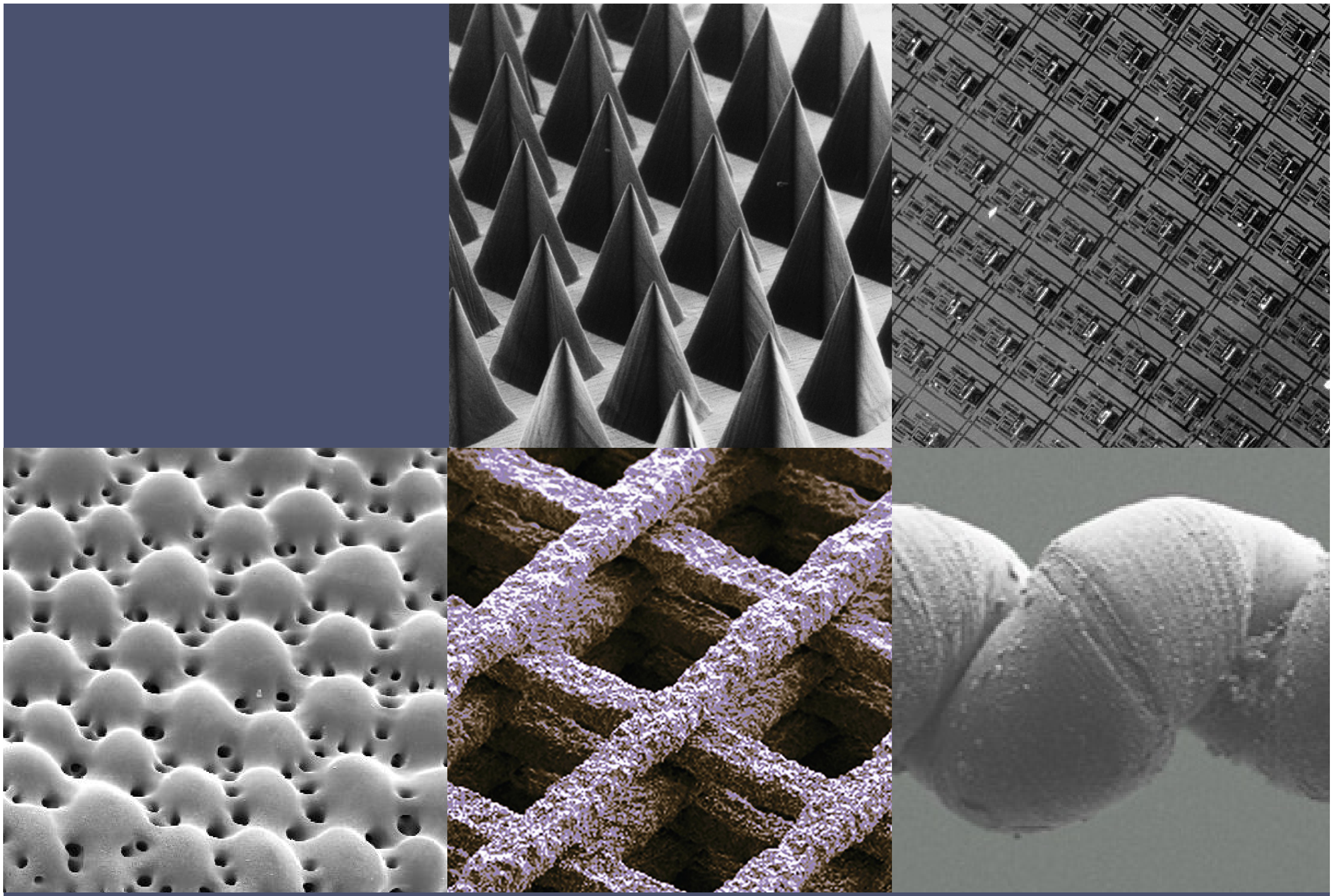
NOVEL MATERIALS

A one-day symposium featuring recent advances in materials science



NATIONAL ACADEMY OF SCIENCES BUILDING
Main Auditorium
2101 Constitution Ave., N.W.
Washington, D.C.

OCTOBER 7, 2015
10:00AM - 4:30PM

The National Academies of
SCIENCES • ENGINEERING • MEDICINE

ABOUT THE SYMPOSIUM

From time to time, units of the Academies conduct symposia in which researchers, government officers, and other professionals exchange information and ideas about important areas of science, engineering, and medicine. This is the second such symposium in a series being conducted by the Air Force Studies Board. This meeting will highlight selected research topics from materials science, an interdisciplinary field yielding new technologies with implications for medical care, manufacturing, and national security. This day-long, invitation-only symposium will feature researchers at the frontiers of materials science research as they present their latest research advancements and participate in an open Q&A session with symposium attendees on the practical and transformational applications of their research. Topics will include advances in 3D printing, biocompatible electronics, biomimetics, nanomaterials, and stretchable electronics.

PROGRAM

09:00	**REGISTRATION OPENS**
10:00	**OPENING REMARKS** Dr. Alton D. Romig, Jr. *Executive Officer of the National Academy of Engineering*
10:20	**INSTEAD OF 2D-PRINTING OVER AND OVER AGAIN: CONTINUOUS LIQUID INTERFACE PRODUCTION OF 3D OBJECTS** Prof. Joseph M. DeSimone *University of North Carolina*
11:00	**MATERIALS FOR BIOCOMPATIBLE ELECTRONICS** Prof. John A. Rogers *University of Illinois at Urbana-Champaign*
11:40	**BREAK FOR LUNCH**
13:00	**EVERYTHING SLIPS: DESIGN OF NOVEL OMNIPHOBIC MATERIALS** Prof. Joanna Aizenberg *Harvard University*
13:40	**FUNDAMENTALS AND APPLICATIONS OF TWO-DIMENSIONAL NANOMATERIAL HETEROSTRUCTURES** Prof. Mark C. Hersam *Northwestern University*
14:20	**THE EVOLUTION OF STRONG, FAST, POWERFUL, DURABLE, AND CHEAP POLYMER ARTIFICIAL MUSCLES FROM CARBON NANOTUBE MUSCLES** Prof. Ray Baughman *University of Texas - Dallas*
15:00	**PANEL DISCUSSION WITH OPEN Q&A**
16:00	**REFRESHMENTS AND INDIVIDUAL DISCUSSIONS**

Instead of 2D-printing Over and Over Again: Continuous Liquid Interface Production of 3D Objects

"3D printing" is a misnomer: it is actually 2D printing over and over again. This lecture will describe a new advance in 3D additive manufacturing that is rapid, continuous and no longer layer-by-layer that promises to advance industry beyond basic prototyping to 3D manufacturing. The new Continuous Liquid Interface Production technology (CLIP) harnesses light and oxygen to continuously grow objects from a pool of resin instead of printing them layer-by-layer. The technology was simultaneously introduced to the scientific community as the cover story in the journal Science and on the stages of TED2015. CLIP technology raises the state-of-the-art in 3D fabrication in four ways:

- GAME-CHANGING SPEED: 25-100 times faster than conventional 3D printing
- COMMERCIAL QUALITY: produces objects with consistent mechanical properties
- MATERIAL CHOICE: enables a broad range of polymeric materials
- MICROFABRICATION: enables complex geometries to be fabricated in the tens of microns size scale

This lecture will introduce CLIP and will describe the opportunities associated with it, including the potential for designing new approaches to medical and drug delivery devices.

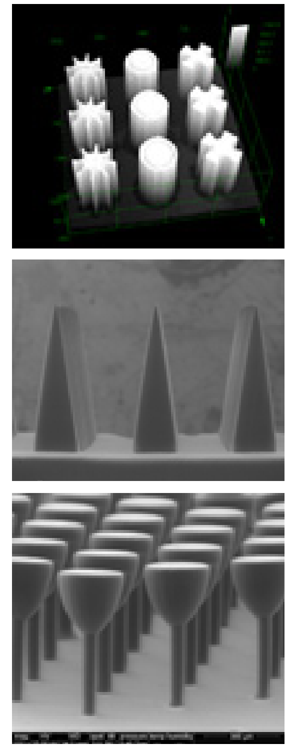


Image Credit: DeSimone Research Group

Joseph M. DeSimone is a prolific inventor, serial entrepreneur and eminent scholar. DeSimone is the Chancellor's Eminent Professor of Chemistry at the University of North Carolina at Chapel Hill, and William R. Kenan, Jr. Distinguished Professor of Chemical Engineering at North Carolina State University and of Chemistry at UNC. DeSimone is also an adjunct member at Memorial Sloan-Kettering Cancer Center. Currently DeSimone is on leave from the university and has assumed the CEO role at Carbon3D in Silicon Valley. DeSimone has published over 300 scientific articles and has over 150 issued patents in his name with over 80 patents pending.

DeSimone is one of less than twenty individuals who have been elected to all three branches of the National Academies: Institute of Medicine (2014), National Academy of Sciences (2012) and the National Academy of Engineering (2005). He is also a member of the American Academy of Arts and Sciences (2005). DeSimone has received over 50 major awards and recognitions including the 2015 Dickson Prize from Carnegie Mellon University; 2014 Industrial Research Institute Medal; 2014 Kathryn C. Hach Award for Entrepreneurial Success from the ACS; 2013 Fellow of the National Academy of Inventors; 2012 Walston Chubb Award for Innovation by Sigma Xi; the 2010 AAAS Mentor Award in recognition of his efforts to advance diversity in the chemistry PhD workforce; the 2009 NIH Director's Pioneer Award; the 2009 North Carolina Award; the 2008 $500,000 Lemelson-MIT Prize for Invention and Innovation; the 2007 Collaboration Success Award from the Council for Chemical Research; the 2005 ACS Award for Creative Invention; the 2002 John Scott Award presented by the City Trusts, Philadelphia, given to "the most deserving" men and women whose inventions have contributed in some outstanding way to the "comfort, welfare and happiness" of mankind; the 2002 Engineering Excellence Award by DuPont; and the 2002 Wallace H. Carothers Award from the Delaware Section of the ACS.

DeSimone, an innovative polymer chemist, has made breakthrough contributions in fluoropolymer synthesis, colloid science, nano-biomaterials, green chemistry and most recently 3D printing. DeSimone is the co-founder of several companies including Micell Technologies, Bioabsorbable Vascular Solutions, Liquidia Technologies and Carbon3D. DeSimone received his BS in Chemistry in 1986 from Ursinus College in Collegeville, PA and his Ph.D. in Chemistry in 1990 from Virginia Tech.

Materials for Biocompatible Electronics

Biology is soft, curvilinear and transient; silicon technology is rigid, planar and everlasting. Electronic systems that eliminate this profound mismatch in properties create opportunities for devices that can intimately integrate with the body, for diagnostic, therapeutic or surgical function with important, unique capabilities in biomedical research and clinical healthcare. Over the last decade a convergence of new concepts in materials science, mechanical engineering, manufacturing and device design has led to the emergence of diverse classes of 'biocompatible' electronics. This talk describes the key ideas, with examples ranging from wireless, skin-like electronic 'tattoos' for continuous monitoring of physiological health to bioresorbable electronics that can serve as non-antibiotic bacteriocides for treating surgical site infections.

Professor John A. Rogers obtained BA and BS degrees in chemistry and in physics from the University of Texas, Austin, in 1989. From MIT, he received SM degrees in physics and in chemistry in 1992 and the PhD degree in physical chemistry in 1995. From 1995 to 1997, Rogers was a Junior Fellow in the Harvard University Society of Fellows. He joined Bell Laboratories as a Member of Technical Staff in the Condensed Matter Physics Research Department in 1997, and served as Director of this department from the end of 2000 to 2002. He currently holds the Swanlund Chair at the University of Illinois at Urbana/Champaign, where he is also Director of the Seitz Materials Research Laboratory. His research has been recognized by many awards including a MacArthur Fellowship (2009), the Lemelson-MIT Prize (2011), the MRS Mid-Career Researcher Award (2013), the Smithsonian Award for American Ingenuity in the Physical Sciences (2013), and the ETH Zurich Chemical Engineering Medal (2015). He is a member of the National Academy of Engineering, the National Academy of Sciences and the American Academy of Arts and Sciences.

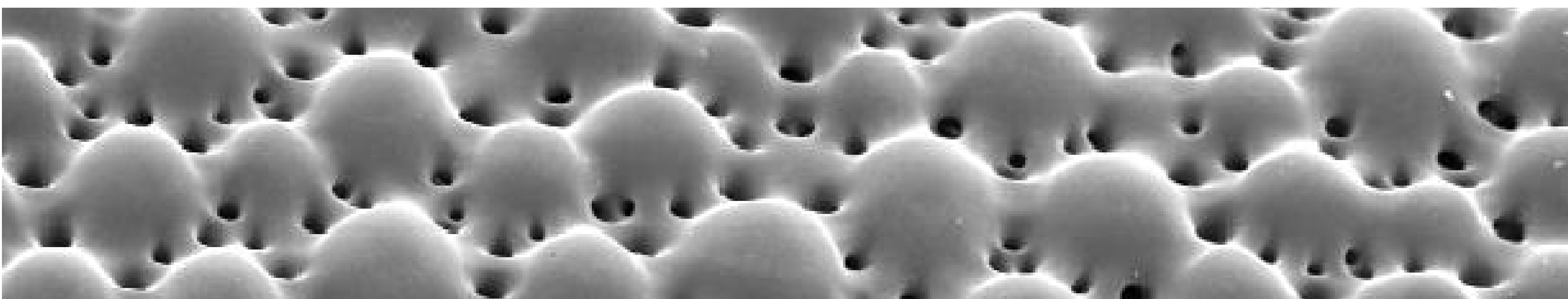
Image Credit: Rogers Research Group

EVERYTHING SLIPS: Design of Novel Omniphobic Materials

Liquids entrapped within a structured solid begin to exhibit unique behaviors often providing the surrounding material with unprecedented properties. Recently we have introduced a new, award-winning strategy (2012 R&D 100 award) to create self-healing, anti-fouling materials (so-called Slippery, Lubricant-Infused Porous Surfaces, or SLIPS). These bioinspired materials that mimic slippery surfaces of a pitcher plant outperform state-of-the-art materials in their ability to resist ice and microbial adhesion, repel various simple and complex liquids, prevent marine fouling, or reduce drag. Generalized, low-cost, and scalable methods to manufacture stable, shear-tolerant SLIPS on glass, ceramics, polymers, fabrics and metals will be presented. We anticipate that slippery surfaces can find important applications as antifouling materials in medicine, construction, naval and aircraft industries, fluid handling and transportation, optical sensing, and as antifouling surfaces against highly contaminating media operating in extreme environments.

Select publications: T.-S. Wong et al. Nature 477 (2011); A.K Epstein et al. Proc. Nat. Acad. Sci. USA 109 (2012); P. Kim et al. ACS Nano 6 (2012); X. Yao et al. Nature Mater. 12 (2013); P. Kim et al. Nano Lett. 13 (2013); D. Daniel et al. Appl. Phys. Lett. 102 (2013); N. Vogel et al. Nature Comm. 4 (2013); C. Shillingford et al. Nanotechnology 25 (2014); S. Sunny et al. Adv. Funct. Mater. 24 (2014); D.C. Leslie et al. Nature Biotech. 32 (2014); J. Cui et al. Nature Mater. 14 (2015); X. Hou et al. Nature 519 (2015)

Image Credit: Joanna Aizenberg, Wyss Institute



Joanna Aizenberg, Amy Smith Berylson Professor of Materials Science and Professor of Chemistry and Chemical Biology at Harvard University, pursues a broad range of research interests that include biomimetics, self-assembly, smart materials, bio-nano interfaces, crystal engineering, surface chemistry, nanofabrication, biomineralization, biomechanics and biooptics. She received the B.S. degree in Chemistry in 1981, the M.S. degree in Physical Chemistry in 1984 from Moscow State University, and the Ph.D. degree in Structural Biology from the Weizmann Institute of Science in 1996.

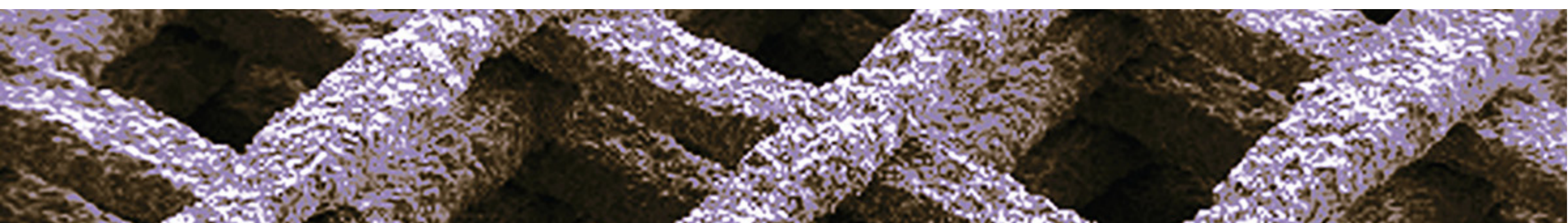
Joanna is the Director of the Kavli Institute for Bionano Science and Technology and Platform Leader in the Wyss Institute for Bioinspired Engineering at Harvard University. She has served at the Board of Directors of the Materials Research Society and at the Board on Physics and Astronomy of the National Academies. She served on the Advisory Board of *Langmuir and Chemistry of Materials*, on Board of Reviewing Editors of *Science* Magazine, and is an Editorial Board Member of *Advanced Materials*.

Aizenberg is elected to the American Academy of Arts and Sciences, American Association for the Advancement of Science; and she is a Fellow of American Physical Society and Materials Research Society. Dr. Aizenberg received numerous awards from the American Chemical Society and Materials Research Society, including Fred Kavli Distinguished Lectureship in Nanoscience, Ronald Breslow Award for the Achievement in Biomimetic Chemistry, Arthur K. Doolittle Award in Polymeric Materials, ACS Industrial Innovation Award, and was recognized with two R&D 100 Awards for best innovations in 2012 and 2013 for the invention of a novel class of omniphobic materials and watermark ink technologies.

Fundamentals and Applications of Two-Dimensional Nanomaterial Heterostructures

Two-dimensional materials have emerged as promising candidates for next-generation electronic and optoelectronic applications. As is common for new materials, much of the early work has focused on measuring and optimizing intrinsic properties on small samples (e.g., micromechanically exfoliated flakes) under idealized conditions (e.g., vacuum and/or cryogenic temperature environments). However, real-world devices and systems inevitably require large-area samples that are integrated with dielectrics, contacts, and other semiconductors at standard temperature and pressure conditions. These requirements are particularly challenging to realize for two-dimensional materials since their properties are highly sensitive to surface chemistry, defects, and the surrounding environment. This talk will thus explore methods for improving the uniformity of solution-processed two-dimensional materials with an eye toward realizing scalable processing of large-area thin-films. For example, density gradient ultracentrifugation allows the solution-based isolation of transition metal dichalcogenides (e.g., MoS2, WS2, MoSe2, and WSe2) and boron nitride with homogeneous thickness down to the single-layer level. Similarly, two-dimensional black phosphorus is isolated in solution with the resulting flakes showing field-effect transistor mobilities and on/off ratios that are comparable to micromechanically exfoliated flakes. In addition to solution processing, this talk will also report on the integration of two-dimensional materials with dielectrics and other semiconductors. In particular, atomic layer deposition of dielectrics on two-dimensional black phosphorus suppresses ambient degradation, thereby preserving electronic properties in field-effect transistors at atmospheric pressure conditions. Finally, p-type semiconducting carbon nanotube thin films are combined with n-type single-layer MoS2 to form p-n heterojunction diodes. The atomically thin nature of single-layer MoS2 implies that an applied gate bias can electrostatically modulate the doping on both sides of the p-n heterojunction concurrently, thereby providing five orders of magnitude gate-tunability over the diode rectification ratio in addition to unprecedented anti-ambipolar behavior when operated as a three-terminal device.

Image Credit: American Chemical Society

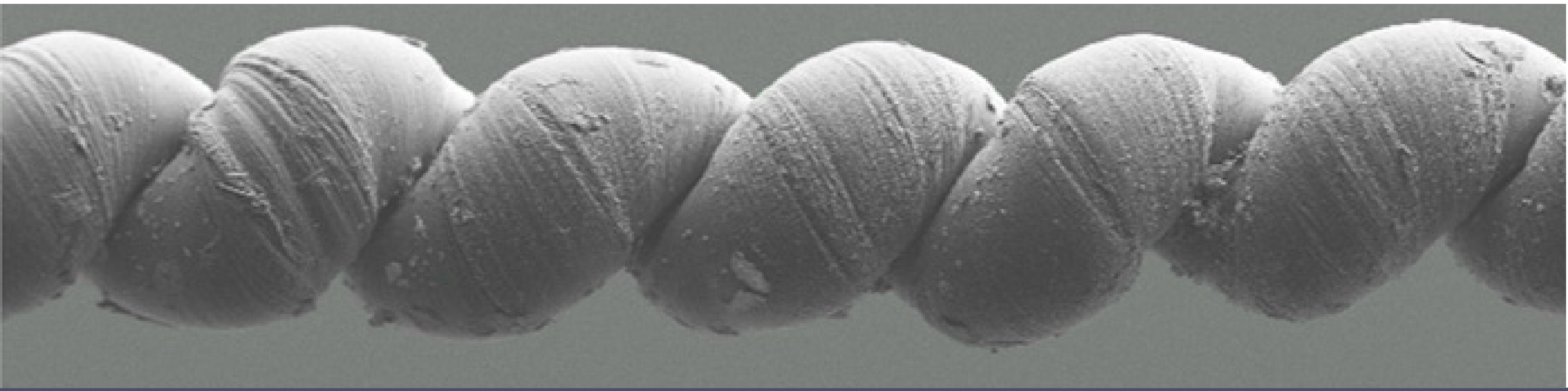


Mark C. Hersam is the Bette and Neison Harris Chair in Teaching Excellence, Professor of Materials Science and Engineering, Chemistry, and Medicine, and Director of the Materials Research Center at Northwestern University. He earned a B.S. in Electrical Engineering from the University of Illinois at Urbana-Champaign (UIUC) in 1996, M.Phil. in Physics from the University of Cambridge in 1997, and a Ph.D. in Electrical Engineering from UIUC in 2000. In 1999, he also performed research at the IBM T. J. Watson Research Laboratory under the support of an IBM Distinguished Fellowship. His research interests include nanofabrication, scanning probe microscopy, semiconductor surfaces, and nanoelectronic materials. As a faculty member, Dr. Hersam has received several awards including the Beckman Young Investigator Award, NSF CAREER Award, ARO Young Investigator Award, ONR Young Investigator Award, Sloan Research Fellowship, Presidential Early Career Award for Scientists and Engineers, TMS Robert Lansing Hardy Award, AVS Peter Mark Award, ECS SES Research Young Investigator Award, MRS Outstanding Young Investigator Award, MacArthur Fellowship, and six Teacher of the Year Awards. Dr. Hersam is the co-founder of NanoIntegris, which is a commercial supplier of high performance carbon nanomaterials. Dr. Hersam is a Fellow of MRS, AVS, APS, AAAS, and SPIE in addition to serving as Associate Editor of ACS Nano.

The Evolution of Strong, Fast, Powerful, Durable, and Cheap Polymer Artificial Muscles from Carbon Nanotube Muscles

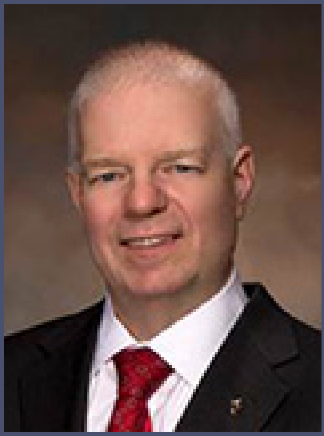
Four successive generations of twist-spun artificial muscles are described that provide both torsional and tensile actuation. Our first generation of twist-spun muscles, which are electrochemically powered by volume changes induced by double-layer charge injection, provide torsional rotation speeds of 590 rpm, and torsional strokes of 250° per millimeter of actuator length, which is 1000 times that for earlier artificial muscles. Our second generation muscles, which require no electrolyte and are based on guest-infiltrated carbon nanotube yarns, can torsionally actuate at 11,500 rpm and deliver 85 times higher power density during contraction than natural muscles. Our third generation muscles, which are thermally, electrothermally, or chemically powered polymer fibers, can rotate at 100,000 rpm, contract by up to 49%, generate 5 times the gravimetric power of a car engine, lift 100 times heavier loads than the same length and weight human muscle, or actuate at 7.5 cycles/s for millions of cycles. These polymer muscles can be cheaply made from fishing line or sewing thread. Our fourth generation of muscles are electrically powered and made from super-elastic carbon nanotube sheath/rubber core fibers.

Image Credit: Baughman Research Group, UT Dallas NanoTech Institute



Ray Baughman became the Robert A. Welch Professor of Chemistry and Director of the NanoTech Institute at the University of Texas in Dallas in August 2001, after 31 years in industry. He is a Member of The National Academy of Engineering and The Academy of Medicine, Engineering and Science of Texas; a Fellow of the American Physical Society and the Royal Society of Chemistry; an Academician of The Russian Academy of Natural Sciences; an honorary professor of six universities in China; and is on editorial or advisory boards of Science, Materials Research Letters, the International Journal of Nanoscience, and the Encyclopedia of Nanoscience and Nanotechnology. Ray has 72 issued US patents and over 368 refereed publications, with over 27,000 citations and a H-factor of 73. He has received the Chemical Pioneer Award of the American Institute of Chemists (1995), the Cooperative Research Award in Polymer Science and Engineering (1996), the New Materials Innovation Prize of the Avantex International Forum for Innovative Textiles (2005), Nano 50 Awards from Nanotech Briefs Magazine for Carbon Nanotube Sheets and Yarns (2006) and for Fuel Powered Artificial Muscles (2007), the NanoVic Prize from Australia (2006), the Scientific American Magazine 50 recognition for outstanding technological leadership (2006), the CSIRO Metal for Research Achievement (2006), the Chancellor's Entrepreneurship and Invention Award (2007), 21 for the 21st Century award (2007), the Alumni Distinguished Achievement Award of Carnegie Mellon University (2007), the Kapitza Metal of the Russian Academy of Natural Sciences (2007), the Graffin Lectureship of the American Carbon Society (2010), named Honorable Yang Shixiang Professor of Nankai University and the Honorable Tang Aoqing Professor of Jilin University in 2010, listed 30th in the Top 100 Material Scientists of the Decade (2000-2010), the Tech Titans Award in Education (2011), Time Magazines 50 Best Inventions of the Year (2011), the SGL Carbon Award of the American Carbon Society (2013), and the Tech Titans Technology Invertors Award (2015).

MEET OUR MODERATOR



Dr. Alton D. Romig, Jr. is the Executive Officer of the National Academy of Engineering. Under Congressional charter, the Academy provides advice to the federal government, when requested, on matters of engineering and technology. As Executive Officer, Dr. Romig is the Chief Operating Officer responsible for the program, financial and membership operations of the Academy, reporting to the President. Prior to joining the Academy, he served as Vice President and General Manager of Lockheed Martin Aeronautics Company Advanced Development Programs, better known as the Skunk Works ®. Dr. Romig spent the majority of his career at Sandia National Laboratories, operated by the Lockheed Martin Corporation. He joined Sandia as a Member of the Technical Staff in 1979 and moved through a succession of R&D management positions leading to appointment as Executive Vice President in 2005. He served as the Deputy Laboratories Director and Chief Operating Officer until 2010 when he transferred to the Skunk Works.

Dr. Romig graduated *summa cum laude* from Lehigh University in 1975 with a BS in Materials Science and Engineering. He received his MS and PhD in Materials Science and Engineering from Lehigh University in 1977 and 1979, respectively. Dr. Romig is a Fellow of ASM International, TMS, IEEE, AIAA and AAAS. Dr. Romig was elected to the National Academy of Engineering in 2003 and the Council of Foreign Relations in 2008. He was awarded the ASM Silver Medal for Materials Research in 1988.

ABOUT THE AIR FORCE STUDIES BOARD

The Air Force Studies Board (AFSB) is part of the Division on Engineering and Physical Sciences of the National Academies of Sciences, Engineering, and Medicine. The AFSB provides independent and informed assessments of subjects important to the United States Air Force.

This event is sponsored by the Office of the Director of National Intelligence and is being conducted under the auspices of the AFSB.