PROGRAM

Scott White Memorial Symposium

Including the 2018 Annual Grantees'/Contractors' Meeting of AFOSR M^4 Program

August 13-16, 2018
Beckman Institute for Advanced Science and Technology
University of Illinois at Urbana-Champaign

Note: All events are in the Beckman Auditorium, Room 1025, unless indicated otherwise

Links to each day: Day 1, Mon 8/13 | Day 2, Tue 8/14 | Day 3, Wed 8/15| Day 4, Thu 8/16

DAY 1: MONDAY, AUGUST 13, 2018

12:45 pm Registration, Lobby of Auditorium

1:00 pm Opening Remarks: Nancy Sottos, University of Illinois

Session: Bio-inspired Materials

1:10 pm "Introduction to Bio-inspired Materials"
Session Chair: Narayana Aluru, University of Illinois
Biosketch: Narayana R. Aluru received his Ph.D. from Stanford University in 1995. He is a professor in the Department of Mechanical Science and Engineering at Illinois and a full-time faculty member in the Beckman Institute Computational Multiscale Nanosystems Group. His fields of professional interest are microelectromechanical systems (MEMS), microfluidics, Bio-MEMS, numerical methods, and parallel algorithms.

1:20 pm Invited Lecture #1: "Towards Autonomic Functionality Using Bimolecular Material Systems"
Don Leo, University of Georgia
Biosketch: Don Leo is currently the dean of the College of Engineering at the University of Georgia. Prior to his tenure as dean, he was a faculty member at Virginia Tech from 1998-2013, where he was a Professor in the Mechanical Engineering Department, Associate Dean for Research and Graduate Studies in the College of Engineering, and a Vice President for the National Capitol Region. He was affiliated with the Center for Intelligent Material Systems and Structures while a faculty member at Virginia Tech. He has also held positions as a DARPA program manager, as a faculty member at the University of Toledo, and as a project engineer at CSA Engineering. He has a B.S. in Aeronautical and Astronautical Engineering from the University of Illinois at Urbana-Champaign, and M.S. And Ph.D. Degrees in Mechanical and Aerospace Engineering from the University of Buffalo.
Abstract: Over the past several years a class of materials that exhibit rudimentary autonomic behavior has been developed based on the stimuli-responsive properties of certain biomolecules. It is well established that certain biomolecules, such as ion channels, exhibit multiple modes of stimuli-responsive properties

that can be triggered and controlled by the application of mechanical, electrical, optical, and chemical stimulus. Our work has focused on the incorporation of these biomolecules into synthetic materials whose properties can be tailored through choice of material composition. Early embodiments of this concept utilized liquid-in-liquid systems to demonstrate stimuli-responsive behavior, but more recently a class of self-supporting materials in polymer matrices have been created. This presentation will overview demonstrations of stimuli-responsive behavior and progress towards creating material networks that exhibit autonomy.

1:55 pm **Invited Lecture #2: "Biomaterial Design of Nanohelix Actuator (*Volticella convallaria*) vs. Synthetic Design of Nanohelix Actuator (Ferromagnetic Shape Memory Alloy/FePd)"**
Minoru Taya, University of Washington

Biosketch Dr. Minoru Taya has been a Professor of Mechanical Engineering, and Adjunct Professor of Materials Science and Engineering, and Electrical Engineering at the University of Washington since 1986. Most recently he became an Adjunct Professor for the School of Dentistry, Oral Health Science, UW. He received a Bachelor of Engineering in 1968 from the University of Tokyo, Japan; Master of Science in Civil Engineering in 1973 and Doctor of Philosophy in Theoretical Applied Mechanics in 1977, both from Northwestern University.

Dr. Taya is currently director of the Center for Intelligent Materials and Systems (CIMS). The intelligent materials that he has been studying are shape memory alloys (SMA), ferromagnetic SMA (FSMA), piezo-composites, electro- and photo-active polymers, and designed actuators based on these materials, including compact ferromagnetic SMA spring actuators, which provides a large stroke and reasonably large force at very high actuation speed. The FSMA actuators are for use in unmanned aircrafts and unmanned ground rover, as well as robotic arms. The electroactive polymers (EAPs) include hydrogels such as Nafion and Flemion, and electrochromic polymers. These EAPs are the key materials for fish fin actuators, smart antenna, and smart window technology. In addition, Dr. Taya has been working on design and processing of several energy-harvesting materials and systems; (i) energy-harvesting electrochromic window (NSF-EFRI) and thermoelectric modules with low-cost and light-weight for UAV combustion chambers (AFOSR). Most recently, Dr. Taya has been working on oral implant materials based on toxic-free SMAs.

Dr. Taya served as Associate Editor for Materials Science and Engineering-A, and ASME Journal of Applied Mechanics, and chair of the Electronic Materials Committee of ASME Materials Division. Dr. Taya is Fellow of ASME, American Academy of Mechanics, and International Editorial Board member of Advanced Composite Materials. He has written three monograph books, (i) "Metal matrix composites" with R.J. Arsenault, Pergamon Press, 1989, (ii) "Electronic Composites", Cambridge University Press, 2005, and (iii) "Bioinspired active and sensing materials and systems" in collaboration with several biologists (E. Van Volkenburgh of University of Washington, M. Mizunami of Hokkaido University, and S. Nomura of National Museum of Nature and Science, Japan).

Abstract: Nanohelices are key building blocks for biological materials with some examples being the α protein and the double helix of DNA. Nanohelix actuators are also seen in some biological species; for example, rapid stalk coiling (thus rapid shrinkage) of Vorticella seems to be driven not by just external Ca2+ ions but also intracellular Ca2+ storage site. Recently three chemists are honored as Nobel Laureates in Chemistry, in 2016 for their pioneering work on design of synthetic molecular motor machines which exhibit both translational and rotational motions under redox reactions and also light-driven stimulus. Despite the promising future in using bioinspired design of molecular machine and nanohelix

engineering, the processing of such synthetic molecular elements and nanohelices in high yield is still in its infancy. Exact control of molecular motors under redox reactions is NOT available. Several processing routes have been attempted to make nanohelices but their yield is still low, ideal helix shape has NOT being processed. While some of these nanohelices are flexible, their size is close to the micron-size. Modeling studies of nanohelices and their devices made of a group of such helical springs has progressed little, although some reports exist for the modeling of metamaterials composed of arrayed nanohelices in plasmon physics and also on drug delivery systems based on micron-helix robots. However, the latter model on micro- robotics assumes that the shape of the helices remain unchanged. No modeling and no processing study has been made on the case of shape-changing flexible nanohelices under applied stimulus or stimuli, which would provide a unique property for nanorobotics design. Ideal nanohelix based nanorobots (NRs) should be flexible and therefore their shapes should change in a precisely controlled manner under applied stimuli.

Taya group studied the actuation mechanisms associated with bulk FSMA FePd to find that the key mechanism of actuation of FePd actuators is stress-induced martensite(SIM) phase transformation under applied magnetic field (either constant or gradient field). Scientific challenge is lack of the phase transformation diagram of nano-sized FSMA active materials. So I will discuss on the new modeling of the phase transformation diagram of nano-sized FePd based on thermodynamics model where the martensite start temperature (Ms) is expected to be shifted toward lower temperature, which is NOT desired for end-users of the FePd NRs. Fortunately, as-processed FePd nanomaterials (both nanorods and nanohelices) possess residual stress, which would promote SIM phase transformation, even at desired room temperature use condition. I will discuss the dislocation punching model by which the correct residual stress in as-processed FePd nanomaterials can be estimated. Recently, we have explored new NR based on flexible FSMA FePd nanohelices, which have been successfully processed. Our FePd NR is composed of a single FePd nanohelix (tail) and FePd nanorod (head) attached in series. The FePd NR can swim under an applied rotational magnetic field, and it can vibrate under an oscillating magnetic field which is verified by our recent molecular dynamics model. We are currently using FePd nanohelix based untethered NRs as treatment of difficult-to-cure cancer cells where targeted cells are expected to undergo cell damage (apoptosis/necrosis) by mechanical stress-induced cell death.

Session: Self-Healing Materials

2:30 pm **"Introduction to Self-Healing Materials"**
Eric Brown, Los Alamos National Lab

Biosketch: Dr. Eric N. Brown is the Division Leader for the Explosive Science and Shock Physics Division at Los Alamos National Laboratory where he oversees the premier research program on energetic materials and dynamic material response in support of National Security. His research has spanned fracture and damage of complex heterogeneous polymers and polymer composites for energetic, reactive, and structural applications including crystalline phase transitions, plasticity, dynamic loading conditions, and self-healing materials. He is the founding Editor-in-Chief of the Journal of Dynamic Behavior of Materials and been named Fellow of the Society for Experimental Mechanics. He has received awards for his technical achievements in solid mechanics and materials science from the ASC, DOE-NNSA, LANL, MRS, SEM, TMS and the University of Illinois. He also serves on committees for TMS, APS and SEM. Eric was a Director's Postdoctoral Fellow and Technical Staff Member in the Materials Science and Technology Division at Los Alamos National Laboratory, Technical Advisor for the Joint DoD/DOE Munitions Technology Program in the Office of the Under Secretary of Defense, and managed the

Neutron Science and Technology Group in the Los Alamos National Laboratory Physics Division. Eric received a B.S. in Mechanical Engineering in 1998 and a Ph.D. in Theoretical and Applied Mechanics (TAM) in 2003, both from the University of Illinois at Urbana-Champaign. While at the University of Illinois he did undergraduate research and pursued his PhD under the advisement of Prof. Nancy Sottos. He worked closely with Scott White and was part of the research team that published the early Nature paper on Autonomic Materials in 2001.

2:40 pm **Invited Lecture #3: "Self-Healing Functionality for Metal Asset Protection"**
Gerald Wilson, Autonomic Materials Inc.

Biosketch: Dr. Gerald Wilson is the Vice President of Technology Development for Autonomic Materials. Inc. (AMI), an advanced materials company based in Champaign, IL. In this role, Dr. Wilson is responsible for the company's research and development, new product development, application development, product scale up and manufacturing functions. Over the last 15 years, Dr. Wilson has developed new chemistries for self-healing coating, adhesives, sealants, composite and biomedical applications. He has authored or co-authored over 50 peer-reviewed articles, conference proceedings and invited lectures and is an inventor on 12 issued and pending patents and applications. Dr. Wilson earned a B.A. in Chemistry from Macalester College, a Ph.D. in Materials Science and Engineering from the University of Illinois at Urbana-Champaign and an M.B.A. with distinction, also from the University of Illinois at Urbana-Champaign.

Abstract: In a 2016 report by the National Association of Corrosion Engineers (NACE), the global cost of corrosion was estimated to be about US$2.5 trillion, which amounts to about 3.4% of global Gross Domestic Product (GDP). Industries such as oil and gas that maintain a disproportionate amount of their assets in extremely corrosive environments bear a disproportionate amount of these costs. Add to these costs the environmental and individual safety consequences of material failure due to corrosion and the case for investing in new technologies geared towards improving corrosion protection can hardly be overstated.

In this talk, we report on novel additives which leverage the incorporation of microencapsulated healing agents into coating systems with a view towards lengthening their service lives and that of their underlying substrates while minimizing the opportunity cost of downtime associated with maintenance. These self-healing additives have been evaluated in a broad range of coating systems selected to provide the asset owner/operator with a range of options aimed at delivering improved readiness and cost savings across the value chain.

In this talk, we will provide an overview of evaluations performed in coating systems based on organic zinc-rich primers, fusion bonded and powder epoxy coatings and low volatile organic content (VOC) water-borne epoxy coatings. Across this range of substrate protection solutions, protection lifetime extensions of up to four-fold have been demonstrated. Using data provided by NACE, a model of the cost savings associated with material and labor expense over the lifetime of an oil rig resulted in savings of US$21 Million for a coating lifetime extension of four-fold.

3:15 pm **Invited Lecture #4: "Thermomechanical Evaluation of Additively Manufactured Polymeric Structures Fabricated With Novel, Multi-Material Filaments"**
Kevin R. Hart, Army Research Lab

Biosketch: Dr. Kevin Hart recently resigned as a Materials Engineer from the US Army Research Lab's Weapons and Materials Research Directorate where he examined novel materials for applications in additive manufacturing. In the fall, Kevin will join the faculty of the Mechanical Engineering department at the Milwaukee School of Engineering in Milwaukee, WI, continuing work on novel materials for additive manufacturing. Under the direction of Profs. Scott White and Nancy Sottos, Kevin studied self-healing of impact damage in vascular fiber-reinforced composites, completing his PhD in early 2016 at The University of Illinois at Urbana-Champaign.

Abstract: Recent studies have shown that post-manufacture isothermal annealing of structures fabricated via FFF may increase the inter-laminar toughness of these parts by over an order of magnitude through reptation of polymer chains at the inter-layer. In these studies, however, the structure was confined to a fixture during annealing to limit deformation via creep and release of residual thermal stresses. In this work, we report on a novel method for fabricating structures via FFF using a dual material filament to create structures with a dual material composition of macro-structurally distinguishable thermomechanical properties. When printed structures are annealed, one material phase softens to increase reptation and healing of the inter-laminar interface, while the other material phase remains geometrically stable during the process, limiting deformation of the structure as a whole. Critical elastic-plastic strain energy release rates of annealed, dual material specimens was evaluated using the single edge notch bend sample geometry and showed marked improvements over homogeneous samples fabricated from either of the individual constituents. Additionally, geometric stability of dual material samples was evaluated using a sag test and show minimal deformation during the high temperature annealing process, enabling free-standing post-process annealing.

3:50 pm Break: Room 1005 Beckman Institute

Session: Self-Healing Electronics and Batteries

4:05 pm “Introduction to Self-Healing Electronics and Batteries”
Session Chair: Paul Fenter, Argonne National Lab

4:15 pm Invited Lecture #5: “Triggered Restoration with Polymer Microcapsules and Molecular Shuttles”
Susan Odom, University of Kentucky

Biosketch: Susan Odom is an Associate Professor of Chemistry at the University of Kentucky, the same institution from which she obtained a B.S. in Chemistry in 2003. As an undergraduate researcher under the guidance of Prof. John Anthony, Prof. Odom synthesized conjugated organic molecules as the emissive components of OLEDs. As a graduate student at Georgia Institute of Technology, under the guidance of Prof. Seth Marder and Dr. Stephen Barlow, she studied triarylamine radical cations as mixed-valent species. A stint at the University of Oxford as a visiting student in Prof. Harry Anderson’s research group (2005) involved synthesizing donor-acceptor dyes as two-photon-absorbing materials. Prof. Odom took a position as a postdoctoral researcher at the University of Illinois, Urbana-Champaign where she developed self-healing electronic materials and damage-indicating microcapsules under the guidance of Prof. Jeffrey Moore, in collaboration with Profs. Scott White and Nancy Sottos. After returning to the University of Kentucky, she initially focused on redox shuttles for overcharge protection of lithium-ion batteries. More recently, her research scope expanded to include redox-active organic materials for non-aqueous redox flow batteries, which she further developed as a visiting scientist in the Brushett (MIT) and Aziz (Harvard) laboratories in 2017-18 on sabbatical. Outside of research, Prof. Odom is involved in educational and outreach activities, including developing custom pigments for use by Lexington artists, and serves as a co-organizer of the Expanding Your Horizons Conference – a STEM conference for middle school girls – at the University of Kentucky.

Abstract: Core-shell microcapsules containing can release their core contents in response to a variety of triggers, including mechanical force, temperature change, magnetic fields, and change in environmental pH. In many cases, capsules can be used to deliver a desired response, without human intervention, to fully or partially restore desirable properties in a damaged material. For example, self-healing of epoxy polymers was demonstrated using microcapsules containing a dicyclopentadiene core and an embedded ruthenium catalyst, in which fracture toughness was recovered after fracture damage. Although most self-healing polymers have utilized polymers with embedded capsules, examples of polymers that utilize room temperature scrambling of components or heating after damage have been reported. Core-shell have also been utilized in damage indication and conductivity restoration. Here I give a summary of my collaborative research projects in the White, Moore, and Sottos groups, highlighting of conductivity restoration using charge transfer salt precursors as well as carbon nanotube and/or graphene suspensions, which were used to restore conductivity in gold lines with manufactured gaps or were damaged in mechanical tests. Further demonstrated is the utilization of organic liquid cores for selfhealing conductive inks, in which binder swelling allowed lowers the resistance of damaged ink lines through particle redistribution.

4:50 pm **Invited Lecture #6: "Electrochemical Stiffness and Solid State Electrolytes in Lithium Ion Batteries"**

Andrew Gewirth, University of Illinois

Biosketch: Professor Andrew A. Gewirth received his A.B. from Princeton University in 1981 and his Ph.D. from Stanford University in 1987. He joined the Illinois faculty in 1988 after postdoctoral work at the University of Texas, Austin. A former Director of the School of Chemical Sciences at the University of Illinois, Professor Gewirth has received a number of awards, among them a Presidential Young Investigator Award and the Department of Energy Outstanding Accomplishment Award in Materials Chemistry. Gewirth's work addresses chemistry at interfaces, especially the solid-liquid interface in studies relevant to fuel cells, batteries, and other energy related devices. Gewirth uses advanced characterization techniques to examine the mechanism of interfacial electrochemical reactions, and uses the resultant understanding to design new materials and catalysts. He has authored over 250 papers, delivered over 200 invited talks, organized several conferences, chaired a US Department of Energy panel examining the future of electrical energy storage devices, and served as the University of Illinois lead for the Center for Electrical Energy Storage EFRC.

Abstract: We present a new technique to probe the electrochemically-induced mechanics of electrodes by calculating the electrochemical stiffness of electrodes via coordinated *in situ* stress and strain measurements. Through the electrochemical stiffness, we elucidate inherent and rate-dependent mechanical responses of graphitic battery electrodes. We find that stress and strain are asynchronous. In particular, stress development is found to lead strain development as different graphite-lithium intercalation compounds are formed. Additionally, our analysis reveals inversely scaled rate-dependent behaviors for stress and strain responses. Stress scales as scan rate while strain scales with charge (or, equivalently, capacity). A similar asynchrony is observed in lithium manganese oxide (LMO) cathode materials, the origin of which also relates to differing origins of stress and strain behavior. These measurements provide a new paradigm for understanding mechanical effects in intercalation systems, such as batteries. Stress arises as resistance to lithiation, while strain arises as a consequence of lithiation. Electrochemical stiffness measurements provide new insights into the origin of the rate-dependent chemo-mechanical degradations, and provide a probe to evaluate advanced battery electrodes.

This talk will also address solid state electrolytes for Li batteries. Quasi-binary thiophosphate-based solid electrolytes (SEs) are attracting substantial interest for lithium batteries due to their outstanding room temperature ionic conductivities. We describe reactions occurring at the solid electrolyte (SE)/Au interface during Li deposition and stripping for two exemplary SE materials: β-Li_3PS_4 (β-LPS) and $Li_{10}GeP_2S_{12}$ (LGPS). We use SERS, XPS, and microscopy (SEM) to evaluate potential dependent changes in the chemistry of these materials at active electrode interfaces. For β-LPS, a partially reversible conversion of PS_4^{3-} to $P_2S_6^{4-}$ was found along with the formation of Li_2S during Li deposition and stripping. In contrast, LGPS exhibited only irreversible changes at potentials below 0.7 V vs. Li^+/Li. The different behaviors likely relate to differences in the structures of the two SE materials, and the availability of easily bridged anion components in close proximity.

5:25 pm Tributes

6:00 pm Adjournment

6:30 pm Reception: Beckman Institute Atrium

Back to Top

Day 2: Tuesday, August 14, 2018

8:00 am General Announcements

Session: Microvascular Composites

8:05 am "Introduction to Microvascular Composites"
Session Chair: Jason Patrick, North Carolina State University

Biosketch: Assistant Professor Jason Patrick obtained his Ph.D. in Structural Engineering from the University of Illinois at Urbana-Champaign in 2014, advised by Professors Nancy Sottos and Scott White, followed by a postdoctoral fellowship at the Beckman Institute for Advanced Science and Technology. In 2017, he joined his B.S./M.S. alma mater in the Department of Civil, Construction, and Environmental Engineering at North Carolina State University (NCSU) as an assistant professor. Jason has 15+ years of experience in research and development of advanced fiber-reinforced polymer composites. He has made significant contributions to the multidisciplinary Autonomous Materials Systems (AMS) Group at Illinois that pioneered self-healing materials, including co-inventing the vaporization of sacrificial components (VaSC) process to create complex microvascular composites and developing the first self-healing laminates with repeatable, *in situ* repair. He has a number of high-impact publications in the area of multifunctional materials, one awarded patent, and several pending patent applications for microvascular fiber-composites that have been licensed and commercialized by an aerospace company. His grand, collaborative research vision is to intimately couple self-sensing (receptor) and self-regulating (effector) functions to achieve truly biomimetic materials systems

. **8:15 am Invited Lecture #7: "Thinking VaSCular: How Thinking About Biology Inspires Materials"**
Aaron Esser-Kahn, University of Chicago

Biosketch: Aaron was born and raised in Bloomfield Hills, Michigan. As a high-school student, he began his interest in research at Wayne State University. He studied chemistry at the California Institute of Technology where he worked in the Tirrell lab. He completed his PhD in chemistry at UC Berkeley as part of the Francis group and the Chemical-Biology Program. He worked as a post-doctoral scholar with Jeffrey Moore and the Autonomous Materials Systems Group at University of Illinois, Urbana-Champaign. Upon completion, Aaron began his independent career at the University of California, Irvine in 2011. In 2017, he and his lab moved to be part of the Institute for Molecular Engineering at the University of Chicago. There he has been working in two areas – synthetic approaches to vaccine design and biomimetic approaches to materials.

Abstract: I will present several papers from my lab on work we conducted towards biologically inspired materials and separation processes. Each of these works stemmed from my time with Scott White and Jeffrey Moore. I will present work on generating a lung-like structure using the VaSC process. In addition, I will present work that grew from this work on the idea of developing a fish-like gas bladder for exchanging gas and a molecular level tool for using cooperativity to capture and release gases. In each case, I will detail the biological inspiration, the approach we took, and the resulting synthetic system. I will try to explain how this approach grew out of work that initiated from Scott's drive and inspiration.

8:50 am Invited Lecture #8: "Microvascular Composites and Their Impact to the Air Force"
Jeff Baur, Air Force Research Lab

Biosketch: Dr. Jeffery Baur is a Principal Engineer within the Composites Branch of Air Force Research Laboratory's Materials & Manufacturing Directorate. He holds a Ph.D. from M.I.T and a B.S. from the University of Cincinnati in Materials Science and Engineering, as well as a B.A. in Physics from Illinois Wesleyan University. In addition to his time in industry and academia, Dr. Baur has worked for the Air Force for more than 22 years as Division Technical Director, Branch Technical Advisor, Research Leader, Program Manager, and in-house researcher. He has published extensively in the area of shape memory morphing composites, microvascular composites, nano-enhanced polymer composites, bio-inspired flow sensors, nonlinear optical materials, and reconfigurable antennas. His current interest are in materials for morphing aerostructures, additive processing of complex polymer composites, and affordable processing of composite structures.

Abstract: Being initially pursued to provide more self-healing material to damaged composites, Professor Scott White helped to pioneer the much broader area of microvascular composites—an area poised to have a significant impact on Air Force applications. In addition to successfully improving self-healing, having a system of microchannels within a light weight structural composite enables a number of additional functions. These including active cooling of high temperature composites, activation and cycling of shape memory composites, adaptive stiffness, actuation, articulation, adaptive RF communications, and pressure sensing. This presentation will highlight the microvascular composite activities at the Air Force Research Laboratory that were in part inspired by the seminal work of Professor White and his team and discuss potential impacts.

Session: Mechanochemistry & Frontal Polymerization

9:25 am "Introduction to Mechanochemistry & Frontal Polymerization"
Charles Diesendruck, Technion

Biosketch: Dr. Diesendruck received his B.Sc. in analytical and environmental chemistry fromBen-Gurion University of the Negev in Israel. After serving in the army and working a few years at Chemada Fine Chemicals, he returned to BGU to complete a M.Sc. and a Ph.D. in organometallic chemistry with Prof. N. Gabriel Lemcoff. Dr. Diesendruck was a postdoctoral fellow at the Beckman Institute for Advanced Science and Technologyat the University of Illinois at Urbana-Champaign, working at the Autonomous Materials Systems Group with Prof. Jeffrey S. Moore. Since October 2014, he is an Assistant Professor in the Schulich Faculty of Chemistry in the Technion - Israel Institute of Technology. His research interests include polymer chemistry, physics and mechanochemistry, the development of new polymer architectures and membranes for alkaline fuel cells.

9:35 am Invited Lecture #9: "Some Polymer Mechanochemistry with Origins tied to Scott White and the Beckman"
Stephen Craig, Duke University

Biosketch: Steve Craig received his undergraduate degrees (B.S. in Chemistry, A.B. in Math) from Duke in 1991. After a year at Cambridge (M. Phil.), he began doctoral work at Stanford, where he received his Ph.D. in 1997. Following his Ph.D., he took a position as a Research Chemist in DuPont Central Research until early 1999, when he moved to a postdoctoral position at The Scripps Research Institute. In 2000, he joined the Department of Chemistry at Duke, where he is now William T. Miller Professor of Chemistry.

Steve first met Scott White at an ARO workshop in January, 2006, and was immediately impressed and inspired by his scientific creativity, infectious personality, and willingness to take on bold ideas.

Abstract: Some of the most exciting opportunities in covalent polymer mechanochemistry can be tied directly back to work performed by Scott White and others of his colleagues in the Autonomous Materials Systems Group at the Beckman Institute at Illinois. In my experience, the impact of those contributions was amplified by a willingness to share ideas early and openly. In that spirit, this talk will present unpublished work from Duke in two areas that build off of seminal contributions from the AMS: mechanochromic force probes and mechanoacids. The phenomenological opportunities are enhanced by direct, quantitative studies of force-activity relationships.

10:10 am **Invited Lecture #10: "Frontal Plymerization for Cure-on Demand Wood Repair and Art"**
John Pojman, Louisiana State University

Biosketch: Dr. John A. Pojman, a native of Chippewa Lake, Ohio, received his B. S. in Chemistry (with a minor in Classics) from Georgetown University in 1984. He earned his doctorate in Chemical Physics in 1988 at the University of Texas at Austin. Pojman then worked for two years at Brandeis University with Irving Epstein. In 1990, he joined the Chemistry & Biochemistry department at The University of Southern Mississippi, where he taught for 18 years. Dr. Pojman joined the Department of Chemistry at Louisiana State University in August 2008, where he is Professor of Macromolecular Science.

Pojman has co-authored one monograph, *An Introduction to Nonlinear Chemical Dynamics*, and co-edited two others. He has served three times as a guest editor for the journal *Chaos*. He has authored 156 peer-reviewed publications and 10 book chapters. Professor Pojman has made 293 presentations and received two patents. He is also co-curated an exhibition on Polymers in Art at the Louisiana Art and Science Museum.

He is the founder and President of Polymer Polymer Products, LLC, which manufacturers 3P QuickCure Clay and 3P QuickCure WoodFiller.

Professor Pojman is an expert on nonlinear dynamics in polymer systems and effective interfacial tension between miscible fluids. He is an avid carp fisherman and amateur herpetologist with a special interest in the aquatic salamanders of Louisiana. He also boasts the world largest collection of pocket protectors.

Abstract: The goal of cure-on-demand polymerization is to create one-pot systems that have a long shelf live but will react rapidly when curing is desired. We use an approach called frontal polymerization in which a localized reaction zone propagates from the coupling of thermal transport and the Arrhenius dependence of the reaction rate of an exothermic polymerization. We demonstrate that frontal polymerization can be used to create a cure-on-demand putty for filling holes in wood, marble, and sheet rock. The putty has a months-to-years shelf life, is a one-pot formulation, can be applied leisurely and then cured rapidly with a flat heat source. Finally, we will explore current efforts to commercialize "3P QuickCure Clay" for the arts and crafts market.

10:45 am **Break: Room 1005 Beckman Institute**

Session: Additive Manufacturing & Microfabrication

11:00 am **"Introduction to Additive Manufacturing & Microfabrication"**
Jerry Qi, Georgia Institute of Technology

11:10 am **Invited Lecture #11: "Multiscale Design of Active Components and Materials and their Realization via Additive Manufacturing"**
Martin Dunn, University of Colorado

Biosketch: Martin L. Dunn is a Professor and Dean of the College of Engineering and Applied Science at the University of Colorado Denver. He joined CU Denver in 2018 after serving as the Founding Associate Provost for Research at the Singapore University of Technology and Design (SUTD) where he oversaw the design and operation of the research and innovation enterprise. He was also a Professor at SUTD and the Founding Director of the National Research Foundation-supported Digital Manufacturing and Design Center. Prior to joining SUTD, he was a Program Director (Mechanics of Materials) in the Civil, Mechanical and Manufacturing Innovation Division at the US National Science Foundation, where he was also the Founding Program Director for the Design of Engineering Materials Systems program. He served the NSF while on leave from the University of Colorado, Boulder (CU) where he was the Associate Dean from Research in the College of Engineering and Applied Science, Chair of the Department of Mechanical Engineering, and a Professor of Mechanical Engineering, holding the Victor Schelke Endowed Chair.

Dunn's research has focused on understanding the mechanics and physics of complex heterogeneous materials through a combination of theory and experiment, and using this understanding to create methods and tools to design and manufacture new materials and components. Most recently this has involved the development of computational design and manufacturing methodologies for multimaterial additive manufacturing, including 4D Printing—an approach that integrates new computational design, manufacturing process, and materials technologies to create environmentally responsive printed components. Dunn has received international recognition and awards for his research accomplishments as well as for products designed with the methods and tools developed from his research. Dunn received a PhD in Mechanical Engineering from the University of Washington and held positions at Sandia National Laboratories and the Boeing Company before joining academia.

Abstract: In this talk I describe our recent developments of a multiscale digital design and manufacturing workflow that simultaneously determines the macroscopic topology and the spatially-variable microstructure of 3D composite components based on a combination of mathematical homogenization, finite element simulation, and multiscale topology optimization. Our approach results in a 3D map of homogenized (anisotropic) composite stiffness, parameterized by microstructure descriptors that depend on the specific additive manufacturing technology used to realize the component. We apply our approach to 3D solid and multilayer plate composite components performing in static and dynamic settings—realizing them by additive manufacturing (both voxel-based photopolymer jetting and direct write technologies), and experimentally validating their performance. As a specific example we design and manufacture a soft robot that mimics a swimming batoid. We also demonstrate the approach in the context of soft multimaterial lattice structures and 4D printing, where components are designed to transform from an as-printed configuration to a new 3D configuration upon heating.

11:45 am **Invited Lecture #12: "From the Microfabrication of Microvascular Networks to the Additive Manufacturing of Multifunctional Composites"**
Daniel Therriault, École Polytechnique de Montréal

Biosketch: Prof. Daniel Therriault is a full professor in the Department of Mechanical and Aerospace Engineering at Polytechnique Montreal. He holds the Canada Research Chair (Tier 2) in Fabricating Microsystems and Advanced Materials and the Safran-Polytechnique Research Chair on the Additive

Manufacturing of Reinforced Polymers. He obtained his Ph.D. in December 2003 from the Department of Aerospace Engineering at the University of Illinois at Urbana-Champaign, where he worked as a member of the Autonomous Materials Systems Group under the guidance of his advisor, Prof. Scott White. He innovated in microfabrication and microfluidics where his patented microfabrication method based on the direct-write assembly of 3D microvascular networks was published in *Nature Materials* (2003) and Advanced Materials (2005). His current research expertise relates to the design and characterization of advanced materials for the additive manufacturing of 3D multifunctional systems. He is the principal investigator of several innovations including breakthrough 3D freeform printing methods (*Adv Mater* 2010, *Small* 2013). His multifunctional printable inks recently generated three patents and two invention disclosures. Furthermore, his laboratory has had a critical role in many collaborative research efforts with industrial partners such as Safran, MDA, Velan, etc. Prof. Therriault was also the academic leader of an NSERC/CRIAQ project with Bombardier, Bell Helicopter, and 3M on the lightning strike protection of composites. The team received the prize for Best Collaborative Research Project at the 8th *CRIAQ* Forum (Montreal, 2016). His current research team is composed of 7 PhDs, 2 MS, 1 PDF, 2 RA and several undergraduate interns.

Abstract: In 2001, the design of a self-healing material using thin microcapsules filled with a healing agent was a major breakthrough originating from Scott White's vision and the hard work of members of the Autonomous Materials Systems Group. One drawback of this material system was the inability to heal the same damaged zone more than once. This presentation provides an overview of the microfabrication method developed for the creation of microvascular systems. Using an extrusion-based deposition method, a 3D interconnected microvascular network is manufactured and used for repeatable healing of polymer systems. Over the last 20 years, the field of additive manufacturing (or 3D printing) has significantly evolved and is now recognized by many as the trigger for the next revolution in fabrication. In conjunction with micro and nanotechnologies, many other functionalities have been developed in composites for enhanced stiffness, very high electrical conductivity, piezoelectricity, 3D freeform printing, etc. Select scientific achievements recently developed by Prof. Therriault and his team are explained while providing insight into the contributions from and interactions with Scott White's team.

12:20 pm **Lunch: Room 1005 Beckman Institute**

Session Chair: Ray Baughman, University of Texas at Dallas

1:20 pm **Keynote #1: "Magnetic Resonance Based Analysis of Damage Evolution and Healing in Connective Tissues and Biomaterials"**
Ellen Arruda, University of Michigan

1:55 pm **Invited Lecture #13: "Design of Active Reconfigurable Antennas Using Origami Principles"**
Dimitris Lagoudas, Texas A&M University

Biosketch: Dimitris C. Lagoudas currently serves as the Associate Vice Chancellor for Engineering Research for the Texas A&M University System and as the Deputy Director of Texas A&M Engineering Experiment Station (TEES), a Texas State Agency under the Texas A&M University System. He is also the Senior Associate Dean for Research for the College of Engineering and a Distinguished University Professor at Texas A&M University. He served as Department Head of Aerospace Engineering, the inaugural Chair of the Materials Science and Engineering graduate program and also as an Associate Vice President for Research at Texas A&M University. He also directed two TEES research centers, one on composite materials and the second one on multifunctional materials and structures.

D.C. Lagoudas received his Diploma in Mechanical Engineering from Aristotle University of Thessaloniki, Greece, his Ph.D. in Applied Mathematics from Lehigh University, and he did his postdoctoral studies at Cornell University, and Max-Planck Institute, Stuttgart, Germany. He has taught at Rensselaer Polytechnic Institute, and spent time at the Beckman Institute at the University of Ilinois at Urbana-Champaign, University of Texas at Austin, Rice University, and Arts et Mėtiers ParisTech, France.

Lagoudas' research focuses on the design, characterization and modeling of multifunctional material systems at nano, micro and macro levels. His research team is one of the most recognized internationally in the area of modeling and characterization of shape memory alloys. He has co-authored more than 500 scientific publications in archival journals and conference proceedings and one of the widely used books on shape memory alloys. He received the 2006 ASME Adaptive Structures and Material Systems Prize and he is the 2011 recipient of the SPIE Smart Structure and Materials Lifetime Achievement Award. He is a Fellow of AIAA, ASME, IOP and SES and was named a University Distinguished Professor at Texas A&M University in 2013.

Abstract: Origami-enabled morphing and reconfigurable structures have become increasingly popular in diverse areas of engineering: deployable space structures, tunable antennas, airplane wings, robotics, biomedical devices, electronics and meta-materials. These origami structures provide desirable engineering characteristics such as portability, reconfigurability, compact storage/deployment capabilities, and reduction in weight and manufacturing complexity. Recently, active or smart materials have been incorporated to drive desired "self-folding" in origami structures. In this work, development and analysis of a prototype parabolic reflector antenna, used as a high-gain antenna in radio telescopes and space and military telecommunication, using origami principles is explored. Novel origami design methodologies of smooth tuck-folding developed by the authors, with the capability to determine a reference planar configuration, pattern of smooth folds and the self-folding kinematics to achieve a desired approximate parabolic shape, are employed. Based on these origami principles, a proof-of-concept prototype is fabricated using laser-cut composite sheet and self-folding from planar to 3D shape is achieved by thermal actuation of structurally embedded shape memory polymer (SMP) active materials. The faceted reflector surface is metallized and radiation characteristics of the antenna, as part of an assembly consisting of a front-feed horn antenna and an excitation source, are measured in a far-field anechoic chamber. Electromagnetic characteristics of the reflector antenna, i.e., gain, directivity, side-lobe levels and power efficiency, are also evaluated using computational electromagnetics approach and compared with the experimental measurements. Combined structural and electromagnetic analysis is also conducted for a range of design parameters (diameter, focal length, and tessellation patterns) to determine antenna configurations with optimal mechanical and electromagnetic characteristics. Finally, shape memory alloy (SMA) actuator wires are utilized to selectively activate facets in the reflector to produce a shaped contour beam with tailored gain level to fit a specific coverage region.

2:20 pm **Young Investigator Program: "Integrated Self-Healing and Self-Sensing using Optical Waveguides in Microvascular Fiber-Composites"**
Jason Patrick, North Carolina State University

2:45 pm **"Room Temperature Liquid Metal Colloidal Suspensions for Self-Healing and Resilient Electronics"**
Chris Tabor, Air Force Research Lab

3:10 pm Break: Room 1005 Beckman Institute

Session Chair: John Kieffer, University of Michigan

3:25 pm **Center of Excellence: "Self-Healing, Regeneration & Structural Remodeling: Transformational Chemistries"**
Jeffrey Moore, University of Illinois

3:50 pm **Center of Excellence: "Self-Healing, Regeneration & Structural Remodeling: Modeling of Rapid Polymerization Fronts"**
Philippe Geubelle, University of Illinois

4:15 pm **Center of Excellence: "Self-Healing, Regeneration & Structural Remodeling: Transient Materials to 4D Printing for Multifunctional Composites"**
Scott White, University of Illinois

Session Chair: Abraham Stroock, Cornell University

4:40 pm **Center of Excellence: "Self-Healing, Regeneration & Structural Remodeling: Characterization and Analysis of Autonomic Composites"**
Nancy Sottos, University of Illinois

5:05 pm **Center of Excellence: "Self-Healing, Regeneration, and Structural Remodeling: Vascular Remodeling and Morphogenic Adaptation"**
Aaron Esser-Kahn, University of Chicago

5:30 pm **Young Investigator Program: "Bio-inspired Artificial Homeostatic Multifunctional Material Microsystems (AHM3)"**
Ximin He, University of California, Los Angeles

5:55 pm **Adjournment**

Back to Top

Day 3: Wednesday August 15, 2018

8:00 am **General Announcements**

Session Chair: Kurt Maute, University of Colorado

8:05 am **Young Investigator Program: "Lessons from Bone to Bio-inspired Tough and Self-Remodeling Aerospace Materials"**
Majid Minary-Jolandan, University of Texas at Dallas

8:30 am **Young Investigator Program: "Bio-inspired Synthesis of Multifunctional Materials with Self-Adaptable Mechanical Properties and Self-Regeneration"**
Sung Kang, Johns Hopkins University

8:55 am **Young Investigator Program: "Tough Gel: A Perfect Platform for Designing Chemo-Mechano-Chemically Responsive Multifunctional Materials"**
Yuhang Hu, Georgia Institute of Technology

9:20 am **"Plant-Mimetic Functional Materials for Thermal Management and Suppression of Freezing"**
Abe Stroock, Cornell University; Noel Holbrook, Harvard University

9:45 am **Break: Room 1005 Beckman Institute**

Session Chairs: Philippe Geubelle & Ioannis Chasiotis, University of Illinois

10:00 am **"Mechanically Adaptive Materials: Property Transformation via Continuous Transitions"**
Rich Vaia and Larry Drummy, Air Force Research lab

10:25am **"Multifunctional Soft Materials and Structures: Modeling, Design and Validation"**
Liping Liu, Rutgers University

10:50 am **"Knowledge-Driven Design and Optimization of New Types of Yarn and Fiber Artificial Muscles"**
Ray Baughman, University of Texas at Dallas

11:15 am ***Invited—Sponsored by ONR Program on Structural Composites & NDE***
"Synthesis and Mechanics of Metal-Graphene Composites"
Sameh Tawfick, University of Illinois

11:40 am **"Bridging High Strength and Dissipation in Carbon Nanotube Composites"**
Walter Lacarbonara and Giulia Lanzara, University of Rome

12:05 pm **Lunch: Room 1005 Beckman Institute**

Session Chair: Jeffery Baur, Air Force Research Lab, & James Thomas, Naval Research Lab

1:05 pm **"3D Printing of Materials and Devices for Integrated Multifunctionality"**
Mike Durstock, Dan Berrigan, and Benji Maruyama, Air Force Research Lab

1:30 pm **"4D Printed Composites for Topology-Transforming Multifunctional Devices"**
Jerry Qi, Georgia Institute of Technology;
Kurt Maute and Martin Dunn, University of Colorado

1:55 pm **"Programmable Elastic Metamaterials for Unprecedented Wave and Dynamic Control"**
Guoliang Huang, University of Missouri; C. T. Sun, Purdue University

2:20 pm **"Damping, Design, Metamaterials"**
Massimo Ruzzene and Alper Erturk, Georgia Institute of Technology;
Paolo Ermanni, ETH Zürich

2:45 pm **"Electronic Damping in Multifunctional Material Systems"**
Dan Inman, University of Michigan

3:10 pm **Break: Room 1005 Beckman Institute**

Session Chair: Mike Durstock, Air Force Research Lab

3:25pm **"Nanocomposite Ion Conductors from Branched Aramid Nanofibers for Zn Thin Film Batteries"**
Nicholas Kotov, University Michigan

3:50 pm ***Co-sponsored by Space Power Program, Low Density Materials & Structural Mechanics Program***
"Damage Tolerance and Durability of Structural Power Composites"
Emile Greenhalgh, Imperial College; Leif Asp, Chalmers University of Technology;
Dan Zenkert, KTH Royal Institute of Technology

4:15 pm **"Principles for Designing Compliant Multifunctional Wing Structures with Integrated Solar Cells for Micro Air Vehicles"**
Hugh Bruck, University of Maryland; Satyandra Gupta, University of Southern California

Session Chair: Somnath Ghosh, Johns Hopkins University

4:40 pm **"Design of Multifunctional Films for Compliant Interface"**
Ioannis Chasiotis, University of Illinois

5:05 pm **"Polymer Composites under Lasers Irradiation: Responsive Interfaces and Nano-scaled Internal Sensing"**
Josh Kennedy, Greg Ehlert, and Jeff Baur, Air Force Research Lab

5:30 pm **"High Temperature Electronics Module Failure Physics and Design"**
Ajit Roy, John Ferguson, and Steven Fairchild, Air Force Research Lab

5:55 pm **Adjournment**

Back to Top

Day 4: Thursday, August 16, 2018

8:00 am **General Announcements**

Session Chair: Leif Asp, Chalmers University of Technology

8:05 am **"Embedded Carbon Nanotube— Based Airflow Sensors for Adaptive Air Systems"**
Ben Dickinson, Greg Reich, and Jeff Baur, Air Force Research Lab

8:30 am **Young Investigator Program: "Super-Expandable Adaptive Sensor Network (SEASN) Enabled by Piezoelectric Polymer Serpentines"**
Nanshu Lu, University of Texas at Austin

8:55 am ***STTR Phase II / MURI'09 Technology Transfer***
"Flexible Sensor Network and Its Embedded Integrated Circuits for Structural Health Monitoring"
Jeffrey Bergman, Acellent Technologies;
Boris Murmann and Fu-Kuo Chang, Stanford University

9:45 am **Break: Room 1005 Beckman Institute**

Session Chair: Fu-Kuo Chang, Stanford University, and Yong Chen, University of California, Los Angeles

10:00 am **"Integrated Multi-Physics, Multi-scale Computational Modeling Framework for Multifunctional Applications"**
Somnath Ghosh, Johns Hopkins University

10:25 am **"Highly Reconfigurable, Multistable Composite with Tunable Morphing Capability"**
Giulia Lanzara and Walter Lacarbonara, University of Rome

10:50 am **Young Investigator Program: "Co-Continuous Metal-Elastomer Foam Actuators for Morphing Wing Micro Air Vehicles"**
Rob Shepherd, Cornell University

11:15 am **Young Investigator Program: "Robotic Fabrics: Multifunctional Fabrics for Reconfigurable and Wearable Soft Systems"**
Rebecca Kramer, Yale University

11:40 am **"Localized and Rapid Variable Compliance Via Phase Changing Matter and Distributed Computation"**
Rob Shepherd, Cornell University; Nicolaus Correll, University of Colorado

12:05 pm **Lunch: Room 1005 Beckman Institute**

Session Chair: Jay Kudva, NextGen Aeronautics, Inc.

1:05 pm **Briefing on AFOSR Basic Research Initiative '16**
Dan Inman, University of Michigan
"Avian-Inspired Multifunctional Morphing Air Vehicles"
(Second Annual Review at Stanford University, Stanford, CA on March 22-23, 2018; University of Michigan / Stanford University / University of California, Los Angeles / Texas A&M University /

University of British Columbia / Royal Veterinary College / University of Rome / ETH Zürich) (PI: Daniel Inman; Co-PIs: Henry Sodano, David Lentink, Fu-Kuo Chang, Yong Chen, Darren Hartl, Douglas Altshuler, Richard Bomphrey, Jim Usherwood, Giulia Lanzara, Walter Lacarbonara, Andre Studart) (PM: Les Lee; Co-PM's: Douglas Smith, Patrick Bradshaw, Russell Cummings, David Garner)

1:55 pm **"Neuromorphic Network Based on Carbon Nanotube/Polymer Composite"**
Yong Chen, University of California, Los Angeles

2:20 pm **"Design of Actively Controlled Microarchitectures with Programmable Mechanical Properties"**
Jonathan Hopkins, University of California, Los Angeles

2:45 pm **"Bio-inspired Reconfigurable System Design via Topology Optimization"**
Greg Reich and Philip Beran, Air Force Research Lab

3:10 pm **Break: Room 1005 Beckman Institute**

Session Chair: Greg Reich, Air Force Research Lab

3:25 pm ***Invited—Sponsored by Structural Mechanics Program***
"Variable Camber Compliant Wing (VCCW)"
James Joo, Air Force Research Lab

3:50 pm ***Co-sponsored by Structural Mechanics Program***
"On-demand Stiffness Selectivity for Morphing Systems"
Andres Arrieta Diaz, Purdue University

4:15 pm ***STTR Phase II***
"Biomimetic Design of Morphing Micro Air Vehicles"
Jay Kudva, Concepts to Systems; Geoffrey Spedding, University of Southern California; Roy Kornbluh, SRI International

Session Chair: Dan Inman, University of Michigan

4:40 pm ***STTR Phase II***
"Biomimetic Design of Morphing Micro Air Vehicles"
Harry Perkinson, TRI Austin; Peter Ifju, University of Florida

5:05 pm **Keynote #2: "Multifunctional Design of Autonomic, Adaptive and Self-Sustaining Systems: An Overview"**
B. L. "Les" Lee, Air Force Office of Scientific Research

5:40 pm **Closing Remarks: Jeffrey Moore, University of Illinois**

5:50 pm **Adjournment**

6:00 pm **Celebration in Beckman Institute Atrium**

Back to Top