate threshold voltage as a function of back-gate voltage.

We have also recently developed and demonstrated a hydrogen peroxide sensor using a boronate-based probe based on AlGaN/GaN HEMT structure. This probe reacts with hydrogen peroxide, affecting the surface charge state. The research was conducted in collaboration with Nate Cady's group at SUNY Poly. The drain current of the HEMT sensor device is sensitive to the concentration of hydrogen peroxide (Fig. 11). These sensors can find applications in detecting and monitoring hydrogen peroxide in biological settings where aberrant levels of hydrogen peroxide are implicated in aging, neurodegenerative diseases and formation of malignant cells.

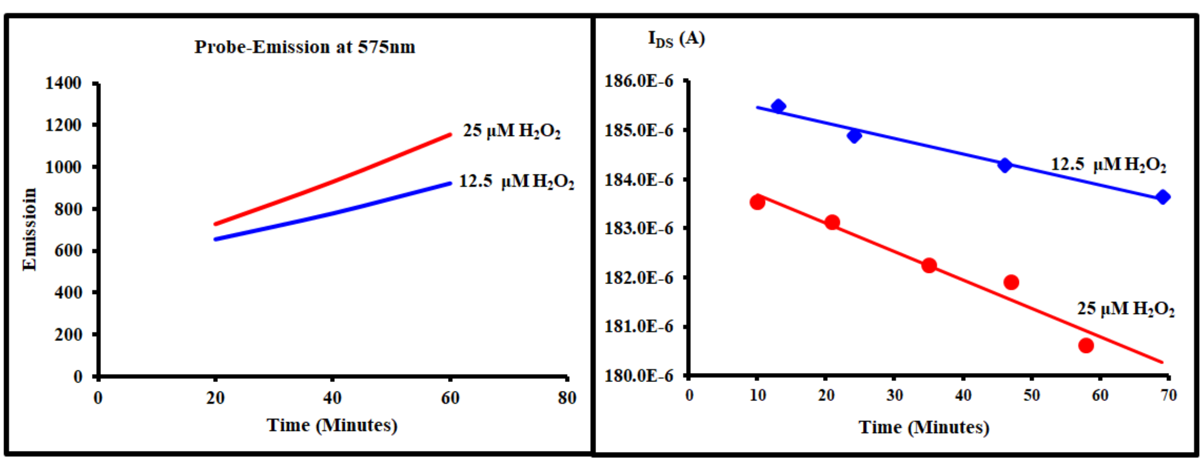


Figure 11. Fluorescence emission over time (left) and real time change in 2DEG current (right) for H_2O_2 solutions of 25 µM (red) and 12.5 µM (blue).

In collaboration with Army Research Lab (ARL), we have been working to develop power HEMT devices with improved reliability and performance. One of the issues with current Schottky gated HEMT technology is the excessive gate leakage from which the devices suffer. The next generation of reliable and enhancement mode AlGaN/GaN based HEMTs) requires further development of high-quality passivation and gate dielectric materials. Passivation dielectric is used to reduce current collapse, and gate dielectric is used to reduce gate-leakage current. However, the introduction of a dielectric layer leads to issues associated with the dielectric/(Al)GaN interface trap states, bulk trap states within the dielectric, and surface defect states. Device properties depend on the dielectric used and the density of these interface, bulk, and surface states associated with the dielectric. Decreasing the density of these trap states is essential for good device quality. For our devices, we are exploring different dielectric materials including aluminum oxide, silicon dioxide, and silicon nitride deposited using atomic layer deposition. In order to decrease the density of trap states, various pre- and post-deposition treatments, such as annealing in forming gas ambient, are utilized. In order to evaluate the dielectric and dielectric/semiconductor interface, we fabricate metal-insulator-semiconductor (MIS) capacitors and measure the capacitance-voltage (C-V) behavior to determine the amount of charge trapped in the dielectric and at the interface (Fig. 12). Additionally, the dielectric can be characterized using STEM/EDS to determine thickness and compositional uniformity (Fig. 13).

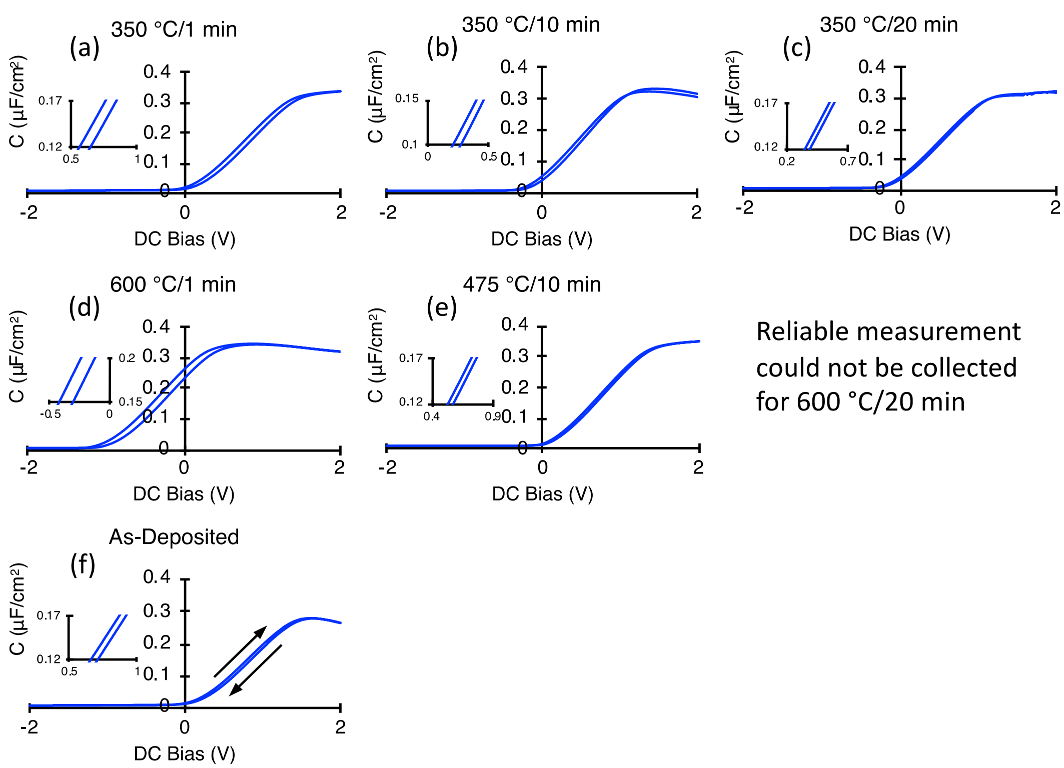


Figure 12. C-V measurement data of Al_2O_3 MIS capacitors with post-dielectric deposition annealing in forming gas at (a) 350 °C for 1 min, (b) 350 °C for 10 min, (c) 350 °C for 20 min, (d) 600 °C for 1 min, (e) 475 °C for 10 min, (f) 600 °C for 20 min, and (g) as-deposited. The arrows indicate the direction of the DC bias sweep. Insets show zoomed in area of hysteresis to show ΔV from sweep up to sweep down. Reduction in hysteresis, indicating reduced trapped charge density, is observed after annealing at low temperature for extended times, while high temperature annealing results in increased trap density.

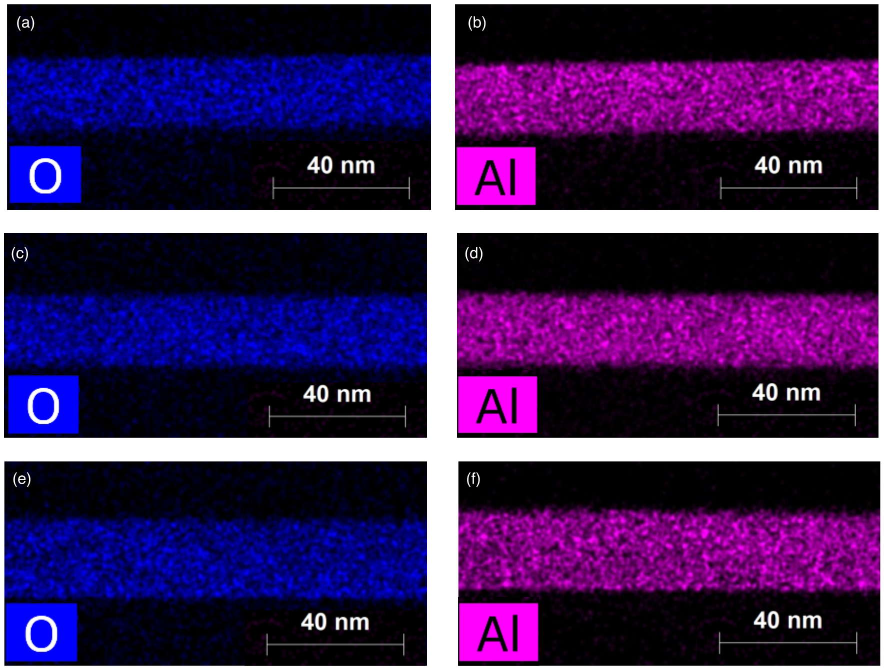


Figure 13. EDS elemental maps showing the spatial distribution of (a) O in the as-deposited sample, (b) Al in the as-deposited sample, (c) O in the sample annealed at 350 °C for 10 min, (d) Al in the sample annealed at 350 °C for 10 min, (e) O in the sample annealed at 600 °C for 20 min, and (f) Al in the sample annealed at 600 °C for 20 min. No diffusion of Al or O is observed after dielectric annealing.

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[2] I. Mahaboob, M. Yakimov, S. Tozier, K. Hogan, E. Rocco**, F. Shahedipour-Sandvik**, "Integrated Body-Diode Back-Gate Control in AlGaN/GaN HEMTs," *The 61st Electronic Materials Conference*, Ann Arbor, MI (2019).

[3] B. McEwen, I. Mahaboob, K. Hogan, E. Rocco, V. Meyers, S. Tozier, A. Lelis, R. Green, F. Nouketcha, **F. Shahedipour-Sandvik**, "Effects of Forming Gas Anneal on the Structure of Al_2O_3/GaN Interface," *The 61st Electronic Materials Conference*, Ann Arbor, MI (2019).

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POWER SEMICONDUCTOR DEVICES

DR. WOONGJE SUNG

Scope: Design, fabrication, and characterization of wide bandgap power semiconductor devices

Goals: 1) Develop efficient, rugged, and reliable power semiconductor devices, 2) Develop low-cost, reliable, repeatable process baseline to fabricate SiC devices, 3) Develop next generation power devices on novel materials such as homogeneous GaN and Ga2O3.

LATERAL SIC MOSFETS AND DIODES FOR POWER ICS APPLICATIONS

Today, Silicon (Si) integrated circuit (IC) technology combines conversion and control functions for low to medium power systems with a maximum of 75 to 100 V lateral double-diffused MOSFETs (LDMOS). The Silicon-On-Insulator (SOI) technology offers a higher voltage up to 600 V but with a very limited current handling capability of 1 to 2 A. Wide bandgap materials such as Silicon Carbide (SiC) and Gallium Nitride (GaN) can provide higher power ratings than Si-based devices due to their material properties. However, the GaN IC technology is hampered with reliability concerns such as a current droop, a lack of avalanche capability, and dynamic on-resistance issues. In contrast, SiC technology is relatively mature; complementary metal-oxide semiconductors (CMOSs) can be implemented; vertical power MOSFETs have been commercialized; the devices are proven to be reliable with track records and market acceptances. SiC MOSFETs have been already implemented in various applications including uninterruptible power supplies (UPSs), hybrid electric vehicles (HEVs), and photovoltaic (PV) converters. Additionally, the implementation of SiC Power ICs will enable many applications that require a wide range of voltage and power ratings such as automotive, industrial, and electronic data processing, energy harvesting, and power conditioning. In order to demonstrate high power ICs on SiC substrates, the fabrication of a large SiC lateral MOSFET is inevitable.

Several groups have already demonstrated SiC lateral MOSFETs on various substrates. However, those lateral MOSFETs failed to demonstrate efficient drift layers in achieving breakdown voltage even when adopting double RESURF or multi-zone approaches. In addition to that, all the previously reported structures were fairly small, as such that the current levels were confined to a several milli-amperes range. In this work, a 600 V, 10 A, SiC lateral MOSFET was demonstrated. The proposed lateral MOSFET features a single RESURF drift layer, achieving a breakdown voltage of 600 V with a 5μm gap between the gate and drain (BV/Lgd = 120 V/μm). The proposed lateral MOSFET was fabricated in a 6-in. wafer foundry company, X-FAB, TX, U.S.A. Fig. 1 shows the SEM cross-sectional view of the fabricated SiC lateral MOSFET. Fig. 2 shows the typical output characteristics of the fabricated lateral MOSFETs on the N+ 4H-SiC substrate. An optical image of the fabricated chip is also shown in the inset of Fig. 2. A further reduction of the specific on resistance would be expected by adopting an innovative gate oxide process, implementing a channel with a high channel mobility, less resistive contact and metal process, and further shrinking the cell pitch (see Table 1). A detailed discussion on the device cell structure, fabrication, and electrical characteristics is provided in the paper [1].

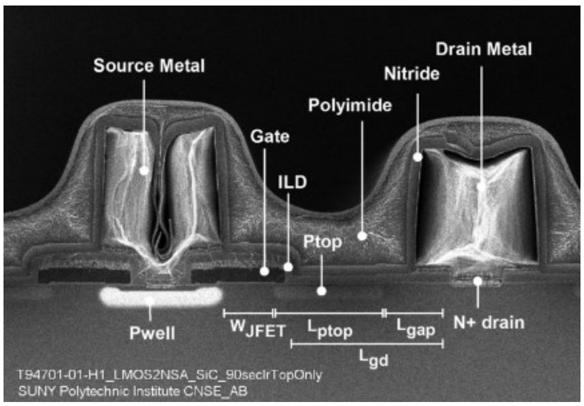


Fig. 1. A SEM cross-sectional view of the fabricated lateral SiC MOSFET. The critical dimensions (W_{JFET}, L_{ptop}, L_{gap}, and L_{gd}), gate, source, drain metal, interlayer dielectric (ILD), and passivation layers (nitride and polyimide) are labeled.

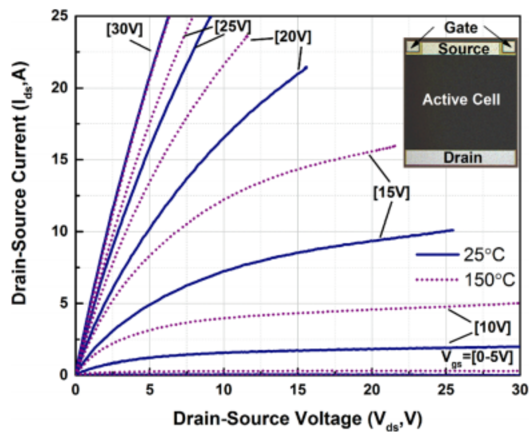


Fig. 2. The typical output characteristics of the fabricated the lateral MOSFETs at 25 °C (blue) and 150 °C (purple). Vgs up to 30 V was applied with 5 V steps. The top-view image of the fabricated device is shown in the inset. Active area: 4.3 mm^2. Total finger width: 194 mm.

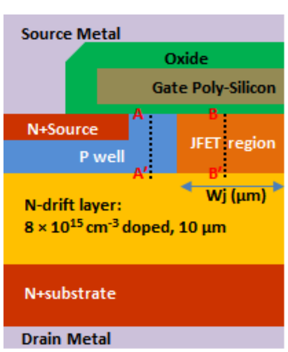
	RT (25 °C)		HT (150 °C)	
Specific resistance	mΩ cm^2	%	mΩ cm^2	%
$R_{Contacts}$	1.21	9	1.48	13
$R_{Channel}$	3.49	25	2.63	23
$R_{Accumulation}$ [a]	0.56	4	0.42	4
R_{JFET} [a]	0.48	3	1.25	11
R_{Drift} [a]	0.17	1	0.45	4
R_{Others} [a]	7.80	57	5.27	46
R_{Total}	13.7	100	11.5	100

[a]Calculated.
Parameters: $V_{gs} = 20$ V, $\mu_{ch} = 17$, $\mu_{accu} = 85$, $\mu_{bulk} = 752$ cm^2/V s.

Table1. Resistance distribution in the SiC lateral MOSFET.

ADVANCEMENT OF 1200V SIC MOSFETS

In the past decade, there has been tremendous progress in the electrical performances of 4H-SiC power MOSFETs resulting in their commercialization. We have established a baseline process to fabricate SiC MOSFETs at a commercial foundry company in previous years (2015 – 2017) [4]. The device and processing technologies have been continuously improved utilizing the baseline process. Fig. 3 depicts a cross-sectional view of a typical SiC planar-gate MOSFET cell design. For a 1.2kV-rated MOSFET, the drift layer is designed to be 8×1015cm-3 doped and 10 μm thick. On-resistance can be reduced through inclusive efforts, such as reduced cell pitch, short channel length with higher channel mobility, and enhanced doping in the JFET region. The channel can be designed to be either accumulation mode or inversion mode. An accumulation mode channel was designed because it generally produces higher channel mobility than an inversion mode channel. In order to reduce the dead space for the current conduction, p+source contact is placed in the orthogonal direction, intermittently. By increasing the doping concentration in the JFET region, on-resistance can be maintained low at a narrower JFET width (Wj) as discussed in [5]. A narrow JFET width reduces the gate to drain capacitance (Cgd) and thus the switching loss. In addition, oxide electric field and channel potential need to be examined to determine the JFET width because, with enhanced JFET doping, the electric field at the gate oxide is expected to increase. As a result of extensive 2-D simulations, it was found that the Wj should be kept less than 1μm to keep the oxide e-field lower than 4MV/cm. It is particularly important to investigate the blocking capability of the SiC MOSFET with increased doping in the JFET region. Fig. 4 compares the blocking characteristics of MOSFETs with and without JFET implants. As shown, it is confirmed that the JFET doping does not degrade the blocking capability. Furthermore, it is observed that the narrower JFET width that was accomplished by the JFET doping actually reduces the leakage currents.



Device name	Doping in the JFET region (Njfet)	JFET region width (Wj)
MOSFET_J_0.7	3×10^{16} cm^{-3}	0.7 μm
MOSFET_J_1.1		1.1 μm
MOSFET_J_1.5		1.5 μm
MOSFET_0.7	8×10^{15} cm^{-3} (No enhanced doping in the JFET region)	0.7 μm
MOSFET_1.1		1.1 μm
MOSFET_1.5		1.5 μm

Fig. 3. Cross-sectional view of fabricated 1.2kV SiC MOSFETs. Design variations of JFET widths and doping concentrations were included.

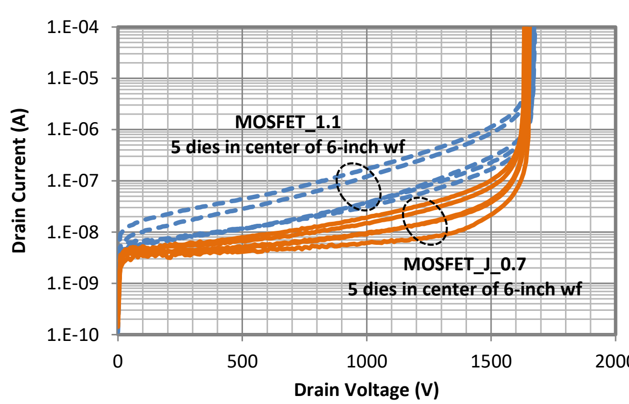
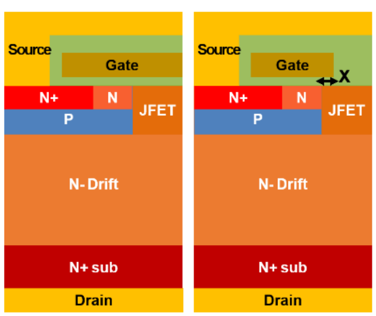


Fig. 4. Comparison of breakdown voltages. MOSFETs with narrower JFET widths show lower leakage currents.

In order to reduce the power dissipation and achieve the efficient switching speed in the high frequency power applications, the MOSFET's parasitic capacitive elements should be also minimized as the power consumption originates from the charge and discharge inside of the MOSFET structure as well as the conduction loss. Reverse transfer capacitance (Cgd) as a Miller capacitance and more specifically gate-to-drain charge (Qgd), which are resulted from the gate-to-drain overlap above a JFET region, are particularly the dominant components limiting the switching speed.

In order to reduce the overlap between gate and drain of a SiC power MOSFET, we've proposed and successfully demonstrated a split gate SiC MOSFET (SiC SG-MOSFET) [6, 7]. Fig. 5 shows the fabricated conventional MOSFET and proposed SG-MOSFET structures with detailed parameters. Fig. 6 depicts the measured gate charge of the MOSFETs and SG-MOSFETs. The gate charge was measured from randomly selected 5 dies across the 6 inch wafer at Vd of 800 V and Id of 10 A. The extracted plateaus (Qgd) for the MOSFETs and SG-MOSFETs are 14.1 nC and 10.9 nC, respectively. The SG-MOSFETs clearly have the smaller Qgd in spite of the bigger JFET density due to the split gate structure. The calculated HF-FOM (Ron·Cgd) and HF-FOM (Ron·Qgd) are about 25% and 31% better than them of the conventional MOSFETs, respectively. A further improvement of the Qgd, Cgd, and HF-FOM in the SG-MOSFETs is expected by narrowing the JFET width to 0.7 μm as both structures show very similar specific on-resistances at the same active area (4.5 mm2). To achieve a further improved HF-FOM, a buffered gate MOSFET (BG-MOSFET) was proposed (see Fig. 7) [8]. As shown in Fig. 8, 2 times better HF-FOM was achieved from BG-MOSFET compared with the SG-MOSFET.



	MOSFET	SG-MOSFE
X width	0.7 μm	0.3 μm
JFET region width (W_{JFET})	0.7 μm	0.9 μm
JFET density (W_{JFET}/W_{cell})	0.25	0.3
Doping in JFET region	3e16 cm^{-3}	

Fig. 5. Cross-sectional view of fabricated 1.2 kV SiC conventional MOSFET (left) and SG-MOSFET (center) cell structures with detailed structural parameters (right). Both have the same channel length of 0.5 μm.

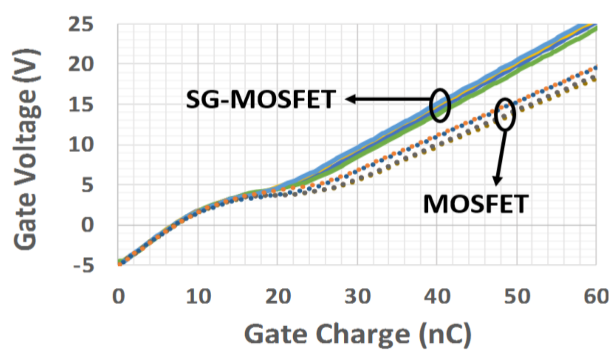


Fig. 6. Measured gate charge of fabricated conventional MOSFETs and SG-MOSFETs out of 5 dies each across the 6 inch wafer at V_d=800V and I_d=10A. The SG-MOSFETs show clearly smaller plateau (Q_{gd}).

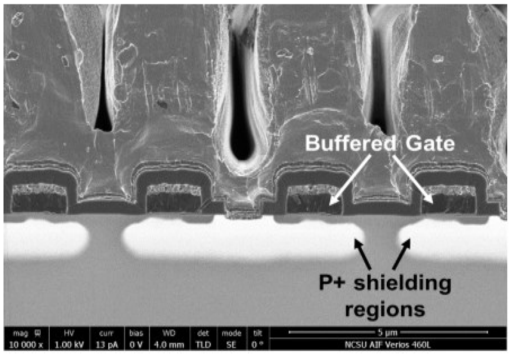


Fig. 7. SEM image for the fabricated Accu BG-MOSFET. It is clearly seen that the split poly-Si gates are buffered by the P+ shielding regions.

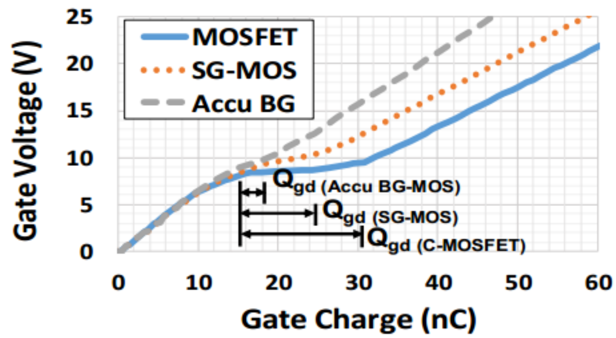


Fig. 8. Measured gate charge at Vd=800V and Id=10A of fabricated SiC Accu C-, SG-, and BG-MOSFETs. Much smaller plateau (Qgd) is observed in the Accu BG-MOSFET.

DEVELOPMENT OF SIC JBS DIODES

SiC is considered as a post-silicon semiconductor for power electronics applications because its superior material properties guarantee lower power losses, higher efficiency, and smaller system volume and weight. Since the first commercialization in the early 2000s, SiC Junction Barrier Controlled Schottky (JBS) diodes have been successfully applied to circuits such as power factor correction (PFC), switched mode power supply (SMPS), solar power conditioner, EV charger, and consumer/industrial electronics. The key performance criteria for SiC JBS diodes are the low forward voltage drop, low reverse leakage current, and high surge current capability. 600V-1200V rated SiC vertical JBS diodes have been developed, following a roadmap, to address aforementioned technical barriers. Numerous efforts, such as adoption of P+ junction barrier and availability of wafers with low defect density, allowed the SiC JBS diode to quickly replace Si PiN diodes in power factor correction, switched mode power supplies, and motor drive applications. Sung's research group, we have been developing SiC JBS diodes with different voltage ratings from 600V to 10kV [9, 10, 11].

1700V-rated 4H-SiC JBS diodes were fabricated in the state-of-the-art 6-inch SiC-dedicated foundry, NY-PEMC (New York- Power Electronics Manufacturing Consortium) [10]. The schematic cross-sectional view of a typical SiC JBS diode's active cell and the edge termination area is shown in Fig. 9. The gap between adjacent p+grids (Schottky width – Ws in Fig. 9) was optimized by investigating the forward voltage drop and the maximum electric field at the middle of the Schottky region using Sentaurus 2D TCAD simulation. Fig. 10 shows the cross-sectional SEM images of silicon test wafers that were prepared for P+ and P-JTE implant steps. The oxide etch processes were optimized to produce vertical sidewalls and to minimize the damage on the SiC surface. This well-defined etch process is crucial for defining critical dimension for the implantation process, especially for the edge termination region. A detailed process flow and descriptions can be found in [9, 10].

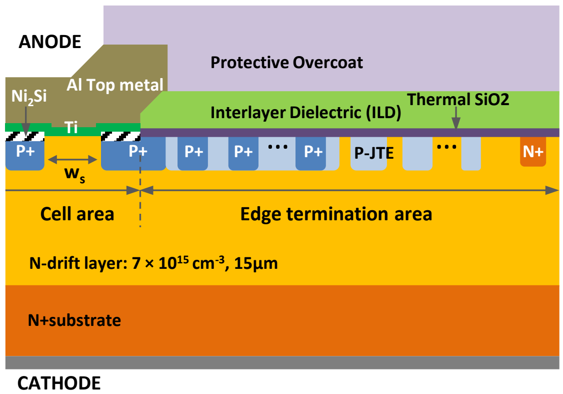


Fig. 9. Cross-sectional view of a 4H-SiC JBS diode. A JTE based edge termination structure was used.

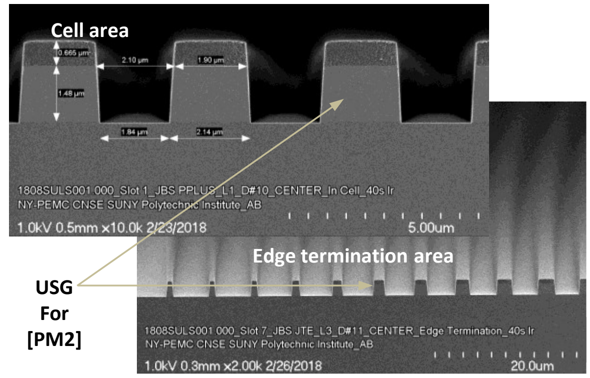


Fig. 10. Scanning Electron Microscopy (SEM) images of patterned USG for blocking P+ (Cell area) and P-JTE (Edge termination area) implant dopants

During the development of 10kV SiC JBS diodes, we've learned that the process recipes should be tailored appropriately for different voltage rating devices [11]. 10kV SiC JBS diodes were fabricated with unexpectedly high voltage drops compared to lesser rated devices of the same kind. After investigation, it was found that the reason for this high knee voltage was due to the channel pinching of the JBS diodes, due to unexpected longitudinal and lateral straggle (see Fig. 11 and Fig. 12). The cause of this unexpected straggle was the low doping concentration of the drift layer, a parameter that is necessary for high rated SiC devices. Designers of high voltage power devices must take this effect into consideration to ensure the best possible electrical characteristics. Possible solutions to consider are: (1) eliminating the JFET implantation combined with more relaxed device dimensions (2) increasing JFET implantation depth (3) mid implantation lattice recovery anneal (4) implement an implant schedule that incorporates decreasing implant energies. Even with implantation of the techniques listed above, designers of high voltage devices on lowly doped drift layers need to be wary of the lateral straggle of high energy implants.

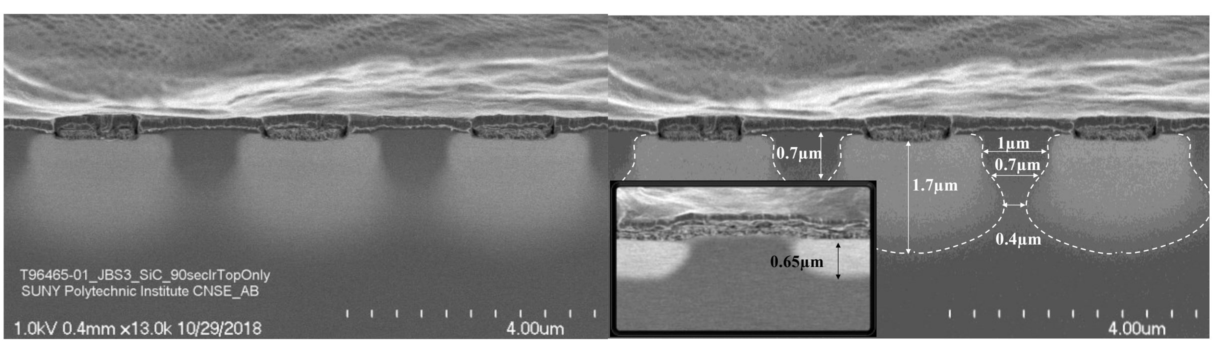


Fig. 11. Cross-sectional SEM images of 10kV JBS diode. The left image shows the original SEM. The right image has additional white lines to outline the P+ implants and give approximated dimensions. The P+ implants show increased lateral straggle after 0.7µm as well as a larger implant depth than expected. The conduction channel narrows to 0.4µm at a depth below the expected P+ implant depth. The inset in the image on the right is a close up of the same P+ implant in a 1.2kV JBS diode. The implants in the inset show an extreme reduction in both depth and lateral straggle.

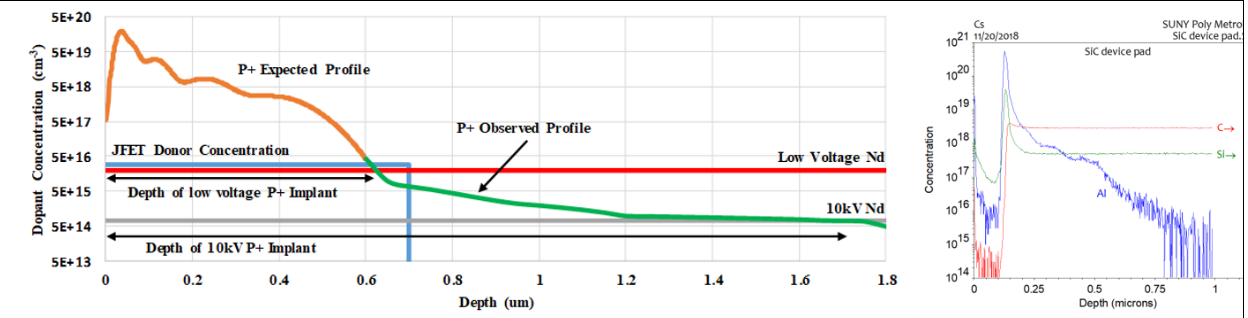


Fig. 12. Diagram of the doping of JBS diode based on the SEM data presented in Fig. 11. The expected P+ profile (orange) was calculated using SRIM software, which does not account for the tail observed, from scatter-in channeling. The measured P+ profile was approximated from the SEM images. Drift (N_d) and JFET concentrations are assumed constant. It is clearly seen the lower donor concentration in the 10kV device allows for the unexpected P+ implant depth not seen in low voltage devices. SIMS pattern is shown on the right, but a concentration below $1x10^{15}cm^{-3}$ could not be detected.

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[2] Nick Yun, Justin Lynch, and **Woongje Sung**, "A Comparative Study of 4H-SiC Lateral and Vertical MOSFETs Fabricated on the same 6-inch Substrates," Submitted to International Conferences on Silicon Carbide and Related Materials (ICSCRM), 2019

[3] Justin Lynch, Nick Yun, and **Woongje Sung**, "A New Junction Barrier Schottky Diode Using a Novel Lateral Architecture on a 4H-SiC Substrate," Submitted to Workshop on Wide Bandgap Power Devices and Applications (WiPDA), 2019

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[11] Justin Lynch, Nick Yun, and **Woongje Sung**, “Design Considerations for High Voltage SiC Power Devices: An Experimental Investigation into Channel Pinching of 10kV SiC Junction

Research funded by: Nissin Ion Equipment Company Limited, DOE, ARL, ONR, ADI.

For more information on Dr. Sung’s research, please visit: https://sunypoly.edu/research/woongje-sung.html

RNA-BASED NANOTECHNOLOGY

DR. SCOTT TENENBAUM

Scope: All areas of RNA Molecular Biology including gene expression, genomics and Cancer biology

Goals: To utilize nanoscale technology to study the role of RNA as a gene regulator and to develop RNA based nanotechnologies

SXRNA: AN RNA-BASED NANOSWITCH

Most medicines interact with proteins in the body, but more recently gene therapies have targeted DNA directly to affect bodily functions. That leaves a third class of molecules completely untapped in terms of medical interventions–RNA. We have found

a way to target and report the presence of any RNA of interest in a living cell. We developed a nano-based technology called sxRNA that can be injected into cells to seek out a specific RNA molecule. If the target is found, the sxRNA switches on the expression of a reporter gene that glows – literally functioning as an indicator light. Accurate reporting of the presence of an RNA molecule could be used to diagnose certain diseases in which certain genetic pathways are overactive and cause pathology. The invention has been patented as a platform technology. That means that rather than creating a single diagnostic or therapeutic tool, the Tenenbaum group is developing the process to be applicable to any medical intervention that involves RNA molecules. In the future, we envision possibilities where instead of creating a mere signal for the presence of a particular RNA, the sxRNA could switch on a gene that repairs faulty cell function or a gene that causes the self-destruction of a cancer cell. When fully developed, the sxRNA platform technology will not only represent a powerful new molecular tool but will also have tremendous potential for the development of novel therapeutics, anti-virals, and even imaging applications with substantial impact on a multibillion dollar industry. “We have developed a novel, breakthrough technology that acts as a Nano-switch mechanism to turn “on” and “off” expression of a protein using RNA rather than DNA. No other RNA based technology allows a similar control of protein expression, and we believe that this RNA based, Nano-switch platform technology, called structurally interacting RNA (sxRNA), has the potential to replace gene therapy and create an entire new therapeutic class commanding a market value of several billion dollars.” sxRNA has the potential to represent a new category of molecular tool/therapeutic that uses the specificity of unique miRNA (or other non-coding RNA) expression to turn “ON” the expression of a gene to repair or kill the cell. we have biophysically characterized in vitro a switch that demonstrated increased binding (by as much as 5X) for the histone stem-loop binding protein (HSLBP). These findings were validated in vivo successfully.

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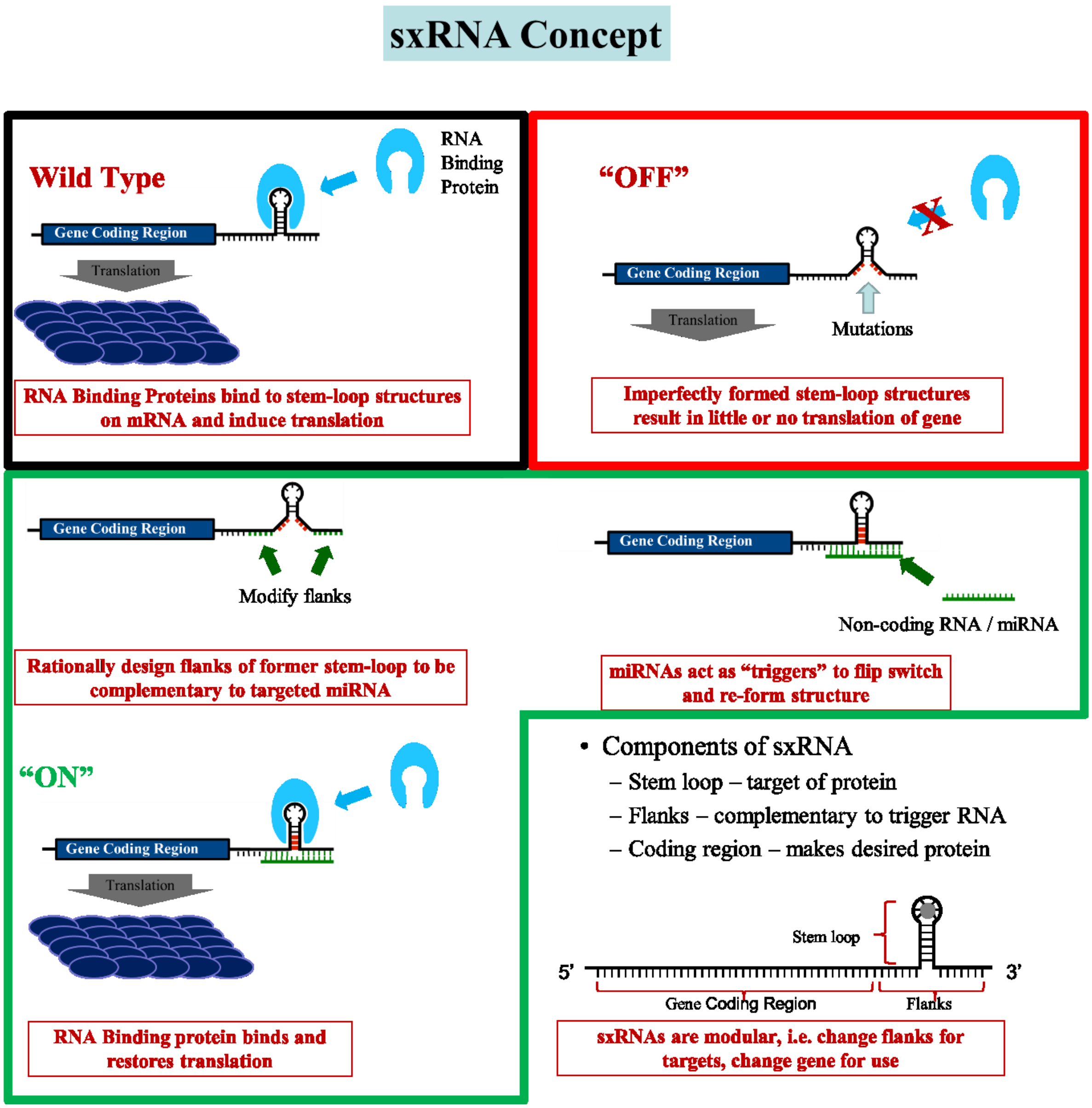


EFFECT OF NANOENVIRONMENTS ON CANCER METASTASIS

There is a growing need for the development of novel platforms to study the metastatic phenotype of cancer cells and their differences from non-metastatic cells from the same line. Our lab's focus is to utilize recent advances in the field of nanolithography to design surface topographies that mimic physical features of the extracellular matrix (ECM) to better elucidate these effects. These defined features will be utilized to investigate fundamental mechanistic questions on the unique ability of metastatic tumor cells to sense and respond to physical cues at this scale. In addition to these features we would also like to investigate the effects of combining these responses to physical cues with known responses to chemotactic and other chemical gradients to better understand their combinatorial effects on cancer cell lines.

In this regard our preliminary data show that interactions with nanoscale topographies are enhanced in metastatic bladder tumor cells as compared to their non-metastatic counterparts. Our data suggest that these unique cellular interactions with lined nanotopography below 100nm could be utilized to distinguish metastatic from non-metastatic cells. This observation is based on key differences in cell morphology, directional migration, anisotropy to underlying features, length and alignment of filopodia and differential pro-migratory signaling. Our next major focus will be to integrate the effects of photodefined gradients with these features for a better understanding of the total system as well as expanding to encompass several varieties of ovarian cancer. This work shows early indication of the mechanisms underlying cancer cell metastasis. We have established an ongoing and active cancer metastasis-working group at CNSE, including faculty members Nadine Hempel, Andre Melendez, Scott Tenenbaum, and Timothy Groves.

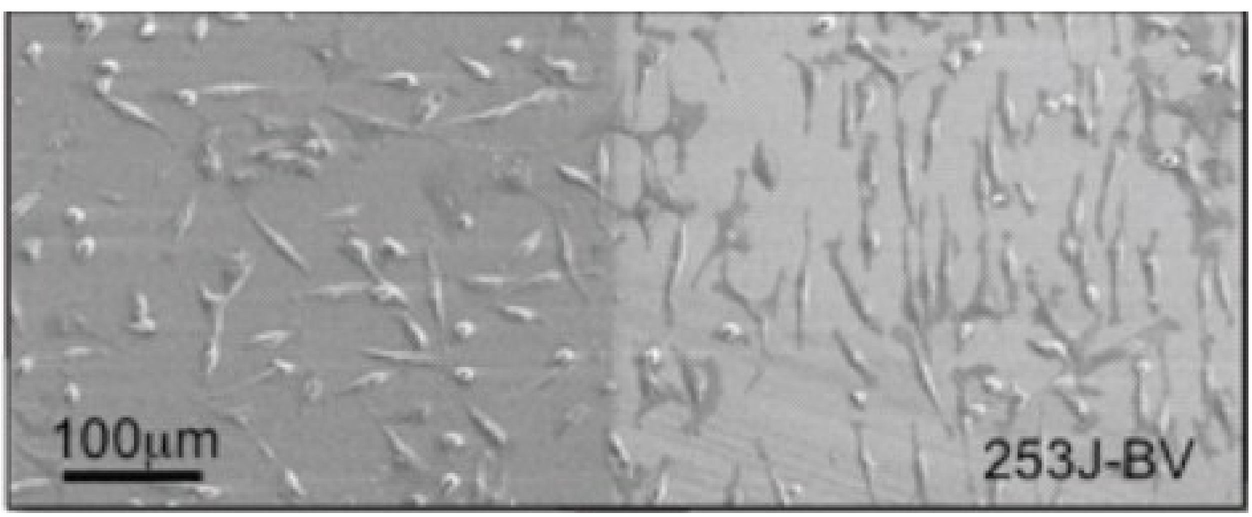
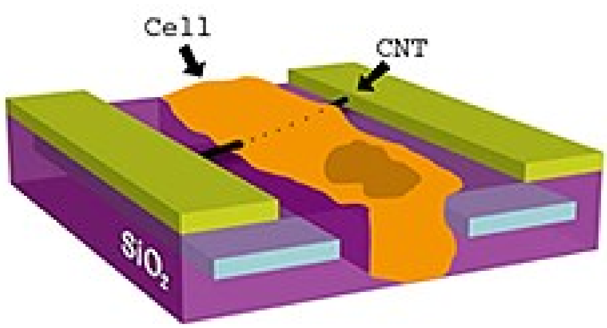


Figure 2 Metastatic Cells on Nanotopography. 253J-BV are metastatic bladder cancer cells derived from the non-metastatic tumor cells 253J. This highly metastatic line was grown both flat and patterned pieces of wafer and grown for 24 hours. Cells were then fixed and dehydrated before being imaged with ESEM.

CARBON NANOTUBE FILED EFFECT TRANSISTORS AS A MULTIMODAL BIOSENSOR

Carbon nanotube field effect transistor (CNTFET) is widely recognized as an excellent platform for chemical and biological sensing. These nanotube/nanowire based field effect transistors are considered to be suitable candidates to potentially replace the current patch-clamp techniques used to study the electrophysiology of cells. Our unique device (CNTFET) design allows us to take advantage of the cell's natural tendency to prefer lower trench regions to grow when allowed to proliferate on a surface with varying topography. These cells in the trench interact with suspended carbon nanotubes, which run across the trench, connecting the two metal contact terminals on either ends. The working principle is that when a voltage bias is applied across the terminals, the cell acts as gate material and effectively changes the current flowing through the carbon nanotube. This results in a characteristic current-output. Cells based on its physiological state, type and condition give different characteristic outputs. The device can thus act as a sensor for study cellular activity. We tested our devices for such biosensor applications by growing M4A4 human breast cancer derived cells on them and found that the interaction with the carbon nanotubes did not dramatically reduce the integrity of the cell membrane. The cell proliferation and growth were normal. The results obtained are encouraging for potentially developing our device as a real-time biosensor. Our future goals involve developing methods for electrical passivation of the metal contacts. This project is done in collaboration with Ji Ung Lee.



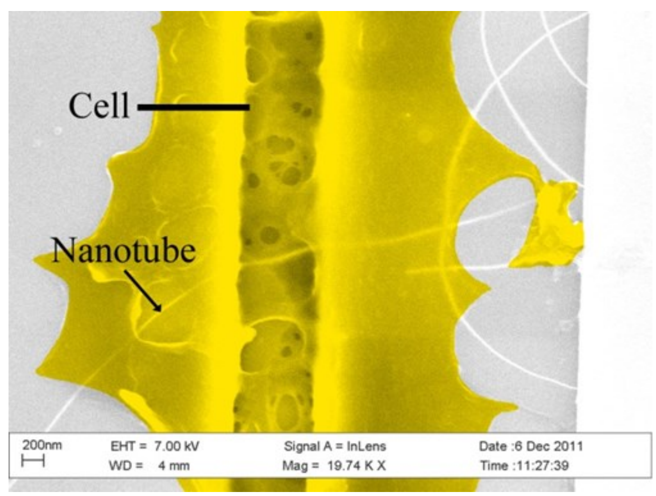


Figure 3 (Left) Schematic of the suspended SWNT device. The M4A4 cell travels into the trench that the suspended SWNT spans, resulting in partial insertion of the nanotube's suspended portion into the cell, with the nanotube remaining functional. (Right) An SEM image of the fixed M4A4 cell and the suspended SWNT showing the location of the carbon nanotube within the cell.

PATENTS

Trans-acting RNA switches

US 8841438 B2

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Research funded by: National Institute of General Medical Sciences

For more information on Dr. Tenenbaum's research, please visit:
http://sxrna.sunycnse.com/nanobio/tenenbaum/

LABORATORY OF ENGINEERING TISSUES AND STEM-CELL NANOTECHNOLOGY

DR. YUBING XIE

Scope: Advanced biomanufacturing, nanobioengineering stem cell organoids, cell-cell communications, tissue engineering and regenerative medicine

Goals: Create 3D μ-tissue complex for understanding stem cell-cancer cell interactions, neuronal differentiation, trabecular outflow physiology and salivary gland regeneration, leading to better treatment of cancer metastasis and eye diseases as well as regenerative medicine for spinal cord injury and salivary gland dysfunction.

SYNTHETIC PLURIPOTENT SIGNALING FOR INHIBITION OF CANCER METASTASIS

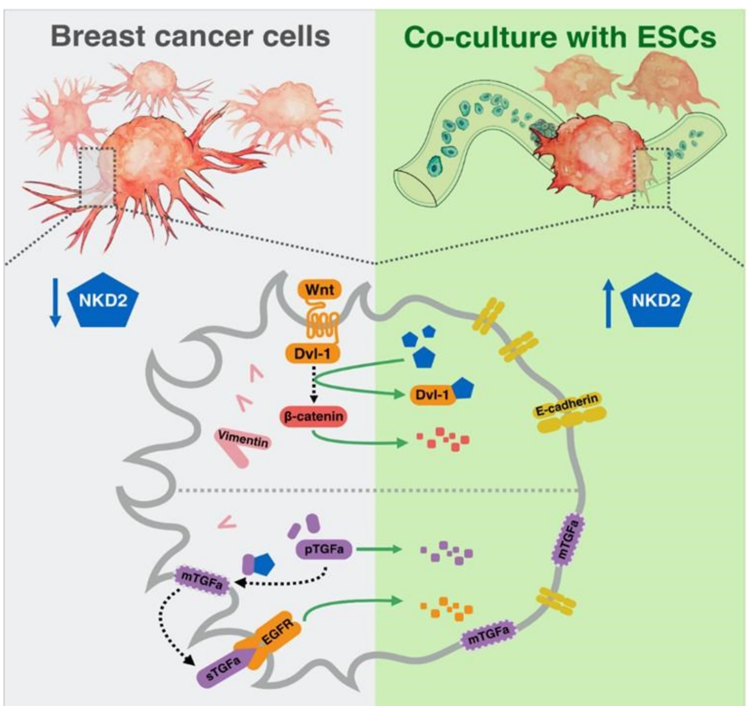

Figure 1: Bioengineered ESC-microstrands restricted growth and metastatic potential of highly aggressive breast cancer cells.

Cancer cells have been linked to embryonic stem cells (ESCs) since the convergence of embryonic signaling pathways in cancer which drive self-renewal and proliferation. ESCs may release certain pluripotent signaling molecules that can restrict cancer metastasis and reprogram metastatic cancer cells into a less aggressive phenotype. It inspires us to establish a novel system based on 3D co-culture of ESCs and tumor cells (Figure 1) to seek molecules that are released by ESCs to extracellular microenvironment with functions of inhibiting growth and metastatic potential of cancer cells and to understand the underlying mechanisms of these molecules for inhibiting cancer metastasis, leading to restriction of metastatic diseases.

PUBLICATIONS AND PRESENTATIONS

B. Mooney, Y.I. Tian, E. Rousseau, **Y. Xie**. Understanding convergent signaling regulation in metastatic breast cancer cells using a bioengineered stem cell microenvironment. Journal of Cancer Metastasis and Treatment, 5:19 (2019).

"ORGANOIDS IN A μ-TUBE" AND BEYOND: ADVANCED BIOMANUFACTURING OF STEM CELL EXPANSION AND DIFFERENTIATION

Generation of engineered tissue organoids from stem cells provides an emerging platform for understanding normal tissue morphogenesis, elucidating abnormal function in diseases, and developing high throughput drug screening/testing system. To mimic in vivo-like organoid differentiation, we have recreated the stem cell microenvironment using microfabrcated hydrogel. Supported by SUNY Poly Faculty Research Seed Grant, we have developed innovative hydrogel encapsulation systems. These hydrogel μ-stand/ribbon/tube culture systems have high handleability and allow mass production with uniform size, high density cell growth, quick release of cells, and direct cell storage. They are easy to use, cost-effective, scalable, versatile, and therefore, commercially viable for advanced biomanufacturing. Using these engineering approaches, we continue to address technical challenges in generation of various organoids with high efficiency and implant neural μ-ribbons for stem cell-assisted spinal cord injury repair in collaboration with Dr. Jan Paluh supported by New York State Department of health Spinal Cord Injury Research Board (SCIRB).

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BIOENGINEERING TRABECULAR MESHWORK FOR HIGH-THROUGHPUT ANTI-GLAUCOMA DRUG SCREENING AND DISCOVERY

Glaucoma is an age-related disease and the leading cause of irreversible blindness. The vision loss in glaucoma is caused by the permanent optic nerve damage due to an increased intraocular pressure (IOP). IOP is the most critical and the only modifiable risk factor for development and progression of glaucoma and is controlled by the outflow (elimination) of the aqueous humor. In human, most of the aqueous humor (up to 90%) drains through the trabecular meshwork (HTM) into Schlemm's canal (HSC), so called conventional outflow pathway. There is a great need of in vitro model of the conventional outflow pathway for understanding physiology and pathophysiology as well as drug screening and testing for glaucoma.

We have invented the Artificial Conventional Outflow System (ACOS) (Figure 2), which provides a unique, valuable in vitro platform for understanding outflow physiology, drug screening and therapeutic development for glaucoma, in collaboration with Drs. John Danias from SUNY Downstate Medical College, Karen Torrejon from Glauconix Bioscience, and Susan Sharfstein. In collaborated with Dr. Yiqin Du from University of Pittsburgh, we further test the feasibility of using stem cells as an unlimited cell source for the ACOS. The use of stem cells offer an alternative HTM and HSC sources for establishing high-throughput 3D HTM complex for drug screening, leading to personalized medicine. We have secured NYS CATN2 MIP grant to support this effort.

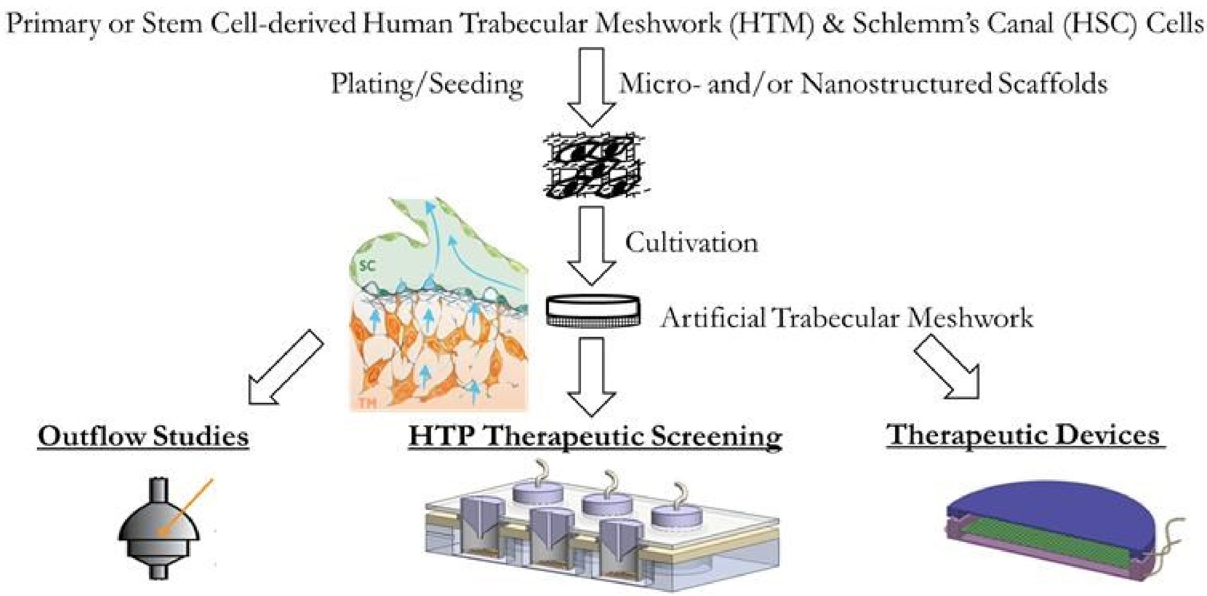

Figure 2. Schematics of bioengineering the Artificial Conventional Outflow System (ACOS) for understanding of outflow physiology, higher throughput (HTP) screening of IOP-modulating agents and development of therapeutics for glaucoma.

PUBLICATIONS

[1] Y.I. Tian, X. Zhang, K. Torrejon, J. Danias, S. Gindina, A. Nayyar, Y. Du, **Y. Xie**. Bioengineering approach to Schlemm's canal-like stem cell differentiation for in vitro glaucoma drug screening. Acta Biomaterialia, in revision

[2] Gretchen Long, Y.I. Tian, K. Torrejon, **Y. Xie**. Simulation and Fabrication of a dual-flow microfluidic device for Schlemm's canal differentiation. New England Science Symposium, April 6, 2019, Boston, MA

“NANOFIBER SCAFFOLD-BASED TISSUE REGENERATION”: ENABLING TECHNOLOGIES TOWARDS STEM CELL-BASED THERAPY

The eye is pioneering cell therapy for advanced disease that involves cell loss. Combining stem cells with bioengineering offers great potentials for functional tissue regeneration and vision restoration. For example, we have developed bioengineering approaches that can provide delivery vehicles for better in vivo integration of retinal pigment epithelial stem cell (RPESC) to the retina, electrospun nanofiber scaffolds and surface chemistry modification for RPESC-derived retinal pigment epithelial cell maturation, leading to stem cell-based therapy to age-related macular degeneration (AMD) (in collaboration with Dr. Sally Temple at Neural Stem Cell Institute).

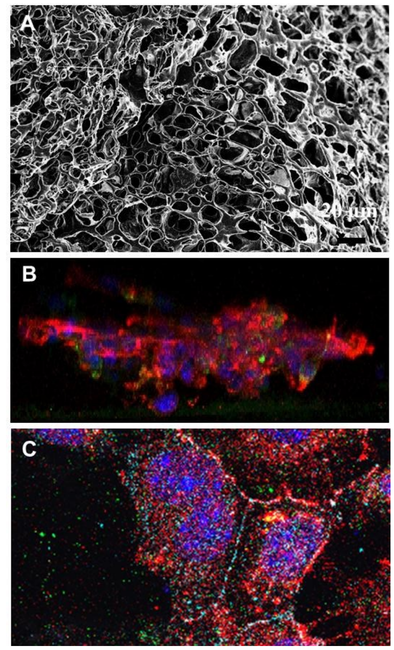

Figure 3. Cryogenic electrospun fibrous sponge scaffold supported in-depth salivary gland cell growth. (A) SEM of the scaffold. Confocal images of (B) the cross-sectional view of stromal cells expressing F-actin (red) and vimentin (green), and (C) salivary gland epithelial cells co-cultured with stromal cells on the scaffold, expressing ZO-1(green) and E-cadherin (red) co-stained with DAPI.

Beyond cell therapy to the eye, chemically modified nanofiber scaffolds show promise for understanding salivary gland regeneration (in collaboration with Drs. Larsen & Sharfstein). In particular, cryogenic electrospinning of alginate provide nanofiber-sponge-like matrix can better mimic the mesenchymal/stromal microenvironment of salivary gland cell growth (Figure 3). Taking advantage of our expertise in alginate hydrogel & stem cell technology, we are creating salivary gland epithelial-stromal co-culture system to recapitulate the salivary gland characteristics and generating mesenchymal stem cell- (MSC-) scaffold construct to understand the role of MSC in limiting salivary gland fibrosis, which tackles a significant unmet clinical problem. We have secured NIH RO1 grant to develop nanofiber scaffolds for salivary gland regeneration in collaboration with Dr. Melinda Larsen from University at Albany.

PUBLICATIONS AND PRESENTATIONS

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[2] Y. Tian, R. Davis, M.R. Zonca Jr, J.H. Stern, S. Temple, **Y. Xie**. “Screening and optimization of potential injection vehicles for storage of retinal pigment epithelial stem cell before transplantation”, Journal of Tissue Engineering and Regenerative Medicine, 13 (1):76–86 (2019).

[3] P. Ramesh, N. Tokranova, L.P.M. Hemachandra, D. Nelson, A. Khlamadze, **Y. Xie**, S. Sharfstein, M. Larsen, J. Castracane. Biomimetic scaffolds targeting regeneration of the salivary gland. The Gordon Research Conference (GRC) on Salivary Glands and Exocrine Biology, February 3 - 8, 2019, Galveston, TX

[4] P. Ramesh, N. Tokranova, L.P.M. Hemachandra, D. Nelson, A. Khlamadze, **Y. Xie**, S. Sharfstein, M. Larsen, J. Castracane. Cryogenically electrospun fibrous sponge scaffolds as stromal extracellular matrix for salivary gland regeneration. 2019 Materials Research Society (MRS) Spring Meeting & Exhibition, April 22-26, 2019, Phoenix, AZ

Research funded by: NYSTAR, National Institute of Dental and Craniofacial Research

For more information on Dr. Xie's research, please visit: https://sunypoly.edu/faculty-and-staff/yubing-xie.html

Center Research

JOINT CENTER FOR CREATIVITY, DESIGN, AND VENTURING (JCCDV)

DR. ROBERT EDGELL
ASSOCIATE PROFESSOR OF TECHNOLOGY MANAGEMENT, CBM
CO-DIRECTOR, JOINT CENTER FOR CREATIVITY, DESIGN, AND VENTURING (JCCDV)

Scope: The JCCDV was formed in November of 2017 by a grant from the State University of New York System Performance Improvements Funds project. The center is co-directed by Drs. Robert Edgell (College of Business Management, CBM) and Daryl Lee (College of Arts & Sciences, CAS) and is supported by funding from sources including the National Endowment for the Arts, NYSTEC, and State University of New York System Performance Improvements Funds. In addition to the co-directors, the center's core team includes Dr. Lisa Berardino (CBM), Dr. Marie-Odile Richard (CBM), Dr. James Staihar (CBM), Dr. Maarten Heyboer (CAS), Dr. Kristina Boylan (CAS), and Dr. Ana Jofre (CAS). In addition, CBM graduate student Elias Zeina joined the team as the center's project manager.

During the 2018-2019 period, the JCCDV team has been collaborating to institutionalize the newly formed Joint Center for Creativity, Design, and Venturing (JCCDV) which will integrate InnovationChallenge New York (ICNY), Creativity and Ethical Venturing (CEV) Minor, Mohawk Valley Mini Maker Faire (MVMMF), research on ethical entrepreneurship, and the Visioneers and Venturers scholarly conference and publication. The JCCDV will enable multiple interdisciplinary activities including research, student engagement, and community engagement and aims to address the following needs:

- Students need: Ethical reasoning, creativity, and venturing efficacy
- Communities need: Brain gain, economic vitality, and sustainability
- SUNY Poly needs: Improved Excels (PIP), institutionalization of key experiential learning components, greater research on economic vitality, and more students engaged in venturing

Goals**:** Accordingly, the JCCDV has the following "Connector" Objectives:

- Curricular: Foster student-based interdisciplinary problem solving, creativity, design culture, and sustainable venturing practices
- Co-Curricular: conduct community-based collaborative experiential learning to aid communities with current challenges
- Research: Provide the means for generating and disseminating new scholarly research on ethical venturing and entrepreneurial capacity development
- Social: Amplify community brain gain by reversing "Brain Drain"

- Economic: Cultivate new ventures and create vitality

TOPIC 1

Research and dissemination: In order to develop both the CEV curriculum and faculty team, we have begun defining and exploring the intellectual content of the minor theme of “re-imagining entrepreneurship” and, more broadly, exploring the connections between the humanities and business management. Dr. Edgell and collaborators presented their related research, Reimagining Entrepreneurship: Design Culture Exposure as a Positive Mediator for Entrepreneurial Capacity (https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3164302), at a major economics conference during fall 2017. This paper was recently published in a scholarly management journal. In spring 2018 the faculty team began planning for a scholarly conference and journal (tentatively titled “Visioneers and Venturers”).

Based on his presentation to the board of Sculpture Space, Dr. Edgell was invited to join Anna D'Ambrosio (President, MWPAI) and Tom Montan (Executive Director, Sculpture Space) to help create the Utica Arts Council. Furthermore, he is currently beginning a collaboration with others including professors from Utica College and leaders of ThINCubator on the Utica MV100 sandbox concept which aims to develop early stage entrepreneurial capacity in the local region.

PUBLICATIONS AND PRESENTATIONS

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Edgell, R. A.. Khasawneh, F., & Moustafellos, J. (2018). Reimagining entrepreneurship: Design culture exposure as a positive mediator for entrepreneurial capacity. Journal of Creativity and Business Innovation, 4, 60-77. Available at SSRN: https://ssrn.com/abstract=3164302 or http://dx.doi.org/10.2139/ssrn.3164302

Imbruce, V., Smart, P., **Edgell, R. A.,** Lee, D., Malazita, J., Rouse, R., Hermsen, L., Newman. R., Goldsmith, M. L., & Hurley, P. (2019). Humanities, STEM, and Management: New interdisciplinary pathways for 21st century learning. “HEDs UP” Panel presentation in the Innovative Teaching and Learning Practices and Assessment track at the Association of American Colleges & Universities (AAC&U) Annual Meeting, Atlanta, Georgia.

Lee, D. & **Edgell, R. A.** (forthcoming 2019) Reimagining Entrepreneurship. Research presentation at SUNY Faculty Development Conference at SUNY New Paltz, New Paltz, New York.

VISIONEERS AND VENTURERS CONFERENCE AND PUBLICATION (V&V)

The JCCDV team is currently designing the first ever, Visioneers and Venturers (V&V) Annual Conference to be held during May 2020. The main purpose of the scholarly conference is “Exploring the Interdisciplinary Connectivity Between the Humanities and Entrepreneurship.” The conference will engage and bring together diverse scholars, practitioners, and students who have varied interests in exploring the interdisciplinary connectivity between the Humanities and Entrepreneurship. It will provide a means for both disseminating existing and generating new lines of inquiry including scholarship, action research, pedagogies, and other collaborations around four key conference themes as follows:

- Reimaging Entrepreneurship and Ethical Venturing
- Creativity, Design Culture, and Design Thinking
- Experiential and Applied Pedagogies
- Interdisciplinary Research

In addition, the JCCDV team will publish companion conference proceedings.

The publication will be both an archive and medium for further disseminating the conference works and the newly generated collaborative lines of inquiry.

Research funded by: Caparo Technologies Inc, SUNY Poly Student Government at Utica, NYS Performance Improvement Funds, NYSTEC.

CENTER FOR GLOBAL ADVANCED MANUFACTURING (CGAM)

DR. NASER HAGHBIN

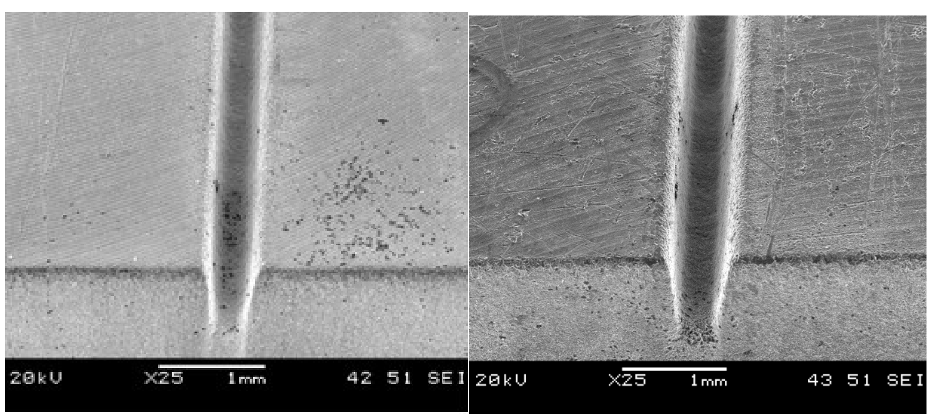
CENTER for GLOBAL ADVANCED MANUFACTURING
CGAM
...Leading NY's Manufacturing Resurgence

Scope: In the CGAM, Haghbin and coworkers research on the advanced manufacturing technologies, including abrasive waterjet micro-machining, laser micro-machining, 3D printing, and coordinate measurement machining (CMM).

Goals: CGAM mission is to (1) reduce cost and improve quality of products, (2) provide technical/operational expertise and support to improve manufacturing processes, (3) provide access to academic/research partners to solve problems, (4) provide access to Equipment Characterization Lab.

MICRO-MACHINING OF CHANNELS USING ABRASIVE WATER JETS (AWJ) AND ABRASIVE SLURRY JETS (ASJ)

Abrasive water jet technology can be used for micro-milling using recently developed miniaturized nozzles. Methodologies were developed to predict the shape of micro-channels milled using high pressure abrasive water jets, and presented a new high pressure abrasive slurry jet micro-machining process. Figure 1 shows typical micro-channels with aspect ratios (depth/width) of about 1.2 machined using an AWJ machine.



(a) (b)

Figure 1: Scanning electron micrographs of micro-channels with aspect ratio 1.2 in (a) SS316L (30 passes) and (b) Al6061-T6 (10 passes), machined under water at Pp=138 MPa, Vt=1000 mm/min, and h=2 mm. [1]

PUBLICATIONS AND PRESENTATIONS

[1] **N. Haghbin**, J. K.Spelt, M. Papini, "Abrasive waterjet micro-machining of channels in metals: Comparison between machining in air and submerged in water," International Journal of Machine Tools & Manufacture, vol. 88, pp. 108–117, 2019.

[2] **N. Haghbin**, Ariana Khakpour, Jeffrey Schwartzentruber, Marcello Papini, "Measurement of abrasive particle velocity and size distribution in high pressure abrasive slurry and water micro-jets using a modified dual disc anemometer," Journal of Materials Processing Technology, vol. 263, pp. 164-175, 2019.

[3] **N. Haghbin**, F. Ahmadzadeh, M. Papini, "Masked micro-channels machining in aluminum alloy and borosilicate glass using abrasive waterjet micro-machining," Journal of Manufacturing Processes, vol. 35, pp. 307-316, 2018.

MICRO-MACHINING OF COLDPLATES AND HEATSINKS USING ELECTRICAL DISCHARGE MACHINING (EDM) AND MICRO-MILLING TECHNIQUES

Without the use of coldplates and heatsinks, chip technology would not be as advanced as it is today. Therefore, increasing the heat dissipation with a more efficient cold plate will allow for high power devices to run with a greater efficiency. Figure 2 shows Isothermal surfaces of steady state temperatures of a micro-cold plate of 635 µm wide fins separated by 635 µm wide channels. The goal for the improved cold plate design was to decrease the fin and channel width to 100 µm using wire EDM and micro-milling techniques. By doing this, the total surface area of the cold plate in contact with the coolant (water) will be increased. This is because there will be more fins in the same cold plate volume, which will result in an increase in total heat dissipation.

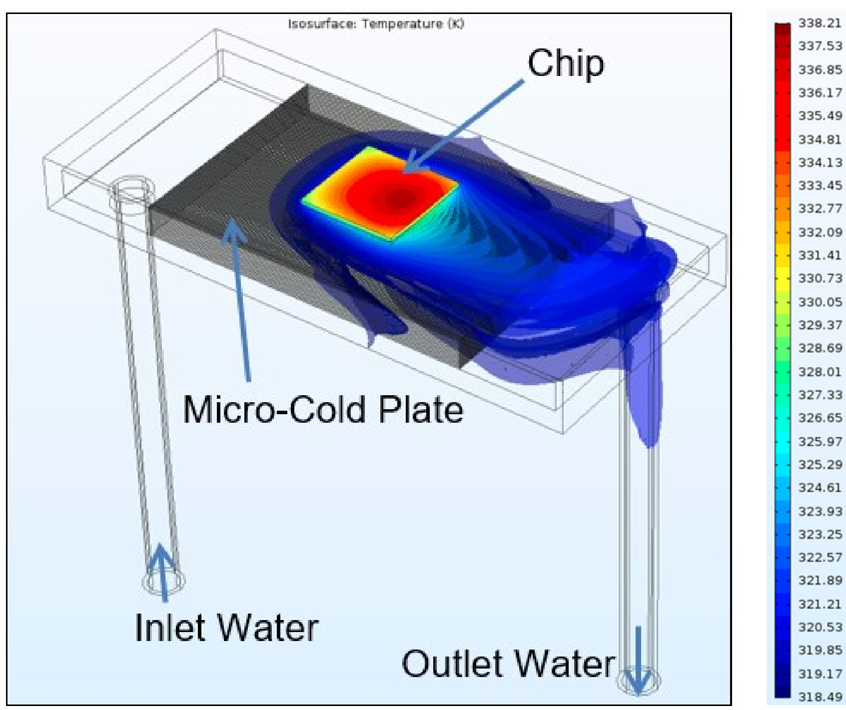


Figure 2: A COMSOL simulation (Isothermal surfaces of steady state temperatures) of a micro-cold plate (total volume: $77 \times 51 \times 6.5$ mm^3 having 635 µm wide fins separated by 635 µm wide channels). Other parameters: a 15x15x.75 mm^3 chip (i.e. heat source) at 250W, 5PSI pressure difference between input and output water flow with 45°C water inlet temperature. Scale to the right in Kelvin.

ADDITIVE MANUFACTURING OF MICRO-FLUIDICS DEVICES AND MICRO-CHANNELS USING 3D PRINTING TECHNIQUES

In the CGAM Additive Manufacturing Lab, many projects have taken place throughout the year 2018 such as (1) FDM Extrusion Modelling, (2) Soft Material (PDMS) Printing, (3) Microchannel Fabrication, (4) Braille Blocks, (5) Suspension 3D printer (6) Polar Coordinate 3D printer, (6) Solar Tracker and Charger (Class Project). For example, soft material printing of Polydimethylsiloxane (PDMS), and other soft materials are useful for microfluidic, biomechanical systems, and medical applications. Processes for single-step fabrication of PDMS microfluidic devices is uncommon. Experiments were performed (Fig. 3) to investigate molding processes for silicone using FDM and Polyjet 3D printing. A modular system for directly jetting PDMS is in the pre-design stage of development.

Figure 3: Prosthetic silicone finger and mold (left), channel mold (right)

PUBLICATIONS AND PRESENTATIONS

D. Bone, R. Payne, **N. Haghbin,** "Additive micro-machining: A comparison between FDM and Polyjet 3D Printing" Proceedings of the 55th NYSETA fall conference, Utica, NY, USA, 2018.

For more information on CGAM, please visit: https://sunypoly.edu/academics/cgam.html

NANOTECHNOLOGY EDUCATION AND WORKFORCE TRAINING

DR. ROBERT GEER

Scope: Our team focuses on nanotechnology education and workforce training content development, deployment, and education program implementation. We focus on semiconductor manufacturing, semiconductor derivative manufacturing, and emerging nanotechnology manufacturing. We develop innovative training programs for the nanotechnology workforce and utilize our nanotechnology training laboratory for technicians and engineers engaged in nanotechnology manufacturing. Our current research and development activities are supported by the National Science Foundation, the SUNY Impact Foundation, GlobalFoundries, and the National Institute of Standards and Technology (NIST).

Goals: Develop, deploy, and disseminate innovative, cutting-edge workforce education content for the nanotechnology manufacturing sectors with a focus on semiconductor manufacturing, semiconductor derivative manufacturing (including 3D CMOS fabrication, power electronics manufacturing, and Integrated Photonics manufacturing).

NANOTECHNOLOGY EDUCATION AND WORKFORCE TRAINING

Our team has developed a suite of unique 3D integration platforms for research and education training led by Ph.D. candidate Robert Carroll (graduated Spring of 2019 and currently employed at GlobalFoundries Fab 8 in Malta, NY. This resulted in two peer-reviewed technical publications (Fig. 1). We have also developed two new nanotech manufacturing training courses (currently being used to train GlobalFoundries tool technicians from Fab 8 in Malta and their East Fishkill fab). The first course, Advanced Workmanship Training includes 40+ hours of content in mechanical systems assembly, basic vacuum technology, advanced vacuum technology and leak detection, electrical component technology, pneumatic systems, and intro to integrated mechatronics and robotics. The 2nd course, Advanced Fluid Power and Mechatronics, includes 40+ hours of content in electro-pneumatics, controls circuitry, PLC operation and basic programming, and mechatronic system operation, fault identification, and system repair. This development resulted in two conference presentations.

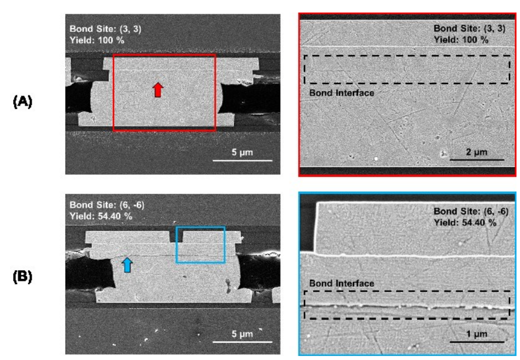


Figure 1 Mechanically prepared cross-sections comparing a high-yield vs. a poor yield bond. High-magnification images on the right of the bond interfaces denoted by the red/blue boxes within the images on the left. (note: arrows denote location of bond interfaces)

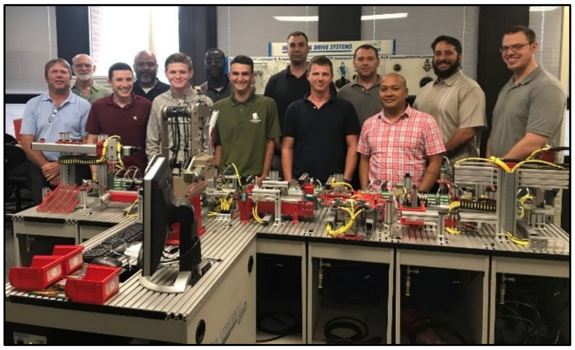


Figure 2 Mechatronics training lab (picture with transitioning soldiers from Fort Drum). This equipment has been complemented by customized PLC training elements.

As part of these efforts our group has developed, fabricated and evaluated a suite of nanotech manufacturing education and training toolsets (see Fig 2). These include a customized basic vacuum technology training system and an advanced vacuum training system. In addition, the PLC and mechatronics systems (Fig. 3) have been complemented by a customized PLC-driven control training suite integrated with our electro-pneumatic systems.

In 2018 we secured funding from the ***National Science Foundation*** and ***GlobalFoundries*** for this content development and implementation with 2-yr college programs, 4-yr college programs, regional PTECH programs and GlobalFoundries Tool Technician and Engineer Training Program.

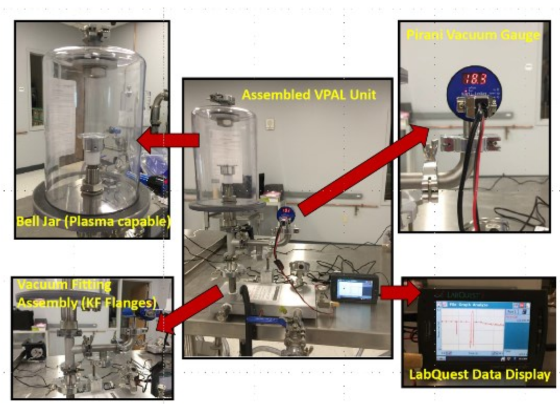


Figure 3 Customized Vacuum/RF Plasma training system developed for NSF NEATEC grant and for GlobalFoundries Tool Technician Training Program.

PUBLICATIONS AND PRESENTATIONS

[1] Robert Carroll, Douglas La Tulipe, Douglas Coolbaugh, and **Robert Geer** "Collective Cu-Cu Thermocompression Bonding Using Pillars," *Journal of Microelectronics and Electronic Packaging*: January 2019, Vol. 16, No. 1, pp. 28-38.

[2] Robert Carroll and **Robert Geer**, "Fault localization in a 3D test assembly using voltage contrast imaging," *Microelectronics Journal* Vol. 87, May 2019, pp. 73-80.

[3] "Two-Tier Vacuum Technology Learning System for Semiconductor and Nanotech Manufacturing Tech Training", **Robert Geer**, Abraham Michelen, Robert Decker, Stephen Stewart, Northeast Advanced Technological Education Center (NEATEC), Albany, NY, *High Impact Technological Education Conference, St Louis, MO, July, 2019.*

[4] "Vacuum Technology and RF Plasma Learning SystemS for Semiconductor and Nanotech Manufacturing Tech Training", **Robert Geer**, Abraham Michelen, Robert Decker, Stephen Stewart, Northeast Advanced Technological Education Center (NEATEC), Albany, NY, *2018 ATE Principal Investigators Conference, Washington D.C.*

NANOTECHNOLOGY EDUCATION OUTREACH

Our team has developed two outreach programs under our NSF and SUNY Impact Foundation grants. The first program is a Newly-Transitioned Veterans Training Program formed in partnership with the U.S. Army Base at Fort Drum in Watertown, NY. This program engages active-duty soldiers transitioning out of the military for a 56-hour Advanced Manufacturing Training Program. Comprised of components focused on mechanical systems, pneumatics, and mechatronics, this program provides hands-on training to prepare newly-transitioned veterans for careers in advanced manufacturing. In 2018/2019 more than 40 transitioning soldiers completed our course with several being offered positions at manufacturers in NYS.

In addition, under the NSF NEATEC grant our team has developed and deployed a series of nanotech education learning modules adapted for use by high school and middle school teachers. Building on our team's outreach over the last several years we saw substantial use of these kits by K-12 teachers throughout the region. This program was selected for a session presentation at the 2018 ATE Principal Investigators conference in Washington, D.C.

Lastly, our team has established a unique Cleanroom Technician Internship Program with the National Institute of Standards and Technology (NIST) in Gaithersburg MD. Interns from around the nation, spend 3 months at NIST's Center for Nanoscale Science and Technology (CNST) as equipment and process technicians in the CNST cleanroom. In 2018/19 we supported 6 interns for 3-month and 6-month experiences at NIST.

In 2018 we secured funding from the ***National Science Foundation***, the ***SUNY Impact Foundation***, and ***NIST*** for these experiential learning programs.

PUBLICATIONS AND PRESENTATIONS

[1] "Preparing Military Personnel for Civilian Technical Positions Pre Separation," Kathleen Alcott and **Robert Geer**, Northeast Advanced Technological Education Center (NEATEC), Albany, NY, *2018 ATE Principal Investigators Conference, Washington D.C.*

[2] "NEATEC Learning Module Use and Impact," Mary Ann Nickloy, Kelly Fahrenkopf, Abraham Michelen, and **Robert Geer**, Northeast Advanced Technological Education Center (NEATEC), Albany, NY, *2018 ATE Principal Investigators Conference, Washington D.C.*

Research funded by: NSF, Globalfoundaries, SUNY Impact Foundation, AFRL