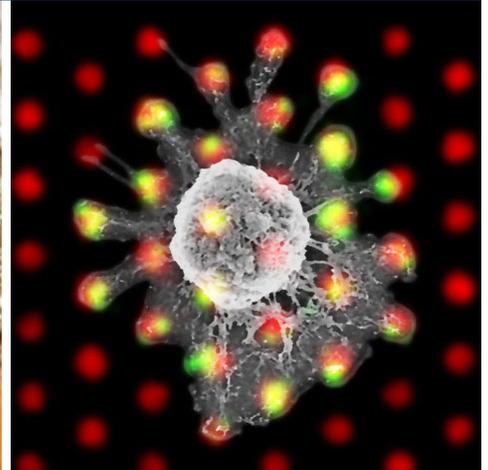
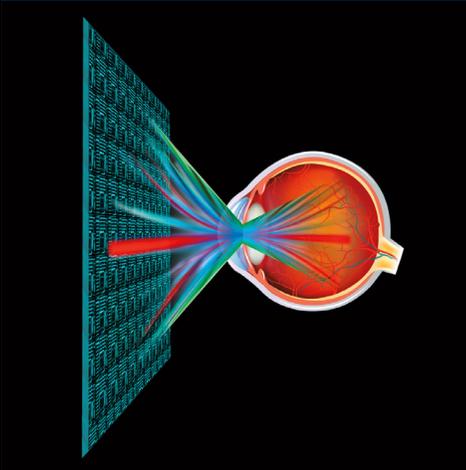


# APAM NEWS

Applied Physics & Applied Mathematics Department,  
with Materials Science & Engineering  
Columbia University in the City of New York



Dear APAM Family,

APAM closes the 2017-2018 school year in good shape and spirits.

Several positive changes have occurred in our Applied Mathematics program. First, Prof.

Michael Tippett, who works on the statistics of extreme climate events and is a key member of our climate modeling program, has been awarded tenure by the University. Second, we successfully recruited one of our applied math graduates, Prof. Kui Ren, to fill the spot created by the departure of Prof. Guillaume Bal. Prof. Ren, who finished his thesis studies under Prof. Bal, is an expert in inverse problems and will contribute greatly to our AM program and Department. We also proclaim our new Calculus-III course, taught by Dr. Drew Youngren, an unqualified success. More than 300 undergraduates took this course for the past two semesters and both the instructor and his team received great reviews.

This spring also brought us sad news. We lost one of the founders of our Department, Dean Robert Gross. He was also the founder of our Plasma Laboratory, which is top-rated in the nation. The Department will work hard and maintain the high standards instituted by Dean Gross.

Finally, I am happy to inform you that I will be stepping down as Chair on June 30, 2018 after six years of service to APAM. On July 1<sup>st</sup>, Prof. Irving Herman will assume this position. Please join me in welcoming him.

Thank you and good bye.

I. Cevdet Noyan, Chair

Images (left-right): New augmented reality glass will include the ability to project aberration-corrected RGB contextual images into the eye (p. 4); Researchers mimic comet moth's silk fibers to make "air-conditioned" fabric (p. 8), and CU Engineers discover geometric underpinnings of T-cell stimulation through precise engineering of T-cell receptor geometry, building a 3D nanofabricated biomimetic surface that simulates the key components of an antigen-presenting cell (p.10)

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## Li Wins 2018 Robert Simon Memorial Prize

The Robert Simon Memorial Prize is awarded annually by the APAM Department to the graduate student who has completed the most outstanding dissertation. This year's prize was awarded to **Dr. Zhaoyi Li**.

Dr. Li received his B.S. in Materials Physics from the University of Science and Technology of China (USTC) in 2011. After graduation, he joined the Department of Applied Physics and Applied Mathematics at Columbia University and received his M.S. Degree in Materials Science in May 2012. In 2013, he joined **Professor Nanfang Yu's** group, where his research focused on exploring the physics and applications of two-dimensional metamaterials, called "metasurfaces".

Zhaoyi received his Ph.D. degree in 2017 with dissertation entitled "Functional Metasurfaces towards Applications: Optical Modulation, Integrated Photonics, and Biomolecular Sensing". He explored strongly correlated perovskites as a new platform for active photonic devices, and demonstrated large, non-volatile and electrical modulation of light over an unprecedented broadband spectrum from the visible to the mid-infrared. He conducted original studies on using metasurfaces to control guided waves, and demonstrated a few novel device functionalities including waveguide mode conversion, on-chip polarization rotation, and highly asymmetric power flow in waveguides. Such metasurface-based devices have substantially reduced footprints and broadband performance compared to conventional photonic integrated devices. He also developed new biosensing platforms by integrating graphene into metasurfaces, realizing, for the first time, simultaneous high-sensitivity and high-specificity detection of protein biomolecules, and breaking the record for high-sensitivity detection of blood sugar.

Working together with colleagues and collaborators, he published four first author papers in journals including *Nature Nanotechnology*, *Advanced Materials*, and *Nature Communications*. He is currently working on metasurface lenses as a postdoctoral fellow at Harvard.

*Robert Simon (1919-2001) spent a lifetime making valuable contributions to the field of computer science. He received a B.A. degree cum laude in Classics from CUNY in '41 and an M.A. in Mathematics from Columbia in '49. He was a Lieutenant in the U.S. Armed forces serving in England, France, and Italy. He worked for 15 years at Sperry's Univac Division and also worked at the Fairchild Engine Division as Director of the Engineering Computer Group. He directed the establishment of several company computer centers at sites throughout the U.S. and was a partner with American Science Associates, a venture capital firm. He was a founder and Vice President of Intech Capital Corporation and served on its board and a founder and member of the board of Leasing Technologies International, Inc. until his retirement. The Prize was established by Dr. Jane Faggen with additional support from friends and relatives of Mr. Simon.*

## APAM Undergraduate Award Winners

The annual APAM Department Senior Dinner and Award Ceremony took place on Thursday, May 3, at Pisticci.

Prof. I. Cevdet Noyan (center) presented the Applied Mathematics Faculty Award to HaoDi Liu (right) and the Applied Physics Faculty Award to Alex Sandomirsky (left).



### Applied Mathematics Faculty Award Winner HaoDi Liu

The Applied Mathematics Faculty Award is presented to an outstanding graduating senior in the applied mathematics program. This year's recipient is **HaoDi (Paul) Liu**. HaoDi came to Columbia as a 3/2 student and quickly distinguished himself by working hard in coursework and asking questions in class. He maintained a GPA above an A and demonstrated a curiosity and depth of knowledge that the faculty found impressive. He worked as a tutor in the Statistics Department and was also a course assistant for Prof. Youngren's Multivariable Calculus course. HaoDi has been admitted to the M.S Operations Research program at Columbia University.

### Applied Physics Faculty Award Winner Alex Sandomirsky

The Applied Physics Faculty Award is presented to an outstanding graduating senior in the applied physics program. This year's recipient, **Alex Sandomirsky**, was an exceptional and conscientious student, earning an A+ in many classes, and maintaining a GPA above an A. He also worked in Prof. Zelevinsky's lab in the Physics Department, where he learned to fine tune optics, set up an automated temperature monitor for the lab, and constructed a heating vessel from a repurposed waste container. He has consistently shown that he is deeply interested in physics and, in the fall, he will begin pursuing a Ph.D. at Yale University, studying particle theory.



## Terban Wins BNL's 2018 Baumert Ph.D. Thesis Award

**Dr. Maxwell Terban** was awarded the 2018 Julian David Baumert Ph.D. Thesis Award from Brookhaven National Laboratory (BNL).

The award, given annually to “a researcher who has recently conducted a thesis project that included significant measurements at NSLS/NSLS-II” (BNL website), was

presented during the NSLS-II and CFN Users' Meeting on May 23, 2018. During the award ceremony, Dr. Terban gave a brief presentation on his thesis which was entitled, “Characterizing the Atomic Structure in Low Concentrations of Weakly Ordered, Weakly Scattering Materials Using the Pair Distribution Function”.

Dr. Terban was nominated for this award by his advisor, **Simon Billinge**, who is a Professor of Applied Physics, Applied Mathematics, and Materials Science at Columbia University and a Scientist at BNL.

## Alumni Reports

**Nicholas Fuller (Ph.D. '02, Solid State Physics)** has been promoted to Director of Cognitive IT Service Foundations at IBM Research. In this new role, Nick will lead the worldwide research strategy for technology services and the IBM Research partnership with IBM's Global Technology Services (GTS) business. Over the past two years, Nick has been leading Technology Services Research, fueling innovation to GTS's Infrastructure Services and Technology Support Services businesses. Under Nick's leadership GTS has successfully launched the IBM Services Platform with Watson— the industry's first AI-infused managed services platform running on IBM's Cloud. Prior to this role, Nick had multiple research and leadership roles in Cloud, Services, and Science and Technology Research. He's also written his memoirs, which were released on Amazon in April 2017.

(Columbia Engineering, Spring 2018)

**Paul Hughes (Ph.D. '16, Plasma Physics)** is an associate research scientist at the Princeton Plasma Physics Laboratory (PPPL). He is currently implementing the improved magnetic diagnostics for the LTX- $\beta$  upgrade project, to better study the effects of the neutral beam on instability drive and to improve the equilibrium reconstruction's robustness to non-axisymmetric eddy currents.

**Masha Kamenetska (Ph.D. '11, Solid State Physics & 2012 APAM Simon Prize Winner)** is now an Assistant Professor of Chemistry and Physics at Boston University. The Kamenetska research group develops and uses novel single molecule nano-manipulation, detection and spectroscopy techniques to understand and control how the structure of the intermolecular interface affects function in biological and man-made devices.

**Ramon Verastegui (Ph.D. '06, Applied Physics)** presented a talk about the applications of machine learning and artificial intelligence applications to finance, options and volatility strategies, at the CBOE Risk Management Conference. Ramon Verastegui is a managing director at Societe Generale.

APAM alumni, **Stewart Prager (Ph.D. '75, Plasma Physics)**, **Don Spero (Ph.D. '68, Plasma Physics)**, and **Jay Kesner (Ph.D. '70, Plasma Physics)**, were featured speakers at the Robert A. Gross Celebration of Life on April 27, 2018. Robert Gross was the 11<sup>th</sup> Dean of SEAS and the Percy K. and Vida L.W. Hudson Professor of Applied Physics. See page 13 for more details.

## Current Student News

Congratulations to **Zane Martin**, a current Atmospheric Science Ph.D. candidate in **Prof. Adam Sobel's** group. Zane was one of 54 students, chosen out of 424 applicants, to receive a NASA Earth and Space Science Fellowship (NESSF).

## 2017-2018 Degree Recipients

**B.S. October 2017:** Triana Steward (AM), Liandong Zhang (AM),

**M.S. October 2017:** Ian Stewart (PP)

**Ph.D. October 2017:** Patrick Byrne (PP), Wilkie Choi (PP), Kate Eckerle (AM), Pubudu Galwaduge (SS), Haixing Li (SS), Hasan Ozen (AM), Chaitanya Rastogi (SS), Dov Rhodes (PP), Ryan Sweeney (PP), Alexander Watson (AM)

**B.S. February 2018:** Yochanan Ben-Ami (AM), Ga Young Lee (AM), Rahi Punjabi (AM), Xian Yang (AP), Edward Yu (AM)

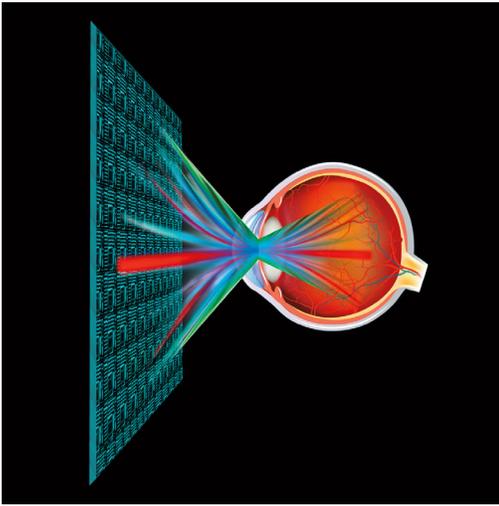
**M.S. February 2018:** Ge Chen (AP), Elizabeth Culbertson (SS), Nishchal Dethe (AM), Rui Feng (MSE), Nathan Fritz (MSE), Yanke Fu (MSE), Songyan Gao (AM), Yizhe Gao (AM), Jiyao Gu (MSE), Yinan Guo (MSE), Shihong He (MSE), Xiang Hua (SS), Kirk Huang (MP), Nikita Kandasami (AM), Huaiyu Li (AM), Xinyue Li (MSE), Hening Liu (MSE), Yinglao Liu (MSE), Conrad Nowak (AP), Saran Pidaparthy (MSE CVN), Boyu Qie (MSE), Anqi Qu (MSE), Elizabeth Ramirez (AM CVN), Yi Ren (MSE), Ogeday Rodop (MSE), Alena Roytlander (MP), Alexander Soloviev (MSE), Kerui Sun (MSE), Zuguang Tian (MSE), Christian Velten (MP), Yuxi Wang (MSE), Liang Wei (AM), Yihui Wei (MSE), Shujian Wen (MSE), Christopher Wright (MSE), Yao Xiao (MSE), Weiheng Xu (MSE), Xiujia Yang (MSE), Season Yang (AM), Xueying Yang (MSE), Pengcheng Yao (MSE), Lingxiang Yu (AM), Fanchen Zeng (AM), Yangyang Zhou (AM), Yiqian Zhu (MSE), Yuxiang Zhu (MSE), Rui Zu (MSE)

**Ph.D. February 2018:** Amy Notis Berger (MSE), Zhaoyi Li (MSE), Maxwell Terban (MSE)

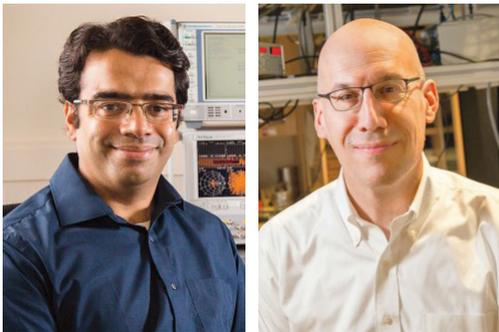
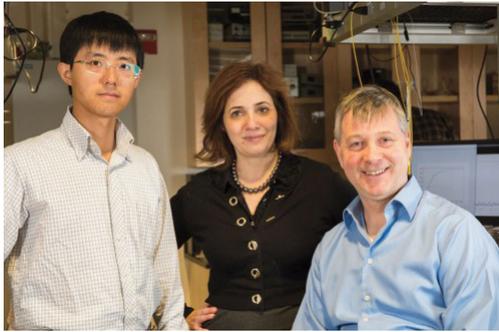
**B.S. May 2018:** Manuel Perez Archila (AM), Xueyi Bu (AM), Justin Calamari (AP), Makani Cartwright (AP), Michael Colucci (AM), Nikolette DeBenedictis (AM), Chang Ge (AM), Michael Hamati (MSE), Juan Huerta (AM), Ingil Hwang (AM), Connie Kang (AP), Yeon Joon Kim (AM), Jaejoon Kim (AM), Suzuka Kokubu (AP), Duhee Lee (AM), Jeffrey Li (AM), Jessica Li (AP), Charles Liang (AP), HaoDi Liu (AM), John Long (AM), Hunter Lum (AM), Benjamin Miller (MSE), Kevin Murphy (AP), Brady Pan (AP), Alex Sandomirsky (AP), Katharine Stein (AM), Christopher Testa (AM), Alexander Vera (AP), Takuya Wakayama (AM), Kristen Wang (AM), Harvey Wu (AP), Jooyeon Yang (AP), Peiying Yu (AM), Qiaochu Zhang (AM),

**M.S. May 2018:** Rui Ding (AM), Joo Won Park (AM), Sa Qu (AM), Jingya Yan (AM), Huiying Zhang (AM), Tyler Cowan (AP), Spencer Desanto (PP), Anya Kogan (AP), Kai Pak (AP), Yumou Wei (AP), Victoria Weller Von Ahlefeld (AP), Michael Berkson (MSE), Michael Di Mare (MSE), Ni Huo (MSE), Nan Ni (MSE), Qi Zhang (MSE)

**Ph.D. May 2018:** Chanul Kim (SS); Nan Shi (MSE), Vernon Wong (MSE)



(Above) As part of its functionality, the new augmented reality glass will include the ability to project aberration-corrected RGB contextual images into the eye, as in the diagram above. (Image credit: Nanfang Yu)



Top row (left-right): Nanfang Yu, Michal Lipson, and James Hone; Bottom row (left-right) Harish Krishnaswamy and Alexander Gaeta (Photos by Timothy Lee Photographers)

## The Team That's Transforming AR Devices

by Marilyn Harris, originally published by *Columbia Engineering*

For consumers, augmented reality (AR) holds out the promise of transforming how we live, work, and play; for the military, this technology could spell the difference between life or death. Current AR ocular devices are far from lightweight or battlefield-ready, and the race is on to develop a compact device that can present critical tactical information as a transparent overlay while freeing both a soldier's hands and focus. Columbia Engineering will play a major role in turning this vision into a reality—recently, a dream team of experts in nanophotonics, materials science, nanofabrication, systems integration, and optics was awarded a four year, \$4.7 million DARPA grant to invent an entirely new approach to AR glasses.

**Michal Lipson**, the Eugene Higgins Professor of Electrical Engineering and a pioneer in the field of silicon photonics holding more than 20 patents, is leading this interdisciplinary team to develop a novel lens material to revolutionize the way AR glasses look and function. In total, the team includes 5 Columbia engineers: **Harish Krishnaswamy** (electrical engineering), **Nanfang Yu** (applied physics), **Alexander Gaeta** (applied physics), and **James Hone** (mechanical engineering), in addition to Lipson. They are joined by **Dmitri Basov** from Columbia's physics department, as well as researchers from UMass Amherst, Stanford University, and Trex Enterprises. The multifunctional AR glasses they're devising, Lipson predicts, will be a "game changer."

Current state-of-the-art AR glasses are large and cumbersome, regardless of whether they project contextual information onto the lens itself or project it onto the retina. The latter method, known as virtual retinal display (VRD), also suffers from limited frame refresh times and requires complex and heavy relay optics, including microelectromechanical mirrors, which render the glasses unwieldy and impractical in the field.

The Columbia team's device improves on the VRD concept. Their innovative lenses will correct dynamically for an individual's ocular aberrations, such as corneal contour, while projecting corrected contextual images—that is, the value-added AR information—directly onto the wearer's retina.

Even at this early stage, their experiments are yielding some intriguing results. "The innovation is in the material and the optical structures," explains Lipson. "The aim is to be able to change the optical properties on the fly, electrically. Instead of transmitting light, the material tilts the beam, enabling high-resolution projection and the ability to detect light, with no moving parts."

Their lens will hinge on the ultrafast generation of arbitrary waveforms, both in the visible and near-infrared (VIS and NIR) spectral ranges, which have been hampered in the past by a lack of actively tunable optical materials. The technology Lipson's team proposes will be based on silicon nitride integrated photonics and incorporate engineered optical materials boasting extremely high electro-optic response with very low losses in the VIS/NIR ranges. In a significant advancement, a tiny laser located on the side of the glasses, perhaps in the frame, will direct the contextual information to the center of each lens. There the beam will be bent and projected onto the retina, appearing as a transparent overlay of the surroundings.

Fabrication of the material will be scalable, according to Lipson. The ultimate deliverable, in addition to dynamically adjusting for corneal aberrations, will be an ultrahigh-resolution, see-through, head-mounted display with vastly improved size, weight, power consumption, and field of view—packaged in a headset no bigger than an ordinary pair of glasses.

Like many other technologies developed for government or defense applications, such practical AR glasses have potential far beyond the military. No doubt researchers are already envisioning uses for task assistance, medicine, maintenance and repair, tourism, and other scenarios yet to be dreamt of.



## Weinstein Receives SIAM's 2018 Martin Kruskal Prize

**Michael I. Weinstein**, Professor of Applied Mathematics and Professor of Mathematics, was selected as SIAM's 2018 Martin Kruskal Prize Lecturer.

The award was given in recognition of "Weinstein's long-standing contributions to the study of nonlinear wave phenomena. He has brought ideas and techniques of classical applied mathematics into a modern form and the deep originality of his work has had a lasting impact on both theory and applications. A distinguished researcher and a prolific and inspiring mentor, he represents the best of our applied mathematics community."

He will receive the award at the SIAM Conference on Nonlinear Waves and Coherent Structures in June 2018 in Anaheim, CA.



## Gang: Engineering for Creative Humanity

by Allison Elliot, originally published by *Columbia Engineering*

*Imagine a world where materials with tailor-made properties could self-assemble into systems that improve almost every area of life.*

Creative thinking can inspire astonishing breakthroughs in engineering—including entirely new materials and systems. **Oleg Gang**, professor of chemical engineering and of applied physics and material science, is among the world's top engineers spearheading the invention of a new class of custom-made nanoscale materials and devices that promise innovative ways to address problems while transforming industries such as manufacturing, medicine, energy, electronics, and telecommunications.

In nature, structures self-assemble through internal instructions and are able to adapt and respond to their environments. This is true on many scales and for many systems, from crystal formation to the biological world. In Gang's lab, researchers work to construct new self-assembling structures based on nanoscale objects—such as man-made nanoparticles or biomolecules borrowed from nature—by both programming the assembly and controlling the properties of the resulting structure. The goal is to create fully designed materials with properties that mimic or even go beyond those found in nature, with the versatile architectures and ability to function as nanoscale machinery.

DNA holds much promise for self-assembly research, as it possesses great flexibility of form as well as the ability to establish a “language” for particle interaction. Yet its inherently fragile nature makes it challenging for use in systems that need to function across a broad range of conditions. Recently, Gang's group was able to mineralize architectures formed by DNA scaffolds and nanoparticles, rendering them stable in extreme temperatures and pressures, a feat that will open up numerous applications.

Gang hopes these advances could one day lead to implants that marry organic and inorganic components and to “smart” materials that can change their shape, appearance, or function according to context.

“There are systems that exist only in our imagination,” says Gang. “I want to figure out the principles that can bring them to reality.”



## Billinge Wins ACA's 2018 Warren Award

Originally published by the ACA

<http://www.americalcrystallography.org/2018-awards>

**Simon Billinge**, Professor of Materials Science, is the recipient of the 2018 Warren Award from the American Crystallographic Association (ACA).

“Materials research seeks to design novel materials where the atomic arrangements on the nanometer scale can be controlled to obtain some desired functionality. One impediment to this is the so-called ‘Nanostructure Problem.’ Billinge is being honored for his role in both highlighting this problem and providing seminal contributions to solving it for a bulk sample of nanoparticles. The nanostructure problem is a statement of the fact that when materials get very small (below about 10 nm), traditional x-ray crystallography breaks down because it is based on Bragg scattering which presumes periodic structures. Billinge's work is built around the use of atomic pair distribution function (PDF) methods. He has championed a generic approach which combines diverse experimental results and theory in a coherent computational framework. He is considered the world leader in characterizing structures of nanomaterials. His most significant contributions have come in the application of sophisticated x-ray and neutron diffraction techniques to study local structure property relationships in complex solid state materials.

Billinge is a committed teacher and mentor. Not only has he made highly significant scientific discoveries, he has further developed the theory underpinning the use of PDF approaches to structure analysis and the software tools needed to exploit this approach. These widely used tools have contributed to the explosive growth in the use of PDF analysis for a wide variety of different structure problems. He has taught numerous workshops and has mentored high school students, undergraduate and graduate students, postdoctoral fellows, and visiting professors.

Billinge is a Fellow of the American Physical Society, a Fellow of the Neutron Scattering Society of America, and received, with his collaborator Takeshi Egami, the J.D. Hanawalt Award from the International Centre for Diffraction Data.”

Prof. Billinge will receive the award and present a lecture on July 22, 2018 during the ACA Annual Meeting in Toronto.

## Faculty Updates

Simon Billinge presented two lectures for the 2018 Busse Lecture Series at the University of Wisconsin's School of Pharmacy. The first talk focused on the advances in total scattering pair distribution function methods for characterizing amorphous and nanocrystalline pharmaceuticals. His second talk centered on finding atoms at the nanoscale for more controlled drug delivery.

Michal Lipson was one of three professors who spoke on the “Spinning Out, In Control” panel at the Columbia Startup Festival sponsored by Women in Science@Columbia. Columbia Technology Ventures reports, “This discussion took a deep dive into three scientists' journeys from innovation to spinout, as well as what life is like at the intersection of university research and the commercial sector.”

After six years of dedicated service, I. Cevdet Noyan is stepping down as the APAM Department Chair and will take a sabbatical next year to focus on research at the Oak Ridge National Lab. APAM warmly thanks Prof. Noyan for his tireless efforts and leadership. Starting in July 2018, Irving Herman, the Edwin Howard Armstrong Professor of Applied Physics, who was the APAM Chair from 2006-2012, will serve as Chair.

Michael Weinstein, along with Ivan Corwin from the Mathematics Department, co-hosted conference on “Transport and localization in random media: theory and applications” at Columbia from May 1-3. The conference presented “recent developments on wave propagation, scattering and diffusion in random media at the interface of probability theory, mathematical physics and partial differential equations.” This conference featured 15 leading researchers and over 60 participants, and was supported by Weinstein's Simons Foundation Math + X Investigator Award, Corwin's Packard Foundation Award, the NSF Research Network, KI-Net, and a grant from the NSF to support participation by junior researchers.

Chris Wiggins, an Applied Mathematics professor who is also a Data Science Institute professor and the Chief Data Scientist at *The New York Times*, helped launch nytDEMO, a group at the NYT devoted to bringing data-science prototypes into products. Wiggins was also part of a team chosen to receive \$100,000 from the inaugural Data Science Institute Seed Funds Program.

Nanfeng Yu was featured in the Harvard University news article, “Changing the color of light: An integrated metasurface converts colors of light over broadband inside a waveguide.” Researchers at Harvard Engineering and Columbia Engineering “have developed a system to convert one wavelength of light into another without the need to phase match.” The research was published in *Nature Communications*.

## Gaeta & Lipson: Dual Frequency Comb Generated on a Single Chip Using a Single Laser

by Holly Everts, originally published by *Columbia Engineering*

*Columbia Engineers are the first to miniaturize dual-frequency combs by putting two frequency comb generators on a single millimeter-sized silicon-based chip; could lead to low-cost, portable sensing and spectroscopy in the field in real-time*

In a paper published in *Science Advances*, researchers under the direction of Columbia Engineering Professors **Michal Lipson** and **Alexander Gaeta** have miniaturized dual-frequency combs by putting two frequency comb generators on a single millimeter-sized chip.

“This is the first time a dual comb has been generated on a single chip using a single laser,” says Lipson, Higgins Professor of Electrical Engineering.

A frequency comb is a special kind of light beam with many different frequencies, or “colors,” all spaced from each other in an extremely precise way. When this many-color light is sent through a chemical specimen, some colors are absorbed by the specimen’s molecules. By looking at which colors have been absorbed, one can uniquely identify the molecules in the specimen with high precision. This technique, known as frequency-comb spectroscopy, enables molecular fingerprinting and can be used to detect toxic chemicals in industrial areas, to implement occupational safety controls, or to monitor the environment.

“Dual-comb spectroscopy is this technique put on steroids,” says Avik Dutt, former student in Lipson’s group (now a postdoctoral scholar at Stanford) and lead author of the paper. “By mixing two frequency combs instead of a single comb, we can increase the speed at which measurement are made by thousandfolds or more.”

The work also demonstrated the broadest frequency span of any on-chip dual comb—i.e., the difference between the colors on the low-frequency end and the high-frequency end is the largest. This span enables a larger variety of chemicals to be detected with the same device, and also makes it easier to uniquely identify the molecules: the broader the range of colors in the comb, the broader the diversity of molecules that can see the colors.

Conventional dual-comb spectrometers, which have been introduced over the last decade, are bulky tabletop instruments, and not portable due to their size, cost, and complexity. In contrast, the Columbia Engineering chip-scale dual comb can easily be carried around and used for sensing and spectroscopy in field environments in real time.

“There is now a path for trying to integrate the entire device into a phone or a wearable device,” says Gaeta, Rickey Professor of Applied Physics and of Materials Science.

The researchers miniaturized the dual comb by putting both frequency comb generators on a single millimeter-sized chip. They also used a single laser to generate both the combs, rather than the two lasers used in conventional dual combs, which reduced the experimental complexity and removed the need for complicated electronics. To produce miniscule rings—tens of micrometers in diameter—that guide and enhance light with ultralow loss, the team used silicon nitride, a glass-like material they have perfected specifically for this purpose. By combining the silicon nitride with platinum heaters, they were able to very finely tune the rings and make them work in tandem with the single input laser.

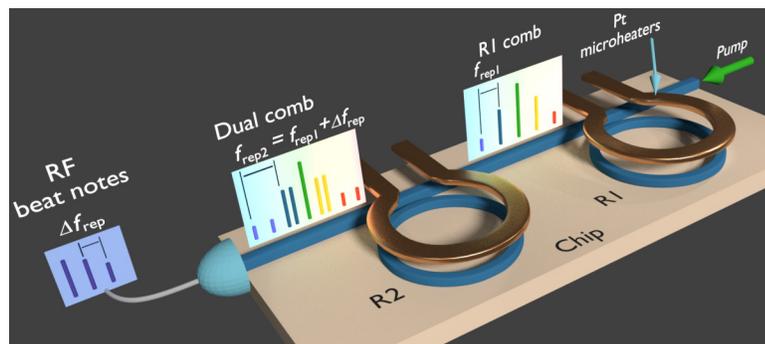
“Silicon nitride is a widely used material in the silicon-based semiconductor industry that builds computer/smartphone chips,” Lipson notes. “So, by leveraging the capabilities of this mature industry, we can foresee reliable fabrication of these dual comb chips on a massive scale at a low cost.”

Using this dual comb, Lipson’s and Gaeta’s groups demonstrated real-time spectroscopy of the chemical dichloromethane at very high speeds, over a broad frequency range. A widely used organic solvent, dichloromethane is abundant in industrial areas as well as in wetland emissions. The chemical is carcinogenic, and its high volatility poses acute inhalation hazards. Columbia Engineering’s compact, chip-scale dual comb spectrometer was able to measure a broad spectrum of dichloromethane in just 20 microseconds (there are 1,000,000 microseconds in one second), a task that would have taken at least several seconds with conventional spectrometers.

As opposed to most spectrometers, which focus on gas detection, this new, miniaturized spectrometer is especially suited for liquids and solids, which have broader absorption features than gases—the range of frequencies they absorb is more spread out. “That’s what our device is so good at generating,” Gaeta explains. “Our very broad dual combs have a moderate spacing between the successive lines of the frequency comb, as compared to gas spectrometers which can get away with a less broad dual comb but need a fine spacing between the lines of the comb.”

The team is working on broadening the frequency span of the dual combs even further, and on increasing the resolution of the spectrometer by tuning the lines of the comb. In a paper published last November in *Optics Letters*, Gaeta’s and Lipson’s groups demonstrated some steps towards showing an increased resolution.

“One could also envision integrating the input laser into the chip for further miniaturizing the system, paving the way for commercializing this technology in the future,” says Dutt.



A compact, integrated, silicon-based chip used to generate dual combs for extremely fast molecular spectroscopy.  
(Image credits: A. Dutt, A. Mohanty, E. Shim, G. Patwardhan)

The study, published in *Science Advances*, is titled “On-chip dual comb source for spectroscopy.”

Authors include: A. Dutt, C. Joshi, and X. Ji (Columbia Engineering and Cornell University); J. Cardenas (Columbia Engineering, now at University of Rochester); K. Luke (Cornell University); Y. Okawachi, A.L. Gaeta, and M. Lipson (Columbia Engineering).

## Pinczuk & Wind: Columbia Engineers Create Artificial Graphene in a Nanofabricated Semiconductor Structure

by Holly Everts, originally published by *Columbia Engineering*

*Researchers are the first to observe the electronic structure of graphene in an engineered semiconductor; finding could lead to progress in advanced optoelectronics and data processing*

Researchers at Columbia Engineering, experts at manipulating matter at the nanoscale, have made an important breakthrough in physics and materials science, recently reported in *Nature Nanotechnology*. Working with colleagues from Princeton and Purdue Universities and Istituto Italiano di Tecnologia, the team has engineered “artificial graphene” by recreating, for the first time, the electronic structure of graphene in a semiconductor device.

“This milestone defines a new state-of-the-art in condensed matter science and nanofabrication,” says **Aron Pinczuk**, professor of applied physics and physics and senior author of the study. “While artificial graphene has been demonstrated in other systems such as optical, molecular, and photonic lattices, these platforms lack the versatility and potential offered by semiconductor processing technologies. Semiconductor artificial graphene devices could be platforms to explore new types of electronic switches, transistors with superior properties, and even, perhaps, new ways of storing information based on exotic quantum mechanical states.”

The discovery of graphene in the early 2000s generated tremendous excitement in the physics community not only because it was the first real-world realization of a true two-dimensional material but also because the unique atomic arrangement of the carbon atoms in graphene provided a platform for testing new quantum phenomena that are difficult to observe in conventional materials systems. With its unusual electronic properties—its electrons can travel great distances before they are scattered—graphene is an outstanding conductor. These properties also display other unique characteristics that make electrons behave as if they are relativistic particles that move close to the speed of light, conferring upon them exotic properties that “regular,” non-relativistic electrons do not have.

But graphene, a natural substance, comes in only one atomic arrangement: the positions of the atoms in the graphene lattice are fixed, and thus all experiments on graphene must adapt to those constraints. On the other hand, in artificial graphene the lattice can be engineered over a wide range of spacings and configurations, making it a holy grail of sorts for condensed matter researchers because it will have more versatile properties than the natural material.

“This is a rapidly expanding area of research, and we are uncovering new phenomena that couldn’t be accessed before,” says **Shalom Wind**, an adjunct faculty member of the APAM Department and co-author of the study. “As we explore novel device concepts based on electrical control of artificial graphene, we can unlock the potential to expand frontiers in advanced optoelectronics and data processing.”

This work is really a major advance in artificial graphene. Since the first theoretical prediction that system with graphene-like electronic properties may be artificially created and tuned with patterned 2D electron gas, no one had succeeded, until the Columbia work, in directly observing these characteristics in engineered semiconductor nanostructures,” says Steven G. Louie, professor of physics, University of California,

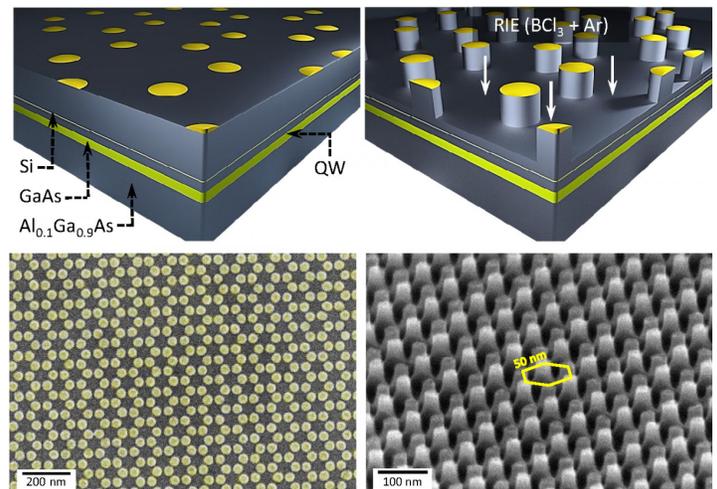
Berkeley, who was not involved in the study. “Previous work with molecules, atoms, and photonic structures represent far less versatile and stable systems. The nanofabricated semiconductor structures open up tremendous opportunities for exploring exciting new science and practical applications.”

The researchers used the tools of conventional chip technology to develop the artificial graphene in a standard semiconductor material, gallium arsenide. They designed a layered structure so that the electrons could move only within a very narrow layer, effectively creating a 2D sheet. They used nanolithography and etching to pattern the gallium arsenide: the patterning created a hexagonal lattice of sites in which the electrons were confined in the lateral direction. By placing these sites, which could be thought of as “artificial atoms,” sufficiently close to one another ( $\sim 50$  nanometers apart), these artificial atoms could interact quantum mechanically, similar to the way atoms share their electrons in solids.

The team probed the electronic states of the artificial lattices by shining laser light on them and measuring the light that was scattered. The scattered light showed a loss of energy that corresponded to transitions in the electron energy from one state to another. When they mapped these transitions, the team found that they were approaching zero in a linear fashion around what is called the “Dirac point” where the electron density vanishes, a hallmark of graphene.

This artificial graphene has several advantages over natural graphene: for instance, researchers can design variations into the honeycomb lattice to modulate electronic behavior. And because the spacing between the quantum dots is much larger than the inter-atomic spacing in natural graphene, researchers can observe even more exotic quantum phenomena with the application of a magnetic field.

The discovery of new low-dimensional materials, such as graphene and other ultrathin, layered van der Waals films that exhibit exciting new physical phenomena that were previously inaccessible, laid the groundwork for this study. “What was really critical to our work was the impressive advancements in nanofabrication,” Pinczuk notes. “These offer us an ever-increasing toolbox for creating a myriad of high-quality patterns at nanoscale dimensions. This is an exciting time to be a physicist working in our field.”



**Image:** Schematic diagram of artificial graphene in a semiconductor. Etched pillars define the positions of quantum dots (red puddles) arranged in a hexagonal lattice. When the spacing between the quantum dots is sufficiently small, electrons can move between them. (Image credit: Diego Scarabelli)

The study, published in *Nature Nanotechnology*, is titled “Observation of Dirac Bands in Artificial Graphene in Small Period Nano-patterned GaAs Quantum Wells.”  
 Authors include: S. Wang, D. Scarabelli, L. Du, S.J. Wind, and A. Pinczuk (Columbia Engineering); Y. Y. Kuznetsova (Columbia University); L.N. Pfeiffer and K. West (Princeton University); G.C. Gardner and M.J. Manfra (Purdue University); and V. Pellegrini (Istituto Italiano di Tecnologia).

## Yu: Researchers Mimic Comet Moth's Silk Fibers to Make "Air-conditioned" Fabric

by Holly Evarts, originally published by *Columbia Engineering*

In exploring the optical properties of the Madagascar comet moth's cocoon fibers, Columbia Engineering team discovers the fibers' exceptional capabilities to reflect sunlight and to transmit optical signals and images, and develops methods to spin artificial fibers mimicking the natural fibers' nanostructures and optical properties

Fabrics made from silkworm fibers have long been treasured for their beautiful luster and refreshing coolness. Columbia Engineering researchers have discovered that fibers produced by the caterpillars of a wild silk moth, the Madagascar comet moth (*Argema mittrei*), are far superior in terms of brilliance and cooling ability. Not only do the comet moth's cocoon fibers have outstanding cooling properties, they also have exceptional capabilities for transmitting light signals and images.

Led by **Nanfang Yu**, assistant professor of applied physics, the team characterized the optical properties associated with one-dimensional nanostructures they found in comet moth cocoon fibers. They were so fascinated by the unusual properties of these fibers that they developed a technique to spin artificial fibers that mimic the nanostructures and optical properties of the natural fibers. The study was published in *Light: Science & Applications*.

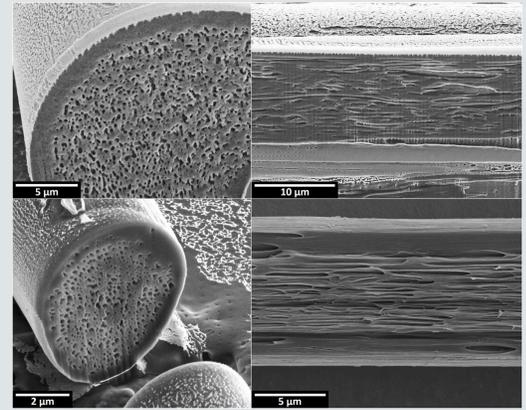
"The comet moth fibers are the best natural fibrous material to block sunlight we've ever seen. Synthesizing fibers possessing similar optical properties could have important implications for the synthetic fiber industry," said Yu, an expert in nanophotonics. "Another amazing property of these fibers is that they can guide light signals or even transport simple images from one end to the other end of the fiber. This means we might be able to use them as a biocompatible and bioresorbable material for optical signal and image transport in biomedical applications."

While individual fibers produced by our domesticated silkworms look like solid, transparent cylinders under an optical microscope, the individual thread spun by the comet moth caterpillars has a highly metallic sheen. The comet moth fibers contain a high density of nanoscale filamentary air voids that run along the fibers and cause strong specular (mirror-like) reflection of light. A single fiber with the thickness of a human hair, about 50 microns in diameter, reflects more than 70% of visible light. In contrast, for common textiles, including silk fabrics, to reach such level of reflectivity, one has to put together many layers of transparent fibers for a total thickness of about 10 times that of a single comet moth fiber. In addition, the high reflectivity of comet moth fibers extends well beyond the visible range into the infrared spectrum—invisible to the human eye but containing about half of the solar power. This, together with the fibers' ability to absorb ultra violet (UV) light, makes them ideal for blocking sunlight, which contains UV, visible, and infrared components.

The ability of comet moth fibers to guide light is an effect known as transverse Anderson localization, and is a result of the filamentary air voids along the fibers: the air voids cause strong optical scattering in the fiber cross-section, providing sideways confinement of light, but presenting no impediment for light propagation along the fibers.

"This form of light guiding—confining light to propagate within the interior of a strand of material with no sideways light leakage—is very different from the one utilized in light transmission through undersea fiber-optic cables, where light confinement is provided by reflection at the boundary between a fiber core and a cladding layer," said **Norman Shi**, lead author of the paper and a Ph.D. student recently graduated from Yu's lab, said. "This is the first time transverse Anderson localization has been discovered in a natural materials system. Our finding opens up potential applications in light guiding, image transport, and light focusing where biocompatibility is required."

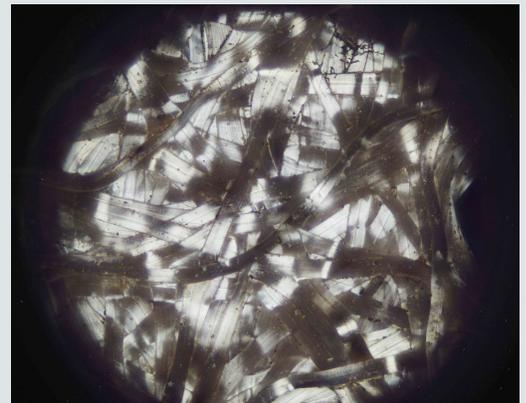
Once Yu's team had characterized the comet moth fibers, they then set to inventing novel fiber pulling methods that emulate the fiber spinning mechanism of the comet moth caterpillar to create fibers embedded with a high density of particulate or filamentary voids. The researchers achieved a density of voids several times higher than that found in the natural fibers: a single bioinspired fiber is able to reflect ~93% of sunlight. They produced these bioinspired fibers using two materials: a natural material (regenerated silk, i.e., liquid precursor of silk fibers) and (continued on page 11)



Above: Scanning electron micrographs of man-made fibers emulating the optical properties of comet moth cocoon fibers. Top row: Transverse and longitudinal cross-sections, respectively, of a synthesized fiber made of regenerated silk containing a high density of filamentary air voids. Bottom row: Corresponding images of a PVDF (polyvinylidene difluoride) fiber containing a high density of filamentary voids.



Above & below: Madagascar comet moth cocoon fibers have a highly metallic sheen. (Image credits: Norman Shi and Nanfang Yu)



The study is titled "Nanostructured fibers as a versatile photonic platform: Radiative cooling and waveguiding through transverse Anderson localization." Authors are: N. Shi, C.-C. Tsai, M.J. Carter, J. Mandal, A.C. Overvig, Y. Yang, and N. Yu (Columbia University); M.Y. Sfeir and M. Lu (Brookhaven National Laboratory); C. L. Craig (Harvard University); G. D. Bernard (University of Washington).

## Yang: Columbia Engineers Develop Flexible Lithium Battery for Wearable Electronics

Originally published by *Columbia Engineering*

*Shaped like a spine, new design enables remarkable flexibility, high energy density, and stable voltage no matter how it is flexed or twisted*

The rapid development of flexible and wearable electronics is giving rise to an exciting range of applications, from smart watches and flexible displays—such as smart phones, tablets, and TV—to smart fabrics, smart glass, transdermal patches, sensors, and more. With this rise, demand has increased for high-performance flexible batteries. Up to now, however, researchers have had difficulty obtaining both good flexibility and high energy density concurrently in lithium-ion batteries.

A team led by **Yuan Yang**, assistant professor of materials science and engineering, has developed a prototype that addresses this challenge: a Li-ion battery shaped like the human spine that allows remarkable flexibility, high energy density, and stable voltage no matter how it is flexed or twisted. The study was published in *Advanced Materials*.

“The energy density of our prototype is one of the highest reported so far,” says Yang. “We’ve developed a simple and scalable approach to fabricate a flexible spine-like lithium ion battery that has excellent electrochemical and mechanical properties. Our design is a very promising candidate as the first-generation, flexible, commercial lithium-ion battery. We are now optimizing the design and improving its performance.”

Yang, whose group explores the composition and structure of battery materials to realize high performance, was inspired by the suppleness of the spine while doing sit-ups in the gym. The human spine is highly flexible and distortable as well as mechanically robust, as it contains soft marrow components that interconnect hard vertebra parts. Yang used the spine model to design a battery with a similar structure. His prototype has a thick, rigid segment that stores energy by winding the electrodes (“vertebrae”) around a thin, flexible part (“marrow”) that connects the vertebra-like stacks of electrodes together. His design provides excellent flexibility for the whole battery.

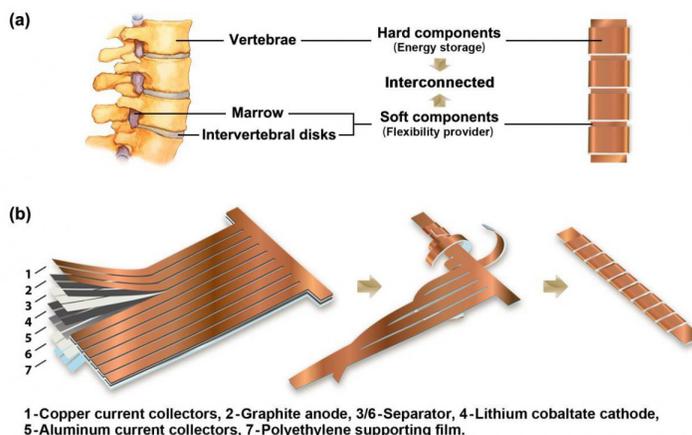
“As the volume of the rigid electrode part is significantly larger than the flexible interconnection, the energy density of such a flexible battery can be greater than 85 percent of a battery in standard commercial packaging,” Yang explains. “Because of the high proportion of the active materials in the whole structure, our spine-like battery shows very high energy density—higher than any other reports we are aware of. The battery also successfully survived a harsh dynamic mechanical load test because of our rational bio-inspired design.”

Yang’s team cut the conventional anode/separator/cathode/separator stacks into long strips with multiple “branches” extending out 90 degrees from the “backbone.” Then they wrapped each branch around the backbone to form thick stacks for storing energy, like vertebrae in a spine. With this integrated design, the battery’s energy density is limited only by the longitudinal percentage of vertebra-like stacks compared to the whole length of the device, which can easily reach over 90 percent.

The battery shows stable capacity upon cycling, as well as a stable voltage profile no matter how it is flexed or twisted. After cycling, the team disassembled the battery to examine the morphology change of electrode materials. They found that the positive electrode was intact with no obvious cracking or peeling from the aluminum foil, confirming the mechanical stability of their design. To further illustrate the flexibility of their design, the researchers continuously flexed or twisted the battery during discharge, finding that neither bending nor twisting interrupted the voltage curve. Even when the cell was continuously flexed and twisted during the whole discharge, the voltage profile remained. The battery in the flexed state was also cycled at higher current densities, and the capacity retention was quite high (84 percent at 3C, the charge in 1/3 of an hour). The battery also survived a continuous dynamic mechanical load test, rarely reported in earlier studies.

“Our spine-like design is much more mechanically robust than are conventional designs,” Yang says. “We anticipate that our bio-inspired, scalable method to fabricate flexible Li-ion batteries could greatly advance the commercialization of flexible devices.”

The study, published in *Advances Materials*, is titled “Bio-inspired, spine-like flexible rechargeable lithium-ion batteries with high energy density.” Authors are: G. Qian, B. Zhu, H. Zhai, N.J. Fritz, Q. Cheng, M. Ning, B. Qie, and Y. Yang (Materials Science and Engineering Program, Columbia Engineering); A. Srinivasan (Mechanical Engineering, Columbia Engineering); X. Liao and X. Chen (Earth and Environmental Engineering, Columbia Engineering); Y. Li (Visual Communication Department, School of the Art Institute of Chicago); S. Yuan (School of Physics, Huazhong University of Science and Technology); J. Zhu, (College of Engineering and Applied Science, Nanjing University).



**Schematic of the structure and the fabrication process of Yang's spine-like battery.** (a) Schematic illustration of bio-inspired design, the vertebrae correspond to thick stacks of electrodes and soft marrow corresponds to unwound part that interconnects all the stacks. (b) The process to fabricate the spine-like battery, multilayers of electrodes were first cut into designed shape, then strips extending out were wound around the backbone to form spine-like structure. (Image credit: Yuan Yang)



### Featured videos:

Flexible Battery, Smart Watch, and Meter & Columbia Engineering Yang Battery Test

<http://engineering.columbia.edu/news/yuan-yang-flexible-lithium-battery>

## Wind: Geometry is Key to T-Cell Triggering

by Holly Evarts, originally published by *Columbia Engineering*

*Columbia Engineers discover geometric underpinnings of T-cell stimulation through precise engineering of T-cell receptor geometry, building a 3D nanofabricated biomimetic surface that simulates the key components of an antigen-presenting cell*

T cells protect the body from foreign substances (known as antigens) and are an essential component of the body's immune system. New immunotherapies that use a patient's own T cells to treat disease have already proven strikingly effective in treating some cancers, and cancer researchers around the world are racing to improve these treatments and apply them more broadly.

The engagement between T cells and antigens sets off the immune response, with cascade of signals within the T cell. The process involves an intricate choreography of receptor proteins and their ligands at or near the surface of the T cell and the antigen-presenting cell (APC).

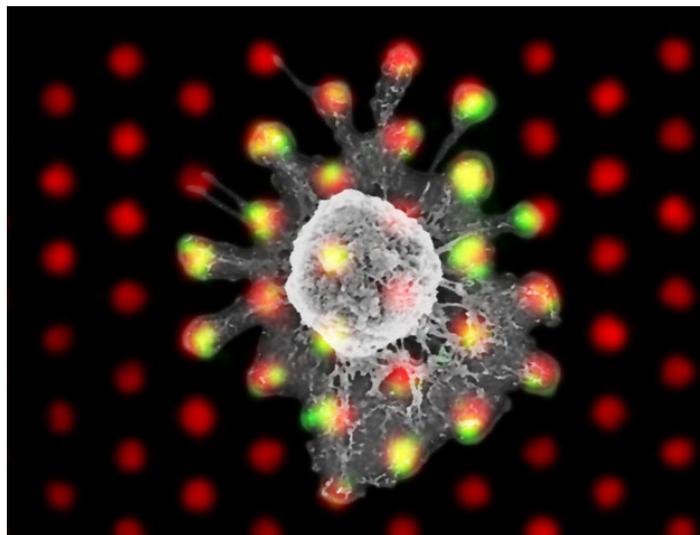
A team of researchers, led by Columbia Engineering Applied Physicist and adjunct professor **Shalom J. Wind** and Oxford University and NYU-Langone Medical Center biologist Michael L. Dustin, has revealed the geometric underpinnings of T-cell triggering through the precise engineering of T-cell receptor geometry in all three dimensions. They used nanofabrication to create a biomimetic surface that simulates the key features of the APC. This surface presents T-cell receptor ligands (molecules that bind to and stimulate receptors on the surface of the T cell) in a variety of different geometric arrangements, with different inter-ligand spacings arranged in clusters of varying size. The findings were published online in *Nature Nanotechnology*.

"Our results could have a significant impact on the field of adoptive immunotherapy, which has been seeing remarkable success recently in treating certain cancers," says Wind. "Our nanoengineering approach has allowed us to investigate the role that geometry plays in T-cell triggering with unprecedented precision and control. We became very interested in determining how important the geometric arrangement of molecules is to the early steps in T-cell stimulation, because this could provide new insight into this process and might even offer a new way to control T-cell activation."

The new advance in the team's nanofabricated biomimetic surfaces, which was key to the study published today, was the development of a way to place the ligands on "nanopedestals" on the surface, effectively controlling the distance between the T cell and the APC, while at the same time controlling the spacing between the individual ligands. They also devised a technique to introduce other molecules that play an important role in the T-cell/APC engagement and allowed them to bind to one another.

The combination of these innovations—the precise geometric control of ligand position together with placing the ligands on the nanopedestals and enabling the additional molecules to play their usual role—led to a striking discovery: a sharp increase in T-cell triggering when the ligand spacing fell below 50 nm. But this threshold appeared only when the T cell was separated from the surface (or APC surface) by about 23 nm, using the nanopedestals. The researchers showed that this was a result stemming from the spatial aspects of CD45, a protein whose physiological role is to inhibit T-cell receptor activation. If the T cell and the APC are very close together, then CD45, which is a "big" molecule, is "squeezed out" of the area, allowing T-cell receptor activation to proceed. With some additional room between the cells, CD45 can prevent this—unless the T-cell receptor ligands are too close to one another (less than 50 nm), in which case, the *lateral* spacing partially squeezes out the CD45.

The role of CD45 exclusion from the T-cell receptor has been a hot topic among immunology researchers: some think it is an absolute requirement for receptor triggering, while others say that it plays only



Composite of a scanning electron micrograph and immunofluorescence image showing a T cell (SEM) on an array of clusters of T cell receptor ligands, fluorescently labeled red. The green fluorescent signal comes from phosphorylation of a component of the T cell receptor, indicating that triggering has occurred (i.e., the T cell has been stimulated). (Image credit: Haogang Cai)

a partial role. "In our study, we were able not only to observe a spatial threshold that shows that CD45 exclusion is important, but also to see that triggering can take place even when CD45 is not entirely segregated from the T-cell receptor region, as long as the spacing is small," says Dustin, who is a professor at the Kennedy Institute of Rheumatology. "Not only does this shed important light on the question of CD45 exclusion, but it suggests a functional role for T-cell receptor packing at close dimensions."

This highly interdisciplinary project combined semiconductor device processing with cellular biology, surface chemistry, and biochemistry. The Columbia team, which included Michael Sheetz, emeritus professor of biological sciences and biomedical engineering and director of the Mechanobiology Institute of Singapore, combined their expertise, taking the tools and techniques originally developed by the semiconductor industry to fabricate transistors and adapting them to address important questions in cell biology. The team has been collaborating on cellular geometry sensing for almost 15 years. They use lithographic patterning, thin film deposition, and etching to create "chips" that are built on microscope slides, rather than silicon wafers. Using the facilities available as part of the Columbia Nano Initiative, they have been able to create arbitrary patterns of individual proteins (far smaller than even the most advanced transistor elements), with precise control over the location of each and every protein.

Dustin noted, "This was a great collaboration, as biologists have struggled with ways to precisely control the space between cells. The Columbia engineers developed a method to effectively 'jack up' the live T cell by 10 nm over a biomimetic surface developed by the NYU/Oxford team. These elements came together to address a fundamental question of relevance to immunotherapy."

The results reported today may have important applications in adoptive immunotherapy and possibly beyond. With the specific knowledge of the geometric parameters underlying T-cell receptor triggering, researchers could improve some therapies by, for example, designing new chimeric antigen receptors (that are the basis for CAR T-cell therapy) with specific geometric features that optimize therapeutic outcomes. Nanofabricated surfaces like the ones used in this work might also be used to improve both T-cell expansion and activation outside the body, possibly increasing the efficiency of this type of immunotherapy and shortening the treatment time. (continued on page 11)

## Yu: Researchers Mimic Comet Moth's Silk Fibers to Make "Air-conditioned" Fabric (Continued from page 8)

a synthetic polymer (polyvinylidene difluoride). While the former is suitable for applications requiring biocompatibility, the latter is suitable for high throughput production.

"The single major difference between our bioinspired fibers and fibers used universally for textiles and apparel is that the bioinspired fibers contain engineered nanostructures, whereas conventional fibers all have a solid core," Yu said. "The capability of structural engineering on the tiny cross-section of a fiber via a high-throughput, high-yield fiber spinning process opens up a new dimension of design—we can infuse completely novel optical and thermodynamic functions into fibers and textiles composed of such fibers. We could transform the synthetic fiber industry!"

These bioinspired fibers could be used for making ultra-thin summer clothing with "air conditioning" properties. Just a few layers of the fibers could make a totally opaque textile that is a fraction of a sheet of paper in thickness. Yet it wouldn't become translucent when the wearer sweats, which is a common problem with conventional textiles. While sweat reduces the opaqueness of common fabrics by reducing the number of fiber-air interfaces that reflect light, it would not affect the nanoscale air voids embedded in the bioinspired fibers. In addition, ultra-thin apparel made of the "porous" fibers would promote cooling through a combination of sweat evaporation, air flow between the microenvironment of the human body and the exterior, and radiation of body heat to the external environment. "Thus, your clothes could give you the ultimate cooling experience through the collective effect of evaporative, convective, and radiative cooling," Yu added.

The Madagascar comet moth is one of the largest in the world, with cocoons spanning 6 to 10 cm in length. The caterpillars make their cocoons in the tree canopy of Madagascar, with plenty of sunlight that could drastically heat the pupae if their cocoons did not possess their reflective metallic sheen. These extraordinary fibers, whose filamentary air voids could be the result of natural selection to prevent overheating, were brought to Yu's attention by Catherine Craig, director of the NGO Conservation through Poverty Alleviation, International. CPALI works with rural farmers in Madagascar to develop sustainable livelihoods that support both people and ecosystems by cultivating and marketing native resources, one product being the fibers produced by the caterpillars of the comet moth.

Yu is currently working on increasing the throughput of producing such bioinspired nanostructured fibers. His lab wants to achieve this with minimal modifications to the common practice of industrial fiber pulling.

"We don't want to drastically change those gigantic fiber spinning machines in use throughout the industry," said Yu. "Instead we want to introduce clever twists to a few critical steps or components so these machines can produce nanostructured, rather than solid, fibers."

## Wind: Geometry is Key to T-Cell Triggering (Continued from page 10)

"This work is really clever," says Carl S. June, a professor of immunotherapy at the Perelman School of Medicine, University of Pennsylvania, and a pioneer of adoptive T-cell transfer therapy, who was not involved with the study. "The direct evidence for a non-linear role played in and out of the plane of the membrane in TCR (T-cell receptor) triggering is quite novel and has implications on the design of CAR T cells. This approach might guide the development of CARs that would have better discrimination between tumor cells and normal cells that have lower densities of target."

Sheetz adds, "This technology can have a much larger role in addressing the general issue of how the spacing between cells as well as between cells and substrates can affect signaling processes."

"Beyond our focus on immunotherapy," Wind notes, "this work shows how the power of transistor fabrication technology can be applied to problems in biomedicine. Following this path promises to lead to more exciting developments in the future."



## Sabbagh Granted Funding for Plasma Stability Research

*Physicist Steven Sabbagh was granted funding for plasma stability research aimed at disruption prediction and avoidance on leading international spherical tokamak*

Preventing disruptions in tokamak plasmas that can halt fusion reactions and damage the interior walls of future devices is a top priority of the U.S. magnetic fusion program. Future fusion reactors must operate without disruptions for lengthy periods of time.

**Steven Sabbagh**, a senior research scientist and adjunct professor in the APAM Department on long-term assignment to the U.S. Department of Energy's (DOE) Princeton Plasma Physics Laboratory (PPPL), has been recently granted a multi-year research project on the Mega Amp Spherical Tokamak - Upgrade (MAST-U) facility at the Culham Centre for Fusion Energy (CCFE). The three-year, \$2M research collaboration will directly address plasma stability analysis and modeling that support disruption prediction and avoidance in tokamaks by uniquely leveraging the low aspect ratio, high elongation, high beta, flexible heating, and 3D coil capabilities of MAST-U. The low aspect ratio of the MAST-U device takes advantage of improved stability afforded by favorable alteration of the magnetic field geometry due to its compact design. Dr. Sabbagh will be joined by APAM senior research scientists **Jack Berkery** and **James Bialek**, and APAM associate research scientist **Young-Seok Park**, together with a post-doctoral research scientist.

Dr. Sabbagh is also lead principal investigator for a multi-institutional international project between Columbia University, the Princeton Plasma Physics Laboratory, and M.I.T. to study the stability and active control of plasmas in the long-pulse Korea Superconducting Tokamak Advanced Research (KSTAR) facility located in Daejeon, South Korea.

The study, published in *Nature Nanotechnology*, is titled "Full control of ligand positioning reveals spatial thresholds for T cell receptor triggering."

Authors are: H. Cai and S.J. Wind (Columbia Engineering); M.P. Sheetz (Columbia Engineering and Arts & Sciences); D. Depoil, V. Mayya, and M. L. Dustin (University of Oxford); and J. Muller (New York University School of Medicine).



## Thomas Morgan Retires

On behalf of the APAM Department's Medical Physics program, **Prof. C.S. Wu** (left) presented **Prof. Thomas L. Morgan** (right) with a plaque in appreciation of his contributions to the program over the past five years.

Dr. Morgan, who has a Ph.D. in Radiological Sciences from the University of California, Irvine, taught Health Physics and Health Physics Practicum in the Medical Physics program while also serving as the Chief Radiation Safety Officer and Executive Director of Environmental Health and Safety at Columbia University.

Prof. Morgan will be retiring from the University in June 2018 to pursue other interests. The APAM Department thanks Prof. Morgan and wishes him great success in his future endeavors.

## Currents Always Find the Fastest Detour

APAM Associate Research Scientist and APAM alum, Jeffrey Levesque (Ph.D. '12, Plasma Physics), wrote the following article which was originally published on the U.S. DOE's website: <https://science.energy.gov>

*Scientists map electrical currents emanating from the boundary of a tokamak plasma, providing new information for reactor design.*

### The Science

In fusion experiments, disruptions of the superhot material, or plasma, can induce large currents in the vacuum vessel wall and surrounding support structures. These currents can transfer between the plasma and vessel wherever plasma comes into contact with the wall. Researchers have mapped these shared current paths using hundreds of magnetic field sensors while avoiding ambiguities encountered in other experiments. For the first time, scientists have directly measured the relationship between helical plasma displacements and toroidal currents flowing through the wall. Wall currents bypass electrical breaks in the wall by transiting through the plasma edge.

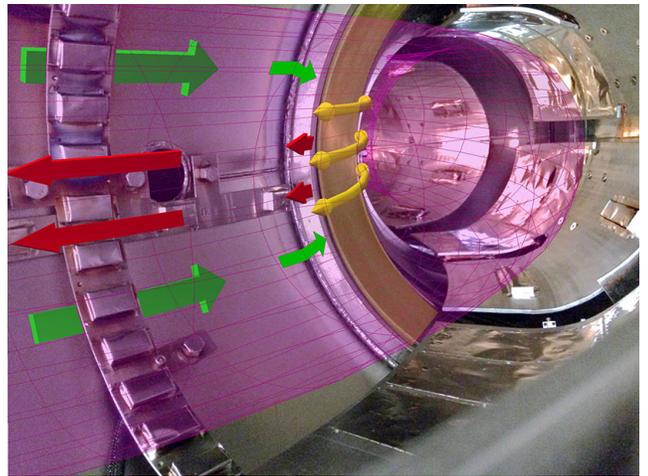
### The Impact

Currents conducting through the walls of a tokamak, a bagel-shaped design that confines superheated plasmas with magnetic fields, interact with local magnetic fields. The interaction produces forces that may be large enough to damage the walls of fusion experiments and future fusion reactors. In a reactor, these forces will be the same magnitude as the thrust from a Saturn V rocket. Accurately predicting these currents and their 3-D paths is vital for designing reactor walls, developing plasma control strategies, and ensuring safe shutdown procedures. With these direct measurements, scientists now have additional information to validate physics models used in the design of fusion reactors.

### Summary

The walls of fusion energy experiments, such as ITER, must be carefully designed to handle large electromagnetic forces. During the abrupt termination of discharges (called "disruptions"), plasma motion and dissipation generate large currents at the plasma boundary, provide paths for current to flow from the plasma to the wall, and cause large electromagnetic forces. The current path at the interface between the plasma and the first wall is under debate among plasma physicists, and experiments are needed to distinguish between various theories and models.

Columbia University scientists and students are now taking a detailed look at how 3-D geometries of the wall, plasma, and magnetic fields affect the currents. Insulating quartz breaks in a unique vacuum vessel have allowed scientists to make or break major electrical connections around the device, revealing how induced currents can thwart attempts at redirecting them during disruptions. When an electrical connection is broken to prevent a current path, the plasma allows current to flow anyway by making a short circuit around the break. Hundreds of magnetic sensors close to the plasma surface now provide comprehensive measurement of the relationship between helical plasma distortions and plasma-wall currents, and show that leading competing theoretical treatments must be combined to explain the full disruption evolution.



Dense magnetic sensor sets close to a tokamak plasma (magenta) reveal possible current paths in the boundary region (red) and wall (green) during a disruption. Currents are found to bypass insulating regions of the wall (yellow) via the plasma. (Image credit: Jeff Levesque)

The study, published in *Nuclear Fusion*, is titled "Measurement of scrape-off-layer current dynamics during MHD activity and disruptions in HBT-EP."

Authors include: J.P. Levesque, J.W. Brooks, M.C. Ablor, J. Bialek, P.J. Byrne, C.J. Hansen, P.E. Hughes, M.E. Mael, G.A. Navratil, and D.J. Rhodes

## APAM in the News

**Irving Herman** was quoted in health and science section of *The Philadelphia Inquirer* in the article, "Is Joel Embiid's size an injury risk? Science explains it all."

**Adam Sobel** was featured in the *Times of India* article, "Historically, biggest disasters are ones that are rare, says scientist Adam Sobel" and the *Scroll.in* article, "Mumbai has never suffered a cyclone – but researchers warn a massive one could hit in future: A team of scientists from Columbia University and M.I.T. is studying the city's cyclone risk." Sobel was also featured on CBS News and in their online article, "Climate scientist calls Trump's global warming tweet an "often debunked assertion."

**Chris Wiggins** was featured in the Columbia Spectator article, "How the Core Curriculum Inspired the NYT's Chief Data Scientist's Latest Project," which highlighted his passion for the Core Curriculum; his new course (Data: Past, Present, Future); and the organization and philosophy behind HackNY - a nonprofit be co-founded in 2010 which organizes student hackathons.

## Data, Algorithms, & Consequences for Society

Dr. Cathy O'Neil, author of *Weapons of Math Destruction*, presented a talk at Columbia University on "Data, Algorithms, and their Consequences for Society". The event, which was co-sponsored by the APAM Department and Columbia University's SIAM Chapter, filled every seat in Davis Auditorium, leaving additional audience members to stand in the back or sit in the aisles.

Cathy O'Neil earned a Ph.D. in math from Harvard, was a postdoc at the M.I.T. math department, and a professor at Barnard College where she published a number of research papers in arithmetic algebraic geometry. She then switched over to the private sector, working as a quant for the hedge fund D.E. Shaw in the middle of the credit crisis, and then for RiskMetrics, a risk software company that assesses risk for the holdings of hedge funds and banks. She left finance in 2011 and started working as a data scientist in the New York start-up scene, building models that predicted people's purchases and clicks. She wrote *Doing Data Science* in 2013 and launched the Lede Program in Data Journalism at Columbia in 2014. She is a regular contributor to *Bloomberg View* and wrote the book *Weapons of Math Destruction: how big data increases inequality and threatens democracy*. She recently founded ORCAA, an algorithmic auditing company.



Above (left-right): Prof. I.C. Noyan, Rachael Keller, (Ph.D. candidate and CU SIAM student organizer), Dr. Cathy O'Neil, and Mel Abler (Ph.D. candidate)



## Dickerson Named Chief Scientific Officer for Consumer Reports

**Dr. James H. (Jay) Dickerson II**, a former postdoctoral research scientist with **Prof. Irving Herman** in Columbia's MRSEC and NSEC from 2002 to 2004, currently is the Chief Scientific Officer for Consumer Reports, the world's preeminent, independent, nonprofit

consumer advocacy organization that works side by side with consumers to create a fairer, safer, and healthier world. Prior to joining Consumer Reports, he was the Assistant Director for the Center for Functional Nanomaterials at Brookhaven National Laboratory and was a tenured Associate Professor in the Department of Physics & Astronomy and the Department of Chemistry at Vanderbilt University.

At Consumer Reports (CR), Dickerson is responsible for scientific and technical oversight of all relevant activities within the organization, with a primary focus on product evaluations and interpretation of scientific data in CR's content, policy, and mobilization initiatives. As well, he oversees the technical robustness of testing protocol and procedure development along with any associated technological innovations. His position also consists of externally facing responsibilities, acting as a key explainer of the scientific basis for CR's work with consumers and as a relationship builder among peer organizations in the scientific community including developing new partnerships. Further, Dickerson plays a key role in ensuring that CR's evaluations promote consumer choice and marketplace changes.

Dickerson's research career investigated emerging techniques for the assembly and deposition of colloidal nanocrystalline materials into thin films and heterostructures, employing dc electric fields to transport and to deposit nanomaterials onto conducting and semiconducting substrates. His research interests also involved the correlation among the size, the arrangement of atoms, and the optical and magnetic properties that are exhibited within nanocrystalline materials, particularly rare earth sesquioxide and rare earth chalcogenide nanocrystals. This involved the synthesis, electron microscopic characterization, and the physical (optical and magnetic) characterization of a variety of nanomaterials, focusing on europium and gadolinium-based nanocrystals and transition metal oxide nanomaterials. Dickerson co-edited *Electrophoretic Deposition of Nanomaterials* (Springer Books), the first comprehensive reference book on the subject, and co-authored *Gas Transport in Solid Oxide Fuel Cells* (Springer Books).

Dickerson has served on the Editorial Board of *Materials Letters* and as the Chair of the Committee on Minorities of the American Physical Society. His honors include a National Science Foundation CAREER Award, a Ralph E. Powe Junior Faculty Award, and a W. Burghardt Turner Fellowship.

## Banerjee Elected Fellow of the Institute of Physics

**Prof. Sarbajit Banerjee**, a former postdoctoral research scientist with **Prof. Irving Herman** and a current chemistry professor at Texas A&M University, was elected a Fellow of the Institute of Physics in January, 2018. In August, 2017 he was named a Davidson Chair Professor of Science at Texas A&M.

## In Memoriam: Robert A. Gross

Originally published by *Columbia Engineering*

The Columbia Engineering community mourns the loss and celebrates the life of **Robert A. Gross**, a scientist, educator, and leader. Professor Gross served as the School's 11<sup>th</sup> dean from 1982 until 1990. He passed away on February 8, 2018 at his home in Chapel Hill, North Carolina. He was 90 years old.

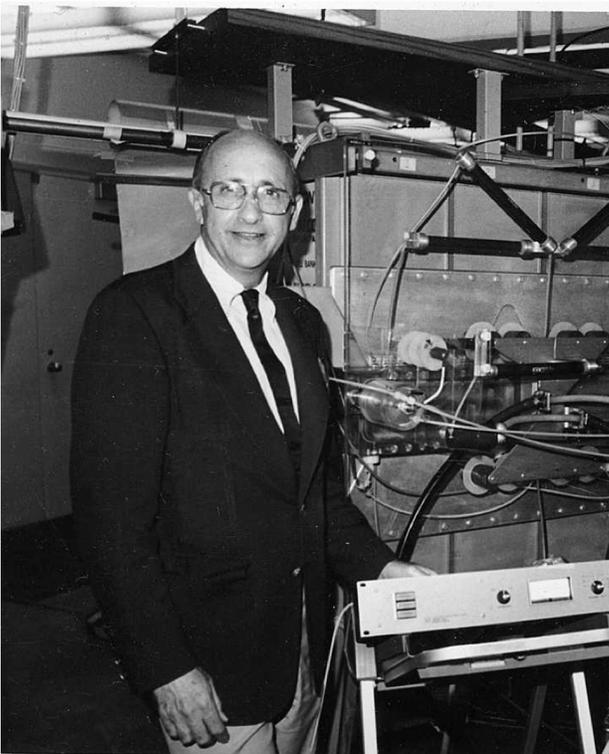
Robert Gross joined Columbia as a Professor of Engineering Science in 1960, having already made significant contributions to the field of supersonic combustion and shock dynamics while an engineer at Fairchild Engine and Airplane Corp. His work in combustion was recognized with the Waverly Gold Medal for New Research and AIAA G. Pendray award.

At Columbia, he explored the emerging field of plasma physics and controlled fusion research. With **C.K. "John" Chu**, he co-founded in 1962 the Columbia Plasma Physics Laboratory which carried out sponsored research of \$2 million per year for 30 years and trained more than 100 scientists and engineers. He took great pleasure teaching and advising his students including 25 doctoral candidates, many of who he continued to mentor throughout their careers. He was also recognized for his excellence in teaching by the Society of Columbia Graduates who honored him in 1974 with the Great Teacher Award. Gross also wrote a seminal textbook, *Fusion Energy*.

Through his research, Gross became a worldwide authority in plasma shock phenomena and the equilibrium and stability of high pressure magnetized plasma systems. He served on numerous Department of Energy advisory committees that defined the direction of fusion power research in the United States.

After serving three years as founding chair of Columbia's Department of Applied Physics and Nuclear Engineering and six years as chair of the Mechanical Engineering Department, Gross was named the 11<sup>th</sup> dean of Columbia School of Engineering and Applied Science.

As dean, he established one of the first National Science and Technology Centers awarded by the National Science Foundation in the area of telecommunications research. Building on this initiative, Dean Gross envisioned a new research building to provide modern experimental research facilities for telecommunications, microelectronics, and computer and information systems. He successfully raised \$36 million in a 40-year no-interest loan and \$6 million gift from the State of New York, allowing Columbia to build a new research facility. Morris A. Shapiro Hall, or the Center for Engineering Physical Science Research (CEPSR), opened in 1992.



Together with his wife, Elee K. Gross, Prof. Gross spent countless hours with undergraduate and graduate students not only during the day, but also at their home in New Rochelle and then later as residents of East Campus and at their apartment on Riverside Drive. His focus on encouraging students, especially those from less privileged backgrounds and those from abroad, was in large part the reason he was so pleased that his former students and others created the Robert A. Gross Scholarship Fund.

Prof. Gross was not just a man of science, but he loved a good political discussion and, with his wife Elee, they were legionary for their attendance, for decades, at Columbia football home games regardless of the weather, and for their passion for attending concerts and enjoying theater.

During his sabbaticals, Prof. Gross — who loved to travel around the world — taught and studied at Leiden University (Netherlands), Stanford University (California) and at the University of Sydney and Flinders University (Australia).

A graduate of the University of Pennsylvania in 1949, Gross earned his Ph.D. in applied physics from Harvard in 1952. Over the course of his career, he received numerous honors, including the Guggenheim Fellowship and the Fulbright-Hays Fellowship twice. He was a Fellow of the American Physical Society and a Fellow of the American Institute of Aeronautics and Astronautics. He was honored for his life's work by Fusion Power Associates in 1993.

Robert Gross, the Percy K. and Vida L.W. Hudson Professor of Applied Physics, retired from Columbia Engineering in 1995.

## In Memoriam: Amiya K. Sen

Originally published by *Columbia Engineering*

The Columbia Engineering community mourns the loss of professor emeritus **Amiya K. Sen**, a noted expert in plasma physics and a respected educator. Sen passed away at his home in Manhattan on March 28, 2018. He was 89 years old.

Sen spent over 50 years on the faculty at Columbia Engineering, which he joined in 1963 in a joint appointment with the Departments of Electrical Engineering and Applied Physics and Applied Mathematics. While at Columbia, Sen became a pioneer in the control and study of drift instabilities in magnetically confined plasma. Drift instabilities are called “universal instabilities,” because they occur in all magnetized plasma, exciting turbulent fluctuations and causing transport of plasma particles and energy across the confining lines of magnetic force. Using a unique laboratory experiment, called the Columbia Linear Machine, Sen and his students were able to excite and observe drift instabilities under a great variety of conditions. The Sen research group made the first controlled observations of drift instabilities excited by gradients of ion temperature, magnetic field strength, and the effects of magnetic electron trapping. Using active feedback techniques, Sen successfully controlled drift instabilities and measured drift wave at both small and large amplitudes. Professor Sen’s research group established new understanding of these fundamental drift instabilities and helping efforts to predict plasma confinement in magnetic fusion energy experiments and in the magnetized plasma in space.

A graduate of the Indian Institute of Science in 1952, Sen earned his M.S. from M.I.T. in 1958, and his Ph.D. at Columbia in 1963. Over the course of his career, Sen published numerous papers in the top archival journal in his field, the *Physical Review Letters*, as well as in several other publications. A fellow of the American Physical Society and IEEE, he also served as a consultant/advisor to the Lawrence Livermore National Laboratory, Princeton Plasma Physics Laboratory, U.S. Department of Energy, and the National Science Foundation. The Society of Columbia Graduates honored him with the Great Teacher Award in 1984.

Amiya Sen retired from Columbia Engineering in 2017.



(Above) Dean Mary Boyce and (below) Professor Emeritus C.K. “John” Chu (Photos by Barbara Alper)



## Robert A. Gross - A Celebration of Life

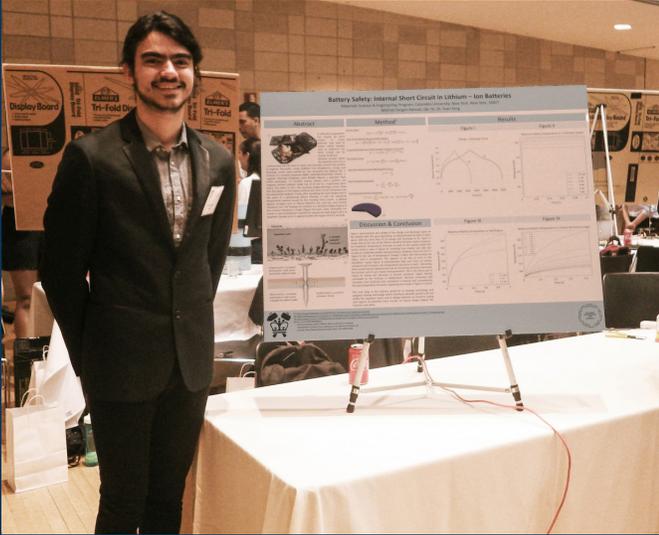
Faculty, students, alumni, family, and friends gathered on April 27, 2018 for the Robert A. Gross Celebration of Life. The event, co-hosted by the APAM Department and the SEAS Dean’s Office, took place in St. Paul’s Chapel and featured talks by colleagues, alumni, and family members of Dean Gross. A reception followed in the APAM Department.

Mary Boyce, the current Dean of SEAS, the Morris A. and Alma Schapiro Professor, and a Professor of Mechanical Engineering, began the event with a warm welcome and introduction. **Gerald Navratil**, the Thomas Alva Edison Professor of Applied Physics, a former Chair of the APAM Department, and a former interim SEAS Dean, who had worked with Dean Gross since 1977, spoke about Dean Gross’s contributions to the development of the APAM Department. Zvi Galil, the current Dean of the College of Computing at Georgia Tech, who is also a SEAS Dean *Emeritus*, the Julian Clarence Levi Professor *Emeritus* of Mathematical Methods and Computer Science, and a former Chair of the Computer Science Department at Columbia University, reflected upon Dean Gross’s contributions to SEAS, including the construction of the CEPSR Building. Dale Meade, the former Deputy Director of the Princeton Plasma Physics Laboratory and the former Head of the Tokamak Fusion Test Reactor Program, along with APAM Alum, **Stewart Prager**, (Ph.D. ‘75), a Professor of Astrophysical Sciences at Princeton University and the former Director of the Princeton Plasma Physics Laboratory, both reflected on Dean Gross’s global impact on fusion energy research.

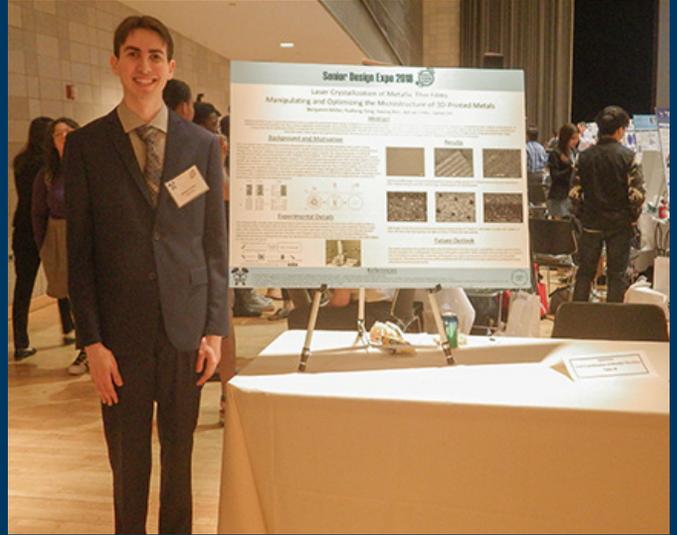
Two of Dean Gross’ doctoral students, **Don Spero** (Ph.D. ‘68), the co-founder and General Partner of New Markets Venture Partners, and **Jay Kesner** (Ph.D. ‘70), a Senior Scientist at the Plasma Science and Fusion Center at M.I.T., provided fond remembrances of their mentor. Life-long colleague and friend, **C.K. “John” Chu**, the Fu Foundation Professor *Emeritus* of Applied Mathematics, a former APAM Department Chair, and co-founder of the Plasma Physics Lab, shared professional and personal recollections. The service concluded with reflections from Dean Gross’ sons, David A. Gross and John-Henry Gross, followed by a rousing arrangement of “Roar, Lion, Roar” played by a string quartet.

# 2018 Senior Design Expo

Two of the APAM Department's Materials Science Seniors participated in the annual Senior Design Expo on May 3, 2018 in Lerner Hall.



**Michael Hamati (Prof. Yuan Yang's Group)**  
"Battery Safety: Internal Short Circuit  
in Lithium-Ion Batteries"



**Benjamin Miller (Prof. James Im's Group)**  
"Laser Crystallization of Metallic Thin Films Manipulating  
and Optimizing the Microstructure of 3D-Printed Metals"

**Contributing Authors:** *Columbia Engineering*, James Dickerson II, Allison Elliot, Holly Evarts, Marilyn Harris, Irving Herman, Jeffrey Levesque, Zhaoyi Li, Kyle Mandli, I.C. Noyan, Cathy O'Neil, Steven Sabbagh

**Photos/Images:** Barbara Alper, Eileen Barosso, Haogang Cai, *Columbia Engineering*, James Dickerson II, Avik Dutt, Jeffrey Levesque, Zhaoyi Li, A. Mohanty, I.C. Noyan, Gauri Patwardhan, Diego Scarabelli, Norman Shi, E. Shim, Jeffrey Schifman, Max Terban, Timothy Lee Photographers, Yuan Yang, Nanfang Yu

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