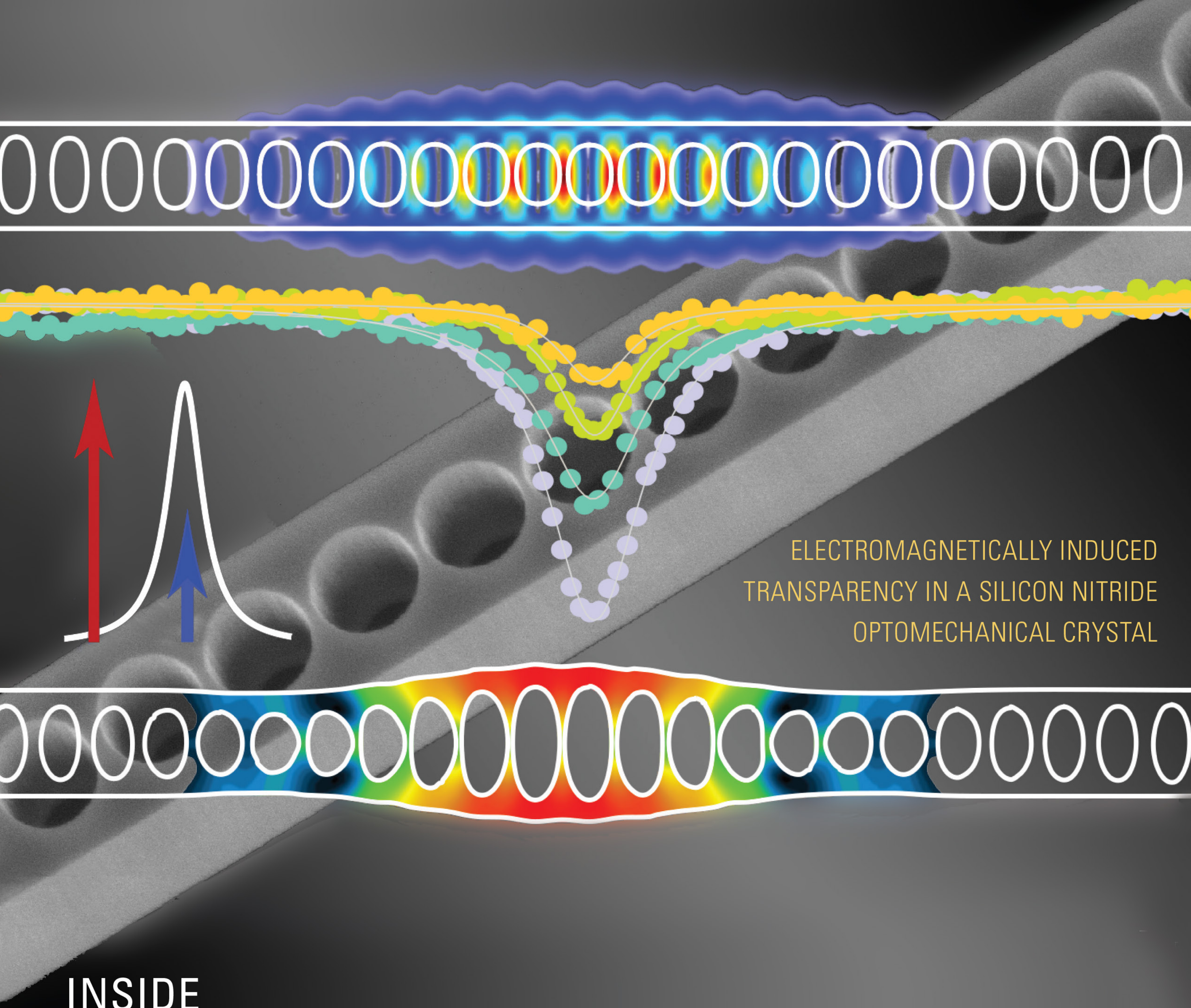
THE CNST NEWS

WINTER/SPRING 2014



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FROM THE DIRECTOR

This issue, I'd like to devote my column to answering the most common questions we get asked about the CNST. Then, I'll have a few questions of my own!

Question: I do not have any ongoing collaborations or projects at NIST and have never worked there. I don't even know anyone at NIST. Can I still use the NanoFab?

Answer: This is probably our most frequently asked question and I understand why it comes about. A common motivation for collaboration is gaining access to needed instrumentation. But the whole purpose of the NanoFab is to allow seamless access without any requirement for collaboration. Our state-of-the-art equipment is there for your use; just contact the NanoFab Manager (Vincent Luciani, nanofab@nist.gov) or user office (nanofabuseroffice@nist.gov) to get started.

Question: Great! So access to the NanoFab is easy! How can the other part of CNST, the NanoLab, help me?

Answer: In the NanoLab, the CNST research staff develops next generation instruments and fabrication processes that go beyond the commercial state-of-the-art tool set available in the NanoFab. Think of the NanoFab as being akin to a world-class hospital, where elaborate and expensive equipment is available and where the support staff is top-flight. The NanoLab would then be closer to a clinical trial, where you work hand-in-hand with our multidisciplinary researchers trying to advance the state-of-the-art. Generally, NanoLab interactions are done on a collaborative, no-fee basis.

Question: So, if I collaborate with somebody in the NanoLab, then I get free access to the NanoFab, right?

Answer: Nope. In order to be fair and to keep the costs for users as low as possible, everybody pays the same rates for accessing the NanoFab, including our own NanoLab researchers.

Question: How hard is it to get access to the NanoFab? How long will it take me?

Answer: We try to make it as easy as possible, requiring only a short form to be submitted. Generally access is within two weeks and we have done it faster when necessary.

Okay, now for you!

Question: How are we doing?

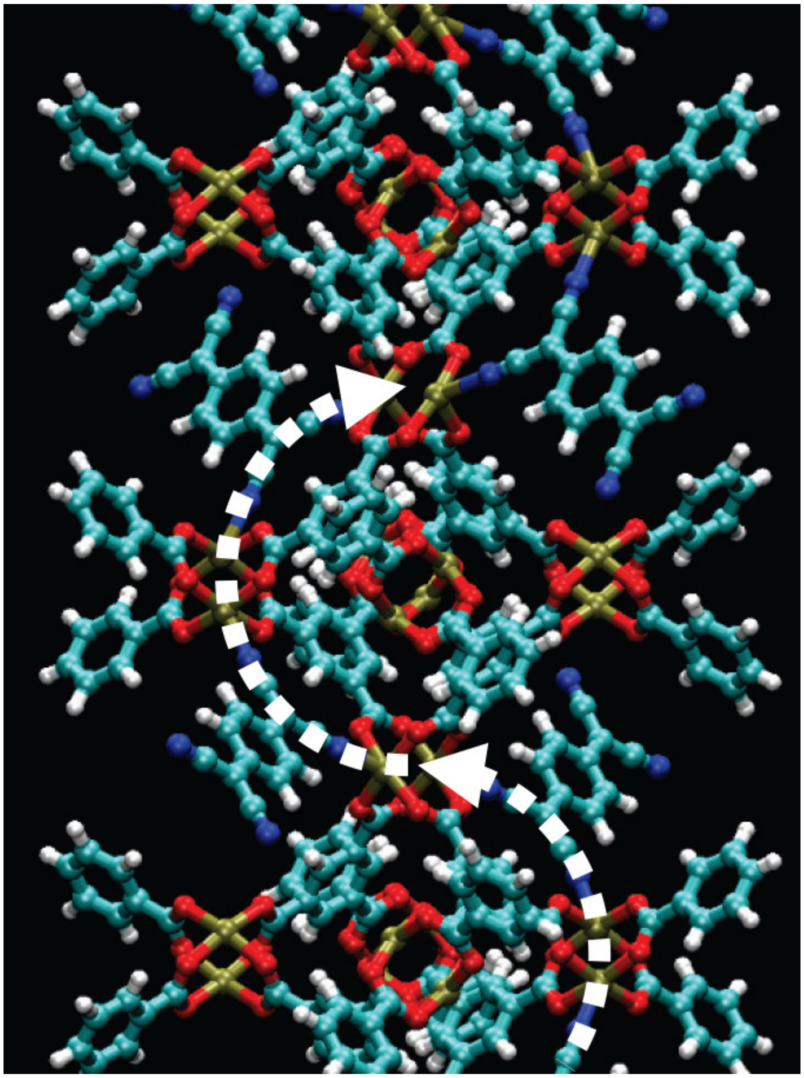
Question: If you have used our facilities, was your experience positive? If we could do better, what would you suggest? What capability or tool do you need that we lack?

Question: If you thought about using our facilities but haven't yet, is there a barrier that we need to know about?

I'd love to hear any comments you might have, positive or negative. Please drop me a note at Robert.Celotta@NIST.gov.

Robert Celotta

BREAKTHROUGH: METAL-ORGANIC FRAMEWORKS THAT ARE ELECTRICALLY CONDUCTING



Credit: M. Foster/Sandia National Labs

Schematic showing electron-sharing tetracyanoquinododimethane molecules bound to copper ions in the framework, enabling electrical conductivity in MOF materials. The dotted white arrows illustrate the mechanism of electrical conductivity in these materials.

Scientists from the CNST and Sandia National Laboratories have added something new to a family of engineered, high-tech materials called *metal-organic frameworks* (MOFs): the ability to conduct electricity. This breakthrough—conductive MOFs—has the potential to make these already remarkable materials even more useful, particularly for detecting gases and toxic substances.

MOFs are three-dimensional crystalline materials with nanoscale pores made up of metal ions linked by various organic molecules. MOFs have huge surface areas, and scientists can easily control the size of their pores and how the pores interact with molecules by tinkering with their chemistries. These characteristics make them ideal for use as catalysts, membranes, or sponges for gas storage or for drug delivery, among other applications.

Thousands of new MOF structures are discovered and characterized each year. While they come in a dizzying array of chemistries and structures, none of them conducts electricity well. The CNST/Sandia team developed a method to modify the electrical conductivity of MOF thin films and to control it over six orders of magnitude. Their findings appear in the journal *Science*.

"MOFs are typically extremely poor electrical conductors because their constituent building blocks, the organic linkers and the metal ions, don't really talk to each other in terms of electrical conduction," says Andrea Centrone, a project leader in the CNST Energy Research Group (ERG). "Our work points to a way of controlling and increasing their conductivity."

The group accomplished this by "infiltrating the insulating MOF with redox-active, conjugated guest molecules." They infused and bound electron-sharing molecules into MOF thin films to create a material that is stable in air and approximately a million times more conductive than the unaltered MOF.

"Based on several spectroscopic experiments, we believe that the guest molecules serve two important purposes: they create additional bridges between the metal ions—copper, in this case—and they accept electrical charge," says ERG project leader Veronika Szalai.

According to Paul Haney, an ERG project leader who provided some modeling for the experimental data, the arrangement of the guest molecules in the MOF creates a unique conductivity mechanism while preserving the benefits of the porous MOF crystalline structure.

These porous and conductive MOFs may be the first in an entirely new class of materials that could be used for sensing, conformal electronics (electronics that can bend and conform to unusual shapes), and other as-yet-unknown applications.

"Our discovery gives chemists and engineers a whole new degree of freedom to tailor these materials for their technological applications," says Centrone. "I would not be surprised if solar cells could be made using this new class of materials."

Tunable electrical conductivity in metal-organic framework thin-film devices, A. A. Talin, A. Centrone, A. C. Ford, M. E. Foster, V. Stavila, P. Haney, R. A. Kinney, V. Szalai, F. E. Gabaly, H. P. Yoon, F. Léonard, and M. D. Allendorf, *Science* **343**, 66–69 (2014).

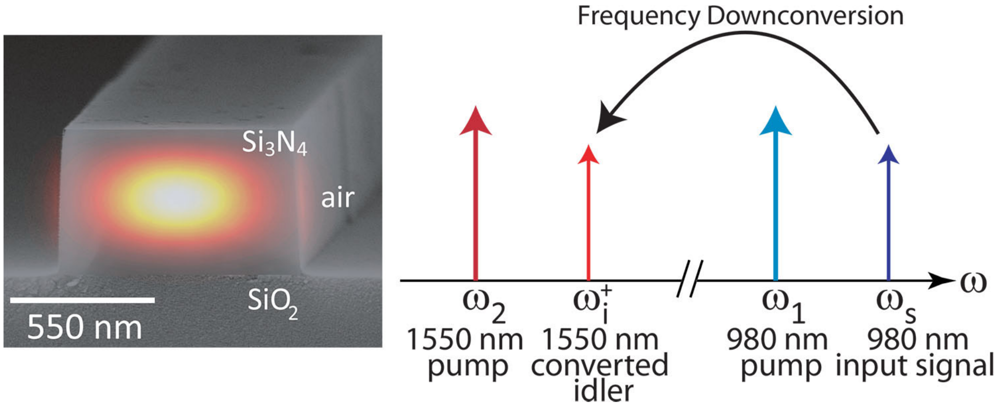
FREQUENCY CONVERSION TO THE TELECOMMUNICATIONS BAND USING A NANOPHOTONICS INTERFACE

Using nanofabricated waveguides in a silicon-based platform, CNST researchers have developed a frequency conversion interface between the telecommunications wavelength band and the optical transition wavelengths found both in quantum dots and in naturally occurring atoms. Optical frequency conversion is an important resource for applications in both classical and quantum information processing, where it can link components of a system that perform optimally at their specific tasks, but operate at different wavelengths.

In this work, the researchers focused on an interface between near-infrared wavelengths below 1000 nm, where systems like semiconductor quantum dots and neutral alkali atoms have their optical transitions, and the telecommunications band of 1550 nm, which is the lowest loss wavelength through which light propagates in an optical fiber. To develop this interface, they built upon previous work (see the Fall 2012 issue of *The CNST News*) in which they demonstrated that a low-noise frequency conversion process called four-wave-mixing Bragg scattering could be realized in silicon nitride waveguides fabricated on a silicon substrate. While that work focused on demonstrating conversion over a range of a few nanometers with conversion efficiencies reaching a few percent, here the authors extended the conversion range to nearly 600 nm. This improvement was made possible by the nature of the four-wave-mixing process, in which the locations of the two pump fields, input signal, and converted signal can be re-arranged while preserving the requirements of energy and momentum conservation.

The authors demonstrated that the process was bi-directional (signals can be converted from 980 nm to 1550 nm and back), and developed designs to interface light at wavelengths all the way down to 637 nm — characteristic of the nitrogen vacancy center in diamond — with the 1550 nm band. All samples were fabricated using CNST NanoFab's thermal oxidation, low pressure chemical vapor deposition, electron beam lithography, and reactive ion etching capabilities.

Future work will be focused on significantly increasing the conversion efficiency levels of these devices by optimizing the geometries and using resonant cavities.



Left: Scanning electron micrograph of the cross-section of a silicon nitride waveguide designed for the frequency conversion with a simulation of the device's optical field profile superimposed. **Right:** As shown in the schematic, in frequency downconversion, an input signal at 980 nm is frequency shifted to the 1550 nm wavelength band through the application of two strong pump lasers. The reverse process of upconversion (shifting an input signal from 1550 nm to 980 nm) was also demonstrated.

A chip-scale, telecommunications-band frequency conversion interface for quantum emitters, I. Agha, S. Ates, M. Davanço, and K. Srinivasan, *Optics Express* **21**, 21628–21638 (2013).

CNST RESEARCHERS PUBLISH REVIEW OF ATOMIC-LEVEL STICK-SLIP BEHAVIOR IN THE ENCYCLOPEDIA OF TRIBOLOGY

Researchers from the University of Pennsylvania, the University of California, Merced, and the CNST have recently published a review chapter on stick-slip behavior at the atomic-level in the Encyclopedia of Tribology. In their review, the collaborators describe the present-day understanding of the atomic-level process by which nanoscale objects interact at sliding contacts.

Atomic-level stick-slip refers to the behavior of a sliding interface, usually an atomic force microscope (AFM) tip sliding along a crystalline surface, where the tip sticks and then slips laterally with respect to the surface. These stick-slip events repeat with the periodicity of the surface's atomic lattice. The stick-slip behavior of both insulating and conducting materials have been studied to reveal interfacial properties, including the degree of commensurability (how well the two surfaces "fit" together at the atomic scale), temperature and load dependencies, and variations in contact stiffness. The chapter provides a brief overview of related experiments and theories and of the different mechanisms that contribute to the stick-slip effect.

The authors end the chapter by describing the potential for stick-slip behavior to be used in applications that enable highly precise manipulation and control of surface or interfacial forces, that allow nanoscale friction to be switched off and on, and that employ stick-slip as a ratcheting mechanism for nanoscale positioning.

Atomic-level stick-slip, R. W. Carpick, A. Martini, and R. J. Cannara, in Encyclopedia of Tribology, edited by Q. J. Wang and Y.-W. Chung (Springer, New York; London, 2013), p. 140–148.

NOW YOU SEE IT: ELECTROMAGNETICALLY INDUCED TRANSPARENCY IN A SILICON NITRIDE OPTOMECHANICAL CRYSTAL

Researchers from the CNST have observed electromagnetically induced transparency at room temperature and atmospheric pressure in a silicon nitride optomechanical system. This work highlights the potential of silicon nitride as a material for producing integrated devices in which mechanical vibrations can be used to manipulate and modify optical signals. The ability to harness the radiation-pressure-based interaction between light and mechanical vibrations in these devices could lead to applications in optical communications and information processing such as optical wavelength conversion and optical signal storage.

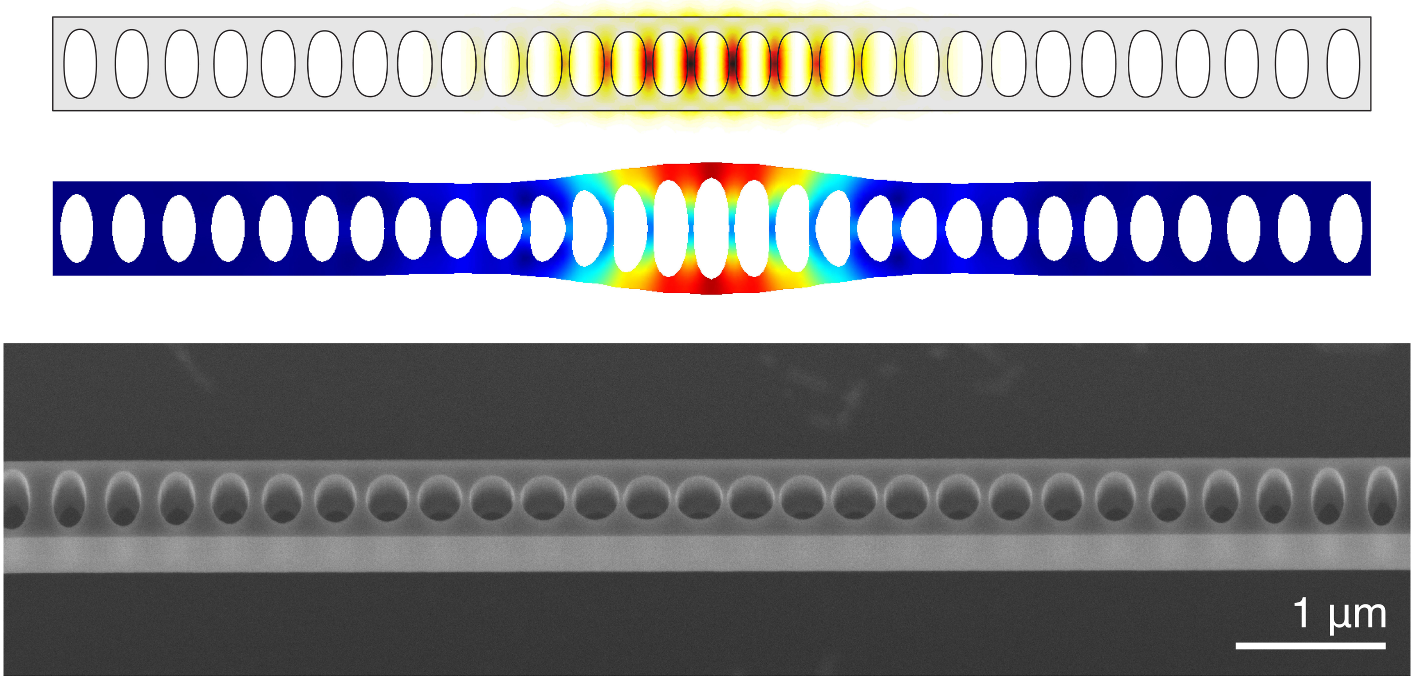
Using the electron beam lithography system and reactive ion etcher available to users at the CNST NanoFab, the researchers produced a line of oval holes with dimensions of a few hundred nanometers on a 700 nm wide, 350 nm thick suspended silicon nitride beam. The finished structure is called a nanobeam optomechanical crystal, and is designed to have complementary mechanical and optical properties.

When near-infrared laser light is injected into the optomechanical crystal, it becomes confined within the etched, suspended beam, within a micrometer-scale region halfway along its length. The sidewalls of the optical confinement region mechanically expand and contract, vibrating at microwave frequencies, forming a so-called breathing mechanical mode. Energy from this breathing mode is added to the stored light, resulting in the generation of a new light signal with a slightly different color (called the anti-Stokes wavelength). This new light signal is also confined within the nanobeam. If an additional probe laser light, now at the anti-Stokes wavelength, is also injected into the crystal, it interferes with the generated optical signal. This interference causes the optomechanical crystal, which originally reflects back light at the anti-Stokes wavelength, to become transparent at that color. This phenomenon, called electromagnetically induced transparency (EIT), has recently been observed in a handful of cavity optomechanical systems at telecom and visible wavelengths. For the first time, the researchers demonstrated the phenomenon at a near-infrared wavelength with the system operating at room temperature and atmospheric pressure and using only moderate optical power.

This result was made possible by designing the system to use radiation pressure to achieve a strong interaction between the stored light and mechanical vibrations of the nanobeam, and by fabricating the device from silicon nitride, a common material in chip-scale devices which is optically transparent over a broad range of wavelengths.

The device demonstrates that optics and mechanics can interact within the silicon nitride platform. It is a first step towards applications that leverage this interaction, including wavelength conversion in which widely spaced optical wavelengths are connected through interaction with the mechanical system. Future work will focus on such wavelength conversion, connecting near-infrared wavelengths planned for quantum information applications, infrared wavelengths used for telecommunications, and possibly even microwave frequencies used in superconducting quantum circuits.

The team included researchers from the CNST, the University of Maryland, and the California Institute of Technology.



Top: Schematic of the crystal geometry, overlaid with a simulation of an optical resonance. **Middle:** Schematic showing a mechanical breathing mode. **Bottom:** Scanning electron micrograph of a silicon optomechanical crystal.

Si_3N_4 optomechanical crystals in the resolved-sideband regime, M. Davanço, S. Ates, Y. Liu, and K. Srinivasan, *Applied Physics Letters*, **104** 041101 (2014).

EXPLAINING INTERACTIONS BETWEEN LIGHT, HEAT, AND CHARGE CARRIERS IN SILICON PHOTONIC MICRORESONATORS

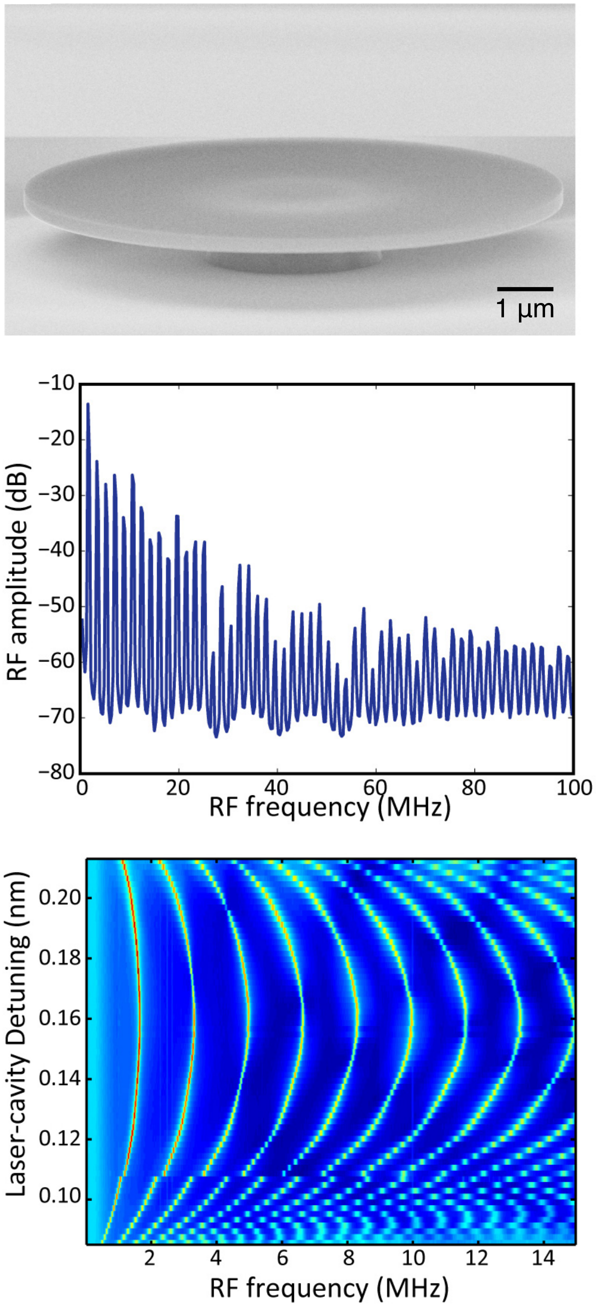
In the March 28th issue of *Physical Review Letters*, researchers from Northwestern University working with researchers from the CNST have presented a new analysis that accurately describes the behavior of silicon photon microresonators in the nonlinear regime, where the amount of light exiting the system is not directly proportional to the amount of light entering it. Their work includes simple equations to provide physical intuition and scaling rules that can be used to design new chip-scale photonic devices, including optically-driven oscillators and switches with potential applications as optical components in computing and communication systems.

The researchers studied a 260 nm thick, 10 µm diameter silicon microdisk resonator fabricated in the CNST NanoFab and optically probed with a continuous infrared laser. When the laser light entering the device is at low intensity, the fraction of that light exiting the device remains constant over time. However, as predicted by the researchers' theory, when the incoming laser intensity is increased past a certain threshold, the exiting light begins to oscillate. Its intensity varies periodically in time. Its frequencies spread across several hundred megahertz and consist of narrow spectral lines which are called a "frequency comb spectrum" because of their resemblance on a graph to the teeth of a comb.

The system's behavior is driven by two-photon absorption, a process by which light is absorbed in the silicon with a strength that depends on the square of the incoming light's intensity. This absorption heats the silicon, changes its refractive index, and generates free charge carriers (e.g., electrons), which further change the refractive index of the silicon and cause additional absorption. This overall interplay between light, heat, and the free charge carriers in the disk leads to a range of interesting behavior, including the experimentally observed oscillations and frequency comb spectrum.

The authors' new theoretical analysis of this behavior combines detailed numerical simulations with a combination of semi-analytic techniques that use approximations to simplify the equations describing the system. This analysis yields simple, yet experimentally verified, expressions for critical quantities such as the frequency comb spacing.

According to the researchers, future work will focus on experimentally studying other regimes of device behavior predicted by the theory and exploring the potential role of such devices in metrology applications.



Top: Scanning electron micrograph of a silicon photonic microdisk resonator which was fabricated in the CNST NanoFab. The researchers studied the nonlinear dynamical behavior caused by the interplay between injected light, heat, and free charge carriers inside the resonator. **Middle:** Frequency spectrum of light exiting the microdisk resonator, exhibiting a "comb" of equally spaced spectral components. **Bottom:** Image plot showing a series of frequency spectra plotted against the detuning, which is the difference between the input laser wavelength and the optical cavity wavelength. The researchers' theoretical analysis accurately models the frequency spacing of the comb lines and how the spacing changes as a function of detuning.

Nonlinear oscillations and bifurcations in silicon photonic microresonators, D. M. Abrams, A. Slawik, and K. Srinivasan, *Physical Review Letters* **112**, 123901 (2014).

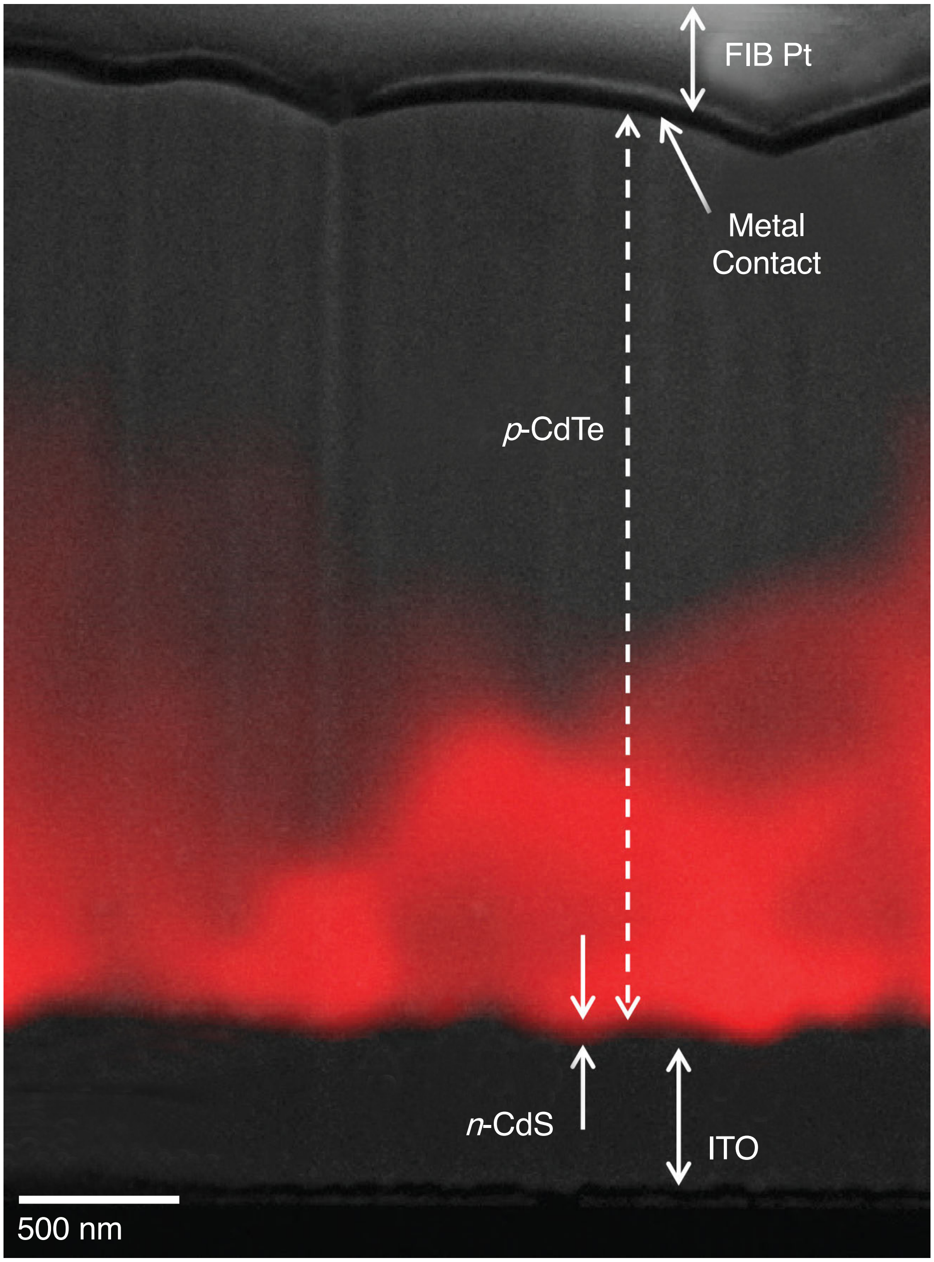
CHARACTERIZING SOLAR CELLS WITH NANOSCALE PRECISION USING A LOW-ENERGY ELECTRON BEAM

CNST researchers have demonstrated a new low energy electron beam technique and used it to probe the nanoscale electronic properties of grain boundaries and grain interiors in cadmium telluride (CdTe) solar cells. Their results suggest that controlling material properties near the grain boundaries could provide a path for increasing the efficiency of such solar cells.

Among thin film photovoltaic solar cells, those made from CdTe are among the most successful on the market. However, the efficiency of commercial cells is still less than half of the theoretical maximum, and the underlying mechanisms for the deficiency are not well understood. CdTe cells are believed to lose current at their material grain boundaries; however, it has also been suggested these grain boundaries have properties that could actually improve carrier collection if they were better understood.

Characterization techniques using focused electron beams to induce currents are increasingly used for investigating the properties of thin film solar cells. The measurements are easier using high energy electrons, but the higher energy reduces the spatial resolution. The researchers extended traditional electron-beam-induced current measurements by using low energy beams to locally excite the CdTe and create current. These beams have a spatial resolution of about 20 nm, small enough to map the photocurrent response inside the grain interiors or at the grain boundaries. The measurements were performed on fragments extracted from a commercial thin film solar cell. Nanoscale electrical contacts were prepared with sizes comparable to a single or a few grains, confining the current path to sizes relevant for understanding current production and loss.

The measurements show that a large fraction of grain boundaries display higher current collection than the grain interiors, seemingly enhancing device performance. However, using 2D finite element simulations, the researchers demonstrated that these grain boundaries also create a large pathway for leakage current, which completely negates the efficiency gains from the enhanced photocurrent collection.



Electron beam induced current (red) superimposed on a scanning electron micrograph (gray). Bright contrast in the vicinity of grain boundaries indicates that these regions have higher carrier collection efficiency than the grain interiors. The use of electron beam induced current to visualize the behavior of photovoltaic cells at these length scales provides a valuable tool for understanding both loss mechanisms within photovoltaic materials as well as internal structures within these materials that may lead to higher overall cell efficiencies.

The researchers believe that their technique provides a valuable tool for visualizing the behavior of photovoltaic cells at the length scales needed to understand both loss mechanisms within photovoltaic materials as well as internal structures within these materials that may lead to higher overall cell efficiencies.

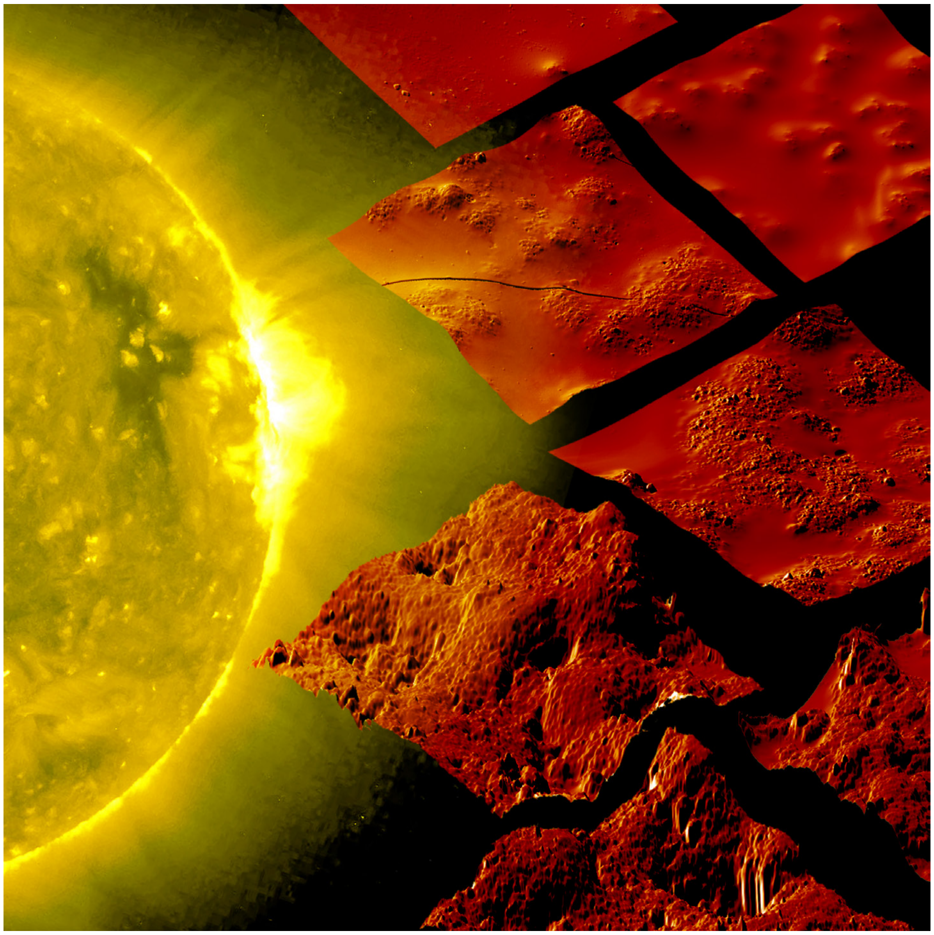
Local electrical characterization of cadmium telluride solar cells using low-energy electron beam, H. P. Yoon, P. M. Haney, D. Ruzmetov, H. Xu, M. S. Leite, B. H. Hamadani, A. A. Talin, and N. B. Zhitenev, *Solar Energy Materials and Solar Cells* **117**, 499–504 (2013).

NEW TESTS EXPLORE SAFETY OF NANOTUBES IN MODERN PLASTICS OVER TIME

Who cares about old plastic? Researchers at the NIST Material Measurement Laboratory (MML) and the CNST do, so that you won't have to years down the road, when today's plastics start to break down and disintegrate from weather exposure. They are working to devise better tests to make sure aging plastics won't turn into environmental or health hazards as time goes by.

Tests like these are more important now than ever, because plastics aren't what they used to be. Modern epoxies are increasingly made stronger, lighter and more resilient with the addition of multiwalled carbon nanotubes (MWCNTs). These nanotubes already enhance plastics used in baseball bats, tennis rackets, bikes and airplanes, and though the tiny tubes appear to be long-lasting, no comprehensive set of tests exists to determine what happens to them over the long haul. A NIST team took steps to change that.

"Some studies have been done about the effect of ultraviolet (UV) light, but not with a large number of analytical methods," says MML's Elijah Petersen. "We wanted to begin developing a suite of tests for evaluating the performance of these nanocomposite materials, so that we can examine their potential risks, if any, during usage."



Exposed to intense ultraviolet light and high temperatures, samples of epoxy containing multiwalled carbon nanotubes deteriorated. Exposure tended to destroy the epoxy, but on the surface remained a network of nanotubes, which NIST tests indicated were less damaged than the epoxy over time.

The team needed a way to simulate the degrading effect of years of high temperature, humidity and sunlight, but without waiting that long for results. They created samples of epoxy with 3.5 percent MWCNTs—a fairly typical mixture quantity—and put them into a NIST-developed device called SPHERE (Simulated Photodegradation via High Energy Radiant Exposure), which pours out powerful UV light into a chamber kept at 50 degrees Celsius and 75 percent humidity. Keeping the samples there for 100 days "was the equivalent of four years in the bright Florida sun," Petersen says.

After exposing the samples to this artificial Florida, the team ran a set of six different tests that analyzed changes ranging from mass to appearance to surface chemistry. One major discovery was that the UV light tended to destroy the epoxy, but on the surface remained a spaghetti-like network of nanotubes, which the group of tests indicated were less damaged by SPHERE exposure than the epoxy matrix.

So are these nancomposite materials stable forevermore? Petersen says the study did not answer every question, but that it should help researchers determine answers more effectively than was possible before by development and optimization of multiple analytical methods.

"We got a lot of new information from the test suite about how nanocomposites degrade," says Petersen, "and the most encouraging thing is that the results of the different tests generally back one another up. We hope the test suite allows for better analysis of the stability of these new plastics, which are growing more common in everyday life."

Methods to assess the impact of UV irradiation on the surface chemistry and structure of multiwall carbon nanotube epoxy nanocomposites, E. J. Petersen, T. Lam, J. M. Gorham, K. C. Scott, C. J. Long, D. Stanley, R. Sharma, J. Alexander Liddle, B. Pellegrin, and T. Nguyen, *Carbon* **69**, 194–205 (2014).

CNST RESEARCHERS DEVELOP FRAMEWORK FOR UNDERSTANDING CURRENT-SWITCHED MAGNETIC DEVICES

An international collaboration led by researchers from the CNST has made significant progress in modeling how electric currents affect the magnetization in some current-switched magnetic devices. While a number of such devices hold promise as low energy electronics, progress on some of the latest ideas has been impeded because different and contradictory models have been proposed to understand how they work and how to best optimize their performance.

Electronic devices based on magnetic materials have the potential to significantly reduce energy consumption below that of CMOS devices because they retain their state even after current has been removed. However, devices that use magnetic fields to switch their magnetization do not scale well to smaller sizes. An alternate approach that scales well has recently been developed. It uses spin currents rather than magnetic fields to transfer information between the electrical current and the magnetization. One promising device is spin-transfer-torque switch magnetic random access memory (STT-MRAM), which is in development in several leading integrated circuit manufacturers. Device designers are searching for ways to reduce the current required to switch the magnetization in order to reduce both device size and energy consumption. One possible mechanism for reducing current is to incorporate materials with strong spin-orbit coupling, where the spin of the particle strongly affects its motion. Several experimental groups have shown remarkable results for switching magnetic bits and for moving domain walls in magnetic nanowires, which have strong spin-orbit coupling.

Common factors in these devices are their reliance on strong spin-orbit coupling and the presence of an interface between different materials. To test the existing theories for explaining their measured behavior, the researchers have taken a variety of approaches with the goals of unifying the disparate models and connecting the models' results to the experimental systems. In one approach, they compute all of the relevant experimental quantities predicted by a widely used theoretical model. They find that this single model cannot consistently explain all of the data, indicating that other important physics is at play in these systems. In a complementary approach, they compute the interfacial spin-orbit coupling and its consequences using first principles techniques. They show that the ability to switch the magnetization by current flow is determined by the extent to which the material with strong spin-orbit coupling induces large spin-orbit splitting, or changes in the electron energy levels, in the ferromagnetic material.

The researchers believe that these analyses form a framework that can help experimentalists select materials to optimize the spin-orbit splitting needed for successful current-switched magnetic devices.

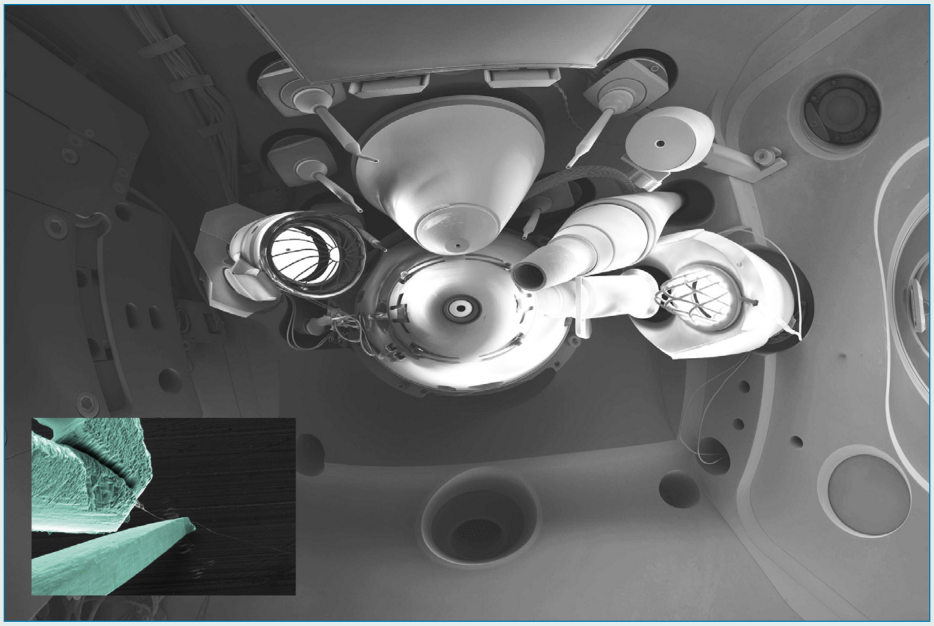
The collaboration included researchers from the CNST; Pohang University of Science and Technology, Korea; Korea University, Korea; and King Abdullah University of Science and Technology, Saudi Arabia.

Chirality from interfacial spin-orbit coupling effects in magnetic bilayers, K. -W. Kim, H. -W. Lee, K. -J. Lee, and M. D. Stiles, *Physical Review Letters* **111**, 216601 (2013).

Current-induced torques and interfacial spin-orbit coupling, K. J. Lee, H. W. Lee, A. Manchon, P. M. Haney, and M. D. Stiles, *Physical Review B* **88**, 214417 (2013).

A VIEW FROM THE INSIDE

Scanning electron micrograph of the inside of one of the NanoFab's two FEI Helios 650 microscopes. Each dual-beam microscope combines a monochromated field emission scanning electron microscope with an advanced focused ion beam column for fast, precise nanomachining and nanoscale structural characterization. The first microscope's enhanced capabilities include nanoscale positioning and *in situ* electrical measurements using a Kleindiek four-probe system with rotating grippers (inset) and a dedicated low-noise vacuum feed through to take electrical signals from the substrate to a parametric tester located outside of the vacuum chamber. The second microscope includes capabilities for simultaneous chemical characterization using energy dispersive x-ray spectroscopy and material crystallographic characterization using electron backscatter diffraction.



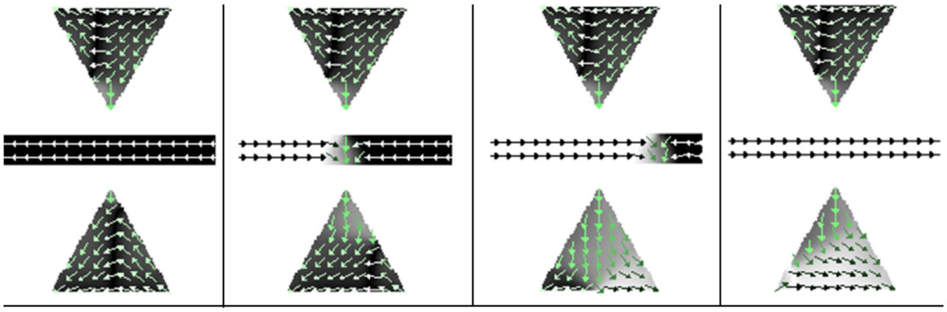
CNST RESEARCHERS DEMONSTRATE FEASIBILITY OF USING DOMAIN WALL CHIRALITY FOR STORING INFORMATION

CNST researchers have found that the chirality of a magnetic domain wall in a nanowire can be used to store information. Recently there has been a great deal of interest in devices that can potentially store information by reading and writing domain walls in nanowire structures. Magnetic domain walls, which separate regions of opposite magnetization, can be moved along the wire using magnetic fields or electrical currents, and they can be detected by magnetic sensors along the wire. In thin nanoscale stripes such as nanowires, the magnetization within a domain wall can either rotate in a clockwise or a counterclockwise direction. The researchers found that, like the presence of the domain wall itself, this domain wall chirality can be sensed using magnetic nanostructures that are patterned near the wires, providing an additional way to store binary data.

Using various magnetic nanostripes and sensing elements that were custom-made in the CNST NanoFab, the researchers systematically explored the sensitivity and reliability of chirality sensing to various geometries. The researchers found that they were able to sense domain wall chirality when triangular elements were placed within 50 nm of the stripe edge. As domain walls of different chiralities pass these triangles, the magnetization in the triangles changes. In a device, the magnetization changes in the triangular elements could be read using either conventional giant magnetoresistance, a method used in commercial hard drives, or other established techniques.

The motion of the domain walls and their interactions with the sensing elements are directly imaged using CNST's scanning electron microscopy with polarization (SEMPA) microscope. The domain wall interactions with the sensor elements were also simulated using NIST's Object Oriented MicroMagnetic Framework (OOMMF) modelling software The experiments and modelling show that changes as small as 10 nm in the dimensions of the elements can affect the reliability of the switching.

This work demonstrates both the feasibility of using domain wall chirality for storing information or for manipulating logic, and the sensitivity of chirality-based device operation to the quality of the nanoscale lithography and the elimination of structural defects during fabrication.



Domain wall chirality can be sensed when triangular elements are placed within 50 nm of the edge a magnetic nanostripe. **Left to right:** as a domain wall (shown as a boundary between white and black regions) in the center stripe passes the triangles, the magnetization in the lower triangles changes.

Field-driven sense elements for chirality-dependent domain wall detection and storage, S. R. Bowden and J. Unguris, *Journal of Applied Physics* **114**, 223904 (2013).

CNST DEPUTY DIRECTOR LLOYD WHITMAN SERVING AS INTERIM DIRECTOR OF THE NATIONAL NANOTECHNOLOGY COORDINATION OFFICE

CNST Deputy Director Lloyd Whitman has been detailed to the National Science and Technology Council (NSTC) to serve as the Interim Director of the National Nanotechnology Coordination Office (NNCO). He is leading the coordination and integration of the scientific research components of the National Nanotechnology Initiative and he assists the co-Chairs of the Nanoscale Science, Engineering and Technology Subcommittee under the NSTC in long-range planning, coordinating with agencies and other NSTC groups and coordination offices. Lloyd will lead the NNCO until a new Director is in place (which is expected to be within 6 months). His appointment follows the recent retirement of NNCO Director Dr. Robert Pohanka.

"Lloyd's broad background in nanotechnology and long involvement with the National Nanotechnology Initiative will help to maintain the Initiative's important work in this economically important domain of science and technology, and will ensure a smooth transition while we conduct a national search for the next NNCO Director," said Dr. Altaf (Tof) Carim, Assistant Director for Nanotechnology at the Office of Science and Technology Policy.

Dr. Whitman has been a representative for both the Department of Defense and for NIST on the National Science and Technology Council, Subcommittee on Nanoscale Science, Engineering and Technology (NSET), and since December 2012 has served as Co-Chair of the NSET.

COMING SOON: NEW TOOLS IN THE NANOFAB

The CNST has acquired a range of new tools which will become available to NanoFab users in the coming months.

Sputtering Cluster System

The CNST has purchased a 4Wave Sputtering Cluster System (SCS) which will be available to users in fall 2014. The new SCS can deposit a variety of high quality thin films with 12 ready-to-deposit materials using ion beam deposition technology. Its cassette-to-cassette and robot wafer handling allow for largely unattended 24/7 deposition capability along with the densest thin films available via physical vapor deposition at room temperature.

The SCS will be able to deposit the following materials: Cr, Au, Fe, Ni, Ti, Pt, Ta, Al, Co, SiO_2, ITO, TiO_2, Ta_2O_5, and Permalloy. For additional information, please contact Gerard Henein, 301-975-5645, gerard.henein@nist.gov.

Lithography Coater System

A new SUSS MicroTec ASC200 Gen 3 automated resist coater, which will be available to users in summer 2014, can spray and spin resist coating and has automated wafer handling and resist baking. The device can apply high quality resist films on wide range of substrate shapes, sizes and topologies with consistent and uniform results. This new resist coater will enhance the quality, repeatability and throughput of NanoFab precision lithographic imaging. For more information, contact Liya Yu, 301-975-4590, liya.yu@nist.gov.

Direct Write E-Beam Lithography System

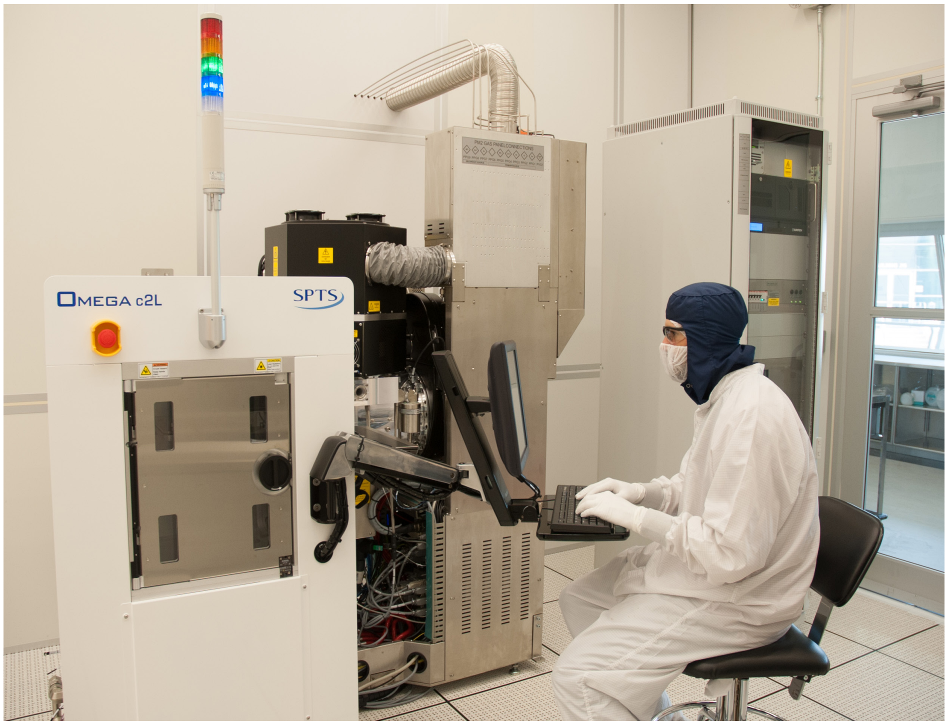
A second JEOL JBX-6300FS direct write electron beam lithography system is going to be installed in the cleanroom in summer 2014. The new state-of-the-art system is used to pattern electron sensitive materials or resists during the fabrication of nanoscale structures and devices. It lithographically defines the nanoscale structures on resist coated substrates using an electron beam focused to nanometer-diameter spot size. The system allows high resolution exposure capability and provides automated substrate processing with batch handling. For more information, contact Rich Kasica, 301-975-2693, rkasica@nist.gov.

Deep Silicon Etcher

The CNST has purchased a new SPTS Omega c2L Rapier deep silicon etcher (DSE) which will be available to users at the end of June. The new DSE etches silicon wafers up to 200 mm in diameter faster than the NanoFab's current deep silicon etcher while providing both smoother sidewalls and better end point detection. The tool can fabricate three-dimensional structures in silicon with very high aspect ratio (greater than 50 to 1) vertical sidewalls. Applications include fabricating microelectromechanical and nanoelectromechanical systems (MEMS and NEMS) such as accelerometers, ink jet heads, pressure sensors, gyroscopes, microphones, microactuators, and lab-on-a-chip devices. For more information, contact Lei Chen, 301-975-2908, lei.chen@nist.gov.

Hydrofluoric Acid Vapor Etcher

A new SPTS μEtch stand-alone hydrofluoric acid (HF) vapor etcher has been installed in the cleanroom in room 215/B102 and is available for reservations through the NEMO system. This tool uses a combination of hydrofluoric acid vapor and alcohol to create a vapor that isotropically etches silicon dioxide without etching silicon. Applications include fabricating microelectromechanical and nanoelectromechanical systems (MEMS and NEMS) such as accelerometers, ink jet heads and pressure sensors. The tool can release microscale and nanoscale silicon structures by etching a sacrificial layer of silicon dioxide underneath a silicon device layer, leaving the silicon structures freely suspended. For more information, contact Rich Kasica, 301-975-2693, rkasica@nist.gov.



NanoFab Engineer Marc Cangemi testing the CNST's new SPTS Omega c2L Rapier deep silicon etcher (DSE). The new DSE etches silicon wafers up to 200 mm in diameter faster than the NanoFab's current deep silicon etcher while providing both smoother sidewalls and better end point detection.

CNST Center for Nanoscale Science & Technology

CENTER FOR NANOSCALE SCIENCE AND TECHNOLOGY

The CNST is a national user facility purposely designed to accelerate innovation in nanotechnology-based commerce. Its mission is to operate a national, shared resource for nanoscale fabrication and measurement and develop innovative nanoscale measurement and fabrication capabilities to support researchers from industry, academia, NIST, and other government agencies in advancing nanoscale technology from discovery to production. The Center, located in the Advanced Measurement Laboratory Complex on NIST's Gaithersburg, MD campus, disseminates new nanoscale measurement methods by incorporating them into facility operations, collaborating and partnering with others, and providing international leadership in nanotechnology.

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SUPPORTING THE DEVELOPMENT OF NANOTECHNOLOGY FROM DISCOVERY TO PRODUCTION

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VISIT THE CNST BOOTH AT THE

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NEW NANOFAB TOOL RESERVATION RULES

In an effort to ensure that tools are available to users when they need them, the CNST is implementing new tool reservation rules for the NanoFab. Users will soon see the new rules when using the NEMO tool reservation system. These tool rules will limit the amount of time and the number of adjacent reservations that a user can schedule for each tool. The rules will be customized for every tool and will be listed on the NEMO tool pages. Beginning in July, the reservation rules for every tool will also be listed on the NanoFab web site. These rules will be modified and optimized over time, based on efficiency data and on input that we receive from our users. Once the system is in place, we ask users to send comments and feedback to nemo@nist.gov.