THE CNST NEWS

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NANOPORES SIMULATE ION CHANNELS

INSIDE

RESEARCHERS BUILD HYBRID PHOTONIC CIRCUIT

SIZING UP NANOPARTICLES

APERIODIC STRUCTURES ACT AS COLOR DIRECTORS

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

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IN THIS ISSUE

Cover: In this simulation of an ion channel, the biological membrane (gray) with an ion channel (center) is immersed in a solution of water and ions. This cross section of a simulation "box" shows the electric potential, the externally supplied "force" that drives ions through the channel. A dazzling pattern emerges in this potential due to the presence of the channel—the colors show the lines of equal potential. The slowly decaying nature of this pattern in space makes simulations difficult. The golden aspect ratio—the chosen ratio of height to width of this box—allows for small simulations to effectively capture the effect of the large spatial dimensions of the experiment. Credit: NIST

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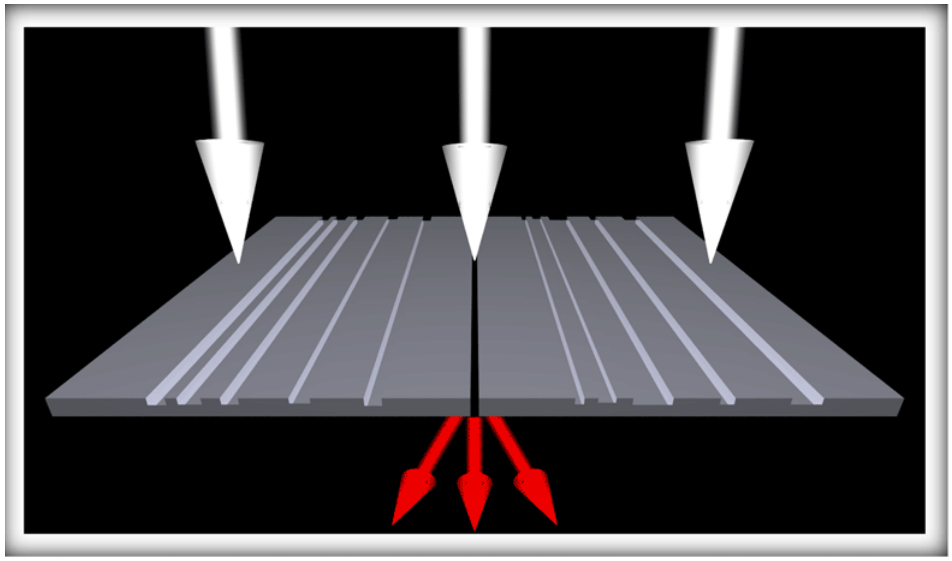
NIST HONORS ACHIEVEMENTS OF THREE CNST STAFF

At NIST's 45th annual awards ceremony last December, CNST senior management advisor Donna Lauren (left) was honored, along with seven colleagues, for creating the Undelivered Order Review application. Jabez McCelland (middle), group leader of the Electron Physics Group, was recognized for a patent that describes a new way to create a bright ion source based on laser cooling an ion beam directly. Henri Lezec (right), a project leader in the Nanofabrication Research Group, was honored for a patent describing the invention of a field emission electron source comprised of an array of conductive sharp tips made of nanoporous silicon carbon.

COLOR ME PURPLE, OR RED, OR GREEN, OR …

NIST researchers develop color filters that respond to the angle of incident light



Schematic shows two different ways that white light interacts with a newly developed device, a directional color filter ruled with grooves that are not uniformly spaced. When white light illuminates the patterned side of the compact metal device at three different angles—in this case, 0°, 10° and 20°—the device transmits light at red, green and blue wavelengths, respectively. When white light incident at any angle illuminates the device from the non-patterned side, it separates the light into the same three colors, and sends off each color in different directions corresponding to the same respective angles. Credit: NIST

Imagine a miniature device that suffuses each room in your house with a different hue of the rainbow—purple for the living room, perhaps, blue for the bedroom, green for the kitchen. A team led by scientists at the CNST has, for the first time, developed nanoscale devices that divide incident white light into its component colors based on the direction of illumination, or directs these colors to a predetermined set of output angles.

Viewed from afar, the device, referred to as a directional color filter, resembles a diffraction grating, a flat metal surface containing parallel grooves or slits that split light into different colors. However, unlike a grating, the nanometer-scale grooves etched into the opaque metal film are not periodic—not equally spaced. They are either a set of grooved lines or concentric circles that vary in spacing, much smaller than the wavelength of visible light. These properties shrink the size of the filter and allow it to perform many more functions than a grating can.

For instance, the device's nonuniform, or aperiodic, grid can be tailored to send a particular wavelength of light to any desired location. The filter has several promising applications, including generating closely spaced red, green and blue color pixels for displays, harvesting solar energy, sensing the direction of incoming light and measuring the thickness of ultrathin coatings placed atop the filter.

In addition to selectively filtering incoming white light based on the location of the source, the filter can also operate in a second way. By measuring the spectrum of colors passing through a filter custom-designed to deflect specific wavelengths of light at specific angles, researchers can pinpoint the location of an unknown source of light striking the device. This could be critical to determine if that source, for instance, is a laser aimed at an aircraft.

"Our directional filter, with its aperiodic architecture, can function in many ways that are fundamentally not achievable with a device such as a grating, which has a periodic structure," said CNST physicist Amit Agrawal. "With this custom-designed device, we are able to manipulate multiple wavelengths of light simultaneously."

Matthew Davis and Wenqi Zhu of the CNST and the University of Maryland, along with Agrawal and CNST physicist Henri Lezec, described their work in the latest edition of *Nature Communications*. The work was performed in collaboration with Syracuse University and Nanjing University in China.

The operation of the directional color filter relies on the interaction between the incoming particles of light—photons—and the sea of electrons that floats along the surface of a metal. Photons striking the metal surface create ripples in this electron sea, generating a special type of light wave—plasmons—that has a much smaller wavelength than the original light source.

The design and operation of aperiodic devices are not as intuitive and straightforward as their periodic counterparts. However, Agrawal and his colleagues have developed a simple model for designing these devices. Lead author Matthew Davis explained, "this model allows us to quickly predict the optical response of these aperiodic designs without relying on time-consuming numerical approximation, thereby greatly decreasing the design time so we can focus on device fabrication and testing."

M.S. Davis, W. Zhu, T. Xu, J.K. Lee, H.J. Lezec and A. Agrawal. Aperiodic nanoplasmonic devices for directional colour filtering and sensing, *Nature Communications*. Published online 7 November 2017.
DOI: 10.1038/s41467-017-01268-y

PLASMONS IN AN OPEN BOX CREATE MINIATURE LASER

Device could become exquisite sensor of environmental chemicals and biological molecules.

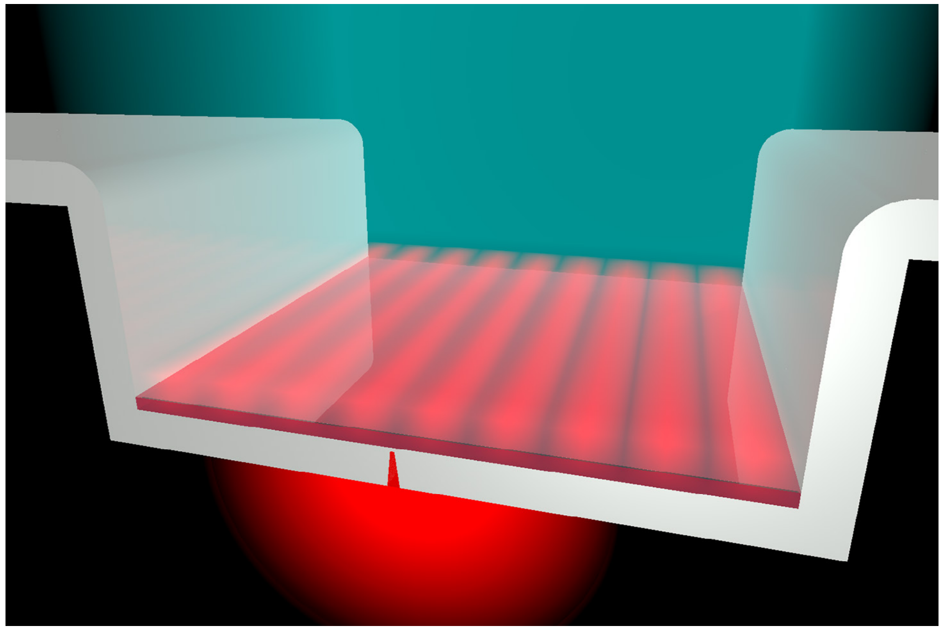
Scientists have developed the first miniature laser in which the light is guided along the floor of an open metallic trench. The laser could act as a nanoscale device to sense minute amounts of pollutants and other chemicals in the environment, or detect the surface binding of biomolecules for medical diagnostics.

Wenqi Zhu of the CNST and the University of Maryland, along with CNST physicists Henri Lezec and Amit Agrawal, described their work in a recent edition of *Science Advances*. The work was performed in collaboration with Nanjing University in China and the University of Michigan.

The development of the new laser relies on the interaction between photons—particles of light—and the sea of electrons that floats along the surface of a metal. Interactions between the photons and ripples in the electron sea yield a special type of light wave, dubbed a surface plasmon polariton (SPP), which is tightly confined to travel only along the metal's surface. This confinement makes the SPPs highly sensitive to anything lying on the metal surface.

As a first step toward building the miniature laser, the team fashioned out of silver a small trench-shaped open cavity in which SPPs can resonate. The cavity is a flat surface flanked by tiny, mirror-like sidewalls that reflect the surface waves back and forth.

Through careful fabrication, the resonant cavity possessed two key properties: all of its interior surfaces were smooth on an atomic scale, varying in thickness by no more than a few nanometers, and its sidewalls were perpendicular with respect to the flat cavity floor. The design, made possible by molding silver using a precisely patterned silicon template, enabled the SPPs to bounce back and forth across the cavity hundreds of times without losing significant energy, like a guitar string sustaining a pure note for a long time. That property, known as high quality factor, or high Q, is essential for constructing a laser. The Q measured by the team is the highest to date for any visible-light resonator using only SPPs.



This artist's illustration of a cavity and sidewalls, made of silver, forms the miniature laser fabricated by scientists working at NIST. The cavity's ultrathin coating (flat red layer) is the amplifying layer used to induce SPP lasing under illumination from above (blue-green light beam); a small amount of the red laser light leaks through a nanoscale notch positioned just below the cavity's floor enabling researchers to monitor small wavelength shifts induced by the presence of the molecules on the cavity floor. Credit: NIST

The high Q also enabled the cavity to act as an extremely selective filter for SPPs—only those with wavelengths that fell within a narrow band could resonate in the cavity. The narrow range is important because it enables the resonant cavity (even before it became part of a laser) to become a highly sensitive detector of tiny changes in its environment—the presence of particulate matter or the addition of a thin film to the cavity's floor. Such changes shift the center of the band of wavelengths that will resonate in the cavity.

"By achieving a narrow resonance, the shift in wavelength is clear, and the open cavity can act as an exquisitely sensitive detector," said Lezec.

After demonstrating that the cavity could be used as a sensor, the team then worked to turn their design into a laser. They did so by adding an ultrathin coating to the cavity that amplified the intensity of the SPP traveling through the structure. This is the first nanoscale laser ever constructed by manipulating an SPP traveling on a single flat metal surface, Lezec noted.

Simulations suggest the SPP laser could become an even more sensitive detector for biological, chemical and environmental materials than using just the resonant cavity. The design of the laser also enables it to be easily integrated into a photonic circuit and may also enable new studies of quantum plasmonics, the nanoscale interaction of matter with the quantum properties of light.

Wenqi Zhu, Ting Xu, Haozhu Wang, Cheng Zhang, Parag B. Deotare, Amit Agrawal and Henri J. Lezec. Surface-Plasmon-Polariton Laser based on a Metallic Trench Fabry-Perot Resonator. *Science Advances*. Published online 6 October 2017. DOI: 10.1126/sciadv.1700909.

ATOMIC BLASTING FORMS NEW DEVICES TO MEASURE NANOPARTICLES

Like sandblasting at the nanometer scale, focused beams of ions ablate hard materials to form intricate three-dimensional patterns. Despite the ability of the beams to finely resolve the lateral dimensions—length and width—it has been unclear how precisely the energetic ions could control the vertical dimension—depth—to produce the next generation of device technologies. Now, researchers at the National Institute of Standards and Technology (NIST) have demonstrated that a standard ion-beam technique can be fine-tuned to make structures with depths controlled to within the diameter of a single silicon atom.

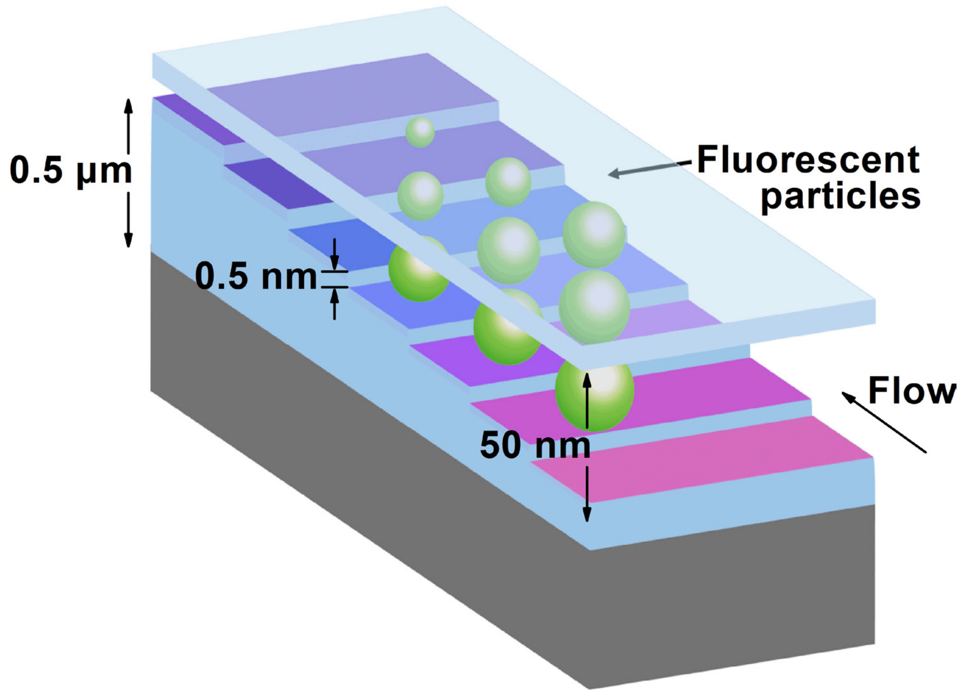
Taking advantage of that newly demonstrated precision, the NIST team used the machining technique to fabricate devices that allow precise measurement of the size of nanoparticles in a liquid. The fluidic devices, which have the potential to be mass-produced, could become a new laboratory standard for determining nanoparticle size. Such measurements could expedite quality control in industrial applications of nanoparticles.

"We have tested and pushed the limits of what is possible to make and measure below one nanometer," said NIST researcher Samuel Stavis. He and his colleagues from NIST and the Maryland NanoCenter at the University of Maryland in College Park reported their findings in a recent issue of *Lab on a Chip*.

Although engineers have for years used ion beams to fix defects in integrated circuits and machine tiny parts in optical and mechanical systems, those applications did not require the depth control the team has now reported.

To realize the full potential of the process, the team explored several ways of using a focused beam of gallium ions to mill the surfaces of silicon, silicon nitride, and silicon dioxide—materials that are common for the fabrication of nanoscale devices used in electronics, optics, and mechanics. The team detailed their process so that NIST users can readily take advantage of and adapt the process for their own work. The researchers used an atomic force microscope, which features a sensitive probe to measure the depth of the topography formed by the ion beam. Careful measurements were important to testing the limits of the ion-beam technique. The facilities at NIST enabled the team to undertake both tasks—precision fabrication and precision measurement.

The team applied the new capability to improve the measurement of the size of nanoparticles. Using a gallium ion beam, the researchers machined staircase patterns in silicon dioxide and then enclosed them to control the flow of fluid at the nanoscale. In some devices, the researchers machined a staircase with a step size of 1.1 nanometers; they machined others with a step size of 0.6 nanometers—just a few atoms in depth.



A nanofluidic staircase machined with subnanometer precision by a focused ion beam separates nanoparticles by size. The device is also a reference material to accurately measure nanoparticle size and compare it to optical brightness, which could aid in the quality control of consumer products. Credit: NIST

The steps of the staircase pattern precisely separated nanoparticles immersed in water according to their size. Nanoparticles flowed in to the deepest step at the bottom of the staircase, but only the smaller ones could ascend towards the shallowest step at the top; larger nanoparticles could not fit through and remain trapped at the bottom set of steps. Fluorescent dye within the nanoparticles enabled the team to record their location with an optical microscope and match that location to the known depth of the staircase.

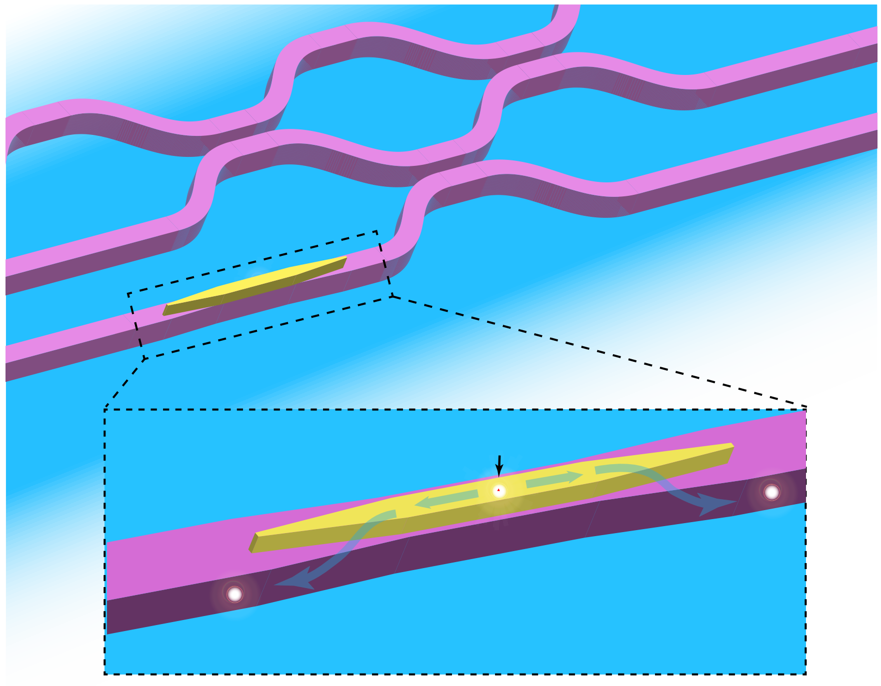
Continued on page 7

HYBRID CIRCUIT COMBINES SINGLE-PHOTON GENERATOR AND EFFICIENT WAVEGUIDES ON ONE CHIP

New architecture could prove essential for high-performance quantum photonic circuits

Scientists at the CNST and their collaborators have taken a new step forward in the quest to build quantum photonic circuits—chip-based devices that rely on the quantum properties of light to process and communicate information rapidly and securely.

The quantum circuit architecture devised by the team is among the first to combine two different types of optical devices, made from different materials, on a single chip—a semiconductor source that efficiently generates single particles of light (photons) on demand, and a network of "waveguides" that transports those photons across the circuit with low loss. Maximizing the number of photons, ideally having identical properties, is critical to enabling applications such as secure communication, precision measurement, sensing and computation, with potentially greater performance than that of existing technologies.



The architecture of this hybrid quantum photonic circuit is among the first to combine on a single chip a reliable generator of individual photons—a quantum dot (red dot), here embedded in gallium arsenide (yellow)—with passive elements such as a low-loss waveguide (purple) that transports the photons Credit: NIST

The architecture, developed by Marcelo Davanco and other NIST researchers along with collaborators from China and the U.K., employs a nanometer-scale semiconductor structure called a quantum dot—made from indium arsenide—to generate individual photons on the same chip as the optical waveguides—made from silicon nitride. Combining these two materials requires special processing techniques. Such hybrid circuit architectures could become building blocks for more complex systems.

Previously, quantum integrated photonic circuits typically consisted of only passive devices such as waveguides and beam splitters, which let photons through or allowed them to coalesce. The photons themselves still had to be produced outside the chip, and getting them onto the chip resulted in losses, which significantly degraded the performance of the circuit. Circuit architectures that did include quantum light generation on a chip either incorporated sources that only produced photons randomly and at low rates—which limits performance—or had sources in which one photon was not necessarily identical with the next. In addition, the fabrication processes supporting these previous architectures made it difficult to scale up the number, size and complexity of the photonic circuits.

In contrast, the new architecture and the fabrication processes the team developed should enable researchers to reliably build larger circuits, which could perform more complex computations or simulations and translate into higher measurement precision and detection sensitivity in other applications.

The quantum dot employed by the team is a well-studied nanometer-scale structure: an island of the semiconductor indium arsenide surrounded by gallium arsenide. The indium arsenide/gallium arsenide nanostructure acts as a quantum system with two energy levels—a ground state (lower energy level) and an excited state (higher energy level). When an electron in the excited state loses energy by dropping down to the ground state, it emits a single photon.

Unlike most types of two-level emitters that exist in the solid state, these quantum dots have been shown to generate—reliably, on demand, and at large rates—the single photons needed for quantum applications. In addition, researchers have been able to place them inside nanoscale, light-confining spaces that allow a large speedup of the single-photon emission rate, and in principle, could also allow the quantum dot to be excited by a single photon. This enables

HYBRID CIRCUIT COMBINES SINGLE-PHOTON GENERATOR AND EFFICIENT WAVEGUIDES ON ONE CHIP (CONT'D.)

the quantum dots to directly assist with the processing of information rather than simply produce streams of photons.

The other part of the team's hybrid circuit architecture consists of passive waveguides made of silicon nitride, known for their ability to transmit photons across a chip's surface with very low photon loss. This allows quantum-dot-generated photons to efficiently coalesce with other photons at a beam splitter, or interact with other circuit elements such as modulators and detectors.

"We're getting the best of both worlds, with each behaving really well together on a single circuit," said Davanco. In fact, the hybrid architecture keeps the high performance achieved in devices made exclusively of each of the two materials, with little degradation when they are put together. He and his colleagues described the work in a recent issue of *Nature Communications*.

To make the hybrid devices, Davanco and his colleagues first bonded two wafers together—one containing the quantum dots, the other containing the silicon nitride waveguide material. They used a variation of a process that had originally been developed for making hybrid photonic lasers, which combined silicon for waveguides and compound semiconductors for classical light emission. Once the bonding was finished, the two materials were then sculpted with nanometer-scale resolution into their final geometries through state-of-the-art semiconductor device patterning and etching techniques.

Although this wafer bonding technique was developed more than a decade ago by other researchers, the team is the first to apply it towards making integrated quantum photonic devices.

"Since we have expertise in both fabrication and quantum photonics, it seemed clear that we could borrow and adapt this process to create this new architecture," notes Davanco.

This work was performed in part at the CNST and also included researchers from NIST's Physical Measurement Laboratory.

M. Davanco, J. Liu, L. Sapienza, C.-Z. Zhang, J.V. De Miranda Cardoso, V. Verma, R. Mirin, S.W. Nam, L. Liu and K. Srinivasan. Heterogeneous integration for on-chip quantum photonic circuits with single quantum dot devices. *Nature Communications*. Published online 12 October 2017. DOI: 10.1038/s41467-017-00987-6

ATOMIC BLASTING FORMS NEW DEVICES TO MEASURE NANOPARTICLES (CONT'D.)

Comparing the nanoparticle sizes indicated by this method with the sizes measured using electron microscopy revealed a match that was accurate to within one nanometer. This good agreement of the different measurements suggests that the devices can serve not only a particle separator but as a reference material for measuring the sizes of nanoparticles.

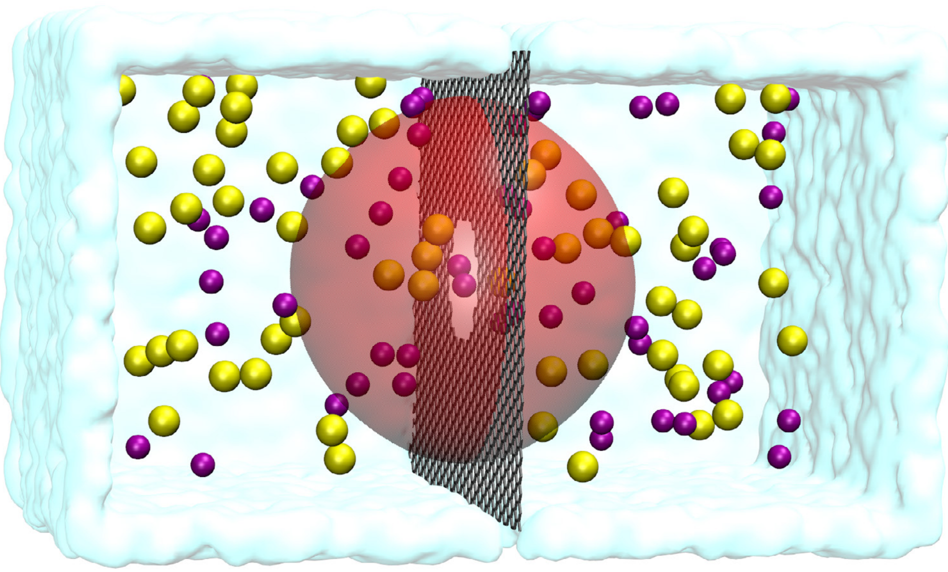
Manufacturers who routinely perform quality control on nanoparticles—determining not only their average size, but how many of the nanoparticles are slightly smaller or larger than average from batch to batch—could benefit from the new technique. The newly fabricated devices, in combination with an inexpensive optical microscope to pinpoint the locations of nanoparticles, offer a potentially faster and more economical route than other measurement techniques, Stavis noted. The team is now investigating how the devices could serve as master molds for the mass production of inexpensive replicas.

Because the nanoparticles were measured with an optical microscope, the NIST team could also explore the relationship between the size of nanoparticles and another key property—their brightness. Clarifying that relationship is important for understanding the properties of such nanoparticles as quantum dots for color displays, gold nanoparticles for biomedical sensors, and other nanoparticles for drug delivery. Several customers of NIST's nanotechnology user facility, the Center for Nanoscale Science and Technology, where the work was conducted, have expressed interest in adapting the technology for measuring both the size and brightness of nanoparticles in these consumer products.

Kuo-Tang Liao, Joshua Schumacher, Henri J. Lezec and Samuel M. Stavis. Subnanometer structure and function from ion beams through complex fluidics to fluorescent particles. *Lab on a Chip* **18**, 139-152 (2018). DOI: 10.1039/C7LC01047H

SCIENTISTS CHANNEL GRAPHENE TO UNDERSTAND FILTRATION AND ION TRANSPORT INTO CELLS

Tiny pores at a cell's entryway act as miniature bouncers, letting in some electrically charged atoms—ions—but blocking others. Operating as exquisitely sensitive filters, these "ion channels" play a critical role in biological functions such as muscle contraction and the firing of brain cells. To rapidly transport the right ions through the cell membrane, the tiny channels rely on a complex interplay between the ions and surrounding molecules, particularly water, that have an affinity for the charged atoms. But these molecular processes have been difficult to model—and therefore to understand—using computers or simpler artificial structures.



Schematic of a graphene nanopore shows an ionic solution partitioned by a graphene monolayer (gray, honeycomb membrane). The purple spheres are potassium ions and the yellow spheres are chloride ions with red indicating the access region. Credit: NIST

Now researchers at NIST and their collaborators have demonstrated that nanometer-scale pores etched into layers of graphene—atomically thin sheets of carbon renowned for their strength and conductivity—can provide a simple model for the complex operation of ion channels and allow scientists to measure a host of properties related to ion transport. In addition, graphene nanopores may ultimately provide scientists with an efficient mechanical filter suitable for such processes as removing salt from ocean water and identifying defective DNA in genetic material.

NIST scientist Michael Zwolak, along with Subin Sahu (who is jointly affiliated with NIST, the University of Maryland NanoCenter and Oregon State University), has also discovered a way to simulate aspects of ion channel behavior while accounting for such computationally intensive details as molecular-scale variations in the size or shape of the channel.

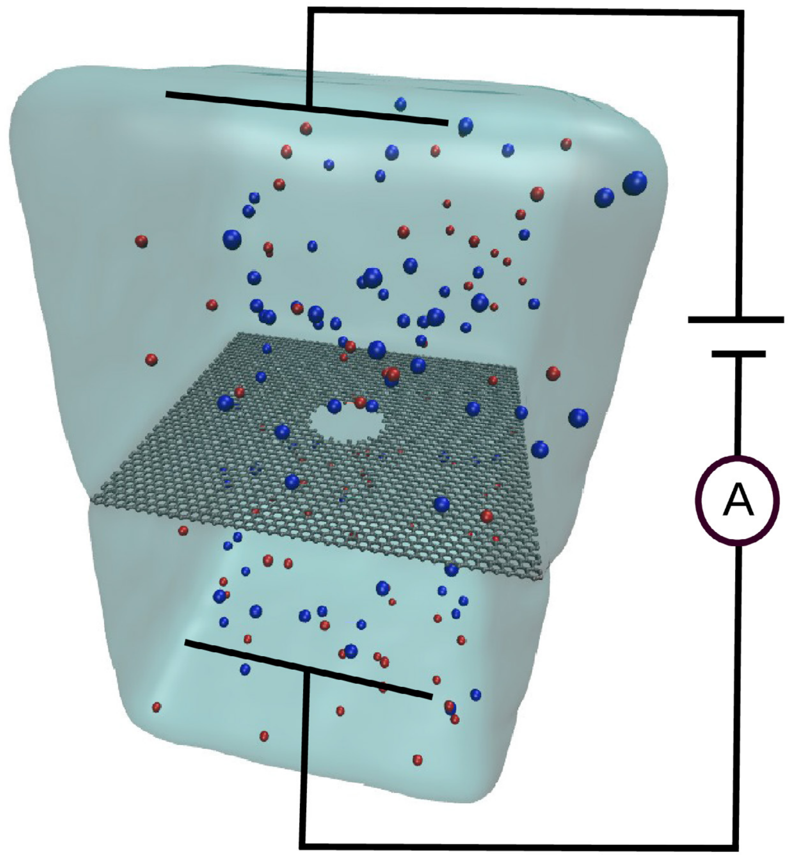
To squeeze through an ion channel, which is an assemblage of proteins with a pore only a few atoms wide, ions must lose some or all of the water molecules that readily bind to them. However, the amount of energy required to do so is often prohibitive, so ions need some extra help. They get that assistance from the ion channel itself, which is lined with molecules having opposite charges to certain ions, and thus helps attract them. Moreover, the arrangement of these charged molecules provides a better fit for some ions versus others, creating a highly selective filter. For instance, certain ion channels are lined with molecules having negative charges distributed in a way that can easily accommodate potassium ions but not sodium ions.

It's the selectivity of ion channels that scientists want to understand better, both as a way to comprehend the function of biological systems and because the operation of these channels may suggest a promising way to engineer non-biological filters for a host of industrial uses.

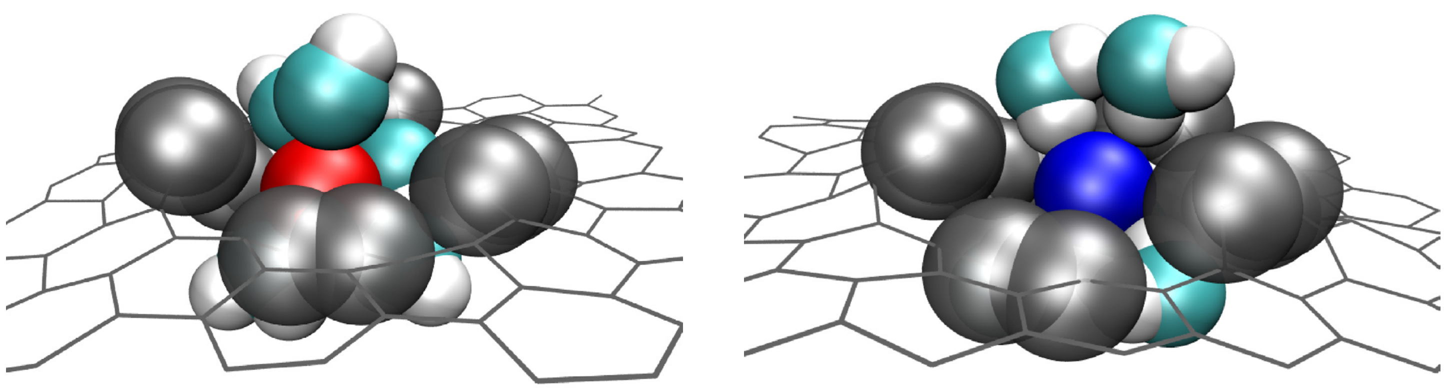
By turning to a simpler system—graphene nanopores—Zwolak, Sahu, and Massimiliano Di Ventra of the University of California, San Diego, simulated conditions that resemble the activity of actual ion channels. For example, the team's simulations demonstrated for the first time that by changing the diameter of the nanopores etched in graphene or adding additional sheets of the single-atom-thick layers, the nanopores become selective, allowing only some ions to travel through. Unlike biological ion channels, however, this selectivity comes from the removal of water molecules only, a process known as dehydration. Graphene nanopores will allow this dehydration-only selectivity to be measured under a variety of conditions, a feat that has not before been accomplished. The researchers reported their findings in recent issues of _Nano Letters_ and _Nanoscale_.

SCIENTISTS CHANNEL GRAPHENE TO UNDERSTAND FILTRATION AND ION TRANSPORT INTO CELLS (CONT'D.)

In two other articles (https://arxiv.org/abs/1708.03327, https://arxiv.org/abs/1711.00472), Zwolak and Sahu address some of the complexity in simulating the activity of ion channels. When theorists simulate a process, they choose a certain size "box" in which they perform those simulations. The box might be bigger or smaller, depending on the breadth and detail of the calculation. The researchers showed that if the dimensions of the simulation volume are chosen such that the ratio of the width of the volume to its height has a particular numerical value, then the simulation can simultaneously capture the influence of the surrounding ionic solution and such thorny details as nanoscale fluctuations in the diameter of the pores or the presence of charged chemical groups. This discovery—what the team calls "the golden aspect ratio" for simulations—will greatly simplify calculations and lead to better understanding of the operation of ion channels, Zwolak said.



A voltage applied across a graphene nanopore drives an ionic current. When the pore is sufficiently small the ions must shed some of the attached water molecule in order to fit through the pore. Credit: NIST



A potassium ion (red sphere, left image) and a chloride ion (blue sphere, right image) crossing a graphene pore both manage to retain many of their associated water molecules—represented by the bound oxygen (cyan) and hydrogen (white) spheres—despite the small size of the pore. Credit: NIST

S. Sahu and M. Zwolak. Maxwell-Hall access resistance in graphene nanopores. In press, *Physical Chemistry Chemical Physics*.

S. Sahu, M. Di Ventra, and M. Zwolak. Dehydration as a Universal Mechanism for Ion Selectivity in Graphene and Other Atomically Thin Pores. *Nano Letters*. Published online 5 July 2017. DOI: 10.1021/acs.nanolett.7b01399

S. Sahu and M. Zwolak. Ionic selectivity and filtration from fragmented dehydration in multilayer graphene nanopores. *Nanoscale*. Published online 25 July 2017. DOI: 10.1039/C7NR03838K

THANKS FOR THE MEMORY: CNST TAKES A DEEP LOOK AT MEMRISTORS

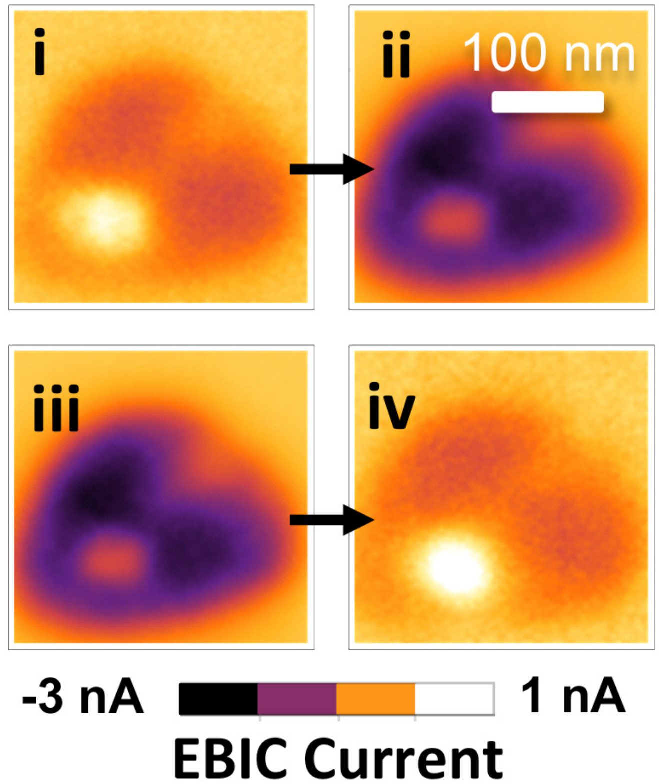
In the race to build a computer that mimics the massive computational power of the human brain, researchers are increasingly turning to memristors. These semiconductor devices, which can vary their electrical resistance based on the memory of past activity, simulate the short-term memory of nerve cells. Just as the ability of one nerve cell to signal another depends on how often the cells have communicated in the recent past, the resistance of a memristor depends on the amount of current that recently flowed through it. Moreover, a memristor retains that memory even when electrical power is switched off.

But despite the keen interest in memristors, scientists have lacked a detailed understanding of how these devices work and have yet to develop a standard tool set to study them.

Now, NIST scientists have identified such a tool set and used it to unveil the inner workings of memristors. Their findings could lead to more efficient operation of the devices and suggest a way to minimize spurious leakage currents.

Brian Hoskins of NIST and the University of California, Santa Barbara, along with NIST scientists Nikolai Zhitenev, Andrei Kolmakov, Jabez McClelland and their colleagues from the University of Maryland NanoCenter in College Park and the Institute for Research and Development in Microtechnologies in Bucharest, reported the findings in a recent *Nature Communications* (https://www.nature.com/articles/s41467-017-02116-9).

To explore the electrical function of memristors, the team aimed a tightly focused beam of electrons at specific locations on the device. The beam excited electrons in a titanium oxide memristor, some of which are knocked free and collected to form ultrasharp images of those locations. The beam also induced four distinct currents to flow within the device. The team determined that the currents are related to the multiple interfaces between materials in the memristor, which consists of two metal (conducting) layers separated by an insulator.



Electron Beam Induced Current Micrographs of a memristor, showing switching from a state of low resistance (i) to high resistance (ii), and from high resistance (iii) back to low resistance (iv) again. The bright resistive switching core is surrounded by a darker region that indicates a path where current may leak out, reducing performance of the memristor. Credit: CNST

"We know exactly where each of the currents is coming from because we are controlling the location of the beam that is inducing those currents," said Hoskins.

In imaging the device, the team found several dark spots—regions of enhanced conductivity—which indicated places where current might leak out of the memristor during its normal operation. These leakage pathways resided outside the core of the memristor—its resistive switching region—rather than within it. The finding suggests that reducing the size of a memristor could minimize or even eliminate some of these unwanted pathways. Although researchers had suspected that might be the case, they had lacked experimental guidance about just how much to reduce the size of the device.

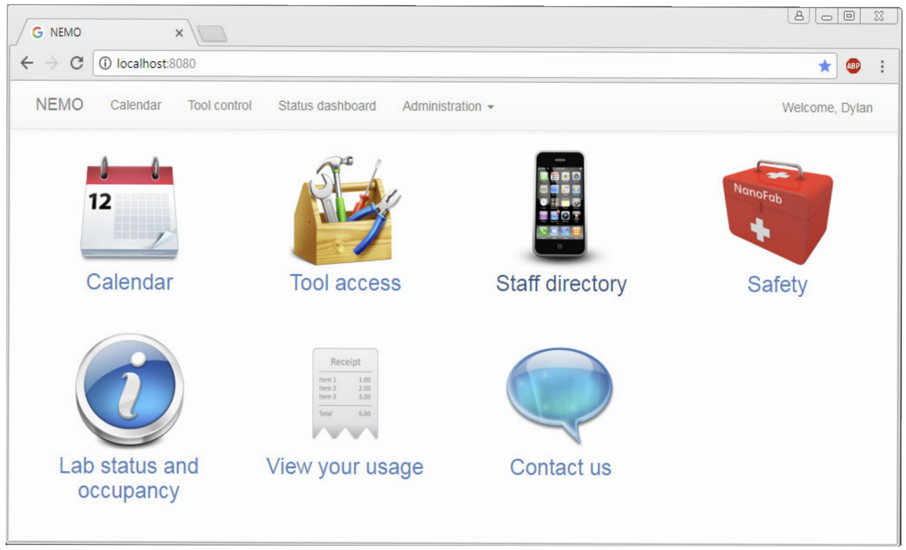
Because the leakage pathways are tiny, involving distances of only 100 to 300 nanometers, "you're probably not going to start seeing some really big improvements until you reduce dimensions of the memristor on that scale," Hoskins said.

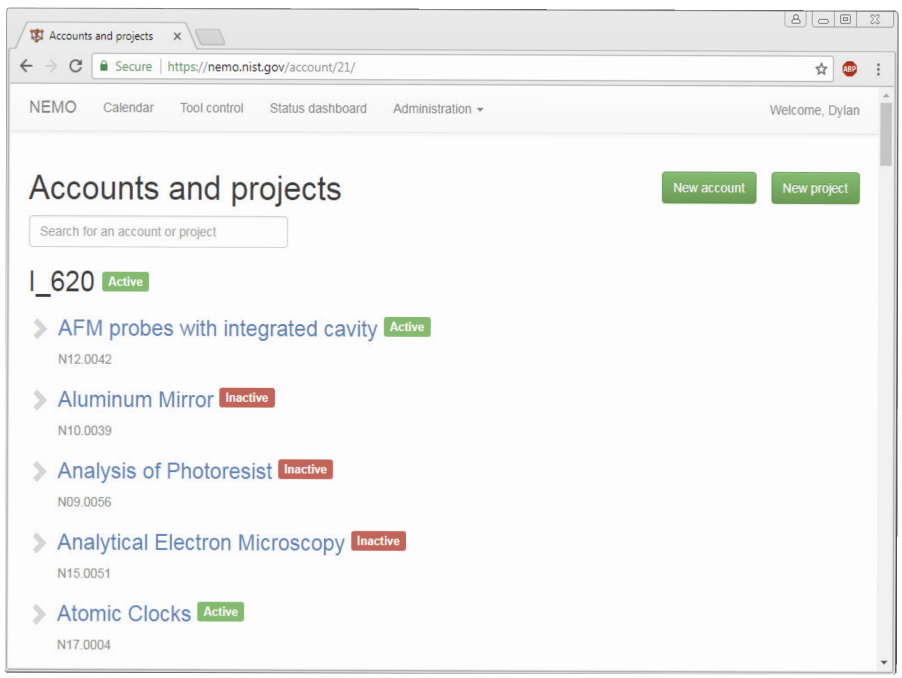
To their surprise, the team also found that the current that correlated with the memristor's switch in resistance didn't come from the active switching material at all, but the metal layer above it. The most important lesson of the memristor study, Hoskins noted, "is that you can't just worry about the resistive switch, the switching spot itself, you have to worry about everything around it." The team's study, he added, "is a way of generating much stronger intuition about what might be a good way to engineer memristors."

Brian D. Hoskins, Gina C. Adam, Evgheni Strelcov, Nikolai Zhitenev, Andrei Kolmakov, Dmitri B. Strukov & Jabez J. McClelland. Stateful characterization of resistive switching TiO_2 with electron beam induced currents. *Nature Communications* **8**, Article number: 1972 (2017). DOI: 10.1038/s41467-017-02116-9

NEMO GOES NATIONWIDE

Making reservations, accessing tools, and maintaining equipment at the CNST's NanoFab got a lot easier five years ago when the CNST developed a customized laboratory management web application. Now other NanoFabs and laboratories across the nation can reap the same benefits. The NanoFab Equipment Management & Operations (NEMO) web application will be released as open source and free software on January 8, 2018.





Screenshots of the NEMO web application. Credit: NIST

Users can customize NEMO for their own laboratory, enabling any customer with a desktop or mobile device to reserve tools, view the operating status of instruments, and seek assistance from laboratory staff.

The web application is written in the Python programming language and uses the Django web framework. It is system independent (can run on Linux, Windows, or Mac) and does not require special hardware to operate.

The CNST hopes to foster a developer community to collaborate on new features and improvements to NEMO. Source code contributions are welcome via GitHub pull requests. The CNST will compile and evaluate these suggestions, modifying NEMO as needed.

"We hope the nanofabrication community will be excited about the release of this software, and we look forward to sharing it," says CNST's software engineer Dylan Klomparens, who developed NEMO.

NEMO is hosted at https://github.com/usnistgov/NEMO

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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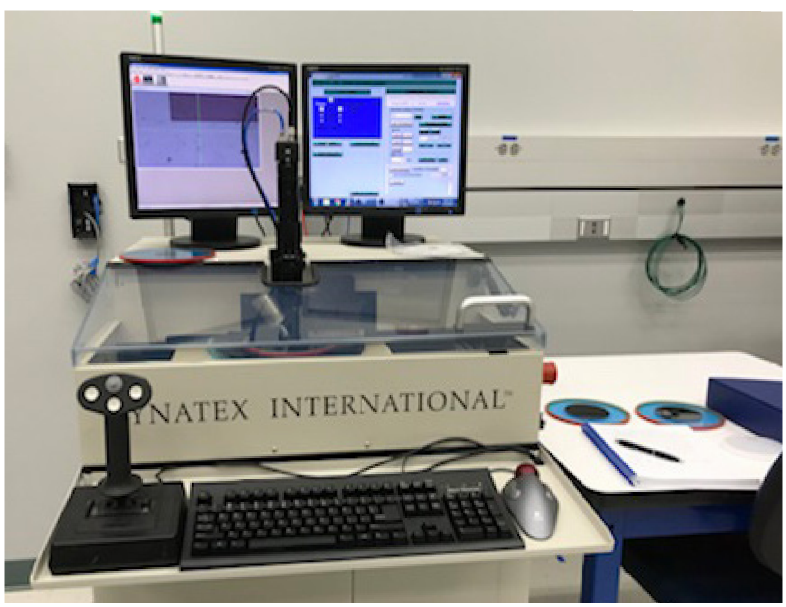
NEW DICING TOOL

The NanoFab has a new Dynatex GSX scribe and break tool. The instrument dices materials for critical applications such as laser diodes, laser bars, Si-Photonics III-IV chips, optoelectronic devices, as well as MEMs and biomedical devices with sensitive structures and coatings. The tool's sharp diamond scribe cuts a V-shaped groove—a scribe line—which acts as a stress concentrator along the desired break. When a force is applied to the wafer, it breaks along that line.

The scribe and break method offers several advantages over a dicing saw for the applications noted above. The scribe and break method is a dry technique that does not use a liquid coolant, which may damage circuits and sensitive devices. The scribe and break technique creates a high-quality mirror finish on the edge of a sample because the sample breaks along a crystal lattice plane. The width of the scribe line is less than 5 micrometers, compared with the 25-micrometer-wide cut by the narrowest saw blade.



The NanoFab's new scribe and break tool. Credit: Dynatex

The GSX performs precision diamond scribe and break dry-dicing for materials such as Indium phosphide, gallium arsenide, gallium nitride and silicon in partial wafer pieces and substrate sizes up to 100 millimeters. It can be operated in an interactive or semi-automatic mode for operator controlled processing.