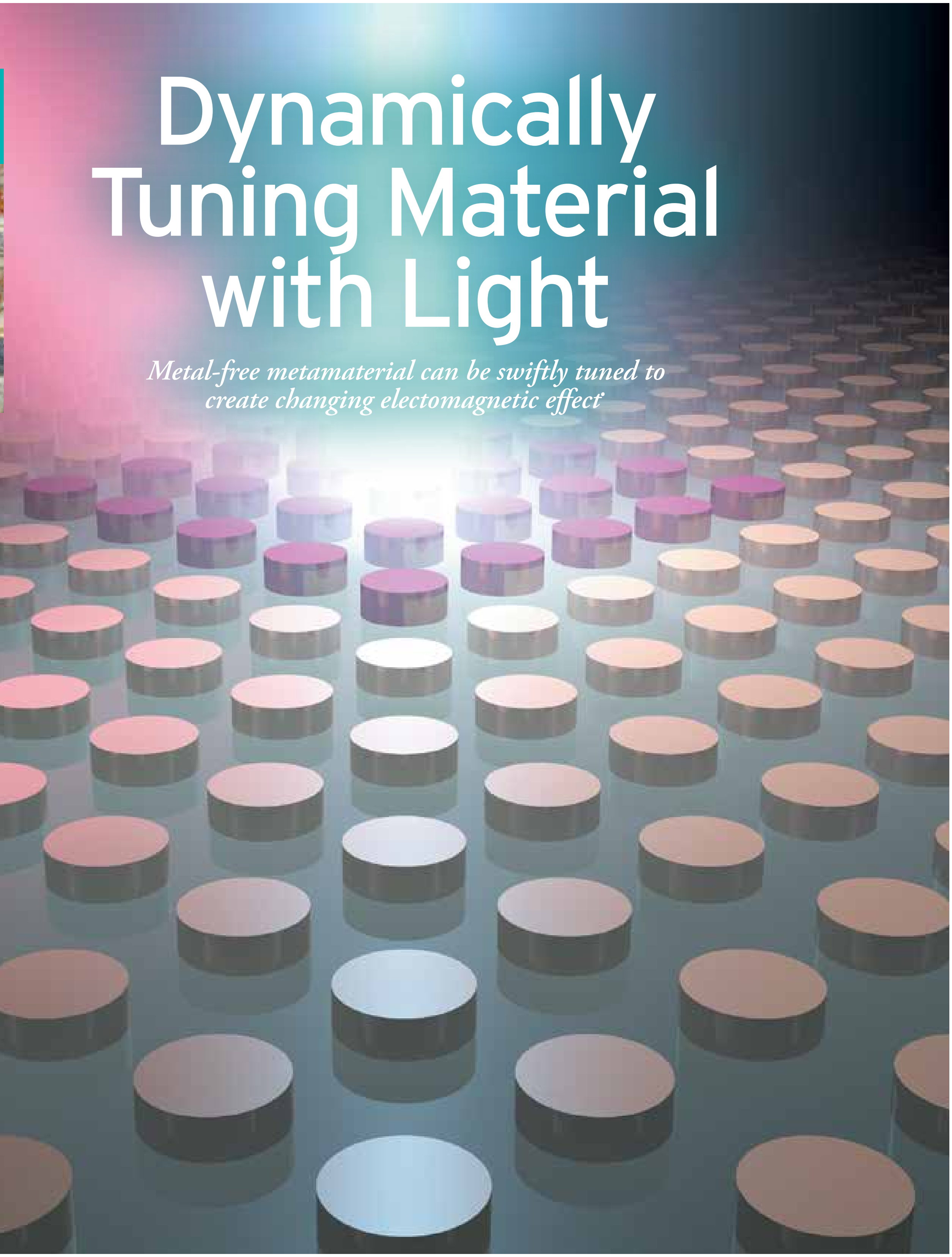
# DukeBroadband

FITZPATRICK INSTITUTE FOR PHOTONICS / DUKE UNIVERSITY

*Engineering light to change the world*

**FACULTY HIGHLIGHTS:**
Nan Jokerst, p. 12



# Dynamically Tuning Material with Light

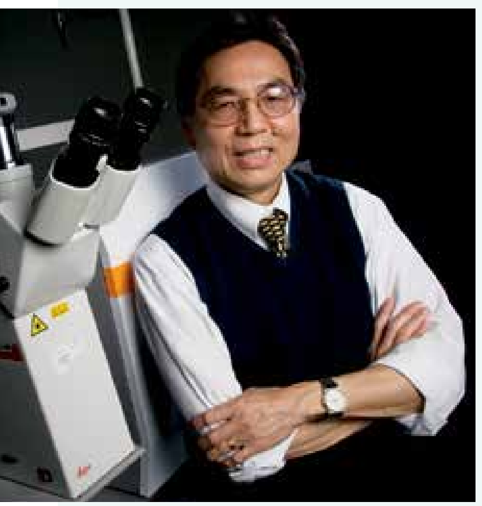
*Metal-free metamaterial can be swiftly tuned to create changing electomagnetic effect*

2018 VOLUME 10 ISSUE 1

## DIRECTOR'S MESSAGE

**Welcome** **to the 2018-2019 issue of *BROADBAND***, the newsletter of the Fitzpatrick Institute for Photonics (FIP).

One of the main goals of the Institute is to promote the interdisciplinary and collaborative spirit between engineers, scientists, medical researchers and clinicians across the Duke campus . The Institute now has a faculty membership that includes over 133 faculty members with participation from 39 departments and institutions ranging from Biomedical Engineering, Electrical and Computer Engineering, Mechanical Engineering & Material Science, Chemistry, Physics, Computer Science, and Mathematics to Anesthesiology, Cell Biology, Chemical Biology, Neurosurgery, Oncology, Orthopedic Engineering, Ophthalmology, Pathology, Pediatrics, Radiology and Surgery as well as Art, Art History & Visual Studies, and Philosophy.



Tuan Vo-Dinh

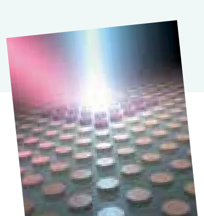
We successfully organized the 2018 FIP Annual Symposium with the Keynote Lecture presented by Steven Chu, 1997 Nobel Laureate in Physics. The meeting also included special topic sessions on *Biophotonics for the Medicine of the Future* and lectures from distinguished speakers, contributed papers, and posters by investigators from academic institutions covering various topics such as biophotonics, nanophotonics, medical robotics, nano & microsystems, global health, and renewable energy photonics. At the the symposium, we organized a special Workshop - Introduction to the Advanced Instrumentation Resources at Duke University.

This year, I had the great opportunity to be among a distinguished roster of invited speakers inaugurating the first *"International Day of Light"* (IDL) proclaimed at the United Nations Educational, Scientific and Cultural Organization (UNESCO) headquarters in Paris, France on May 16, 2018. The IDL event, which UNESCO plans to make annual, was intended to raise worldwide awareness of the many ways that light impacts modern society and to consider how advances in light-based science and technology can aid in achieving goals in education and sustainable development. Also, at the Institute, a campus-wide group of students and postdoctoral associates were celebrating the IDL event by presenting their light-based research at the *2018 FIP International Day of Light Colloquium*.

I invite you to visit our website at www.fitzpatrick.duke.edu to learn more about our faculty, research programs, and activities.

I hope you have a successful and enjoyable year.

**Professor Tuan Vo-Dinh**
Director, Fitzpatrick Institute for Photonics
R. Eugene and Susie E. Goodson Professor of Biomedical Engineering
Professor of Chemistry



**ON THE COVER:** A rendering of dynamical control of metal-free metamaterials. The red color depicts light used to modify behavior of the silicon cylindrical array, and blue color represents the incident terahertz radiation.

**SPEAKER:**
**Tuan Vo-Dinh**

# International Day of Light in Paris

*UN Educational, Scientific and Cultural Organisation Raising Worldwide Recognition of Light's Importance*

Duke photonics expert Tuan Vo-Dinh, director of the Fitzpatrick Institute for Photonics, R. Eugene and Susie E. Goodson professor of biomedical engineering and professor of chemistry, was among a distinguished roster of speakers in Paris on May 16, 2018 inaugurating the first "International Day of Light" at the United Nations Educational, Scientific and Cultural Organisation (UNESCO) headquarters. Dr. Vo-Dinh spoke of the "Light Empowering Humanity."

The event, which UNESCO plans to make annual, is intended to raise worldwide awareness of the many ways that light impacts modern society and to consider how advances in light-based science and technology can aid in achieving goals in education and sustainable development. The program included international experts and Nobel Laureates, cultural interludes, light painting displays, an exhibit from the Mexican Museum of Light, a photonics science show, and interior and exterior displays to highlight the unifying power of light.

The Fitzpatrick Institute for Photonics was a Gold Level Sponsor at the Inaugural International Day of Light.

**https://today.duke.edu/2018/04/tuan-vo-dinh-be-part-international-day-light-paris**

## NEW FIP FACULTY

**Gaurav Arya** models the motion and interactions of atoms and molecules to predict macroscopic properties of "soft matter" for applications ranging from solar energy to cancer diagnosis and treatment. Some of his many projects include studying nanoscale devices made entirely from genetic material by folding DNA, understanding how the structure of DNA is packaged, and using simulations to devise strategies for fabricating coatings made out of polymers carrying silver nanocubes within to harness solar energy.

**Kenneth Brown** joins a growing effort at Duke to build a reliable, scalable quantum computer using ion traps—while also applying the technology to other fields from astrophysics to biomedical engineering. The technology is based on suspending ultra-cooled atoms using an electromagnetic field in an ultra-high vacuum, where precise lasers manipulate their quantum states. But the ion traps can also be used to move and sort individual cells floating in a single drop of liquid or to discover what sorts of atoms and molecules are in outer space.

**Peter Fecci** is the director of the Duke Brain Tumor Immunotherapy Program and has exceptional expertise in brain tumor immune-evasion and possesses remarkable vision for collaborative and paradigm-shifting approaches to intracranial cancers. Some of his most notable work involves researching ways of getting the body's own T-cells to locate and attack glioblastomas.

**Roarke Horstmeyer** focuses on building new microscopes, cameras and computer algorithms to create better biomedical images. One of his primary projects involves building a new type of microscope that can capture gigapixel-sized images and simultaneously classify what is present within the images to quickly and efficiently diagnose diseases within the bloodstream or in small tissue sections. Another project looks to learn how new techniques to record high resolution movies at over one million frames-per-second can be applied to neuroscience.

...continued on page 5

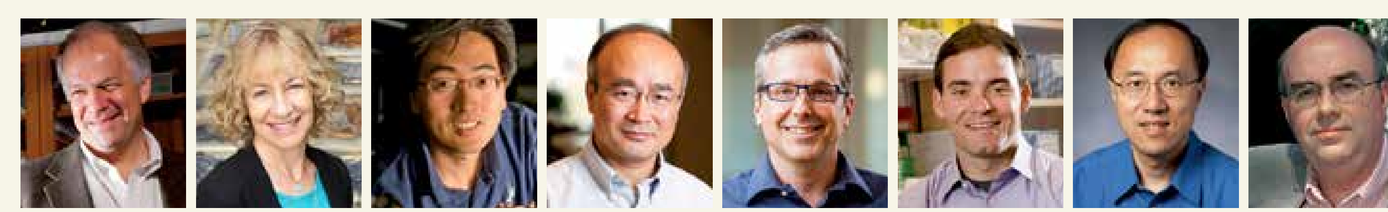
## PARTICIPATING DEPARTMENTS AND INSTITUTIONS

**145 Faculty Members | 39 Participating Departments, Centers, and Institutions at Duke University**

The Fitzpatrick Institute for Photonics is an extremely interdisciplinary Duke effort to advance photonics and optical sciences. The institute leverages Duke's faculty from the Pratt School of Engineering, Trinity College of Arts and Sciences, and the Duke School of Medicine to explore problems at the boundary nexus of nano-bio-info-opto convergence.

**DEPARTMENTS**

- Anesthesiology
- Art, Art History & Visual Studies
- Biochemistry
- Biology
- Biomedical Engineering (BME)
- Cell Biology
- Chemistry
- Civil & Environmental Engineering (CEE)
- Computer Science
- Dermatology
- Electrical and Computer Engineering (ECE)
- Environmental Sciences & Policy
- Environmental Toxicology
- Gastroenterology
- Geriatrics
- History
- Immunology
- Literature
- Mathematics
- Mechanical Engineering and Materials Science (MEMS)
- Molecular Genetics and Microbiology
- Neurobiology
- Neurosurgery
- Obstetrics and Gynecology
- Oncology
- Ophthalmology
- Orthopaedic Surgery
- Pathology
- Pediatrics
- Pharmacology & Cancer Biology
- Philosophy
- Physics
- Radiation Oncology
- Radiology
- Surgery
- Center for Applied Genomics and Precision Medicine
- Duke Cancer Institute
- Duke Global Health
- School of Medicine
- School of Nursing



**FIP RESEARCH PROGRAMS AND DIRECTORS, LEFT TO RIGHT: Biophotonics:** Joseph Izatt **Nano & Micro Systems:** Nan Jokerst **Quantum Optics and Information Photonics:** Jungsang Kim **Systems Modeling, Theory & Data Treatment:** Weitao Yang **Photonic Materials:** Steven Cummer **Advanced Photonics Systems:** Charles Gersbach **Nanophotonics:** Fan Yuan **Novel spectroscopes:** Warren Warren

Fitzpatrick Institute for Photonics

# FELLOWSHIPS

The Fitzpatrick Institute for Photonics (FIP) is able to offer several graduate student fellowships through the continued support and generosity of the Fitzpatrick Foundation and Mr. John T. Chambers.

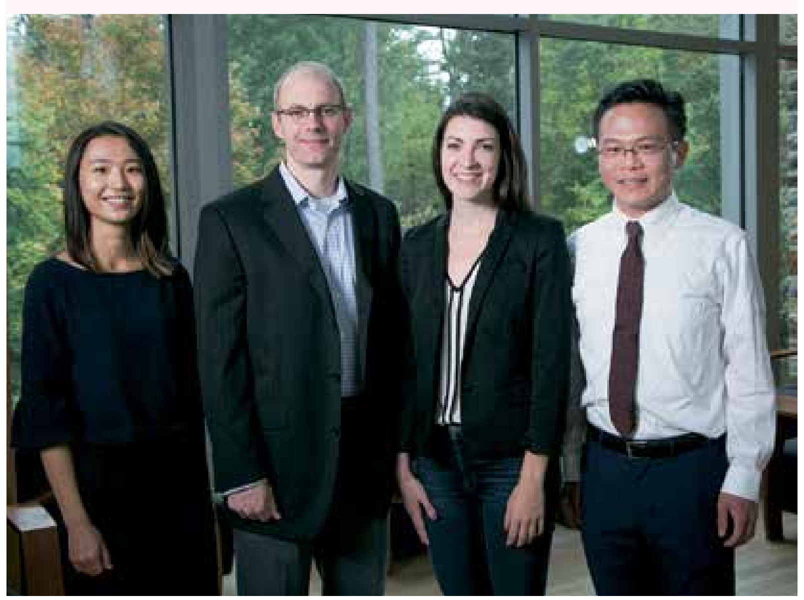
**THE SCHOLARS PROGRAM** provides existing Duke graduate students within the FIP approximately $49,000 each toward their stipend, tuition remission, grad school fees and health insurance for two years. This program is designed to reward the most outstanding individuals within FIP for their accomplishments and potential. Each candidate, nominated by a FIP professor, was judged on the criteria of demonstrated excellence in their academic studies, research and projects that involved inter-group or interdisciplinary research stimulating new collaborations among FIP faculty.

**THE FELLOWS PROGRAM**, used as recruiting tool for the top candidates, provides incoming graduate students a one year fellowship program, which awards $10,000 top-up on their stipend and $1000 towards educational travel. Each candidate is nominated by a FIP professor and judged on the criteria of research accomplishments, research potential, personal qualities and collaborative potential.

The Fitzpatrick Institute for Photonics is pleased to announce the recipients of the **John T. Chambers Scholars** and **John T. Chambers Fellows** for the 2016-17 academic year!

2017 - 2018 Chambers Fellows
Yuqi Tang and Kristen Hagan

2016-2018 Chambers Scholars
George Bullard and Qiwei Zhan



*Left to right:* Yuqi Tang (Fellow), George Bullard (Scholar), Kristen Hagan (Fellow), Qiwei Zhan (Scholar)

CHAMBERS FELLOWS

## Where are they now?

**Amy Martinez** earned her PhD in 2016 in Dr. Nimmi Ramanujam's Biomedical Engineering lab. Her pursuit of a career in research administration led her to Vanderbilt University Medical Center (VUMC), where she now serves as a Program Officer in the Office of Research. Amy's favorite part of her role is that she's always learning and trying something new. She assists faculty with finding and applying for funding, coordinates scientific oversight of VUMC's shared scientific resources, and advises on student and postdoc policies. While her specific priorities are always evolving, Amy currently manages a newly established program to train surgeons/interventional physicians in basic science research, and provides project support for a research initiative to genotype >80,000 Vanderbilt patients. Amy credits the Chambers fellowship with her aptitude to quickly absorb new ideas and pivot between multiple projects. "The ability to understand and disseminate a range of scientific concepts is critical for a Program Officer. The Chambers fellowship placed me at the intersection of diverse science and engineering fields, and allowed me to form relationships with faculty, administrators, and peers. I'm grateful for the experience, which prepared me for a role in which I support a spectrum of biomedical research priorities." Amy also stays connected to Duke by serving on the Duke Nashville Women's Forum steering committee.

Dr. Amy (Frees) Martinez
Program Officer, Office of Research
Vanderbilt University Medical Center

**2017-19 | FITZPATRICK SCHOLAR**

## Andrew Boyce

The Fitzpatrick Institute for Photonics (FIP) was able to award a two-year graduate student fellowship through the continued support and generosity of the Fitzpatrick Foundation. Each candidate was nominated by a FIP Professor and judged on the criteria of research accomplishments, research potential, personal qualities and collaborative potential.

## CHECK OUT OUR LATEST TRAINING PROGRAM!

### Master of Engineering in Photonics & Optical Sciences

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*along with...*

### Certificate in Photonics for MS and PhD students

**CURRICULUM:** Photonics courses focused on technical areas of interest, a research presentation, and attendance at a minimum of four FIP seminars.

**IDEAL CANDIDATES:** Doctoral students in any technical field who wish to gain greater depth of skill and exposure to photonics and optical sciences.

**DURATION:** Flexible. Courses can be taken at any time during the student's tenure at Duke while working towards a primary degree.

## NEW FIP FACULTY ...continued from page 3

**Natasha Litchinitser** works with metamaterials that manipulate waves like light and sound through its structure rather than its chemistry. Her research has shown how metamaterials can be used to dynamically switch the structure of a beam of light from a simple circular beam to a vortex, which could encode information through multiplexing. Other projects involve topological photonics and using mathematical models to design very different structures which scatter light in exactly the same way.

**Christine Payne** seeks to provide foundations for engineering new nanoparticles for medical applications as well as understanding how nanoparticles in commercial products like sunscreen affect the body. The other half of her research focuses on developing electrically conductive polymer wires thinner than a single cell, which could have a range of applications from treating brain disorders to helping tissues heal.

**Amanda Randles** develops and applies high-performance computing to biomedical problems. Her largest effort, known as HARVEY, models the movement of red blood cells throughout the body. Mapping 500 billion fluid points using a supercomputer with 1.6 million cores (individual processors), HARVEY marked the first time a researcher has been able to effectively model the flow of blood at the cellular level. The visionary program is already fostering discoveries that could improve the diagnosis, prevention and treatment of human diseases.

**Michael Rubinstein** is an internationally recognized expert in the fields of polymer theory and computer simulations who will contribute to the growing interdisciplinary focus on collaborative polymer and soft-matter research across Duke. His research focuses on various properties of polymeric systems—a type of soft matter composed of long chains of repeating units. His aim is to understand and model their various properties so researchers can design new materials that demonstrate more interesting and useful characteristics based on what functions the material needs to perform.

**Tatiana Segura** engineers soft matter hydrogel biomaterials that support and promote cell growth to unlock the body's innate ability to repair damaged or diseased tissue. Her research focuses on developing an artificial material to mimic and replace the aging extracellular matrix that surrounds and supports all of the cellular functions of our organs and tissues. Her research has already formed a spinout company called Tempo Therapeutics for skin treatments that is focusing on hard-to-treat wounds such as those that can lead to amputations.

**Shyni Varghese**'s research focuses on musculoskeletal tissue repair, regenerative medicine, disease biophysics and organ-on-a-chip technology. As a leader in the field of biomaterials and stem cells, her work will help understand the role of the cellular microenvironment on cancer progression; design devices for recruiting and activating patient's own cells to promote tissue repair and regeneration; and identify molecular pathways involved in diseases such as fibrosis and osteoporosis.

*Left to right:* Jungsang Kim (ECE), Michael Duncan (OSA), Steven Chu (Nobel Laureate - Keynote), Tuan Vo-Dinh (BME), Maiken Mikkelsen (ECE).

**HIGHLIGHTS:**

# 2018 FIP Symposium

*March 12-13, 2018 | Duke University, Durham, NC, USA*

We successfully organized the 2018 FIP Annual Symposium with the Keynote Lecture presented by **Dr. Steven Chu**, 1997 Nobel Laureate in Physics, former Secretary of Energy, William R. Kenan, Jr. Professor of Humanities and Sciences, Stanford University. Dr. Chu was awarded the Nobel Prize for his contributions to laser cooling and atom trapping. Dr. Chu was also the recipient of the 2018 FIP Pioneer Award (photo of award presentation to the left). The meeting's special topic session "From Microscopy to Nanoscopy: Unveiling Matters and Living Systems" presented lectures from distinguished speakers as well as contributed papers and posters by investigators from academic institutions covering various topics such as biophotonics, nanophotonics, medical robotics, nano & microsystems, global health, and renewable energy photonics.

Additional highlights of the meeting included:

Courtney Johnson presenting at FIP poster session.

**Dr. Ji-Xin Cheng**, Moustakas Chair Professor in Photonics and Optoelectronics, Boston University, **Dr. Laura Fabris**, Assoicate Professor, Department of Materials Science and Engineering, Rutgers University, **Dr. Tatyana Smirnova**, Associate Professor, Physical Chemistry, Department of Chemistry, North Carolina State University, **Dr. Peter So**, Professor of Mechanical Engineering and Biological Engineering, Massachusetts Institute of Technology, **Dr. Susan Trammell**, Associate Professor of Physics and Optical Science, University of North Carolina at Charlotte delivered Invited Lectures for the FIP symposium. If you missed these highlights, you can see the videos here: **http://fitzpatrick.duke.edu/fip-annual-symposia**

On the morning of the second day of the symposium, we organized a special morning Symposium Workshop - Introduction to the Advanced Instrumentation Resources at Duke University. The workshop committee gave short presentations of their resources and followed with lab tours of the new Cryo-EM System, Advanced Light Imaging and Spectroscopy (ALIS) and the High Intensity Gamma-Ray Source (HIGS).

Dr. Steven Chu and Tuan Vo-Dinh

**Symposium Chair:** Tuan Vo-Dinh, Director, Fitzpatrick Institute for Photonics
**Symposium Manager:** August Burns, Department Business Manager, Fitzpatrick Institute for Photonics
**Scientific Program Committee:** Steve Cummer, Charles Gersbach, Nan Jokerst, Jungsang Kim, Warren Warren, Weitao Yang, Fan Yuan
**Symposium Workshop Program Co-Chairs:** Nan Jokerst and Warren Warren
**Symposium Workshop Program Committee:** Lisa Cameron, Martin Fischer, Mark Walters, Ying K. Wu ■


**The Corporate Partnership Program** (CPP) is established to strengthen interactions between FIP faculty and industrial developers, and to enhance the translational aspects of our educational and research programs. Our current CPP members are Hamamatsu Photonics, BD Technologies, Cisco and Optimax. With the improving economy and the emergence of strong partners in photonics, the Institute will continue to strengthen its industrial relations programs in the coming years.

Partners have access to a website containing an overview summary of key topics and areas of active research activities at the FIP which also displays their corporate logo as a member of our CPP. During the FIP Annual Meeting, the Corporate Partners are provided with an industry booth, a program listing all FIP faculties and also displaying the partners' corporate logo as a CPP member. The Corporate Partners also receive information about our FIP professors, research topics, and graduate students. Throughout the year we provide our Corporate Partners with recruiting assistance via exclusive access to resumes of students who are approaching graduation. Representatives of all Corporate Partners are invited to attend our special Seminar Series, guest lectures, presentations and special events. Corporate Partners may also join our faculty members and students in accessing our collection of student theses and dissertations.

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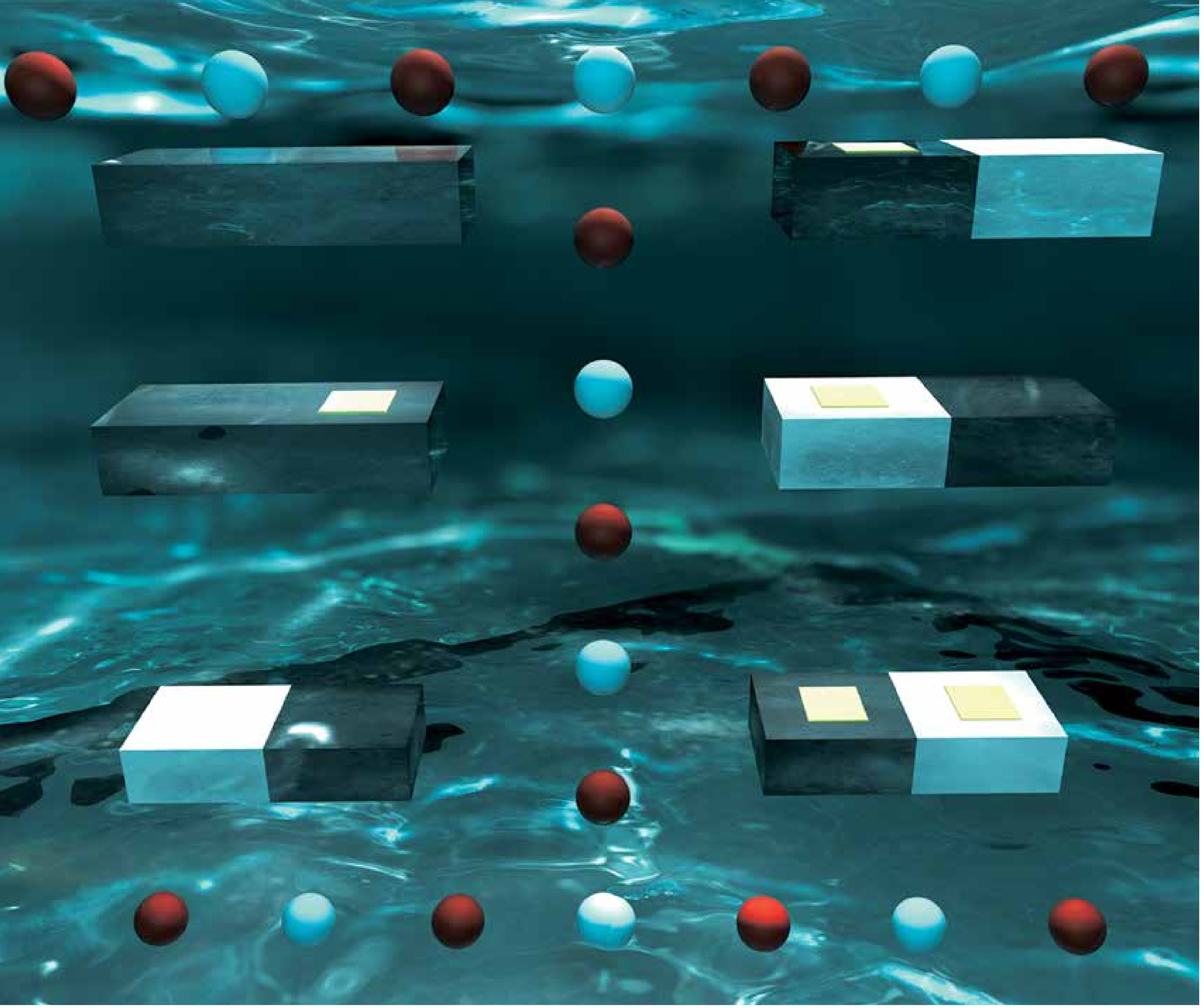


# Reconfigurable Custom Silicon Nanoparticles

*Technology could form the basis for applications such as artificial muscles or reconfigurable computer processors*

Nan Jokerst

While self-assembling particles are a hotbed of modern scientific research, nobody has created a system like Nan Jokerst.

With the fabrication facilities available in Duke's Shared Materials Instrumentation Facility (SMIF), Jokerst has created the world's first custom semiconductor microparticles that can be steered into various configurations repeatedly while suspended in water.

"We've engineered and encoded multiple dynamic responses in different microparticles to create a reconfigurable silicon toolbox," said Ugonna Ohiri, a recently graduated doctoral student in Jokerst's lab. "By providing a means of controllably assembling and disassembling these particles, we're bringing a new tool to the field of active matter."

While previous researchers have worked to define self-assembling systems, few have worked with semiconductor particles, and none have explored the wide range of custom shapes, sizes and coatings that are available to the micro- and nanofabrication industry. Engineering particles from silicon presents the opportunity to physically realize electronic devices that can self-assemble and disassemble on demand. Customizing their shapes and sizes presents opportunities to explore a wide-ranging design space of new motile behaviors.

"Most previous work performed using self-assembling particles has been done with shapes such as spheres and other off-the-shelf materials," said Nan Jokerst, the J. A. Jones Professor of Electrical and Computer Engineering at Duke. "Now that we can customize whatever arbitrary shapes, electrical characteristics and patterned coatings we want with silicon, a whole new world is opening up."

Jokerst and Ohiri collaborated with Orlin Velev, the INVISTA Professor of Chemical and Biomolecular Engineering at NC State, to characterize six different engineered silicon microparticle compositions that could move through water, synchronize their motions, and reversibly assemble and disassemble on demand.

The thin film particles are 10-micron by 20-micron rectangles that are 3.5 microns thick and are fabricated using Silicon-on-Insulator (SOI) technology. Since they can be made using the same fabrication technology that produces integrated circuits, millions of identical particles could be produced at a time.

"The idea is that eventually we're going to be able to make silicon computational systems that assemble, disassemble and then reassemble in a different format," said Jokerst. "That's a long way off in the future, but this work provides a sense of the capabilities that are out there and is the first demonstration of how we might achieve those sorts of systems."

That is, however, only the tip of the proverbial iceberg. Some of the particles were fabricated with both p-type and n-type regions to create p-n junctions -- common electrical components that allow electricity to pass in only one direction. Tiny metal patterns were also placed on the particles' surfaces to create p-n junction diodes with contacts. In the future, researchers could even engineer particles with patterns using other electrically conductive or insulating materials, complex integrated circuits, or microprocessors on or within the silicon.

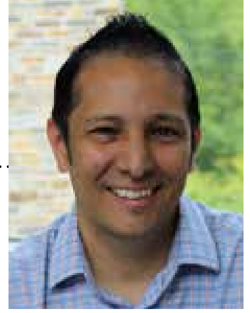
**"By providing a means of controllably assembling and disassembling these particles, we're bringing a new tool to the field of active matter."**

"This work is just a small snapshot of the tools we have to control particle dynamics," said Ohiri. "We haven't even scratched the surface of all of the behaviors that we can engineer, but we hope that this multidisciplinary study can pioneer future studies to design artificial active materials." ■

Dr. Ugonna Ohiri, using electric fields to assemble, disassemble, and re-assemble arrays of silicon microparticles and micro devices.

"Reconfigurable engineered motile semiconductor microparticles," by Ugonna Ohiri, C. Wyatt Shields IV, Koohee Han, Talmage Tyler, Orlin Velev and Nan Jokerst, Nature Communications, No. 1791, 2018.

COVER STORY



Willie Padilla

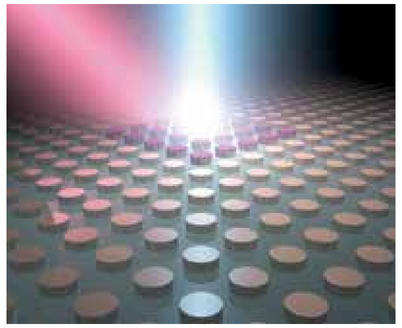
# Dielectric Metamaterial is Dynamically Tuned by Light

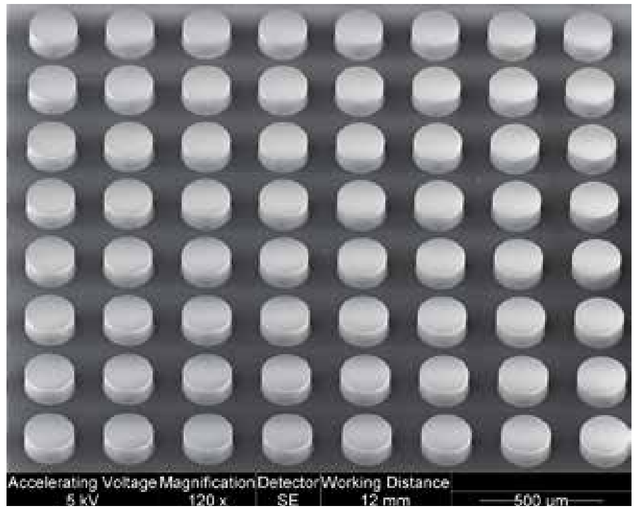
*Metal-free metamaterial can be swiftly tuned to create changing electromagnetic effects*

Willie Padilla uses light to tailor the behavior of absorption by building the first metal-free, dynamically tunable metamaterial for controlling electromagnetic waves.

A metamaterial is an artificial material that manipulates waves like light and sound through properties of its structure rather than its chemistry. Researchers can design these materials to have rare or unnatural properties, like the ability to absorb specific ranges of the electromagnetic spectrum or to bend light backward.

"These materials are made up of a grid of separate units that can be individually tuned," said Padilla, professor of electrical and computer engineering at Duke. "As a wave passes through the surface, the metamaterial can control the amplitude and phase at each location in the grid, which allows us to manipulate the wave in many of different ways."






*Left:* A rendering of dynamical control of metal-free metamaterials. The red color depicts light used to modify behavior of the silicon cylindrical array, and blue color represents the incident terahertz radiation. *Right:* Scanning electron microscope displays the metamaterials – an array of silicon cylindrical resonators, fabricated in the Shared Materials Instrumentation Facility at Duke University.

In the new technology, each grid location contains a tiny silicon cylinder just 50 microns tall and 120 microns wide, with the cylinders spaced 170 microns apart. While silicon is not normally a conductive material, the researchers bombard the cylinders with a specific frequency of light in a process called photodoping. This imbues the material with metallic properties by exciting electrons on and within the cylinder.

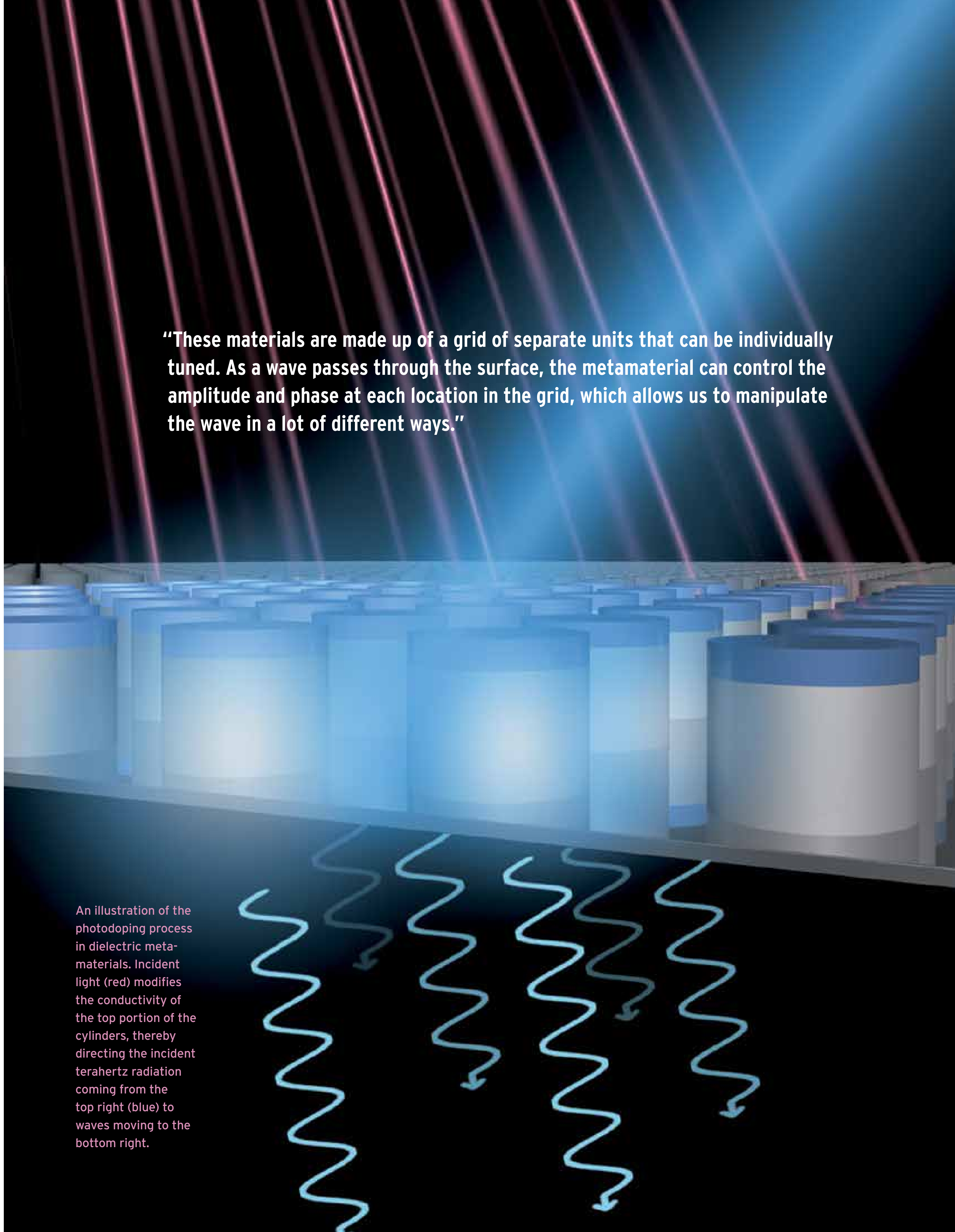
These newly freed electrons cause the cylinders to interact with electromagnetic waves passing through them. The size of the cylinders dictates what frequencies of light they can interact with, while the angle of the photodoping affects how they manipulate the electromagnetic waves. By purposefully engineering these details, the metamaterial can control electromagnetic waves in an arbitrary fashion.

Thus far the technology has been used to manipulate terahertz waves—a band of the electromagnetic spectrum that sits between microwaves and infrared light. Controlling this wavelength of light could improve broadband communications between satellites or lead to security technology that can easily scan through clothing. The approach could also be adapted to other bands of the electromagnetic spectrum simply by scaling the size of the cylinders.

"We're demonstrating a new field where we can dynamically control each point of the metasurface by adjusting how they are being photodoped," Padilla said. "We can create any type of pattern we want to, allowing us to form lenses or beam-steering devices, for example. And because they're controlled by light beams, they can change very fast with very little power."

While Padilla is more interested in the basic demonstration of the physics behind this technology, he says that it does have a few salient features that make it attractive for devices.

"Because it is not made of metal, it won't melt, which can be a problem for some applications," said Padilla. "It has subwavelength control, which gives you more freedom and versatility. It is also possible to reconfigure how the metamaterial affects incoming waves extremely quickly, which our group is planning to explore for use in dynamic holography." ■



"These materials are made up of a grid of separate units that can be individually tuned. As a wave passes through the surface, the metamaterial can control the amplitude and phase at each location in the grid, which allows us to manipulate the wave in a lot of different ways."

An illustration of the photodoping process in dielectric metamaterials. Incident light (red) modifies the conductivity of the top portion of the cylinders, thereby directing the incident terahertz radiation coming from the top right (blue) to waves moving to the bottom right.

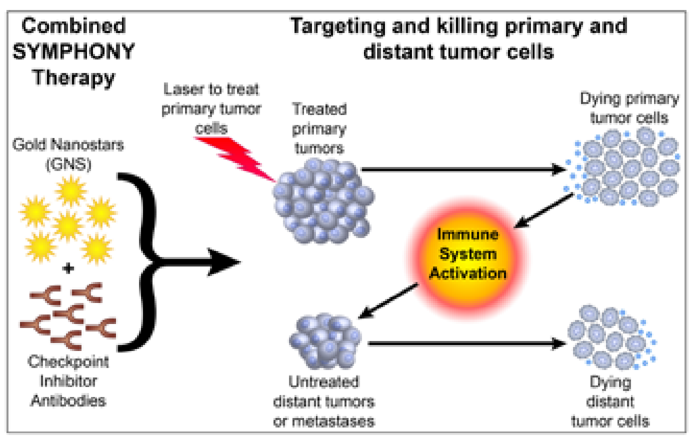
# Gold Nanostars and Immunotherapy Vaccinate Mice Against Cancer

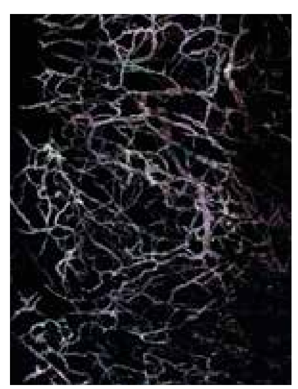
*New treatment heating gold nanostars with infrared light cures and vaccinates mouse in small proof-of-concept study*

By combining an FDA-approved cancer immunotherapy with an emerging tumor-roasting nanotechnology, Tuan Vo-Dinh is looking to fulfill a dream. The combination improved the efficacy of both therapies in a proof-of-concept study using mice, and also attacked satellite tumors and distant cancerous cells. The result was two completely cured mice, one of which was effectively vaccinated one against the disease.

"The ideal cancer treatment is non-invasive, safe and uses multiple approaches," said Vo-Dinh, the R. Eugene and Susie E. Goodson Professor of Biomedical Engineering, professor of chemistry, and director of the Fitzpatrick Institute for Photonics at Duke University. "We also aim at activating the patient's own immune system to eradicate residual metastatic tumors. If we can create a long-term anticancer immunity, then we'd truly have a cure."

The new approach relies on a "photothermal immunotherapy" technology that uses lasers and gold nanostars to heat up and destroy tumors in combination with an immunotherapeutic drug. This photothermal therapy hinges on nanoparticles accumulating preferentially within a tumor due to its leaky vasculature.



**SYMPHONY:** Synergistic Immuno Photo Nanotherapy. By disabling the tumor immune resistance and simultaneously ablate individually cancer cells we can trigger a powerful thermally enhanced systemic immune response to rapidly eradicate locally aggressive and metastatic cancer [Ref: Liu et al, , Scientific reports 7 (1), 8606 (2017)]

Vo-Dinh has pioneered a unique type of nanoparticle called gold nanostars that have multiple sharp spikes, causing them to capture the laser's energy more efficiently. This allows them work with less exposure, making them more effective deeper within a tissue.

After teaming up with colleagues Brant Inman and Greg Palmer in the Departments of Surgery and Radiation Oncology at Duke University Medical Center, and Paolo Maccarini of Duke Biomedical Engineering, Vo-Dinh combined this gold nanostar therapy with a cancer immunotherapy recently cleared by the FDA and in clinical use.

Many tumors overproduce a molecule called PD-L1, which effectively disables T cells, the immune system's main soldiers. Several pharmaceuticals are being developed to attempt to block the action of PD-L1, allowing the immune system to destroy cancerous cells.

In a recent experiment, the Duke researchers injected bladder cancer cells into both hind legs of a group of mice. After waiting for the tumors to grow, the researchers tried different types of treatments—but only on one of the legs.

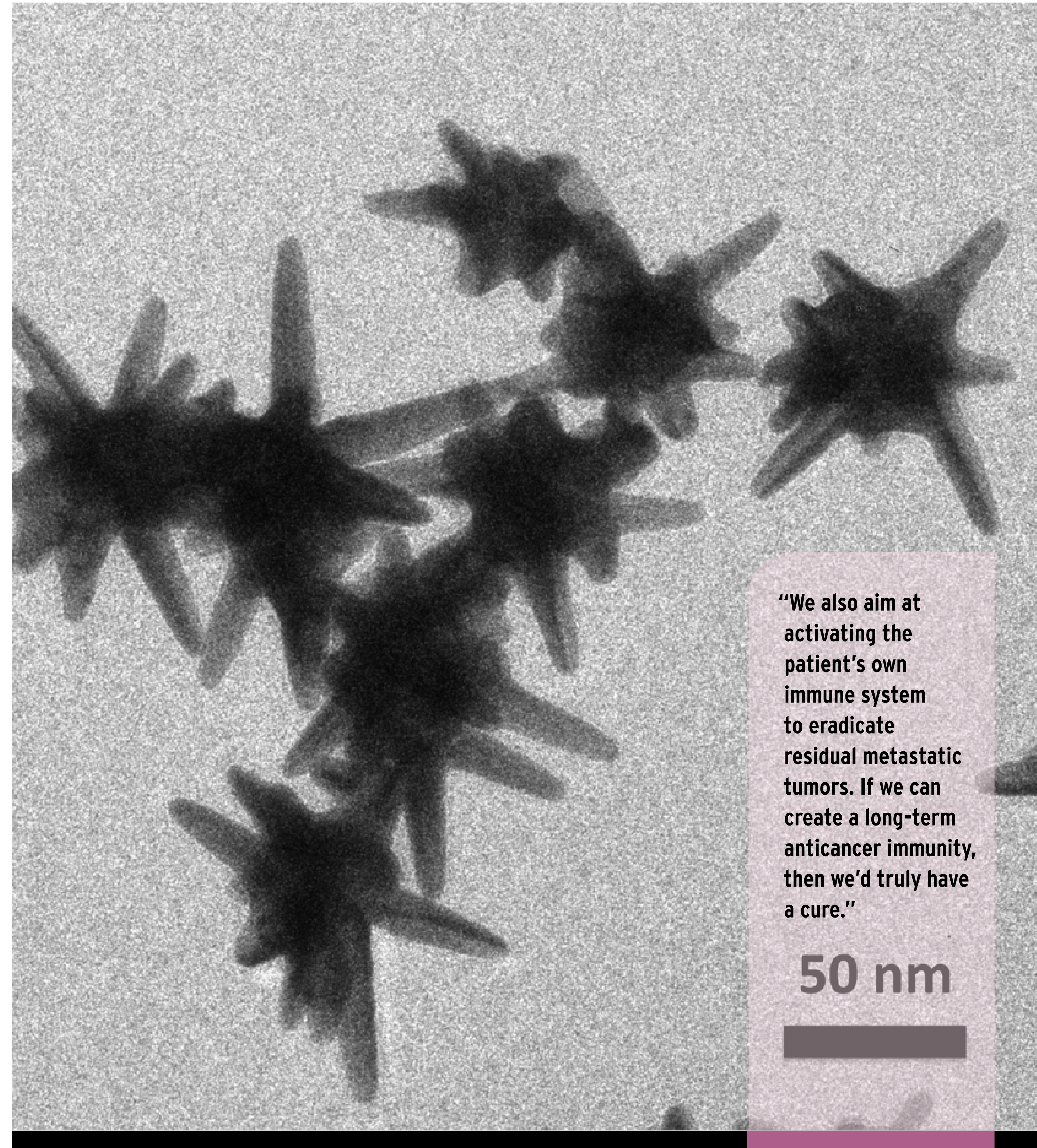
Those receiving no treatments all quickly succumbed to the cancer, as did those receiving only the gold nanostar phototherapy, because the treatment did nothing to affect the tumor in the untreated leg. While a few mice responded well to the immunotherapy alone, with the drug stalling both tumors, none survived more than 49 days.

The group treated with both the immunotherapy and the gold nanostar phototherapy fared much better, with two of the five mice surviving more than 55 days.

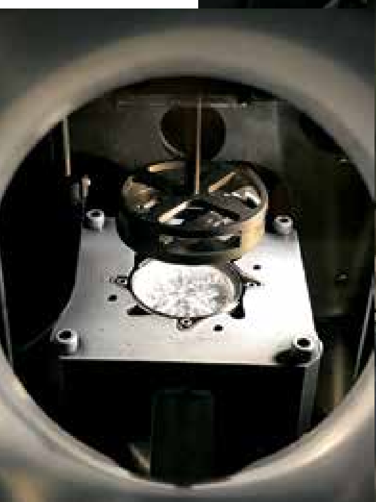
"When a tumor dies, it releases particles that trigger the immune system to attack the remnants," said Vo-Dinh. "By destroying the primary tumor, we activated the immune system against the remaining cancerous cells, and the immunotherapy prevented them from hiding."

The combined treatment worked so well that one mouse was still alive nearly a year afterward with zero recurrence of the cancer. Even a month later, when the researchers injected more cancerous cells, the mouse's immune system attacked and destroyed them without a problem, indicating a vaccine effect in the cured mouse.

"This is our goal—our dream," said Vo-Dinh. ■




**"We also aim at activating the patient's own immune system to eradicate residual metastatic tumors. If we can create a long-term anticancer immunity, then we'd truly have a cure."**



Various view inside and outside of the RIR-MAPLE chamber. The white circle at the center of the table is a frozen solution containing the molecular building blocks for the solar cell material, which is blasted by lasers, vaporizing the solution which carries the materials to coat the bottom of the target above.



Arienne Stiff-Roberts

# Laser Evaporation Technology to Create New Solar Materials

*Delicate hybrid organic-inorganic crystals open new possibilities for light-based technologies*

Adrienne Stiff-Roberts and David Mitzi are using pulsed lasers to create hybrid thin-film materials for new generations of solar cells, light-emitting diodes and photodetectors that would otherwise be difficult or impossible to make.

Perovskites are a class of materials that—with the right combination of elements –have a crystalline structure that makes them particularly well-suited for light-based applications. Their ability to absorb light and transfer its energy efficiently makes them a common target for researchers developing new types of solar cells.

The most common perovskite used in solar energy today, methylammonium lead iodide ($MAPbI_3$), can convert light to energy just as well as today's best commercially available solar panels. And it can do it using a sliver 100 times thinner than a typical silicon-based solar cell.

$MAPbI_3$ is one of the few perovskites that can be created using standard industry production techniques, though it still has issues with scalability and durability. To truly unlock the potential of $MAPbI_3$ and other perovskites, new manufacturing methods are needed.

The mixture of organic and inorganic molecules in a complex crystalline structure, however, can be difficult to make. Organic elements are particularly delicate, but are critical to the hybrid material's ability to absorb and emit light effectively.

"$MAPbI_3$ has a very simple organic component, yet is a very high-performing light absorber," said David Mitzi, the Simon Family Professor of Mechanical Engineering and Materials Science at Duke. "If we can find a new manufacturing approach that can build more complex molecular combinations, it will open new realms of chemistry for multifunctional materials."

Mitzi is teaming up with colleague Adrienne Stiff-Roberts, professor of electrical and computer engineering at Duke, to demonstrate just such a manufacturing approach. The technique is called Resonant Infrared Matrix-Assisted Pulsed Laser Evaporation, or RIR-MAPLE for short, and was developed by Stiff-Roberts at Duke over the past decade.

The original MAPLE technique involves freezing a solution containing the molecular building blocks for the perovskite, and then blasting away a dimple from the frozen block with a laser in a vacuum chamber. This creates vapor that travels upward, coating the bottom surface of any object hanging overhead. Once enough of the material builds up, the process is stopped and the product is heated to crystallize the molecules and set the thin film in place.

In Stiff-Roberts's RIR version of the technology, the laser's frequency is specifically tuned to the molecular bonds of the frozen solvent. This causes the solvent to absorb most of the energy, leaving the delicate organics unscathed.

"The RIR-MAPLE technology is extremely gentle on the organic components of the material," said Stiff-Roberts. "That also makes it much more efficient, requiring only a small fraction of the organic materials to reach the same final product."

**"The RIR-MAPLE technology is extremely gentle on the organic components of the material. That also makes it much more efficient, requiring only a small fraction of the organic materials to reach the same final product."**

Although no perovskite-based solar cells are yet available on the market, there are a few companies working to commercialize solution-processed $MAPbI_3$ and other closely related materials. Currently, the materials made by Mitzi and Stiff-Roberts don't reach the same efficiency values as those made with traditional solution-based processes.

But the duo says that's not their goal.

"While solution-based techniques can also be gentle on organics and can make some great hybrid photovoltaic materials, they can't be used for more complex and poorly soluble organic molecules," said Stiff-Roberts. "With this demonstration of the RIR-MAPLE technology, we hope to open a whole new world of materials to the solar cell industry," continued Mitzi. "We also think these materials could be useful for other applications, such as light-emitting diodes, photodetectors and X-ray detectors." ■

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