

# Material Matters

The Quarterly Magazine of NIST's Material Measurement Laboratory

Winter 2016

*Nanoworld "Snow Blowers"  
Head Health Challenge Winners  
Measuring Next Gen Computer Chips*

**NIST**

National Institute of  
Standards and Technology  
U.S. Department of Commerce

# About NIST's Material Measurement Laboratory

Formed in 2012, the Material Measurement Laboratory (MML) is one of two metrology laboratories within the National Institute of Standards and Technology (NIST). The laboratory supports the NIST mission by serving as the national reference laboratory for measurements of matter, providing broad support for the chemical, biological, and material sciences. Our fundamental and applied measurement science research expands possibilities for determining the composition, structure, and properties of manufactured, biological, and environmental materials, and the processes that create them. In addition, MML drives the development and dissemination of tools, including measurement protocols, certified reference materials, critically evaluated data, and best practice guides, that help assure quality measurements of matter. Our research and measurement services support areas of national importance, including:

- Advanced materials, from nanomaterials to structural steels to complex fluids
- Energy, from characterization and performance of fossil and alternative fuels to next-generation renewable sources of energy
- The environment, from the measurement of air quality, water, mitigation of climate change, the health of marine environments, and the safety of nanomaterials
- Food safety and nutrition, from contaminant monitoring to ensuring the accuracy of nutrition labels
- Health care, from clinical diagnostics and precision medicine to the reproducibility of biological data
- Infrastructure, including assessment of the country's aging buildings, bridges, and pipelines for refurbishment, reuse, and repair
- Manufacturing, from lightweight alloys for fuel-efficient automobiles to biomanufacturing, advanced electronics, and data for chemical manufacturing
- Safety, security, and forensics, from contraband residue detection to ensuring the performance of body armor materials to DNA-based human identity testing

MML also coordinates the NIST-wide Standard Reference Materials® (SRM) and Standard Reference Data programs, which include production, documentation, inventory, marketing, distribution, and customer service.

MML is home to nearly 1,000 staff members and visiting scientists. Organizationally, the laboratory is divided into six divisions, dedicated to maintaining cutting edge facilities and the technical expertise required to achieve our mission in the biological, chemical, and material sciences. Our organization includes several campuses and strategic partnerships:

- NIST main campus in Gaithersburg, MD: Home of MML headquarters and five of the six MML Divisions
- NIST Boulder Laboratories in Boulder, CO: Home of MML activities including pipeline research and mechanical properties assessment
- Hollings Marine Laboratory in Charleston, SC, where NIST staff work side-by-side with scientists from NOAA, the South Carolina Department of Natural Resources, the College of Charleston, and the Medical University of South Carolina to provide the science, biotechnology, and standards needed to understand links between environmental conditions and the health of marine organisms and humans
- The Institute for Bioscience and Biotechnology Research in Rockville, MD, where scientists from NIST, the University of Maryland College Park, and the University of Maryland School of Medicine conduct research on measurement science and standards issues associated with advanced therapeutics, proteomics, and biomanufacturing
- Brookhaven National Laboratory in Upton, NY where, in partnership with the U.S. Department of Energy, MML has established instrumentation on what will be the brightest source of synchrotron soft and tender X-rays in the U.S., which will enable unprecedented analysis of a broad range of materials technologies including flexible electronics, highly engineered nanoparticles, and next generation semiconductor structures
- The Joint Initiative for Metrology in Biology program between MML and Stanford University, where NIST staff work side-by-side with Stanford faculty, groups, and commercial affiliates to develop standards and tools that enable translation of innovations in quantitative and engineered biology to clinical and commercial practice

*Cover image: Electron micrograph of surface-directed nanochannels formed on the surface of the semiconductor indium phosphide. Nanochannels are formed using a gold-catalyzed vapor-liquid-solid etch process and their locations are defined by the deposited gold pattern.*

*Credit: Marti/JILA*

# A Message from the MML Director

MML researchers advance measurement science, standards, and technology to promote innovation in industry, leading to more accurate screening for explosives, more powerful and reliable consumer electronics, and a better understanding of cancer and other diseases—to name just a few examples.

So that our research may contribute to new knowledge and more effective, more competitive products, we make the results of our work public in peer-reviewed journals; NIST publications, protocols, and technical reports; and through the publication and dissemination of research data. In a typical year, NIST scientists and engineers publish about 2,000 articles and technical reports across a wide range of disciplines and in prestigious journals such as *Science*, *Nature*, *Analytical Chemistry*, and *PNAS*. Each issue of *Material Matters* contains just a small representation of MML's published research.

Much of our work is conducted in collaboration with members of industry, academia, or other government agencies. In 2015, 80% of NIST publications included authors from 1,000 universities, companies, other government agencies. In addition to contributing to publications, our collaborators directly transfer NIST technical expertise by sharing with their home organizations the new knowledge and skills gained through collaboration.

MML is also dedicated to increasing public access to NIST's research data. The Office of Data and Informatics is pioneering new ways to make big data—a national resource and strategic asset—widely available, discoverable, and usable.

Publications, data, and the collaborations that help produce them are just a few of the ways that we disseminate research results to the public. NIST formally defines technical transfer broadly to also include visiting researchers, educational programs, conferences, consortia, and more—all activities in which MML engages. You will learn more about those in future editions of *Material Matters*.



**Laurie Locascio, Ph.D.**  
*Director, Material Measurement Laboratory*  
NIST

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# Nanoworld “Snow Blowers” Carve Straight Channels in Semiconductor Surfaces

Note: A version of this story previously appeared in NIST’s TechBeat on December 28, 2015.

In the nanoworld, tiny particles of gold can operate like snow blowers, churning through surface layers of an important class of semiconductors to dig unerringly straight paths. The surprising trenching capability, reported by scientists from NIST and IBM,<sup>1</sup> is an important addition to the toolkit of nature-supplied “self-assembly” methods that researchers aim to harness for making useful devices.

Foreseeable applications include integrating lasers, sensors, wave guides and other optical components into so-called lab-on-a-chip devices now used for disease diagnosis, screening experimental materials and drugs, DNA forensics and more. Easy to control, the new gold-catalyzed process for creating patterns of channels with nanoscale dimensions could help to spawn entirely new technologies fashioned from ensembles of ultra-small structures.

Preliminary research results that began as lemons—a contaminant-caused failure that impeded the expected formation of nanowires—eventually turned into lemonade when scanning electron microscope images revealed long, straight channels.

“We were disappointed, at first,” says NIST MML research chemist Babak Nikoobakht. “Then we figured out that water was the contaminant in the process—a problem that turned out to be a good thing.”

That’s because, as determined in subsequent experiments, the addition of water vapor served to transform gold nanoparticles into channel diggers, rather than the expected wire makers. Beginning with studies on the semiconductor indium phosphide, the team teased out the chemical mechanisms and necessary conditions underpinning the surface-etching process.

First, they patterned the surface of the semiconductor by selectively coating it with a gold layer only a few nanometers thick. Upon heating, the film breaks up into tiny particles that become droplets. The underlying indium phosphide dissolves into the gold nanoparticles above, creating a gold alloy. Then, heated water vapor is introduced into the system. At temperatures below 300 degrees Celsius (572

degrees Fahrenheit), the tiny gold-alloy particles, now swathed with water molecules, etch nanoscale pits into the indium phosphide.

But at 440 degrees Celsius (824 degrees Fahrenheit) and above, long V-shaped nanochannels formed. The channels followed straight paths dictated by the regularly repeating lattice of atoms in the crystalline semiconductor. During the process, indium and phosphorous atoms interact with oxygen atoms in the water molecules on the surface of the gold alloy droplet. The oxidized indium and phosphorous evaporate, and the droplet advances, picking up more semiconductor atoms to oxidize as it goes.

The result is a series of crystalline grooves. The dimensions of the grooves correspond to the size of droplet, which can be controlled.

In effect, the droplet is the chemical equivalent of the auger on a snow blower that, instead of snow, burrows through the top portion of the semiconductor and ejects evaporated bits, Nikoobakht explains.

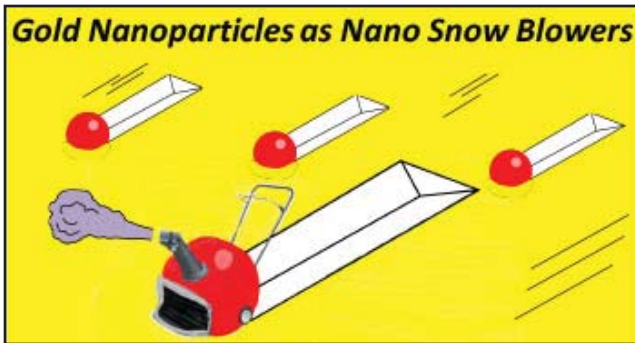
The team observed the same phenomena in gallium phosphide and indium arsenide, two more examples of semiconductors formed by combining elements from the third and fifth columns of the periodic table. Compound semiconductors in this class are used to make LEDs, and for communications, high-speed electronics and many other applications. Nikoobakht believes that, with adjustments, the etching process might also work for creating patterns of channels on silicon and other materials.

Controllable, fast and flexible, the “bottom up” channel-fabrication process shows promise for use on industrial scales, the researchers suggest. In their article, the teams describe how they used the process to etch patterns of hollow channels like those used to direct the flow of liquids, such as a blood sample, in a microfluidic device, or lab on a chip.

- Mark Bello, NIST

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1. B. Nikoobakht, A. Herzing, S. Muramoto, and J. Tersoff, Vapor-Liquid-Solid Etch of Semiconductor Surface Channels by Running Gold Nanodroplets. *Nano Letters*, vol. 15, issue 12, Dec. 9, 2015. DOI: 10.1021/acs.nanolett.5b04051



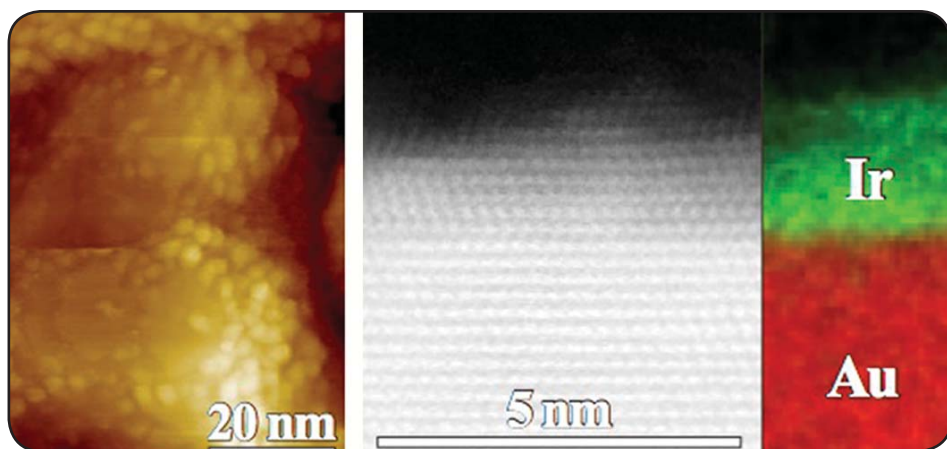
## NIST MML Co-hosts Third U.S. Government Workshop on Magnetic Tunnel Junctions

On November 4, 2015, NIST MML, the Laboratory for Physical Sciences (LPS), and the U.S. Department of Energy’s Kansas City Plant co-hosted the third U.S. Government Workshop on Magnetic Tunnel Junctions (MTJ) at LPS in College Park, MD. Magnetic tunnel junctions (MTJs) are thin-film structures consisting of two conducting magnetic layers separated by a nanometer thick insulating barrier. Owing to the tunneling magnetoresistance effect, the MTJ exhibits a large difference in resistance between anti-parallel and parallel magnetization configurations of the two layers. This, and the fact that modern fabrication techniques can pattern billions of voltage-addressable pillars from an MTJ film grown directly on semiconducting nanoelectronics, has driven worldwide interest in developing MTJs for use as a new solid state memory – the magnetic random access memory.

Over 50 attendees participated in person or via video teleconference. The workshop explored the current and future domestic sources for MTJ-based technologies including fast, high-density, non-volatile MRAM, a strategic technology for high-performance computing and radiation-hard, embedded memory for USG defense and aerospace applications. Industry leaders from IBM, Honeywell Aerospace, NVE Corp., Qualcomm, Avalanche Technologies, Everspin, Raytheon BBN, Spin Transfer Technologies and Northrup Grumman delivered lectures on their company’s product roadmap for emerging MRAM applications, including on-chip, ultrafast RAM in support of emerging terabyte-density FLASH, low-power-consuming microcontrollers for wearables and the Internet of Things, as well as Gbit/in<sup>2</sup>, radiation-hard memories as drop-in replacements for DDR3 SRAM. A roundtable discussion concluded the workshop and examined potential enabling solutions to accelerate MTJ-MRAM development in support of USG needs for high performance computing and rad-hard memory. The industry leaders all highlighted challenges to R&D due to limited domestic manufacturing options for MTJ-MRAM. The USG agencies expressed an interest in supporting fundamental research in support of the emerging technologies. Future strategy discussions are imminently needed to bridge fundamental research and commercial MRAM development. A workshop report with action items is being drafted, likely to address challenges to be addressed at a fourth USG workshop on MTJs in September/October 2016.

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# NIST Process Expands Catalyst Options for Electrolysis and Fuel Cells



Gray center section shows individual atomic layers of iridium NIST scientists deposited, one layer at a time, atop a base of gold, with the boundary between the two metals clarified by the green/red image at right. A top view is shown at left in gold. The deposition technique, which also works with other important metals, could produce economical catalysts for hydrogen fuel cells and water electrolysis. Credit: Moffat/NIST

Note: A version of this story previously appeared in NIST's TechBeat on November 19, 2015.

Remember that pair of gold electroplated earrings you bought years ago at the mall? (Oh yes, you do). Key to crafting their allure was the ability to place an ever-so-thin layer of valuable metal atop a less costly base material. This same strategy will be central to building the "engines" of future hydrogen-powered cars, and scientists at NIST have developed<sup>1</sup> a way to do it more effectively with metals rarer than gold.

The new method could yield better and more economical options for creating hydrogen fuel.

Fuel cells work by splitting off hydrogen from a larger source molecule—preferably by passing an electric current through water, a process called electrolysis. As you might recall from high school chemistry, splitting molecules is easier if you've got the right catalyst. For electrolysis in fuel cells, platinum often fills the bill.

Immerse two platinum electrodes—or con-

ductors—in water, add electricity, and you've got pure hydrogen gas at one electrode surface and oxygen at the other. Reverse the process by feeding hydrogen and oxygen to the respective electrodes and the result is a fuel cell that produces electricity, leaving only pure water as a by-product.

Another metal right near platinum in the periodic table, iridium, is even more adept at producing oxygen, but it is extremely rare. Unfortunately, using either one of these precious metals can break the bank. Even in the very small amounts needed, the high cost of the catalyst and scaling of the associated fabrication processes currently limit the practicality of a hydrogen economy.

Obviously, simple and inexpensive methods for making platinum and iridium coatings as thin as possible while maintaining—or better yet, enhancing—their performance would be welcome, as would alternative materials for use as catalysts.

That's where NIST's efforts come in. In 2012, team members found<sup>2</sup> a way to deposit one-atom-thick layers of platinum onto a gold base. The findings were encouraging, and the group subsequently extended the method to deposit the metal catalyst on less expensive substrates, such as nickel.

The team then set their sights on iridium, a more efficient, but even rarer catalyst.

"We wanted to see whether we could extend the rapid, one-step 'wet' atomic-layer-deposition method to other metals and substrates," says NIST materials scientist Tom Moffat. "So, we've been exploring different catalyst-substrate combinations to see if we can optimize bimetallic interactions to further improve performance, and thereby, broaden the range of options for designers of fuel cells and related devices."

The effort paid off, as the team now has shown their technique can rapidly electroplate ultrathin layers of several metals in the periodic table—known as the platinum group—onto gold and more affordable base metals, such as nickel.

For example, even a minimal amount of iridium, the most attractive candidate in the group, proved effective in producing hydrogen fuel and the oxygen needed to burn it with the ultrathin films matching or exceeding the best reported activity metrics for bulk iridium electrodes.

- Chad Boutin, NIST

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1. S.H. Ahn, H. Tan, M. Haensch, Y. Liu, L.A. Bender-sky and T.P. Moffat. Self-terminated electrodeposition of iridium electrocatalysts. *Energy and Environmental Science*, DOI: 10.1039/C5EE02541A, Oct. 30, 2015

2. See <http://www.nist.gov/mml/msed/platinum-121212.cfm>

## First Book on Hard X-ray Photoelectron Spectroscopy

The first complete book and up-to-date summary of the state of the art in HAXPES, edited by NIST MML scientist Joseph Woicik, is now available (*Hard X-ray Photoelectron Spectroscopy (HAXPES)*, J.C. Woicik (Ed.), Springer International Publishing Switzerland (2016)). The book motivates readers to harness the powerful capabilities of HAXPES in their own research. The chapters (two co-authored by Woicik) are written by experts and include historical work, modern instrumentation, theory, and applications spanning from physics to chemistry, materials science, and engineering. In consideration of the rapid developments of the technique, several chapters include highlights that illustrate future opportunities as well.

Through advances in both electron-spectrometer and photon-source instrumentation, NIST researchers at the NIST beamlines of the

National Synchrotron Light Source, Brookhaven National Laboratory, have been developing HAXPES, utilizing tunable X-rays in the extended 2 – 10 keV photon-energy range. Due to the relatively unlimited electron escape depths at these energies, HAXPES has emerged as a powerful, non-destructive tool that has general application to the study of the true bulk and buried-interface properties of complex-materials systems with industrial significance. Of its many advantages, HAXPES can study "real" samples taken directly from air without the need for additional surface preparation; it has also opened up other research areas that include: (1) The study of highly correlated and spintronic electron systems with surface and interface compositions and structures that are different from their bulk, (2) the combination of energy and angle measurements (X-ray standing wave,

photoelectron diffraction, and angle-resolved valence photoemission) to produce elementally, chemically, and spatially specific electronic and chemical structure, (3) the study of realistic prototypical multilayer-device and catalytic structures under both ambient and in-operando conditions, (4) the ability to tune the photoelectron inelastic mean-free path and the X-ray penetration depth to chemically depth profile buried layers, interfaces, and nanoparticles with the specific nanometer and mesoscopic length scales relevant to modern industry, and (5) the possibilities of both high-resolution 2-dimensional chemical imaging with depth resolution (photoelectron microscopy) in addition to time-resolved photoemission.

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# NFL, Under Armour, GE & NIST Announce Five Winners of Head Health Challenge III

*Note: A version of this story previously appeared on [www.nist.gov](http://www.nist.gov) on December 15, 2015.*

The National Football League (NFL), Under Armour, GE, and NIST recently announced the five winners of Head Health Challenge III, an open innovation competition to support the discovery, design, and development of advanced materials that better absorb or dissipate impact. The new materials have the potential to improve the performance of protective gear, playing surfaces, and equipment for athletes, members of the military and others.

Each of the winners will receive \$250,000 to advance their work in developing state-of-the-art materials. A panel of leading experts in the field of materials science selected these five winners from 125 entries because they met the challenge's technical criteria to maximize energy absorption and minimize momentum transfer. One overall Head Health Challenge III winner will be selected from the five awardees to receive a \$500,000 grand prize.

"The innovations in material science that we've seen in this challenge will have significant applications in a range of equipment that will better protect our athletes, soldiers, children and others," said Jeff Miller, NFL Senior Vice President of Health and Safety Policy.

Alan Gilbert, Director healthymagination, GE said, "I'm encouraged to see the progress from our collaboration with NIST. The goal of convening the brightest engineers, scientists and inventors was to advance and produce better materials for preventing injury, better tools for physicians, and better treatments for patients. Based on what we've seen from these five winners, we are moving in a positive direction."

Kevin Haley, President, Product & Innovation, Under Armour said, "By utilizing our open innovation platform, we've discovered some of the most forward-thinking material innovators that will positively affect the future of impact protection. Our hope is that the groundbreaking work being done by our five winners will help drive material innovation in the name of safety across a variety of applications and we are extremely impressed with the progress made to-date."

"The winning materials show a great deal of ingenuity in their approaches to energy absorption and have the potential to improve the next generation of protective systems," said Under Secretary of Commerce for Standards and Technology and NIST Director Willie E. May. "Our NIST experts are looking forward to working with the winning research teams as they further develop their innovative materials."

The Challenge III award winners are:

- Alba Technic, LLC (Winthrop, Maine) has developed a patented, shock-absorbent honeycomb material with an outer layer that diverts the energy from a fall or hit. The material is normally soft and compliant, but upon impact, the outer layer changes into a hard shell to spread the energy and protect the user from injury.
- Charles Owen Inc. (Lincolnton, Ga.) made cellular structures that use a stacked, origami-like design to optimize energy absorption. The essential building block of this winning material is a double corrugated sheet of the material, whose ability to fold efficiently was originally developed for applications in areas such as solar array packing in the space industry.
- Corsair Innovations (Plymouth, Mass.) has developed a textile that uses tiny, spring-like fibers to repel rotational and linear impacts, thereby reducing potential damage. Unlike foam materials, this textile is washable, breathable, wicks sweat and can be easily engineered to meet impact performance requirements.
- Dynamic Research Inc. (Torrance, Calif.) and 6D Helmets LLC are collaborating to evolve 6D's single-impact suspension technology for use in repeated impact conditions. The suspension technology consists of a multi-layer, suspended internal liner system that allows the outer layer to move independently of the inner layer in order to reduce the effect of both angular and linear impact forces.
- University of Michigan (Ann Arbor, Mich.) researchers designed a lightweight, multi-layered composite that includes a viscoelastic material. This material can be uniquely utilized to help limit the force of multiple and repeated impact events.

The finalists will work with the HHC III partners to optimize their materials over the coming year.

The Challenge III judges were:

- Jeff Crandall, professor in Engineering and Applied Sciences at the University of Virginia
- Sharon Glotzer, Ph.D., professor of Chemical Engineering at the University of Michigan
- Heinrich Jaeger, Ph.D., professor of Physics at the University of Chicago
- Michael Maher, program manager for the Defense Sciences Offices at the Defense Advanced Research Projects Agency (DARPA)



*NIST MML materials scientist Michael Riley prepares a sample of material for a drop test that will reveal its ability to absorb and dissipate energy. This was one of a series of tests that helped the Head Health III judges identify five materials that held the most promise for bringing improvements to protective gear. Photo credit: Earl Zubkoff*

- Tresa Pollock, Ph.D., chair of the Materials Department at the University of California – Santa Barbara
- Alton D. Romig, Ph.D., former vice president and general manager of Advanced Development Programs Engineering and Advanced Systems, known as Skunk Works, for Lockheed Martin Aeronautics
- Alan Taub, Ph.D., professor of Materials Science and Engineering at the University of Michigan.

Head Health Challenge III, part of the larger Head Health Initiative, a four-year, \$60 million collaboration between GE and the NFL, is one of three open innovation challenges to invest up to \$20 million in research and technology development to better understand, identify and protect against brain injury. Challenge I focused on discovering imaging and methods for diagnosis and prognosis of mild traumatic brain injuries, and in July 2015, six grand prize winners were awarded \$500,000 to further their revolutionary research. Challenge II focused on new technologies to monitor, identify and protect against mild traumatic brain injury, and in December 2015, three grand prize winners were announced. The winners could receive up to \$1 million over the next year to continue to advance their innovations.

The Head Health Challenge III collaboration helps implement a pledge by NIST and the Department of Commerce to invest resources to accelerate the development of materials that can protect against concussions, made at the White House's Healthy Kids and Safe Sports Concussion Summit in May 2014.

For more information about the Head Health Challenge, visit [headhealthchallenge.com](http://headhealthchallenge.com).

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## Mixing Modern Materials? NIST Math App Helps You Manage Your Mashup

*Note: A version of this story previously appeared in NIST's TechBeat on December 22, 2015.*

Imagine you're baking a special cake, one in which the shape of each mote of spice mixed into the batter can have a profound effect on your dessert's color, its taste, its texture on the tongue. That's a rough description of creating new lightweight materials for aircraft, cars and windmills that use tiny nanoparticles as ingredients, and scientists at NIST have made<sup>1</sup> recipe development a more palatable job.

Polymers—a large class of materials that includes plastics—play a vast number of roles in daily life, but they lack many properties that would make them even more

useful. As in cooking, a way around these limitations is to mix in other ingredients that have the right properties. Polymers conduct electricity poorly, for example, but adding carbon nanotubes (CNTs) or graphene sheets forms a strong, lightweight “nanocomposite” whose electrical conductivity can be more than a million times higher.

But the variety of options can confound designers. If they can find the right combination of polymer and particles, manufacturers can mix up a nanocomposite that has just the right properties for a job—be it strength, flexibility, conductivity, or a host of others. But with so many polymers and nanoparticles to choose from, devising the best recipe is often a matter of trial and error. That's largely because there has been no way to predict the resulting mix's capabilities based on what each ingredient can do. Why not? In a word, math.

The effect the added particles have on the polymer is profoundly influenced by their shape. But it's hard to account for the complex shapes of the particles mathematically; in fact, it's a famously difficult math problem. So it's tough to create models that account for this essential design variable. Materials designers have been forced to model their mixtures using the assumption that all particles were shaped like spheres—an unrealistic picture, to say the least.

“It's been called the ‘spherical cow’ approach,” says NIST materials scientist Jack Douglas. “It isn't

too helpful when your particle is shaped like a bush or a dust-bunny or crumpled paper, which are what nanoparticles can look like in a mixture. CNTs, for example, aren't the idealized tubes you often see in magazines; their complicated shape depends sensitively on the exact conditions under which the particles are made.”

The team dealt with this issue by exploiting a kernel idea from a seven-decade-old math paper by Shizuo Kakutani, who suggested a way of more realistically modeling particle shapes in material property calculations. Using his ideas for practical materials science would have required far more number-crunching power than was available in

Kakutani's day, but modern computers make this class of problems easier to handle. The team first created virtual nanoparticles that have the same physical shape as the real-world particles they want to analyze, and they then calculated the relevant properties using a publicly available software package (ZENO) developed partly at NIST.

“We generate thousands of examples of the shapes we want, enough to represent variation in the real world,” says Douglas. “That gives us enough information to make general statements about their behavior in the mix.”

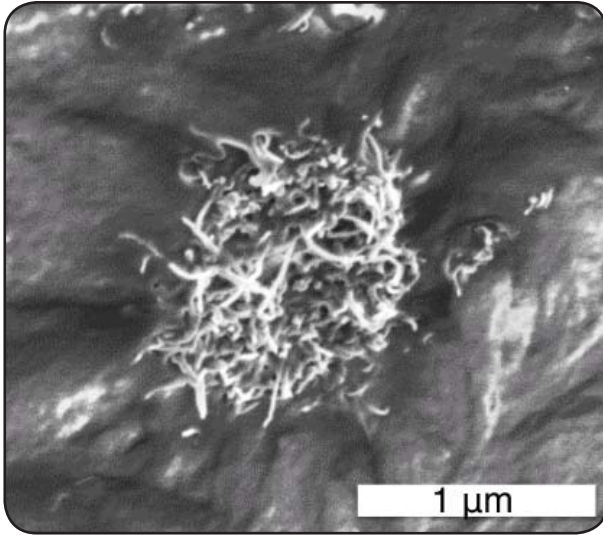
Since polymer nanocomposites are central to many developing technologies relating to the energy, auto and airline industries, Douglas says, this theoretical effort promises to have an appreciable impact. The team's paper focuses on mixing CNTs or graphene with polymers, but the math has wider application.

“We can use it in any problem in which objects of complex shape arise,” he says. “For example, we are currently applying it to classify the shapes of stem cells as well as to biometric data.”

—Chad Boutin, NIST

Contact: Jack Douglas, [jack.douglas@nist.gov](mailto:jack.douglas@nist.gov)

1. F. Vargás-Lara, A.M. Hassan, E.J. Garboczi, and J.F. Douglas. Intrinsic conductivity of carbon nanotubes and graphene sheets having a realistic geometry. *Journal of Chemical Physics* 143, 204902 (2015); doi:10.1063/1.4935970



*A carbon nanotube in the wild can look more like a dust bunny than a simple tube. NIST's new modeling approach improves scientists' ability to predict shape-related influences on the behavior of polymer mixtures, including nanocomposites. Credit: NIST*

## Transforming Biological Imaging: A Unique Tool for Quantitative Measurement

Coherent Raman imaging (CRI) has the ability to identify organelles, tissue types and sub-types rapidly and non-invasively. However, there is a fundamental challenge within the coherent Raman imaging (CRI) community: the generation of Raman spectra that are quantitatively comparable between samples and optical systems. This challenge arises from the necessity of isolating Raman vibrational signatures from a coherent background that is co-generated in CRI. Current *in silico* methods of Raman spectral extraction are theoretically correct under certain idealized conditions, but under practical conditions result in acknowledged but undefined errors. Additionally, the intuitive methods developed to account for these errors give the appearance of correctness—but appearances may be deceiving. The net result is far more serious than just perturbed spectra: it creates an environment in which biological findings cannot be reliably ascertained from the dense spectral information (permutations of ~1,000 color channels), but rather are limited to the spatial information in a pseudocolor image (3-4 colors).

At NIST MML, Charles Camp Jr. and colleagues<sup>1</sup> have re-developed the Raman signal isolation method and incorporated robust, physically-grounded error correction methods to account for experimental conditions. Theoretically and experimentally, this work shows superior agreement between spectra collected under different operating conditions and on different optical systems. Through this work and publically available software for extracting Raman signatures quantitatively and comparably (“CRIkit”)<sup>2</sup>, the researchers hope to revolutionize the CRI community's ability to generate robust, reliable spectra, and to disseminate raw hyperspectral imagery for community data mining and scientific transparency.

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1. C. H. Camp Jr., Y. J. Lee, and M. T. Cicerone, “Quantitative, comparable coherent anti-Stokes Raman scattering (CARS) spectroscopy: Correcting errors in phase retrieval.” *Journal of Raman Spectroscopy* (2015). Available in Early View.

2. Coherent Raman Imaging Toolkit: [github.com/CoherentRamanNIST/CRIkit](https://github.com/CoherentRamanNIST/CRIkit)

## NIST Hydrogen Material Test Facility

### Objective

The establishment of hydrogen fuel-cell powered vehicles as viable alternatives to fossil-fuel powered vehicles is a pathway to increase U.S. energy independence and reduce harmful emissions that contribute to global climate change. Automakers, including Toyota, Hyundai, Nissan, Daimler, Honda, and GM, now have commercially available fuel-cell vehicles, but the infrastructure to generate, store, and distribute hydrogen fuel is not yet in place. The objective of the NIST Hydrogen Materials Project is to provide the underpinning science, data, and models for code and standards development to enable safe and economical transport, delivery, and storage of hydrogen fuel.



### Impact and Customers

NIST is working in collaboration with the U.S. Department of Transportation (DOT) and the U.S. Department of Energy (DOE) to realize safe and cost effective solutions for hydrogen transportation and storage. Pipelines are the safest, most economical way to transport fuels. However, current codes and standards for the transport of hydrogen are overly conservative because they are based on incomplete data generated over 30 years ago. The implementation of advanced steels and appropriate safety factors via code changes will dramatically reduce the as-delivered cost of hydrogen fuel while maintaining safe operation. Based on 2011-2012 industry cost estimates, this improvement would mean that the use of modern X70 steel rather than X52 steel would result in a savings of over \$1 million per mile of pipeline.

The story is similar for the pressure vessels used to store hydrogen fuel. While the codes and standards for pressure vessels have a successful track record, they are based on tests that do not address in-service conditions and failure modes. A fundamental understanding of the behavior of materials in the presence of pressurized hydrogen gas is needed to realize new designs and incorporate advanced steels, which have the potential to significantly reduce costs.

The data and models generated at NIST are being used as a basis to reevaluate and rewrite the American Society of Mechanical Engineers (ASME) and the International Organization for Standardization (ISO) codes and standards for hydrogen pipeline and pressure vessels, respectively. Ultimately, changes in these codes will enable costs savings that will be realized by hydrogen producers and pipeline operators such as Evraz, Air Liquide, Air Products, Praxair, and PG&E, as well as the previously mentioned automakers, and ultimately those that choose fuel-cell powered vehicles for transportation.

### Approach

The NIST Hydrogen Material Test Facility for measuring mechanical properties of structural materials in pressurized hydrogen was developed in response to the national need to grow the hydrogen economy. The facility was developed with a focus on fatigue measurements of pipeline materials in high-pressure hydrogen gas, but its capabilities are applicable to many high-pressure gas environments—particularly flammable gases—and it has most recently been used to investigate pressure vessel materials in hydrogen.

Pipelines operate at very low loading frequency, which generally increases their lifetime. However, with hydrogen, low-loading frequency is an issue because the time per cycle is long enough for hydrogen to completely diffuse to a crack tip where damage per loading cycle is maximized. Testing of fatigue in these conditions requires a long time to generate statistically significant data sets. To address this challenge, the Hydrogen Materials Project team is pursuing two approaches. First, the team is pioneering new techniques and automation to reduce measurement time. This approach is complemented by the development and validation of models to reduce the amount of data needed to characterize the pipeline and pressure vessel materials.

The facility houses two load frames, each with a high-pressure test chamber, which can be run simultaneously and at different hydrogen (or other gas) pressures. One chamber can test a single specimen in a gas atmosphere at up to 138 MPa, and the other can test up to 10 specimens simultaneously in gas pressurized up to 34 MPa. The measurements are remotely and automatically operated for safety, reliability and repeatability. The plumbing for gas supply was designed and built to operate in a fail-safe manner, so that—upon loss of power, air pressure or ventilation—numerous interlocks prevent further gas supply to the laboratory. Additionally, hydrogen sensors monitor the laboratory for leaks. A program was developed to automate the gas supply and pressure maintenance of the two high-pressure test chambers, which allows for 24/7 operation. This program also monitors all power and safety systems so that the gas supply system can be shut off in an orderly manner upon sensing one of the interlocks. Automatic text messages are sent to members of the team if any critical error is encountered by the system, such as a hydrogen alarm, loss of compressed air or loss of laboratory ventilation.

For recently completed measurements on pipeline steels, the test matrix included four different steels, two hydrogen gas pressures, and three cyclic loading frequencies. Modern pipeline steels such as X52 and X70, as well as an older X52 alloy were measured. Older alloys have different microstructures and different chemistries, and therefore may behave differently in hydrogen. Industry members of the ASME B31.12 Committee on Hydrogen Piping and Pipelines have given us guidance on which materials to test and continue to guide us on the priorities for the modeling effort. Prior to this work there was no information on fatigue crack growth of modern pipeline steels in hydrogen gas.

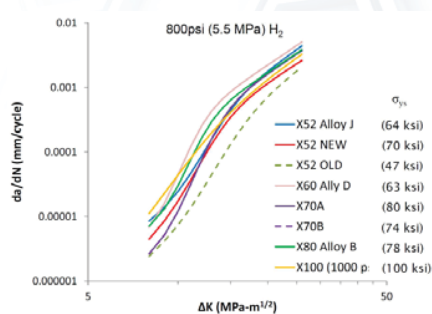


## Accomplishments

While there is still a shortage of facilities in the U.S. capable of performing mechanical measurements in pressurized hydrogen, the startup of the NIST Hydrogen Material Test Facility in 2008 increased public capacity more than ten-fold over the existing test infrastructure. The dramatic increase in capacity was in large part due to the innovations that enabled simultaneous measurement of up to ten fatigue crack growth specimens at a time. This advance, which recently resulted in NIST Patent 9,188,519 on Multiple Specimen Testing, reduced the time needed by years to generate the data for an ASME code change.

The initial focus of the new facility was to determine how accelerated testing at higher cyclic frequencies related to actual operating conditions. Hydrogen pipelines are expected to experience pressure cycles because of peak demand up to a few times per day. Performing measurements at these low frequencies would take unreasonably long times, but NIST scientists were able to demonstrate that fatigue crack growth rates (FCGR) were minimally dependent on cyclic frequency up to the frequencies needed to perform tests in weeks or months, rather than years. With the increased measurement throughput, six pipeline steel alloys were evaluated, and the results demonstrated that FCGR in hydrogen is not a function of steel strength, but rather a function of the microstructural makeup of the steel alloys.

The extensive dataset was also used to develop a phenomenological model of FCGR as a function of hydrogen gas pressure and loading frequency. The model element for the relationship between fatigue crack growth and cyclic loading frequency now allows all future tests to be conducted at 1 Hz. Constitutive relations have been included that provide a predictive capacity. A parametric sensitivity analysis was also completed to aid real-life pipeline design. Parameters that pipeline operators would use, such as pipe wall thickness, operating pressure, pressure ratio and loading frequency are used as inputs. Lifetime in the form of number of cy-

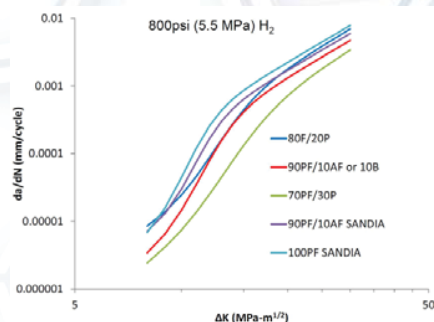


FCGRs for pipeline steels with a range of measured yield strengths showing no relationship between yield strength and FCGR.

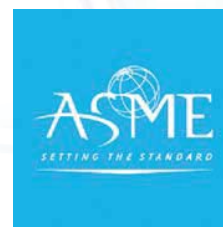
cles to failure is given as the output. The model has identified the upper and lower bounds of the FCGR for proposed pipeline materials, which forms the basis for the revision to the code for the design of safe and cost-effective hydrogen pipelines.

The phenomenological model is now being further developed into a physics-based model that will require more fundamental properties, such as microstructure and diffusivity, and will be fully predictive of the material behavior in a hydrogen gas environment, providing input for design of future alloys.

Current work is focused on understanding the FCGR of the welds used to construct and join pipeline, and NIST continues to work with industry partners from the ASME B31.12 Committee on Hydrogen Piping and Pipelines, DOT, and DOE to develop a complete picture of how hydrogen affects every component of the pipe, including the base metal, welds, and heat-affected zones should future revisions to the code become necessary because of our findings. Future work will focus on completing tests to calibrate the model for these materials, tests conducted on model materials to better understand the contribution of the microstructural constituents, and expanding to include steels for pressure vessels, and materials used in filling stations.



FCGRs for pipeline steels containing varying percentages of polygonal ferrite (F), pearlite (P), bainite (B), and acicular ferrite (AF). FCGR can be seen to increase with increasing percentage of polygonal ferrite.



## Learn More

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# NIST and Intel Get Critical (Dimensions) with X-rays

Note: A version of this story previously appeared in NIST's TechBeat on October 20, 2015.

Researchers from NIST and Intel reported<sup>1</sup> success using an X-ray scattering technique to accurately measure features on a silicon chip to within fractions of a nanometer, or about the width of a single silicon atom.

The achievement could make the experimental technology known as CDSAXS (critical-dimension small angle X-ray scattering) a top contender in the race to develop new in-line process control tools for measuring vanishingly small features on next-generation computer chips.

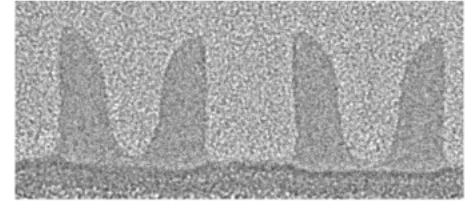
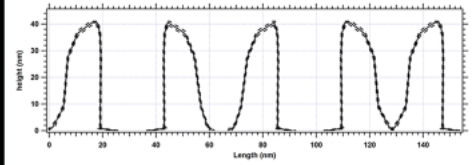
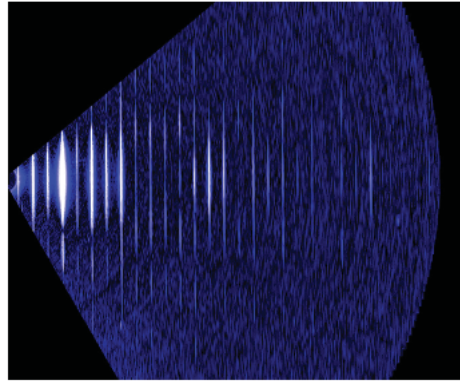
"The semiconductor industry is running out of measurement methods that work non-destructively on their ever-smaller next-generation nanostructures," says NIST materials scientist R. Joseph Kline. "These are by far the smallest and most complex shaped nanostructures characterized by CDSAXS. The results show that CDSAXS has the resolution to meet next-generation metrology requirements."

With the size of lines, trenches, holes and other features on silicon slices shrinking to single-digit nanometers, measurement tools long used to monitor chip production are approaching their limits. Factor in the growing complexity of chip design—such as building stack-like transistors instead of flat ones, a shift begun with Intel's introduction of FinFET transistors in 2011—and it's easy to understand why semiconductor manufacturers are eager for improved measurement capabilities.

The NIST and Intel researchers used CDSAXS to measure dimensions on silicon wafers fabricated at Intel's research facilities with a periodic array of asymmetric lines. The array was made by pitch quartering, a method that quadruples the number of interconnect lines in a space that normally would accommodate only one. The intricate arrays of lines were made using multiple patterning steps chip makers now must employ to create features beyond the capabilities of existing light-based printing equipment. Throughout, getting precise measurements is critical; misalignments during the sequential patterning process can result in systematic errors, or flaws, in a chip.

A flaw of particular concern—and a focus of the NIST-Intel study—is pitch error, variations in the distance from one line edge to the next.

"The semiconductor industry has not only decreased product dimensions, but we've also developed increasingly complex 3D structures. These structures are becoming very difficult to characterize non-destructively with conventional in-line SEM [scan-



An example CDSAXS scattering pattern (left) shows the interference patterns created by the shape of the nanostructure, which ultimately yield a "best fit" shape model (top, right). The corresponding cross-sectional image (bottom), obtained with a transmission electron microscope, shows the nanostructure measured by NIST and Intel researchers. Credit: R.J. Kline/NIST

ning electron microscope]," said Scott List, principal engineer in Intel's Components Research Group. "Early results of NIST's state-of-the-art CDSAXS measurements of these nanometer-sized structures have provided very useful atomic scale resolution of their 3D profiles."

In the custom-made sample scrutinized in the study, lines resembling shark fins were 12 nanometers wide. The space between lines varied ever so slightly—by less than 0.5 nanometer—from a pitch of 32 nanometers.

CDSAXS measurements of periodic pitch errors—deviations from 32 nanometers—were accurate to within 0.1 nanometer; and measurements of line shapes were accurate to about 0.2 nanometer.

Since 2000, NIST has been pioneering the application of small-angle X-ray scattering to meet the ever-more demanding measurement needs of the semiconductor industry, which, for decades, has been doubling the density of transistors on a chip about every two years in accordance with Moore's Law. Today's leading-edge integrated circuits squeeze several billion transistors on a slice of silicon smaller than a typical postage stamp.

Currently used dimensional metrology tools rely on visible and ultraviolet light with wavelengths much larger than the features being measured. The X-rays used in CDSAXS have a wavelength less than 0.1 nanometer, much smaller than the dimensions of features on future generations of computer chips. CDSAXS exploits the short wavelength of X-rays and their sensitivity to differing densities of electrons in the materials they strike.

The noncontact, non-destructive technique does not require any sample preparation, and it works with test structures already used by semiconductor makers. CDSAXS, however, does not yield the equivalent of an X-ray picture of, for example, a broken wrist. Rather,

patterns of X-rays scattered by electrons in the nanostructure are captured by a detector, providing data to be crunched by computers to solve for the original shape.

The analyses compare the pattern of scattered X-rays to carefully developed shape models of arrays of nanostructured features on a surface. This data-fitting procedure may go through several million rounds before achieving a satisfactory match between simulated and measured patterns of electron densities.

Following other studies demonstrating the capabilities of CDSAXS for a host of nanoscale measurements, the NIST-Intel study on complex samples representative of next-generation semiconductor manufacturing shows that CDSAXS can deliver the desired dimensional resolution.

The results should provide further impetus for ongoing efforts to develop compact sources of X-rays with the intensity required for in-line CDSAXS in semiconductor manufacturing facilities. The NIST-Intel, proof-of-concept study was conducted at the Advanced Photon Source (APS) at Argonne National Laboratory, which measures 1,104 meters in circumference—more than 12 football fields around—and accommodates more than 60 experiments at one time. Previous CDSAXS studies were conducted at APS or similar experimental facilities, known as synchrotron light sources.

- Mark Bello, NIST

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1. D.F. Sunday, S. List, J.S. Chawla and R.J. Kline, "Determining the shape and periodicity of nanostructures using small-angle X-ray scattering," *J. Appl. Cryst.* (2015). <http://dx.doi.org/10.1107/S1600576715013369>

# NIST Takes (Some of) the Stress Out of Engineering New Materials

*Note: A version of this story previously appeared in NIST's TechBeat on November 13, 2015.*

Stress: What does it feel like to you? Maybe like pressure from multiple directions, trying to push and pull and twist you all at once? If so, you've described it the same way engineers describe stress on a solid object—and a team including scientists at NIST has taken a major step toward measuring it usefully in cutting-edge materials.

Their work provides the first method<sup>1</sup> for measuring all the varied pushing, pulling and twisting at tiny scales within a solid object—a longstanding goal. It's an important step toward the ultimate goal of predicting a material's capabilities directly from its composition and internal structure.

The performance of a novel material—such as 3-D printed metals or lightweight materials for future cars—depends largely on how well it can handle stress. But gauging a material's capabilities isn't as simple as taking a chunk of it, pushing and pulling on the whole thing, and measuring its strength in each direction. The chunk's interior can be extremely complicated with large stresses that change drastically from place to place. So materials scientists need to use a special X-ray machine at Argonne National Laboratory to look within the chunk, one tiny piece at a time, with each piece smaller than a cubic micrometer.

As you might imagine, that in itself is a pretty stressful job.

"Most times when I examine a new material, I don't get any sleep that night," says NIST's Lyle Levine. "It can take 24 hours or more of continuous work to characterize a single tiny sample."

It used to be even harder. In 2006 the team found<sup>2</sup> a way to X-ray samples, but they could only measure the stress in a single direction, and only by hand. Their latest research builds on the 2006 findings and permits them to measure all the stresses in every direction, thanks to two innovations they made in the use of light and shadow.

First, it turns out that X-rays will reflect off of a material in different directions if you vary their wavelength. By doing so, the team can generate different reflections that reveal the stress in one direction and then another—all without changing the sample's position. They also found that they could get a clearer view by moving a small wire through the X-ray beam to block out distracting reflections that often come from other places in the sample.

Their approach has allowed them to measure the "tensor," or full set of stresses, in cubic sections just 250 nanometers per side—the level of resolution that materials scientists need to be able to predict a material's performance.

(Each section's volume is about 8 million times smaller than a cube with the thickness of a human hair).

What materials physicists like Levine want next—aside from sleep—is some automated process to make all these measurements quickly. Levine thinks they know how to make them more than 7,000 times faster, but warns that you shouldn't hold your breath waiting. Creating the necessary technology may be as much as 10 years of work away.

"We now have a method for measuring the full tensor," Levine says. "But it's still slow and difficult. So the next step is to develop new technology that will make it much faster and easier for people to use."

Which would—you guessed it—make life for materials scientists way less stressful.

- Chad Boutin, NIST

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1. L. Levine, C. Okoro and R. Xu. Full elastic strain and stress tensor measurements from individual dislocation cells in copper through-Si vias. *IUCrJ* (International Union of Crystallography Journal), doi:10.1107/S2052252515015031, Nov. 2015 issue.

2. See <http://www.nist.gov/mml/msed/new-080306.cfm>

## NIST MML Researchers Find Evidence of a Molecular Boundary Lubricant at Snakeskin Surfaces

NIST MML researchers, working with an international research team, have chemically and structurally imaged a molecular boundary lubricant at snakeskin surfaces whose structure could prove critical to mimicking the optical and mechanical properties that snake scales possess. The slithering locomotion of snakes requires additional frictional properties and resistance against wear. The peculiar locomotion of snakes has inspired engineers for years. For example, robotics researchers are trying to mimic the snake's capability to negotiate a range of challenging terrain types.

The unique NIST Soft X-ray Microscope at the National Synchrotron Light Source (NSLS), enabled the work of the research team (with members from NIST's Synchrotron Science Group, Oregon State University's School of Chemical, Biological, and Environmental Engineering, the Zoological Institute of Kiel University, and the Max Planck Institute for Polymer Research Germany), which was recently published in the *Journal of the Royal Society Interface* 12: 20150817.

During slithering locomotion the ventral scales at a snake's belly are in direct me-



chanical interaction with the environment, while the dorsal scales provide optical camouflage and thermoregulation. Recent work has demonstrated that compared to dorsal scales, ventral scales provide improved lubrication and wear protection. While biomechanical adaption of snake motion is of growing interest in the fields of material science and robotics, the mechanism for how ventral scales influence the friction between the snake and substrate, at the molecular level, is unknown.

This research characterized the outermost surface of snake scales using sum frequency generation (SFG) spectra and near-edge X-ray absorption fine structure (NEXAFS) images collected from recently shed California kingsnake (*Lampropeltis californiae*) epidermis. SFG's nonlinear optical selection rules provide information about the outermost surface of materials; NEXAFS takes advantage of the shallow escape depth of the electrons to probe the molecular structure of surfaces. Analysis of the data revealed the existence of a previously unknown lipid coating on both the ventral and dorsal scales. Additionally, the molecular structure of this lipid coating closely aligns to the biological function: lipids on ventral scales form a highly ordered layer which provides both lubrication and wear protection at the snake's ventral surface.

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Credit: Tobias Weidner

## Global NISTmAb Partnership Published as ACS Book Series

Monoclonal antibody therapeutics make up six of the top ten selling drugs in the world and are used to treat serious and life-threatening conditions such as rheumatoid arthritis and cancer. These molecules contain many complex structural attributes that must be thoroughly characterized as part of their development, manufacturing, and regulatory approval. A recently completed international crowd-sourcing effort to characterize a monoclonal antibody is now the basis for a three volume book series. The books are expected to serve as a resource for the development of analytical and biophysical methods used by the biopharmaceutical industry for measuring this important class of therapeutic.

Janssen Pharmaceuticals and Novavax approached NIST MML in late 2012 with an interest in developing an American Chemical Society (ACS) book on the analytical characterization of therapeutic monoclonal antibodies. Nearly simultaneously NIST received a significant quantity of an IgG1 monoclonal antibody material that was donated to NIST by MedImmune LLC, a major biopharmaceutical company. The intent was to develop this IgG1 material, now known as the NISTmAb, into a NIST reference material, an effort being led by NIST scientist John Schiel. NIST proposed sharing the NISTmAb material with authors of the book such that subject matter experts for a particular analytical method would generate data using the NISTmAb material as

their sample. These data would then serve as the basis for book chapters describing the numerous analytical methods used to characterize monoclonal antibodies. In addition, in cases where the same analytical methods were used by different groups, the use of the common, shared material allowed comparison of results between different laboratories. The publication of the final volume marks the culmination of this remarkable collaborative effort that involved over 100 scientists from the biopharmaceutical industry, analytical instrument companies, academia, FDA, NIST, and other organizations.

Volume One of *State-of-the-Art and Emerging Technologies for Therapeutic Monoclonal Antibody Characterization* was published in December 2014. The first volume, "Monoclonal Antibody Therapeutics: Structure, Function, and Regulatory Space," provides an industry-driven discussion of this critical therapeutic class, associated regulatory considerations, and the role reference materials play in biopharmaceutical development. Notable pioneers in the field contributed chapters on development of protein therapeutics and biochemical functions essential to their therapeutic efficacy for treating diseases such as cancer and autoimmune disorders.

Volume Two, "Biopharmaceutical Characterization: The NISTmAb Case Study," centers on the NISTmAb as a vehicle for highlighting

the different stages of characterization when developing a monoclonal antibody product. Multiple participating partners were recruited to cover each topic and produce datasets with state-of-the-art methods to characterize various attributes such as amino acid primary structure, post-translational modifications, glycosylation, and protein particulates. Volume Two of this series provides an exhaustive cross section of monoclonal antibody characterization and a detailed discussion of product quality attributes. The collective analysis throughout Volume Two therefore provides a very holistic picture of the NISTmAb and demonstrates the potential utility of class-specific reference materials like the NISTmAb.

In Volume Three, "Defining the Next Generation of Analytical and Biophysical Techniques," experts describe new, cutting-edge technologies being developed to characterize protein therapeutics in the biopharmaceutical industry. Analytical methods treated include nuclear magnetic resonance spectroscopy, a variety of specialized forms of mass spectrometry, emerging microfluidic platforms, bioinformatics, and laboratory automation.

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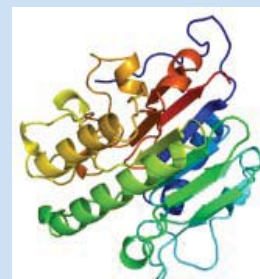
### NIST MML Researchers Reported Extreme Expression of DNA Repair Protein Apurinic/Apyrimidinic Endonuclease 1 (APE1) in Human Breast Cancer

NIST MML researchers have attempted, for the first time, to identify and quantify human apurinic/aprimidinic endonuclease 1 (APE1) levels in human tissues. They used liquid chromatography-tandem mass spectrometry using a stable isotope-labeled full length APE1 as an internal standard, which is the chemically and physically identical analogue of APE1. Human disease-free breast tissues and malignant breast tumors were chosen to determine whether APE1 can be identified and quantified, and whether differences exist between the levels of APE1 expression in these tissues.

APE1 is a DNA repair protein in the base excision repair pathway (BER), which cleaves apurinic/aprimidinic (AP) sites generated by removal of modified DNA bases by DNA glycosylases in the first step of BER. APE1 provides over 95% of the total AP-site endonuclease function in mammals, and also possesses a redox regulatory portion with multiple other functions. The critical nature of APE1 functions is demonstrated by early embryonic lethality in APE1 deficient mice,

by increased oxidative stress, mutagenesis and cancer incidences in partially APE1 deficient mice, and by loss of neuronal cell function due to defects in APE1 activity. Other adverse effects that are caused by depletion, and inhibition or downregulation of APE1 include apoptosis (programmed cell death), and sensitization to DNA-damaging agents. Moreover, APE1 polymorphisms (discontinuous genetic variations) are associated with the disposition to cancer.

In their work, NIST researchers showed that APE1 expression is drastically increased in malignant breast tumors when compared to disease-free breast tissues. This observation is on a par with the highly significant expression of APE1 in human mammary gland epithelial adenocarcinoma cells (MCF-7) when compared with MCF-10A normal cells of the same origin. These findings suggest that breast cancer cells may be dependent on APE1 functions for survival. However, all cancers are not identical and APE1 expression differs among many human solid cancers. This fact points to the importance of the accurate measurement



APE1 in human tissue.

of APE1 expression levels in disease-free tissues and malignant tumors, if APE1 is to be used as a reliable biomarker for novel cancer treatment strategies and for the development of APE1 inhibitors as anticancer drugs. This work is the first to report on the positive identification and absolute quantification of APE1 in human tissues using mass spectrometry and a stable isotope-labeled analogue of APE1 as an internal standard.

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## NIST MML Researcher Teams with NOAA and EPA to Study the Effects of Asian Dust Particles on Climate

In the Gobi Desert of southern Mongolia and northern China, and the Taklamakan Desert of western China, storms produce dust that can be carried aloft for thousands of miles, even reaching the continental U.S. The amount of dust produced by these storms, and prolonged interaction with solar radiation, have a significant impact on climate over a large portion of the globe.

NOAA's Mauna Loa Observatory (MLO) on the northern slope of the volcano in Hawaii is ideally situated for sampling Asian dust. A NIST MML researcher, Joe Conny, has collaborated with NOAA and EPA to study how individual Asian dust particles absorb and scatter light, to understand whether the particles warm the atmosphere by absorbing it, or cool the atmosphere by scattering it. Air mass back trajectories and satellite imagery predicted when MLO would most likely encounter the Asian dust, and therefore, which samples collected at MLO likely contained the dust.

Dust-containing samples were analyzed by automated scanning electron microscopy (SEM) and energy dispersive X-ray spectrometry (EDX), after which particles were sorted into compositionally-distinct types. Particles containing mainly the minerals dolomite and calcite were identified as Asian dust. Particles containing mainly anhydrite (anhydrous calcium sulfate) were likely in the same air mass as the Asian dust, but were identified as other than Asian dust.

The shape and internal composition of individual particles were determined using focused ion-beam (FIB) SEM and FIB tomography. The optical absorption and scattering properties of the particles were then calculated using the discrete dipole approximation method, inputting the three-dimensional shape and composition information derived from FIB tomography.

Calculations of the single scattering albedo (SSA, fraction of total light interacting with the particle that is scattered) for the Asian dust ranged from 0.80 to 0.97, which straddles the critical SSA for warming vs. cooling (0.86). For the particles identified as other than Asian dust (anhydrite), SSA was higher (0.90 to 0.97), and thus above the critical SSA. SSA variations were explained by the complex refractive index, which accounted for absorbing trace impurities in the particle, the presence of soot on the particle, and also particle size and shape. For comparison, optical properties of equivalently-sized geometric shaped (spheres, cubes, and tetrahedra) particles were also calculated. For such ideal particles, SSA was almost always lower than the actual particles.

This work was presented at the American Geophysical Union Meeting in San Francisco, December 2015.

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## Strong NIST Contributions Continue in ISO/TC 276: Biotechnology

ISO/TC 276: Biotechnology held its Working Group (WG) meetings in Tokyo, Japan on October 26-30, 2015. Ten U.S. delegates attended the meeting (three from NIST, one from FDA, one from USDA, one from CAP, and four from industry: GE Healthcare, Pluristem, Akron Biotech, and CDI). All five WGs discussed paths to advance standards. MML's Sheng Lin-Gibson (Chair of the U.S. TAG and convenor of WG3: Analytical Methods) and Sumona Sarkar (U.S. expert for WG3, and technical lead for cell counting work items) presented a path to continue development of a two-part cell counting standard. The WG reached consensus in addressing comments and a path forward for these 2 items. In addition, an *in silico* data set developed by NIST was presented to support the development of Cell Counting Part 2: Experimental Design and Statistical Analysis and several countries volunteered to participate in an *in silico* inter-lab study (Japan and UK are already participating).

Lin-Gibson also led the discussion for the development of cell characterization standards and facilitated the discussion of four proposals related to nucleic acid/genomic measurements in WG3. In WG 4: Bioprocessing a number of items were considered for current and future work including: 1) Raw/Ancillary Materials, 2) Equipment, and 3) Cell Culture and Separation. NIST is contributing to the development of a three-part standard on Raw/Ancillary Materials for manufacturing cells for therapeutic use. In WG 5: Data Processing and Integration, Lin-Gibson helped to clarify the scope of a preliminary work item: a guide for downstream data processing and integration.

In addition to WG meetings, Lin-Gibson and Sarkar attended a U.S.-Japan Joint Cell Counting Study Meeting with numerous Japanese experts presenting their experimental and *in silico* data analysis results using the NIST proposed methods. The Japan team made a number of recommendations as next steps, which will be considered. Finally, Lin-Gibson and Sarkar had an in-person and WebEx meeting with Pluristem scientists to discuss ongoing collaborations on cell counting. Pluristem offered to conduct additional experiments based on NIST experimental designs for sensitivity analysis of key factors in cell counting robustness (i.e., inter-device, inter-operator and inter-day variability).

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## First NIST-FDA Workshop on Standards for Pathogen Detection via Next-Generation Sequencing Held at NIST

The NIST-FDA Workshop on Standards for Pathogen Detection via Next-Generation Sequencing was held October 27-28, 2015 at the NIST Gaithersburg campus. The purpose of the workshop was to seek input on defining reference materials, reference data and reference methods for assessing analytical sensitivity, specificity, and relative performance of NGS-based pathogen detection devices/assays. A total of approximately 70 attendees were present during the two day workshop. Attendees included representatives from various federal government agencies, national laboratories, industry, medical institutes, and academia, targeting the primary users/adopters of these standards.

The first day included talks from subject matter experts on topics including clinical and public health applications, with special attention on the standards needs from sample preparation, sequencing, and bioinformatics. In particular, the needs for working with samples containing mixtures of organisms were discussed. The second day included a presentation by NIST staff on a prototype reference sample and sub-

sequent analysis. These data were made publicly available (<http://www.ncbi.nlm.nih.gov/bioproject/PRJNA297045>), and numerous requests for the test sample have come from government, academic, and industrial partners, highlighting the unmet demands in this space. The workshop also featured break-out sessions and a poster session that focused on pathogen constituent selection criteria, sample makeup, characterization parameters, bioinformatics interpretation, and strategies for crowd-sourcing the material characterization to concomitantly accelerate development and adoption by the community.

The next workshop is scheduled for October 2016 at NIST Gaithersburg. We will update the community on our progress for reference samples, as well as discuss the potential for pre-analytical variability characterization using whole-organism samples.

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# Recent NIST MML Awards and Recognitions

## Green Honored at the 2015 American Association for Clinical Chemistry Conference



Ashley Beasley Green received two awards at the 2015 American Association for Clinical Chemistry (AACC) Conference. Green, a staff scientist in MML's Bioanalytical Science Group, was the recipient of the prestigious National Academy of Clinical Biochemistry (NACB) Distinguished Abstract Award for the abstract entitled "Development of a Reference Measurement System for Urine Albumin" at the 2015 AACC Conference in Atlanta, Georgia. The abstract was one of 41 abstracts selected for scientific excellence by a panel of NACB fellows out of 773 accepted abstracts for the annual meeting. Green was acknowledged in the conference program, during the conference Awards Ceremony and at a special NACB Awards Luncheon. The poster highlighted the Urine Albumin Standardization efforts at NIST, in collaboration with the National Kidney Disease Education Program (NKDEP) and the International Federation of Clinical Chemistry (IFCC) Working Group for the Standardization of Albumin Assays in Urine (WG-SAU). Green also received the 2015 Mass Spectrometry and Separation Sciences (MSSS) Division of AACC Poster Recognition Award during the 2015 AACC Conference.

## Bradley Elected to Board of Directors of the Cryogenic Engineering Conference



During the 2015 Cryogenic Engineering Conference/International Cryogenic Materials Conference CEC/ICMC, held in Tucson June 28 to July 2, 2015, NIST MML mechanical engineer Peter Bradley was elected to the Board of Directors of the Cryogenic Engineering Conference. The voting takes place at the conference and all attendees (about 700) are eligible to vote. Bradley will serve a 6 year term (3 conferences). He is one of three new board members (one from academia, one from government, and one from private industry) that replace three outgoing members. Bradley represents government and was one of three government representatives nominated for the position. Typical government representatives are from such agencies as DoD, DoE, NASA, NIH, and NIST. Duties of the board of directors are to plan and manage the Cryogenic Engineering Conference and attend meetings of the joint CEC/ICMC. The CEC is an international conference, but managed by U.S. representatives. It is the largest cryogenics conference in the world and held every two years.

## Phinney is Chair-Elect for the ACS Division of Analytical Chemistry



Karen Phinney, group leader of MML's Bioanalytical Science Group, has been elected to the position of Chair Elect for the American Chemical Society Division of Analytical Chemistry. Phinney will serve as Chair Elect in 2015-2016, Program Chair for 2016-2017 and Chair of the ACS Division of Analytical Chemistry in 2017-2018. She has been an ACS member since 1985, and previously served as chair of the Division of Analytical Chemistry Subdivision of Chromatography and Separations Chemistry. Her expertise is in chromatographic and electrophoretic separation techniques and their application to quantitative measurements. Her work has included the development of analytical methods for vitamins and other analytes in dietary supplements, and she is currently coordinating the development of several serum-based Standard Reference Materials for analytes of nutritional significance. She is also guiding efforts to develop reference materials for the proteomics and metabolomics communities. She has authored or co-authored more than 30 publications describing these activities.

## Pritchett Receives Burks-Houck Professional Leadership Award



The National Organization for the Professional Advancement of Black Chemists and Chemical Engineers (NOBCChE) selected Jeanita Pritchett, a research chemist in MML's Organic Chemical Measurement Science Group, for the Burks-Houck Professional Leadership Award. This award recognizes Pritchett's leadership and service in the scientific community, performed while also engaging measurement science and innovation activities. The award was presented September 22, 2015, at the 42nd NOBCChE meeting held in Orlando, Florida. This award is named after Dr. Winifred Burks-Houck, a noted environmental organic chemist working at Lawrence Livermore National Laboratory, who was also the first female president of NOBCChE.

## Bruno Wins ACS Colorado Section Award



Tom Bruno, group leader of MML's Experimental Properties of Fluids Group, received the Colorado American Chemical Society Section Award for excellence in research in November 2015. The Section Award, started in 1967, is given to a Colorado chemist with an extensive and impactful career in chemistry. Bruno has an extensive record of impactful research on properties of fuel mixtures, explosives, reacting fluids, and environmental pollutants. He and his group also work on supercritical fluid extraction and chromatography, development of novel analytical methods, and novel detection devices for chromatography. Among his nine patents is the Advanced Distillation Curve method for fuel characterization, which resulted in a Department of Commerce Silver Medal in 2010. He was also awarded the Department of Commerce Bronze Medal in 1986 for his work "on the thermophysics of reacting fluids." He has published 250 research papers, and seven books, one of which, the Handbook of Basic Tables for Chemical Analysis, is the fifth best-selling book in analytical chemistry. He serves as associate editor of the CRC Handbook of Chemistry and Physics, and as the North American Editor for Fuel Processing Technology. He is internationally recognized for applying fundamental engineering science towards resolution of realistic industrial problems. His nominators describe him as an innovative, flexible, creative and efficient researcher.

# Selected Recent Publications

*MML researchers publish more than 400 journal articles each year. Here are a few recent examples:*

J. M. Zook, H. M. Parikh, D. Chen, H. K. Iyer, M. L. Salit, W. Losert, "SVClassify: a method to use multiple datasets to classify candidate structural variants into true positives and false positives" *Genome Research*, Vol. 17, (16-Jan-2016) (PubID: 918034)

E. J. Garratt, B. Nikoobakht, "Surface-directed Nanoepitaxy on a Surface with an Irregular Lattice" *Advanced Materials*, 8 pp., (08-Jan-2016) (PubID: 919085)

A. C. Johnston-Peck, J. P. Winterstein, A. D. Roberts, J. S. DuChene, K. Qian, B. C. Sweeny, W. D. Wei, R. Sharma, E. A. Stach, A. A. Herzing, "Oxidation State Sensitive Imaging of Ceria by Atomic-Resolution Low Angle Annular Dark Field Scanning Transmission Electron Microscopy" *Ultramicroscopy*, pp. 52-60, (17-Dec-2015) (PubID: 917862)

A. H. Harvey, J. W. Lovell-Smith, R. Feistel, O. Hellmuth, S. A. Bell, M. Heinonen, J. R. Cooper, "Metrological challenges for measurements of key climatological observables, Part 4: Atmospheric relative humidity" *Metrologia*, Vol. 53, No. 1, pp. R40-R59, (15-Dec-2015) (PubID: 918620)

A. S. Boggs, H. J. Hamlin, J. C. Nifong, B. L. Catron, R. H. Lowers, T. M. Galligan, S. E. Long, L. J. Guillette Jr., "Urinary iodine and stable isotope analysis to examine habitat influences on thyroid hormones among coastal dwelling American alligators" *Environmental Science & Technology*, pp. 5-13, (09-Dec-2015) (PubID: 918231)

B. Nikoobakht, A. A. Herzing, S. Muramoto, J. Tersoff, "Vapor-Liquid-Solid Etch of Semiconductor Surface Channels by Running Gold Nanodroplets" *Nano Letters*, Vol. 15, No. 12, pp. 8360-8364, (24-Nov-2015) (PubID: 919575)

S. C. Barron, N. T. Nguyen, N. V. Nguyen, M. L. Green, M. P. Patel, "An apparatus for spatially resolved, temperature dependent near infrared reflectance measurements for identifying thermochromic transitions in combinatorial thin film libraries" *Review of Scientific Instruments*, Vol. 86, No. 11, pp. 1-11, (18-Nov-2015) (PubID: 918569)

D. W. Siderius, V. K. Shen, W. P. Krekelberg, G. Y. Gor, C. J. Rasmussen, N. Bernstein, "Relation Between Pore Size and the Compressibility of a Confined Fluid" *Journal of Chemical Physics*, Vol. 143, 5 pp., (18-Nov-2015) (PubID: 918911)

C. Presser, "Thermal Signature Measurements for Ammonium Nitrate/Fuel Mixtures by Laser Heating" *Thermochimica ACTA*, Vol. 623, pp. 120-135, (01-Nov-2015) (PubID: 918336)

L. Zhang, C. Q. Burdette, M. M. Phillips, C. A. Rimmer, R. K. Marcus, "Determination of Isoflavone Content in SRM 3238 Using Liquid Chromatography-Particle Beam/Electron Ionization Mass Spectrometry" *Journal of Aoac International*, Vol. 98, No. 6, pp. 1483-1490, (01-Nov-2015) (PubID: 917087)

J. M. Gorham, W. A. Osborn, J. W. Woodcock, K. C. Scott, J. M. Heddleston, A. R. Hight Walker, J. W. Gilman, "Detecting Carbon in Carbon: Application of Differential Charging to Obtain Information on the Chemical Identity and Spatial Location of Carbon Nanotube Aggregates in Composites by Imaging X-ray Photoelectron Spectroscopy" *Carbon*, Vol. 96, 9 pp., (24-Oct-2015) (PubID: 918341)

K. Sarafin, R. Durazo-Arvizu, L. Tian, K. W. Phinney, S. S. Tai, J. Camara, H. W. Vesper, J. M. Merkel, E. Green, C. T. Sempos, S. P. Brooks, "Standardizing 25-Hydroxyvitamin D values from the Canadian Health Measures Survey" *American Journal of Clinical Nutrition*, pp. 1044-1050, (30-Sep-2015) (PubID: 917157)

J. M. Zook, M. L. Salit, "Benchmarks for genome sequencing" *Cell*, Vol. 1, (23-Sep-2015) (PubID: 919330)

D. R. Black, D. A. Windover, M. H. Mendenhall, A. Henins, J. J. Filliben, J. P. Cline, "CERTIFICATION OF STANDARD REFERENCE MATERIAL 1976B" *Powder Diffraction*, Vol. 30, No. 3, pp. 1-6, (15-Sep-2015) (PubID: 917765)

E. Coskun, P. Jaruga, P. T. Reddy, M.M. Dizdar, "Extreme expression of DNA repair protein apurinic/apyrimidinic endonuclease I (APE1) in human breast cancer as measured by liquid-chromatography isotope-dilution tandem mass spectrometry" *Biochemistry*, Vol. 54, No. 38, pp. 5787-5790, (15-Sep-2015) (PubID: 919226)

*Full-text versions of many papers and a full list of MML publications can be accessed through the NIST Publications Database at [www.nist.gov/publication-portal.cfm](http://www.nist.gov/publication-portal.cfm)*

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