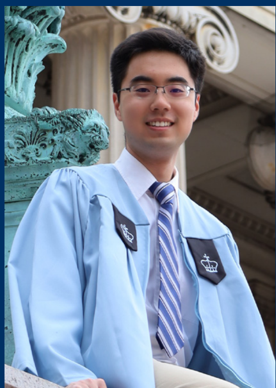
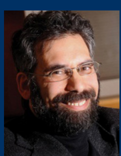
APAM NEWS

School of Engineering & Applied Science, Columbia University
Department of Applied Physics & Applied Mathematics
with Materials Science & Engineering







Dear APAM Community,

We are delighted to share the remarkable accomplishments of our students, faculty, scientists, and alumni as another exciting school year comes to a close. We begin by extending our heartfelt congratulations to the 2023-2024 graduating students in Applied Physics (AP), Applied Mathematics (AM), Materials Science, and Medical Physics. Despite the challenges of the past four years, the class of 2024 has persevered, thrived, and excelled. In particular, we congratulate our three undergraduate faculty award winners for excellence in AM, AP, and Material Science, as well as Stephanie Malek, this year's Simon's Prize winner, for her outstanding thesis work on "Nonlocal Metasurfaces." We wish all of our graduates success in their future endeavors and welcome them as esteemed APAM alumni.

We also celebrate the remarkable accomplishments of our faculty and research scientists, who have achieved groundbreaking scientific progress across a wide array of fields including advanced photonics, fundamental material science, quantum materials, plasma physics, applied mathematics, and climate dynamics (including a thought-provoking essay in *Nature* on "Are we all doomed?"). These achievements exemplify the exceptional intellectual excellence and diversity across APAM. Moreover, we showcase the numerous awards and honors bestowed upon our faculty, acknowledging their remarkable contributions to research and teaching.

Finally, we want to extend a warm welcome to Marri Davis as our new Departmental Administrator and recognize Professor Irving Herman, now the Edwin Howard Armstrong Professor *Emeritus* of Applied Physics, for his distinguished career in Applied Physics and thank him for his years of dedicated service to the department, including three terms as Department Chair. We wish him well in his retirement and look forward to his continued wit and wisdom as a welcome member of APAM.

Thank you all for your continued support and dedication to the APAM community.

Best,
Marc Spiegelman, APAM Chair

Cover images: (left-right) 2024 APAM graduates Kaiwen Zhang, Sophia Guizzo, William Boyes, Thomas Harris, and Emily Fernandez

APAM Senior Award Winners

Prof. Marc Spiegelman, APAM Chair, presented awards to three outstanding seniors at the 2024 APAM Senior Dinner and Award Ceremony. Each winner was selected by the APAM faculty in recognition of their outstanding academic achievements.

Sophia Guizzo
Applied Physics Faculty Award Winner

This year's Applied Physics Faculty award winner, **Sophia Guizzo**, has engaged in multiple research projects within the Applied Physics department. As a sophomore, Sophia was an undergraduate researcher in the Venkataraman Group where she studied the effect of localized electric fields on chemical reactions. She has spent the last two years conducting research in the Columbia Plasma Physics Lab, where she worked on the initial design of an experiment to measure cryogenic pellet ablation with applications to fusion energy technology. More recently, Sophia leveraged computational tools to assess the effect of plasma shaping on stability in tokamak fusion reactors. Outside of research, Sophia served as a project manager of Columbia Engineers Without Borders for two years. In this role, she led a trip to Uganda to repair a solar microgrid system that powers local schools and businesses. She is also a teaching assistant for the introductory physics sequence for scientists and engineers. Sophia will be staying at Columbia as a PhD student in Applied Physics to study plasma physics with applications to fusion energy.

Kaiwen Zhang
Applied Mathematics Faculty Award Winner

This year's Applied Mathematics Faculty Award Winner, **Kaiwen Zhang**, is driven by a persistent interest in mathematical problems arising in real-world phenomena. He challenged himself with advanced courses, studying analytical and numerical techniques that produce precise and meaningful insights on mathematical systems. In the senior seminar, collaborating with Anna Mazhar and Siyuan Qiu, he studied cloaking in electromagnetism through the lens of inverse problems. By analyzing invariance under change-of-variable of associated PDEs and related bilinear form estimates, the team presented a scenario in which a large volume of abnormal conductivity can appear identical to a small or nonexistent volume in terms of boundary measurements. The conclusion has implications in medical imaging and resource detection. Supervised by Prof. Kui Ren, he explored stochastic gradient Langevin dynamics, designing energy functions and experimenting the balance of randomness and gradient descent in optimization algorithms using an original step-wise performance visualization tool. He has also gained interest in variational analysis in research reading mentored by Jackson Turner and supervised by Prof. Michael Weinstein. In the reading project, he investigated symmetry-breaking behavior in nonlinear time-independent Hartree equation and the underlying competition between potential energy and nonlinear energy as the solution scales in mass. Outside of school, he has gained industry exposure through internships at Deloitte Canada and Mercer China. After graduating from Columbia, he will pursue a PhD in Mathematics at the Courant Institute of New York University, where he wishes to build on the passion he obtained at APAM, and investigate many more problems in fundamental or applied mathematics.

Kaylynn Chen
Rhodes Prize for Materials Science Winner

This year's winner of the Francis B. F. Rhodes Prize for Materials Science, **Kaylynn Chen**, is interested in experimental quantum computing, specifically superconducting quantum computing hardware. She was involved in a summer internship at MIT's Lincoln Lab Group 89 (Quantum Information and Integrated Nanosystems) developing a code framework for automating the calibration of superconducting qubits and creating a simulation program for efficient software testing. At Columbia University, she worked with Professor James Hone in the Mechanical Engineering Department and Dr. Kin Chong Fong of Raytheon BBN to fabricate hybrid Van der Waals transmon qubits. Her Senior Design Project focused on performing second harmonic generation, a nonlinear optics measurement, on tungsten diselenide crystals to benchmark superconducting qubit device parameters. After graduating with a minor in computer science, she will be pursuing a PhD in Applied Physics at Yale University with plans to research quantum networking and quantum transduction.

Malek Wins 2024 Simon Prize

Dr. Stephanie Malek is the winner of the 2024 Simon Prize for the most outstanding dissertation in the APAM Department. She received her PhD from Columbia University in October 2023, advised by Prof. Nanfang Yu. Her dissertation, "Nonlocal Metasurfaces for Active and Multifunctional Wavefront Shaping," focused on flat, nanostructured optical devices that leverage a deep understanding of symmetry to enable new optical functionalities. A core contribution of her graduate work was experimentally demonstrating metasurfaces that shape the optical wavefront at multiple selected colors but otherwise remain transparent to broadband light. Such devices have potential towards applications in augmented reality headsets and ultrathin zoom lenses. After graduation, Stephanie has continued in metasurface research as a postdoctoral appointee at the Center for Integrated Nanotechnologies at Sandia National Laboratories.

History of the Robert Simon Memorial Prize

The Simon Prize is awarded annually by the APAM Department to the graduate student who has completed the most outstanding dissertation. Robert Simon (December 25, 1919–February 11, 2001) received a BA degree cum laude in classics from the City College of New York in 1941, where he was elected to Phi Beta Kappa, and an MA in mathematics from Columbia University in 1949. Between 1941 and 1944, Mr. Simon was a lieutenant in the United States Armed Forces serving in England, France, and Italy. He participated in the D-Day operation as a navigator for a plane that dropped paratroopers in the vicinity of Omaha Beach. General Dwight Eisenhower personally shook his hand and wished him well the night before the D-Day assault. Mr. Simon, who was born and lived in New York City, spent a lifetime making valuable contributions to the field of computer science. Starting in 1953, he worked for 15 years at Sperry's Univac Division in various capacities including marketing, planning, systems engineering, systems programming, and information services. He also spent a year working at the Fairchild Engine Division as director of the Engineering Computer Group. He personally directed the establishment of several company computer centers at sites throughout the United States. Between 1969 and 1973, he was a partner with American Science Associates, a venture capital firm. Mr. Simon was a founder and vice president of Intech Capital Corporation and served on its board from 1972 to 1981 and a founder and member of the board of Leasing Technologies International, Inc. from 1983 until his retirement in 1995. The prize was established in 2001 by Dr. Jane Faggen with additional support from friends and relatives of Mr. Simon.

Student Spotlights

William Boyes, PhD '24 Applied Physics, Plasma Physics

Future Plans: Postdoc at General Atomics

Highlights at Columbia? I had an incredible experience at DIII-D and APAM Fridays were nice

Emily Fernandez, BS '24 Applied Mathematics

Future Plans: Joining Synchrony's Business Leadership Program as a data analyst on their Credit Team in NYC

Highlights at Columbia? My favorite memory from Columbia has been my Applied Math Senior Seminar. The course was essential to me building my confidence and skills as a mathematician and allowed me to study an intersection of fields that I love: music recommendation systems built on different machine learning algorithms. I also have immense gratitude for the Computer Science (CS) Department. CS is a passion that I haphazardly stumbled into my sophomore year and have taken courses in every semester since because I find it so engaging and fun to work through.

What has Columbia taught you? The most important thing that I learned in Columbia is that it is okay to feel challenged. In fact, it is expected, and there is always a path to clarity through community. It is so crucial to ask questions and to rely on peers for their insights and support along the academic and personal journey that is college. I will forever treasure the friends I made at Columbia but know that the SEAS camaraderie I've been lucky enough to experience these past years will hold an extra special place in my heart.

Blake Garber, BS '24 Applied Mathematics

Future Plans: Masters Degree (MAFN @ Columbia)

Highlights at Columbia? Hard work is rewarded. The mandatory seminar for APAM majors was an amazing experience that highlighted the real world uses of all of our studies. It was a great capstone experience for me.

Thomas Harris, BS '24 Applied Mathematics

Future Plans: I'm now a PhD student at Teacher's College studying math education. I want to teach college mathematics and conduct education research on student generated teaching materials for college students.

Highlights at Columbia? Dynamical Systems, Statistical Inference, Topology, Fourier Analysis were really interesting.

What has Columbia taught you? "You don't know unless you believe." - Amir Sagiv

Angeliki Stougiannou, BS '24 Applied Mathematics

Future Plans: MS/PhD Earth and Environmental Engineering

Highlights at Columbia? Favorite classes: Analysis and Optimization and APMA senior seminar projects

What has Columbia taught you? The beginners mindset - never assume you know all the answers and make creativity the core of your engineering practice.

Michael Tulskikh, BS '24 Applied Mathematics

Future Plans: I'm going to work over the summer, and then move to Australia to work remotely as a mathematical analyst while I travel for a year. After that, I plan to pursue full time traveling, and hopefully join the peace corps in Armenia after I visit Australia.

Highlights at Columbia? I really enjoyed the math courses I got the opportunity to take. The senior seminar class was also fun as it allowed me to explore an area of science I previously knew practically nothing about.

Victor Zhou, BS '24 Applied Mathematics

Future Plans: Work at New York Life and study for FINRA exams and CFA

Highlights at Columbia?
Joining in Columbia POPS and taking Modern Analysis.

Congratulations 2023-2024 Graduates!

October 2023 BS: William Kim (AP), Austin Tao (AM)

October 2023 MS: Matthew Park (AM), Regan Wang (AM), Yuhao Zhang (AM)

October 2023 MPhil: Sean Cohen (AM), Xiaoyan Huang (AP), Chenxing Luo (MSE), Joseph Wild (MSE)

October 2023 PhD: Huaiyu Li (AM), Stephanie Malek (MSE), Ivan Mitevski (AM), Alex Saperstein (AP), Wentao Xu (AM)

February 2024 BS: Thomas Harris (AM)

February 2024 MS: Wencheng Bao (AM), Mounir Baroudi (AM), Jiaguo Bei (AM), Alexander Benanti (AM), Anson Braun (AP), Daniel Burgess (AP), Tingpei Cai (AM), Hong Cao (AM), Amelia Chambliss (AP), Zhibin Chang (AP), Haotian Chen (MSE), Yang Chen (AP), Eduardo Drucker Binder (AP), Tingyi Fei (AM), Danqing Feng (AM), Shi Feng (AM), Craig Fouts (AM), Alyssa Gadsby (MP), Mateo Gomez (AM), Haopeng Hu (AP), Zhongxiu Hu (MP), Jiaqi Huang (AP), Abdullah Hyder (AP), Jun Hsuang Jen (MP), Micheal Jones (MP), Humza Khan (AM), Ye Lei (AM), Yihan Li (MSE), Victor Lin (AM), Mingrui Liu (AP), Yi-Chen Liu (MSE), YuXuan Liu (AP), Cheng Long (AM), Hao Long (MSE), Marco Masciantonio (MP), Fansu Meng (AM), Ziyun Miao (MSE), Aman Nayak (AM), Matthew Notis (AP), Susanne O'Hare (MP), Oluwatamilore Olushina (MSE), Teng Qu (MSE), Melanie Russo (AP), Daniel Schmuckler (MSE), Chaonan Sheng (MSE), Cheng Shi (AM), Nalat Sornkhampan (AP), Andres Stenberg (AM), Yuhao Su (AM), Xinyi Tan (AM), Georgii Tifaniuk (MSE), Evelyn Wallace (AM), Minghao Wang (AM), Ruoxi Wang (AM), Ryan Wang (AM), Wanchen Wang (AM), Xinyu Wang (AM), Xuan Wang (AM), Yuxin Wang (AM), Qian Wu (AM), YiXun Xu (AM), Baohua Yan (AM), Yuxuan Yang (MSE), Eric Yi (MSE), Fengyuan Zhang (AM), Jiazhen Zhang (AP), Ruinin Zhang (MSE), Ziyong Zhang (AM), Qitong Zhao (AM), Yeshiyuan Zhou (MSE), Yuxuan Zhu (AM), Aviv Zohman (MSE)

February 2024 MPhil: Paulina Czarnecki (AM), Luke Holtzman (MSE), Madison Ihrig (AM), Ling Lan (AM), Juan Riquezes (AP), Edith Zhang (AM)

February 2024 PhD: Todd Elder (AP), Yi-Fang Wang (AP)

May 2024 BS: Elizabeth Baranes (AM), Amin Ben Brahim (AM), Guanting Chen (AP), Kaylynn Chen (MSE), Shuran Chen (AM), Da Hyun Choo (AM), Eliot Felske (AP), Emily Fernandez (AM), William Finkelstein (AM), Tomas Fiure (AM), Natalia Forero (AM), Ananya Gandhi (AM), Charles Grill (AP), Sophia Guizzo (AP), Maximo Jalife (AM), Shloka Janapaty (AM), Kayla Kim (AM), Sangyoon Kim (AM), Jonas Kolker (AP), Celine Lee (AM), Eojin Lee (AM), Joonsoo Lee (AM), Woosuk Lee (AM), Mier Liu (MSE), Yelissa Lopez (AP), Yunhao Mai (AM), Anna Mazhar (AM), Ciro Salcedo (AP), Mihir Shetty (AP), Geonwoo Shin (AM), Boren Song (AM), Ceaser Stringfield (AP), Jonathan Sucuc Socoy (AM), Michael Tulskikh (AM), Shiya Wang (AM), Xingze Wang (AM), Kunlun Wu (MSE), Emilie Xu (AM), Kaiwen Zhang (AM), Victor Zhou (AM), Wenyi Zhu (AM)

May 2024 MS: David Adler (MSE), Alexandra Baldelli (AM), Xueyi Bu (AM), Minrui Chen (AM), Stephan Gabillard (AM), Mengfan Gong (AM), Jacob Halpern (AP), Megan Handa (AM), Siyao Jiang (AM), Xin Jin (AM), Nikhil Sriram Kabilan (MP), John Koerner (AM), Daniel Letzler (AP), Paul Nicholas (AP), Jacob Rabinowitz (AP), Allison Reiling (AP), Hanshu Shao (AM), Madeline Weinstein (AM), Bryce Wilkins (AM), Hongyu Zhai (AM), Junfeng Zhang (AM)

May 2024 MPhil: Xuanjing Chu (MSE), Tianqi Wan (MSE)

May 2024 PhD: William Boyes (AP), Vahe Gharakhanyan (MSE), Boting Li (AP)

AP: Applied Physics | AM: Applied Mathematics |
MSE: Materials Science & Engineering | MP: Medical Physics

Yuan Yang

Yang Wins 2024 CUAFA Young Investigator Award

Yuan Yang is the recipient of the Columbia University Asian Faculty Association's (CUAFA) 2024 Young Investigator Award. This annual award recognizes outstanding Columbia faculty members of Asian heritage and allies.

Yuan Yang is currently an associate professor of materials science in the APAM Department at Columbia Engineering. He received his BS in physics at Peking University in 2007, followed by PhD in materials science and engineering at Stanford University in 2012. After three years as a postdoc in the Department of Mechanical Engineering at MIT, he joined Columbia University in 2015. His research focuses on materials designs for energy applications, including energy storage, thermal management and chemical separation. He has published more than 100 peer-reviewed papers with a total citation of over 30,000 times and a H-index of 65. He was a Scialog fellow on Advanced Energy Storage. He won Materials Today Rising Star Award in 2022, 3M Non-tenured Faculty Award in 2021, and MIT Technology Review 35 under 35 – China in 2019.

CUAFA honored Prof. Yang, along with Prof. Mae M. Ngai, the recipient of CUAFA's 2024 Distinguished Lifetime Achievement Award, on February 24th at the Third Annual Fundraising & Gala Dinner in collaboration with the Columbia Global Centers, Beijing.

Katayun Barmak

Advances in Experimental Study of Grain Growth in Thin Films

An invited review article titled "Advances in Experimental Study of Grain Growth in Thin Films," was recently published in *JOM*. The project is led by APAM Professor **Katayun Barmak** (Philips Electronics Professor) and **Matthew Patrick** (PhD Candidate, Materials Science) in collaboration with Professor Jeffrey Rickman (Physics; Materials Science, Lehigh University, PA).

The article focuses on recent experimental studies of microstructure in polycrystalline thin films, making the case that these materials are an ideal platform for unravelling the problem of grain growth. The development of a prescriptive theory of this phenomenon is bottlenecked in part by a lack of dynamic experimental data. The authors argue that the "columnar" microstructure of thin films simplifies data acquisition and interpretation as compared to bulk materials.

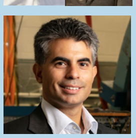
Thanks to the versatility and recent developments in S/TEM instrumentation and the recent application of deep learning to TEM images of polycrystalline films by the Barmak Group, a one-stop, non-destructive, experimental platform is now being developed with the capabilities to study the detailed, local dynamics of microstructural evolution and grain growth at time-resolutions not possible in other systems. For a video summary of the grain growth project, see **https://www.youtube.com/watch?v=AGOxVZ7ToRs**.

Using Nanotechnology to Uncover Details of a Medieval Manuscript

Prof. Katayun Barmak was featured in the Columbia News article, "Using Nanotechnology to Uncover Details of a Medieval Manuscript: How Columbia conservators, Nano Initiative scientists, and a music scholar used state-of-the-art technology to examine a score." Read the full article at: https://rb.gy/ua4s6f

Faculty Updates

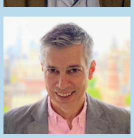
Michal Lipson (the Higgins Professor of Electrical Engineering and Professor of Applied Physics), **Alex Gaeta** (the Rickey Professor of Applied Physics and Materials Science), and colleagues were issued a U.S. patent for "Microresonator-Frequency-Comb-Based Platform for Clinical High-Resolution Optical Coherence Tomography". Learn more about their patent at: https://patentcenter.uspto.gov/applications/17367884



Carlos Paz-Soldan (Associate Professor of Applied Physics), was featured in the article, "Companies say they're closing in on nuclear fusion as an energy source. Will it work?" published online by NPR (https://www.npr.org).

Adam Sobel's essay, "Are we all doomed? How to cope with the daunting uncertainties of climate change," was published in *Nature* (https://www.nature.com/articles/d41586-024-00790-6). Sobel (Professor of Applied Physics and Applied Mathematics and of Earth and Environmental Sciences) also presented the talk, "How doomed are we: climate change and the limits of science," on May 9th, as part of a series of scientific meetings on "Climate Change and Museums" hosted by the Hellenic National Archaeological Museum.

Chris Wiggins (Associate Professor of Applied Mathematics and Systems Biology), and **Eunji Kim** (Assistant Professor of Political Science), received a Columbia University Cross-Disciplinary Frontiers Course award from the Office of the Provost for their interdisciplinary course titled, "Persuasion at Scale".



Wiggins, who is the Chief Data Scientist at *The New York Times*, was recently featured in the article "Algorithms are everywhere" by *MIT Technology Review*. He gave the keynote address at Northwestern Mutual Data Science Institute's AI symposium, "Bridging Innovation & Impact." The event, hosted by the University of Wisconsin-Milwaukee, included over 700 in-person and virtual attendees, 24 speakers and 31 poster presenters. Wiggins presented three sessions at the AI Summit London 2024 on "Decoding AI Agility," "How Data Happened," and "Benefits of a Well-Designed Data Strategy for AI." Wiggins also presented a Distinguished Lecturer Seminar and Fireside Chat at Northeastern University on "How Data Happened: A History from the Age of Reason to the Age of AI."

Photos (top-bottom): Alex Gaeta and Michal Lipson, Carlos Paz-Soldan, Adam Sobel, and Chris Wiggins

Recent Publications

Michal Lipson: Hinney, J., Kim, S., Flatt, G.J.K. et al. Efficient excitation and control of integrated photonic circuits with virtual critical coupling. *Nat Commun* 15, 2741 (2024). https://doi.org/10.1038/s41467-024-46908-2

Renata Wentzcovtich: Cobden, L., Zhuang, J., Lei, W. et al. Full-waveform tomography reveals iron spin crossover in Earth's lower mantle. *Nat Commun* 15, 1961 (2024). https://doi.org/10.1038/s41467-024-46040-1

Latha Venkataraman

Venkataraman Receives Humboldt Research Award

Latha Venkataraman, the Lawrence Gussman Professor of Applied Physics and Professor of Chemistry, has received a Humboldt Research Award. She will be working on Surface Physics, Solid State and Surface Physical Chemistry, and Material Characterisation in collaboration with her host, Prof. Dr. Ferdinand Evers, at the Institut für Theoretische Physik, Universität Regensburg, Regensburg. The Alexander von Humboldt Foundation gives financial awards to leading researchers and internationally renowned scientists "whose fundamental discoveries, new theories or findings have had a lasting effect on their discipline beyond their immediate research area and who are expected, moreover, to continue producing outstanding research in the future." (Humboldt Foundation) The €60,000 award enables recipients to work in Germany anywhere from six months to a full year.

Using Light to Precisely Control Single-Molecule Devices

Researchers flip the switch at the nanoscale by applying light to induce bonding for single-molecule device switching

By Holly Evarts, Originally published by Columbia Engineering

In a new *Nature Communications* study, Columbia Engineering researchers report that they have built highly conductive, tunable single-molecule devices in which the molecule is attached to leads by using direct metal-metal contacts. Their novel approach uses light to control the electronic properties of the devices and opens the door to broader use of metal-metal contacts that could facilitate electron transport across the single-molecule device.

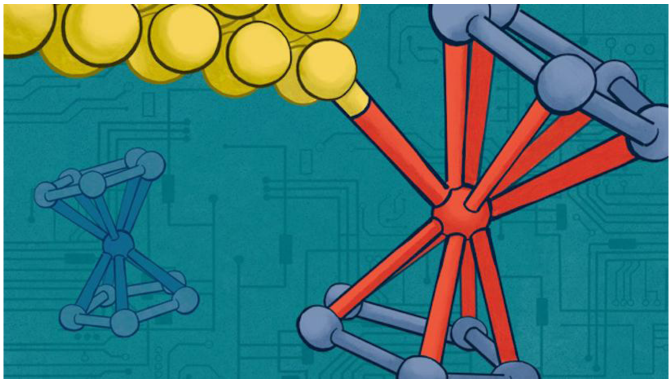


Image Credit: Woojung Lee

The challenge: As devices continue to shrink, their electronic components must also be miniaturized. Single-molecule devices, which use organic molecules as their conductive channels, have the potential to resolve the miniaturization and functionalization challenges faced by traditional semiconductors. Such devices offer the exciting possibility of being controlled externally by using light, but -- until now - researchers have not been able to demonstrate this.

"With this work, we've unlocked a new dimension in molecular electronics, where light can be used to control how a molecule binds within the gap between two metal electrodes," said **Latha Venkataraman**, a pioneer in molecular electronics and Lawrence Gussman Professor of Applied Physics and professor of chemistry at Columbia Engineering. "It's like flipping a switch at the nanoscale, opening up all kinds of possibilities for designing smarter and more efficient electronic components."

The approach: Venkataraman's group has been studying the fundamental properties of single-molecule devices for almost two decades, exploring the interplay of physics, chemistry, and engineering at the nanometer scale. Her underlying focus is on building single-molecule circuits, a molecule attached to two electrodes, with varied functionality, where the circuit structure is defined with atomic precision.

Her group, as well as those creating functional devices with graphene, a carbon-based two-dimensional material, have known that making good electrical contacts between metal electrodes and carbon systems is a major challenge. One solution would be to use organo-metallic molecules and devise methods to interface electrical leads to the metal atoms within the molecule. Towards this goal, they decided to explore the use of organo-metallic iron-containing ferrocene molecules, which are also considered to be tiny building blocks in the world of nanotechnology. Just like LEGO pieces can be stacked together to create complex structures, ferrocene molecules can be used as building blocks to construct ultra-small electronic devices. The team used a molecule terminated by a ferrocene group comprising two carbon-based cyclopentadienyl rings that sandwich an iron atom. They then used light to leverage the electrochemical properties of the ferrocene-based molecules to form a direct bond between the ferrocene iron center and the gold (Au) electrode when the molecule was in an oxidized state (i.e. when the iron atom had lost one electron). In this state, they discovered that ferrocene could bind to the gold electrodes used to connect the molecule to the external circuitry. Technically, oxidizing the ferrocene enabled the binding of a Au0 to an Fe3+ center.

"By harnessing the light-induced oxidation, we found a way to manipulate these tiny building blocks at room temperature, opening doors to a future where light can be used to control the behavior of electronic devices at the molecular level," said the study's lead author **Woojung Lee**, who is a PhD student in Venkararaman's lab.

Potential impact: Venkataraman's new approach will enable her team to extend the types of molecular terminations (contact) chemistries they can use for creating single-molecule devices. This study also shows the ability to turn on and off this contact by using light to change the oxidation state of the ferrocene, demonstrating a light-switchable ferrocene-based single-molecule device. The light-controlled devices could pave the way for the development of sensors and switches that respond to specific light wavelengths, offering more versatile and efficient components for a wide range of technologies.

The team: This work was a collaborative effort involving synthesis, measurements, and calculations. The synthesis was done primarily at Columbia by Michael Inkpen, who was a post-doc in the Venkataraman group and is now an assistant professor at the University of Southern California. All the measurements were made by Woojung Lee, a graduate student in the Venkataraman group. The calculations were performed both by graduate students in the Venkataraman group and by collaborators from the University of Regensburg in Germany.

What's next: The researchers are now exploring the practical applications of light-controlled single-molecule devices. This could include optimizing device performance, studying their behavior under different environmental conditions, and refining additional functionalities enabled by the metal-metal interface. Read the article online at: **https://doi.org/10.1038/s41467-024-45707-z**

Michael Weinstein

Pseudo-Magnetism in Photonics: From a Mathematical Theory to Experiment

While magnetic fields deflect the path of charged particles, such as electrons, they do not directly influence the path of light. In 2021, Professor **Michael I. Weinstein** (APAM), in a collaboration with Professor Mikael C. Rechtsman and his graduate student Jonathan Guglielmon in the Physics Department at Penn State University, GR&W, published a mathematical theory [3] that demonstrated how to engineer a 2D non-magnetic photonic crystal in which photons of light would move in a manner analogous to the motion of electrons under the influence of a magnetic field.

GR&W took motivation from the analogous effect known in condensed matter physics for the 2D material graphene, a one atom thick arrangement of carbon atoms which has the symmetries of a honeycomb tiling of the plane. After its discovery [4], it was observed that appropriately strained graphene induces electrons to behave as though they flowed in the presence of an out-of-plane magnetic field exhibiting Landau level electronic spectra with high density of electronic states.

Is such an effect possible for photons as well? It turns out that the tight binding mathematical model (a discrete low energy approximation) on which the condensed matter predictions for graphene rest, does not apply to 2D and 3D photonic crystals. A continuum theory applicable to Maxwell's equations of electromagnetism was needed, and this is what GR&W put forward in [3] for general scalar wave equations. Its extension to incorporate the vectorial effects of Maxwell equations was carried out as part of the experimental work in [2]. The full vectorial theory is needed and gives an excellent match with experiment.

In particular, GR&W showed that a non-uniformly deformed (strained) photonic (or other wave-propagating) continuous medium with honeycomb spatial symmetries, gives rise to effective magnetic and effective electric fields, which would influence the propagation of light waves. The dynamics of spatially- and frequency-concentrated "wave-packets" of light is described by a system of Dirac equations with the effective field potentials. When a strained pattern is chosen to produce a constant perpendicular effective magnetic field, photonic Landau levels are induced in the structure. These are infinitely degenerate (in practice, very highly degenerate) states of light that can be used to enhance light-matter interactions. They could potentially be used to more efficiently generate quantum light in the form of entangled pairs of photons, or increase the emission from quantum emitters such as quantum dots or crystalline defect centers. Further, this work suggests strategies for inducing topological phenomena in photonic and other wave systems, which are analogous to those in quantum materials such as topological insulators.

GR&W's predictions [3] were recently experimentally observed by the Penn State group of M.C. Rechtsman. An excellent match with theory is achieved with no free free fitting parameters! These results are reported on in an article which has very recently appeared in *Nature Photonics*; see Barsukova et. al.,[2]. The results of independent experiments, also confirming the theory were published by the group of E. Verhagen in the Netherlands [1].

References: [1] R. Barczyk, L. Kuipers, and E. Verhagen. "Observation of Landau levels and chiral edge states in photonic crystals through pseudomagnetic fields induced by synthetic strain". Nature Photonics (2024). [2] M. Barsukova, F. Grisé, Z. Zhang, S. Vaidya, J. Guglielmon, M. I. Weinstein, L. He, B. Zhen, R. McEntaffer, and M. C. Rechtsman. "Direct Observation of Landau Levels in Silicon Photonic Crystals". Nature Photonics (2024). [3] J. Guglielmon, M. C. Rechtsman, and M. I. Weinstein. "Landau levels in strained two-dimensional photonic crystals". Phys. Rev. A 103 (2021), p. 013505. [4] K. S. Novoselov, A. K. Geim, S. V. Morozov, D. Jiang, M. I. Katsnelson, I. V. Grigorieva, S. V. Dubonos, and A. A. Firsov. "Two-dimensional gas of massless Dirac fermions in graphene". Nature 438 (2005), pp. 197–200.

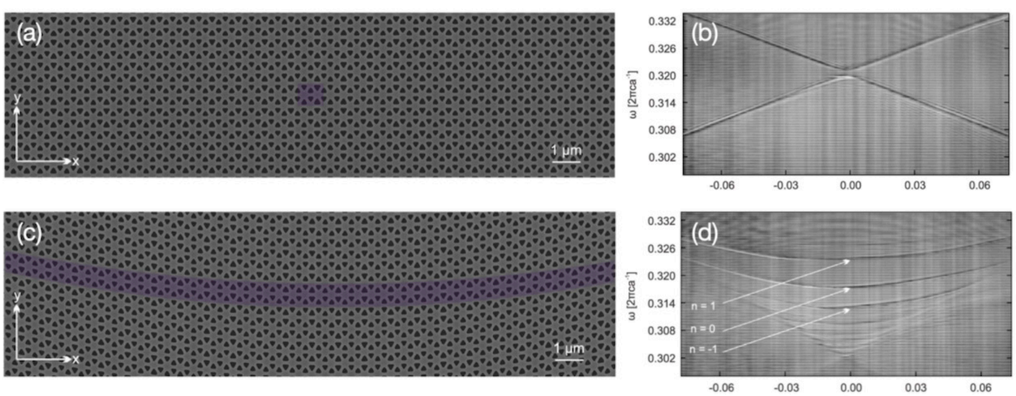
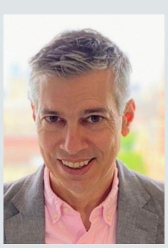


Figure 1. From Barsukova et. al. *Nature Photonics* [2]. Unstrained and strained photonic crystals and their spectra. (a) Scanning electron microscope image of photonic crystal structure, with a unit cell shown in purple; (b) experimentally-observed reflectance spectrum, showing the Dirac point with a small gap resulting from perturbations to the structure in fabrication; (c) similar to (a) but after the coordinate transformation corresponding to the strain is applied; (d) resulting spectrum showing Landau levels. In (b) and (d), the horizontal axis labels ky [2*pi / a], the y-component of the wavevector, n indicates the Landau level indices, and the lattice constant is denoted by a.

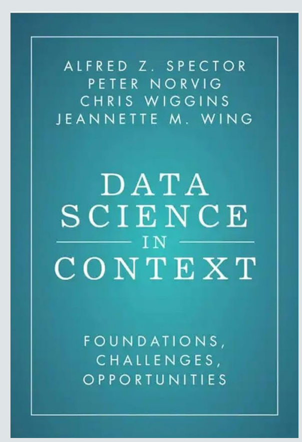
Spector, Norvig, Wiggins, & Wing Receive 2024 Prose Award

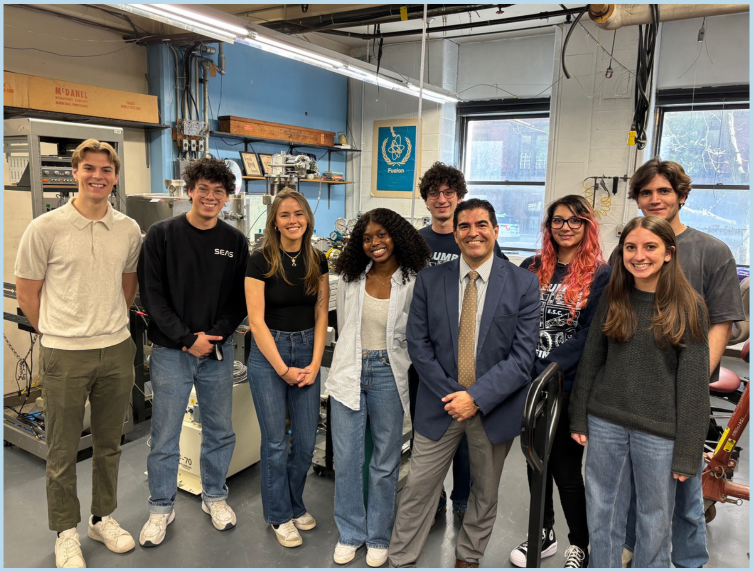


Chris Wiggins

Alfred Spector, Peter Norvig, **Chris Wiggins**, and Jeannette M. Wing have been awarded the 2024 Prose Award in the category of Computing and Information Sciences for their book, **Data Science in Context: Foundations, Challenges, Opportunities**.

Description: Data science is the foundation of our modern world. It underlies applications used by billions of people every day, providing new tools, forms of entertainment, economic growth, and potential solutions to difficult, complex problems. These opportunities come with significant societal consequences, raising fundamental questions about issues such as data quality, fairness, privacy, and causation. In this book, four leading experts convey the excitement and promise of data science and examine the major challenges in gaining its benefits and mitigating its harms. They offer frameworks for critically evaluating the ingredients and the ethical considerations needed to apply data science productively, illustrated by extensive application examples. The authors' far-ranging exploration of these complex issues will stimulate data science practitioners and students, as well as humanists, social scientists, scientists, and policy makers, to study and debate how data science can be used more effectively and more ethically to better our world.





Leader of US DOE Fusion Energy Sciences Office Visits Plasma Lab

Dr. Jean Paul Allain, the Associate Director of Science for Fusion Energy Sciences (FES) within the Department of Energy, visited the APAM Department this spring to engage with the people, experiments, and research of APAM's Plasma Physics program.

Dr. Allain leads the funding agency that primarily supports the Columbia Plasma Physics Laboratory, providing over $5 million annually. During his visit, Dr. Allain met with the Plasma Physics faculty, including Professors Michael Mauel, Gerald Navratil, Elizabeth Paul, and Carlos Paz-Soldan, as well as students and researchers in the Plasma Physics Laboratory. Undergraduate and graduate students presented the group's work with on-campus fusion technology experiments, stellarator plasma and magnet experiments, and tokamak plasma experiments. Dr. Allain was shown early design concepts for future experiments at the lab as well as the group's theoretical work. In addition, Dr. Allain visited with leadership team at SEAS and had brunch with several students.

Katayun Barmak

Graphene Gets Cleaned Up

*Columbia Engineers link oxygen to graphene quality and develop new techniques to reproducibly make the wonder material at scale. The work was supervised by Professor James Hone (Mechanical Engineering) and co-led by **Katayun Barmak (APAM)**, with Abhay Pasupathy and Cory Dean (Physics) providing key contributions.*

By Ellen Neff, Originally published by Columbia Engineering

Graphene has been called "the wonder material of the 21st century." Since its discovery in 2004, the material—a single layer of carbon atoms—has been touted for its host of unique properties, which include ultra-high electrical conductivity and remarkable tensile strength. It has the potential to transform electronics, energy storage, sensors, biomedical devices, and more. But graphene has had a dirty little secret: it's dirty.

Now, engineers at Columbia University and colleagues at the University of Montreal and the National Institute of Standards and Technology are poised to clean things up with an oxygen-free chemical vapor deposition (OF-CVD) method that can create high-quality graphene samples at scale. Their work, published May 29 in *Nature* **https://doi.org/10.1038/s41586-024-07454-5**, directly demonstrates how trace oxygen affects the growth rate of graphene and identifies the link between oxygen and graphene quality for the first time.

"We show that eliminating virtually all oxygen from the growth process is the key to achieving reproducible, high-quality CVD graphene synthesis," said senior author James Hone, Wang Fong-Jen Professor of Mechanical Engineering. "This is a milestone towards large-scale production of graphene."

Graphene has historically been synthesized in one of two ways. There's the "scotch-tape" method, in which individual layers are peeled from a bulk sample of graphite (the same material you'll find in pencil lead) using household tape. Such exfoliated samples can be quite clean and free from impurities that would otherwise interfere with graphene's desirable properties. However, they tend to be too small—just a few tens of micrometers across–for industrial-scale applications and, thus, better suited for lab research.

To move from lab explorations to real-world applications, researchers developed a method to synthesize large-area graphene about 15 years ago. This process, known as CVD growth, passes a carbon-containing gas, such as methane, over a copper surface at a temperature high enough (about 1000 °C) that the methane breaks apart and the carbon atoms rearrange to form a single honeycomb-shaped layer of graphene. CVD growth can be scaled up to create graphene samples that are centimeters or even meters in size. However, despite years of effort from research groups around the world, CVD-synthesized samples have suffered from problems with reproducibility and variable quality.

The issue was oxygen. In prior publications, co-authors Richard Martel and Pierre Levesque from Montreal had shown that trace amounts of oxygen can slow the growth process and even etch the graphene away. So, about six years ago, Christopher DiMarco, GSAS'19,designed and built a CVD growth system in which the amount of oxygen introduced during the deposition process could be carefully controlled.

PhD students Xingzhou Yan and Jacob Amontree continued DiMarco's work and further improved the growth system. They found that when trace oxygen was eliminated, CVD growth was much faster—and gave the same results every time. They also studied the kinetics of oxygen-free CVD graphene growth and found that a simple model could predict growth rate over a range of different parameters, including gas pressure and temperature.

The quality of the OF-CVD-grown samples proved virtually identical to that of exfoliated graphene. In collaboration with colleagues in Columbia's physics department, their graphene displayed striking evidence for the fractional quantum Hall effect under magnetic fields, a quantum phenomenon that had previously only been observed in ultrahigh-quality, two-dimensional electrical systems.

From here, the team plans to develop a method to cleanly transfer their high-quality graphene from the metal growth catalyst to other functional substrates such as silicon — the final piece of the puzzle to take full advantage of this wonder material.

"We both became fascinated by graphene and its potential as undergraduates," Amontree and Yan said. "We conducted countless experiments and synthesized thousands of samples over the past four years of our PhDs. Seeing this study finally come to fruition is a dream come true.

"Unzipping" 2D Materials With Lasers

The new technique can modify the nanostructure of bulk and 2D crystals without a cleanroom or expensive etching equipment

By Ellen Neff, Originally published by Columbia Engineering

In a new paper published in the journal *Science Advances*, researchers at Columbia Engineering used commercially available tabletop lasers to create tiny, atomically sharp nanostructures, or nanopatterns, in samples of a layered 2D material called hexagonal boron nitride (hBN).

While exploring potential applications of their nanopatterned structures with colleagues in the Physics Department, the team found that their laser-cut hBN samples could effectively create and capture quasiparticles called phonon-polaritons, which occur when atomic vibrations in a material combine with photons of light.

"Nanopatterning is a major component of material development," explained engineering PhD student **Cecilia Chen**, who led the development of the technique. "If you want to turn a cool material with interesting properties into something that can perform specific functions, you need a way to modify and control it."

The new nanopatterning technique, developed in the lab of Professor **Alexander Gaeta**, is a simple way to modify materials with light—and it doesn't involve an expensive and resource-intensive clean room.

A Nanoscale Paradox: Several well-established techniques exist to modify materials and create desired nanopatterns, but they tend to require extensive training and expensive overhead. Electron beam lithography machines, for example, must be housed in carefully controlled clean rooms, while existing laser options involve high heat and plasmas that can easily damage samples; the size of the laser itself also limits the size of the patterns that can be created.

The Gaeta lab's technique takes advantage of what's known in the optics and photonics community as "optical driving." All materials vibrate at a particular resonance. Chen and her colleagues can enhance those vibrations by tuning their lasers to that frequency—corresponding to a wavelength of 7.3 micrometers, in the case of hBN—which they first demonstrated in research published last November in *Nature Communications*. In the newly published work, they pushed hBN to even more intense vibrations, but rather than damaging the underlying atomic structure, the lasers broke the crystal lattice cleanly apart. According to Chen, the effect was visible under the microscope and looked like unzipping a zipper.

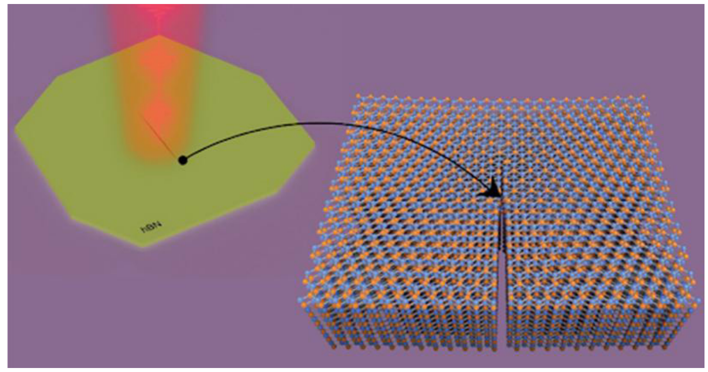
The resulting lines across the sample were atomically sharp and much smaller—just a few nanometers—than the mid-infrared laser wavelengths used to create them. "Usually, you need a shorter wavelength to make a smaller pattern," said Chen. "Here, we can create very sharp nanostructures using very long wavelengths. It's a paradoxical phenomenon."

Small Structures, Big Physics: To explore what they could do with their nanopatterned samples, the engineering team teamed up with physicist Dmitri Basov's lab, which specializes in creating and controlling nano-optical effects in different 2D materials—including creating phonon-polaritons in hBN. These vibrating quasiparticles can help scientists "see" beyond the diffraction limit of conventional microscopes and detect features in the material that give rise to quantum phenomena. They could also be a key component to miniaturizing optical devices, as electronics have become smaller over the years.

"Modern society is based on miniaturization, but it's been much harder to shrink devices that rely on light than electrons," explained physics PhD student and co-author **Samuel Moore**. "By harnessing strong hBN atomic vibrations, we can shrink infrared light wavelengths by orders of magnitude."

Ultrasharp edges are needed to excite phonon-polaritons—normally, they are launched from the sides of flakes of hBN prepared via what's known as the "Scotch tape" method, in which a bulk crystal is mechanically peeled into thinner layers using household tape.

Cecilia Y. Chen et al. Unzipping hBN with ultrashort mid-infrared pulses. Sci. Adv.10,eadi3653(2024). DOI:10.1126/sciadv.adi3653



The Gaeta Lab "unzips" hexagonal boron nitride with a mid-infrared laser tuned to the material's resonant frequency. The result is an atomically sharp line. Credit: Gaeta Lab, Columbia Engineering

However, the team found that the laser-cut lines offer even more favorable conditions for creating the quasiparticles. "It's impressive how the laser-cut hBN regions launch phonon polaritons even more efficiently than the edge, suggesting an ultra-narrow unzipped hBN region that strongly interacts with infrared light," said Moore.

As the new technique can create nanostructures anywhere on a sample, they also unzipped two lines in parallel. This creates a small cavity that can confine the phonon-polaritons in place, which enhances their nano-optical sensitivity. The team found that their unzipped cavities had comparable performance in capturing the quasiparticles to conventional cavities created in clean rooms. "Our results suggest that our preliminary structures can compete with those created from more established methods," noted Chen.

Escaping the Clean Room: The technique can create many customizable nanopatterns. Beyond two-line cavities, it can create any number of parallel lines. If such arrays can be produced on-demand with any desired spacings, it could greatly improve phonon-polaritons' imaging ability and would be a huge achievement, said Moore.

A break can be extended as long as desired once started, and samples as thick as 80 nanometers and as thin as 24 nanometers have been unzipped—theoretically, the bound could be much lower. This gives researchers plenty of options to modify hBN and explore how its nanopatterning can influence its resulting properties, without having to gear up in a clean room bunny suit. "It really just depends on your ultimate goal," said Chen.

That said, she still sees plenty of room to improve. Because hBN is a series of repeating hexagons, the technique only produces straight or angled lines meeting at either 60° or 120° at the moment, though Chen thinks combining them into triangles should be possible. Currently, the breaks can only occur in-plane as well; if they can determine how to target out-of-plane vibrations, they could potentially shave a bulk crystal down into different three-dimensional shapes. They are also limited by the power of their lasers, which they spent years carefully tuning to work stably at the desired wavelengths. While their mid-IR setup is well-suited to modifying hBN, different lasers would be needed to modify materials with different resonances.

Regardless, Chen is excited about the team's concept and what it might be able to do in the future. As a member of the ultrafast-laser subgroup in the Gaeta Lab, Chen helped with their transition from creating and studying high-powered lasers to using those as tools to probe the optical properties of 2D materials.

That problem shared similarities to other problems Chen tackles in her time outside the lab as a boulderer, a form of rock climbing in which climbers scrabble up low, rugged rock faces without harness equipment to catch them if they fall. "In bouldering, the potential climbing routes are called problems, and there's no right answer to solving them," she said. The best solutions cannot be brute forced, she continued: "You have to come up with a plan or you won't be successful, whether figuring out how to exploit macroscopic features in a boulder or microscopic ones in a tiny crystal."

High-Quality Microwave Signals Generated From Tiny Photonic Chip

Researchers create a compact, all-optical device with the lowest microwave noise ever achieved for an integrated chip

By Meeri Kim, Originally published by Columbia Engineering

Michal Lipon & Alex Gaeta

In a new *Nature* study, Columbia Engineering researchers have built a photonic chip that is able to produce high-quality, ultra-low-noise microwave signals using only a single laser. The compact device — a chip so small, it could fit on a sharp pencil point — results in the lowest microwave noise ever observed in an integrated photonics platform.

The achievement provides a promising pathway towards small-footprint ultra-low-noise microwave generation for applications such as high-speed communication, atomic clocks, and autonomous vehicles.

The challenge: Electronic devices for global navigation, wireless communications, radar, and precision timing need stable microwave sources to serve as clocks and information carriers. A key aspect to increasing the performance of these devices is reducing the noise, or random fluctuations in phase, that is present on the microwave.

"In the past decade, a technique known as optical frequency division has resulted in the lowest noise microwave signals that have been generated to date," said **Alexander Gaeta**, David M. Rickey Professor of Applied Physics and Materials Science and professor of electrical engineering at Columbia Engineering. "Typically, such a system requires multiple lasers and a relatively large volume to contain all the components."

Optical frequency division – a method of converting a high-frequency signal to a lower frequency – is a recent innovation for generating microwaves in which the noise has been strongly suppressed. However, a large table-top-level footprint prevents such systems from being leveraged for miniaturized sensing and communication applications that demand more compact microwave sources and are broadly adopted.

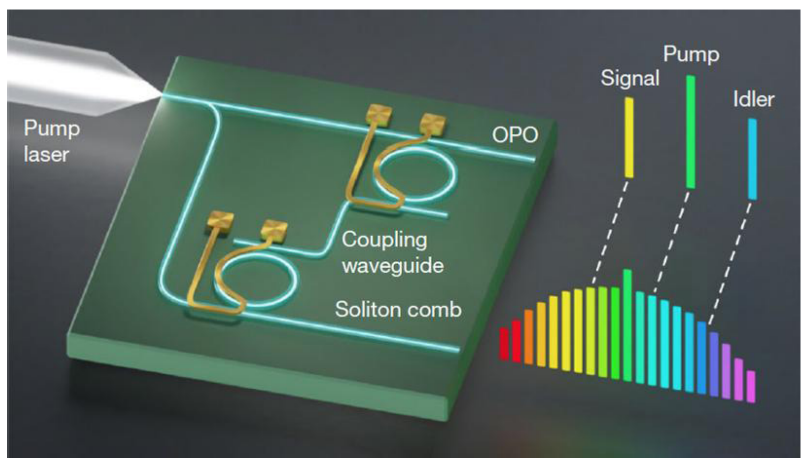
"We have realized a device that is able to perform optical frequency division entirely on a chip in an area as small as 1 mm2 using only a single laser," said Gaeta. "We demonstrate for the first time the process of optical frequency division without the need for electronics, greatly simplifying the device design."

The approach: Gaeta's group specializes in quantum and nonlinear photonics, or how laser light interacts with matter. Focus areas include nonlinear nanophotonics, frequency-comb generation, intense ultrafast pulse interactions, and generation and processing of quantum states of light.

In the current study, his group designed and fabricated an on-chip, all-optical device that generates a 16-GHz microwave signal with the lowest frequency noise that has ever been achieved in an integrated chip platform. The device uses two microresonators made of silicon nitride that are photonically coupled together.

A single-frequency laser pumps both microresonators. One is used to create an optical parametric oscillator, which converts the input wave into two output waves - one higher and one lower in frequency. The frequency spacing of the two new frequencies is adjusted to be in the terahertz regime. As a result of the quantum correlations of the oscillator, the noise of this frequency difference can be thousands of times less than the noise of the input laser wave.

The second microresonator is adjusted to generate an optical frequency comb with a microwave spacing. A small amount of light from the oscillator is then coupled to the comb generator, leading to synchronization of the microwave comb frequency to the terahertz oscillator that automatically results in optical frequency division.



A high-level schematic of the photonic integrated chip, developed by the Gaeta lab, for all-optical optical frequency division, or OFD – a method of converting a high-frequency signal to a lower frequency. Credit: Yun Zhao/Columbia Engineering

Potential impact: The work from Gaeta's group represents a simple, effective approach for performing optical frequency division within a small, robust, and highly portable package. The findings open the door for chip-scale devices that can generate stable, pure microwave signals comparable to those produced in laboratories that perform precision measurements.

"Eventually, this type of all-optical frequency division will lead to new designs of future telecommunication devices," he said. "It could also improve the precision of microwave radars used for autonomous vehicles."

The team: Gaeta, along with **Yun Zhao** — who was a graduate student and is now a post-doc in the Gaeta Lab — and research scientist **Yoshitomo Okawachi**, conceived the project's core idea. Then, Zhao and post-doc **Jae Jang** designed the devices and performed the experiment. The project was done in close collaboration with Eugene Higgins Professor of Electrical Engineering and Professor of Applied Physics **Michal Lipson** and her group. **Karl McNulty** from the Lipson group fabricated the photonic chip at both Columbia and Cornell University. TheTerremoto Shared High-Performance Computing Cluster, a service provided by Columbia University Information Technology (CUIT), was used to model the noise properties of optical parametric oscillators.

Zhao, Y., Jang, J.K., Beals, G.J. et al. All-optical frequency division on-chip using a single laser. Nature 627, 546–552 (2024). https://doi.org/10.1038/s41586-024-07136-2

Gaeta and Lipson's research was featured in several online media outlets, including Phys.org, United Business Journal, Tech Briefs, List 23, SciTech Daily, and Semiconductor Engineering

Researchers Find First Experimental Evidence for a Graviton-like Particle in a Quantum Material

The results, continuing the legacy of late Aron Pinczuk, are a step toward a better understanding of gravity.

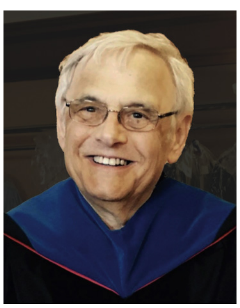
By Ellen Neff, Originally published by Columbia Quantum Initiative News

A team of scientists from Columbia, Nanjing University, Princeton, and the University of Munster, writing in the journal *Nature*, have presented the first experimental evidence of collective excitations with spin called chiral graviton modes (CGMs) in a semiconducting material. A CGM appears to be similar to a graviton, a yet-to-be-discovered elementary particle better known in high-energy quantum physics for hypothetically giving rise to gravity, one of the fundamental forces in the universe, whose ultimate cause remains mysterious.

The ability to study graviton-like particles in the lab could help fill critical gaps between quantum mechanics and Einstein's theories of relativity, solving a major dilemma in physics and expanding our understanding of the universe.

"Our experiment marks the first experimental substantiation of this concept of gravitons, posited by pioneering works in quantum gravity since the 1930s, in a condensed matter system," said **Lingjie Du**, a former Columbia postdoc and senior author on the paper.

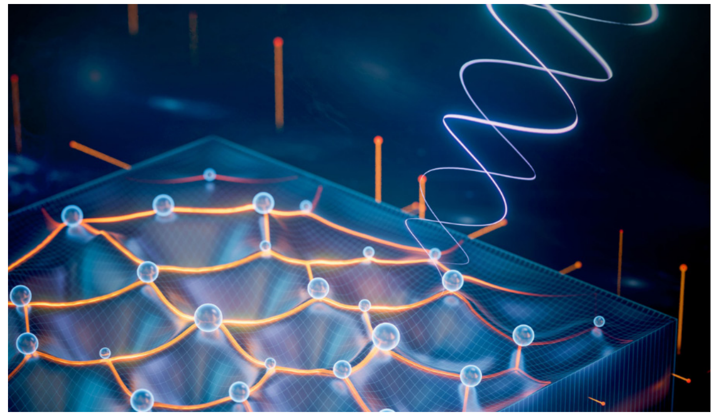
The team discovered the particle in a type of condensed matter called a fractional quantum Hall effect (FQHE) liquid. FQHE liquids are a system of strongly interacting electrons that occur in two dimensions at high magnetic fields and low temperatures. They can be theoretically described using quantum geometry, emerging mathematical concepts that apply to the minute physical distances at which quantum mechanics influences physical phenomena. Electrons in an FQHE are subject to what's known as a quantum metric that had been predicted to give rise to CGMs in response to light. However, in the decade since the quantum metric theory was first proposed for FQHEs, limited experimental techniques existed to test its predictions.



Aron Pinczuk

For much of his career, the Columbia physicist **Aron Pinczuk** studied the mysteries of FQHE liquids and worked to develop experimental tools that could probe such complex quantum systems. Pinczuk, who joined Columbia from Bell Labs in 1998 and was a professor of physics and applied physics, passed away in 2022, but his lab and its alumni across the globe have continued his legacy. Those alumni include article authors **Ziyu Liu**, who graduated with his PhD in physics from Columbia last year, and former Columbia postdocs Du, now at Nanjing University, and Ursula Wurstbauer, now at the University of Münster.

"Aron pioneered the approach of studying exotic phases of matter, including emergent quantum phases in solid state nanosystems, by the low-lying collective excitation spectra that are their unique fingerprints," commented Wurstbauer, a co-author on the current work. "I am truly happy that his last genius proposal and research idea was so successful and is now published in *Nature*. However, it is sad that he cannot celebrate it with us. He always put a strong focus on the people behind the results."



Light probing a chiral graviton mode in a fractional quantum Hall effect liquid. Credit: Lingjie Du, Nanjing University

One of the techniques Pinczuk established was called low-temperature resonant inelastic scattering, which measures how light particles, or photons, scatter when they hit a material, thus revealing the material's underlying properties. Liu and his co-authors on the *Nature* paper adapted the technique to use what's known as circularly polarized light, in which the photons have a particular spin. When the polarized photons interact with a particle like a CGM that also spins, the sign of the photons' spin will change in response in a more distinctive way than if they were interacting with other types of modes.

The new paper in *Nature* was an international collaboration. Using samples prepared by Pinczuk's long-time collaborators at Princeton, Liu and Columbia physicist Cory Dean completed a series of measurements at Columbia. They then sent the sample for experiments in low-temperature optical equipment that Du spent over three years building in his new lab in China. They observed physical properties consistent with those predicted by quantum geometry for CGMs, including their spin-2 nature, characteristic energy gaps between its ground and excited states, and dependence on so-called filling factors, which relate the number of electrons in the system to its magnetic field.

CGMs share those characteristics with gravitons, a still-undiscovered particle predicted to play a critical role in gravity. Both CGMs and gravitons are the result of quantized metric fluctuations, explained Liu, in which the fabric of spacetime is randomly pulled and stretched in different directions. The theory behind the team's results can therefore potentially connect two subfields of physics: high energy physics, which operates across the largest scales of the universe, and condensed matter physics, which studies materials and the atomic and electronic interactions that give them their unique properties.

In future work, Liu says the polarized light technique should be straightforward to apply to FQHE liquids at higher energy levels than they explored in the current paper. It should also apply to additional types of quantum systems where quantum geometry predicts unique properties from collective particles, such as superconductors.

"For a long time, there was this mystery about how long wavelength collective modes, like CGMs, could be probed in experiments. We provide experimental evidence that supports quantum geometry predictions," said Liu. "I think Aron would be very proud to see this extension of his techniques and new understanding of a system he had studied for a long time."

Jiehui Liang, Ziyu Liu, et al. Evidence for chiral graviton modes in fractional quantum Hall liquids. *Nature* 2024. DOI:10.1038/s41586-024-07201

Celebrating the Retirement of Professor Irving P. Herman

After a long and distinguished career at Columbia University, **Irving P. Herman** has retired and is now the Edwin Howard Armstrong Professor *Emeritus* of Applied Physics.

Professor Herman graduated with SB and PhD degrees in physics from the Massachusetts Institute of Technology in 1972 and 1977. From 1977-1986 he was a member and section leader in O-group within the Physics Department at the Lawrence Livermore National Laboratory, where he was engaged in research in laser isotope separation of deuterium and tritium, and the use of direct laser writing in thin film processing. In 1986, he joined the faculty in the Department of Applied Physics and Applied Mathematics (APAM) of Columbia University and was named the Edwin Howard Armstrong Professor of Applied Physics in 2016. He directed the Columbia Materials Research Science and Engineering Center (MRSEC) from 1998-2010 and was Director of the Columbia Optics and Quantum Electronics IGERT (Integrative Graduate Education and Research Traineeship program) from 2015-2019. From 2006-2012, he was chair of the Department of Applied Physics and Applied Mathematics and he was re-elected chair in 2018. He has served in the Columbia University Senate since 2017.

Professor Herman's research advanced fundamental aspects and applications of laser interactions with matter, optical diagnostics of thin film processing, including by real-time monitoring, and nanoscience. His research included properties of nanocrystals and films composed of nanocrystals, van der Waals layers, optical physics of the solid state, molecular and chemical physics, thin film processing, and optical spectroscopy. His group studied the optical properties of semiconductor and metal oxide nanocrystals and how to assemble them into films by controlled evaporation and electrophoretic deposition (electric field directed assembly).

Professor Herman is an elected Fellow of the American Physical Society and of Optica, the former for "distinguished accomplishments in laser physics, notably the development and application of laser techniques to probe and control materials processing".

Professor Herman has written two comprehensive books: the monograph "Optical Diagnostics for Thin Film Processing" (Academic Press, San Diego) and the textbook "Physics of the Human Body" (Springer, Berlin-Heidelberg-New York), now in its second edition. In 2020, Professor Herman also published "Coming Home to Math: Become Comfortable with the Numbers that Rule Your Life" (World Scientific), an explanatory book designed to help adults become more at ease using math.

At Columbia, he developed three interactive seminars on ethics which were presented annually to students in the APAM Department at Columbia Engineering. Professor Herman is also known for his witty and humorous writings about academia, including "The Laws of Herman", as well as his extensive writings on running, humor, and music.

The APAM Department warmly congratulates and thanks Professor Herman for his dedication, service, and outstanding leadership over the years. He inspired and touched the lives of countless people during his time at Columbia and he will be greatly missed.

Current APAM Department Chair, Professor Marc Spiegelman, said, "Professor Herman's wisdom, integrity and leadership has been integral to APAM's success. And personally, his friendship and guidance has been, and will continue to be invaluable. I am forever grateful. We wish him the best in his post retirement adventures and look forward to seeing him frequently in the Department."

Irving Herman, Edwin Howard Armstrong Professor *Emeritus* of Applied Physics.

(left-right) Professors Gerald Navratil, Michael Mauel, and Irving Herman

(above) Professor Irving Herman in his lab
(below) Retirement celebration for Irving Herman

Informing Tokamak Design with State-of-the-Art Physics Modeling

A team of plasma physics researchers at Columbia provide essential information leading to refinements in the design of a next-generation tokamak.

By Alexander Battey, Ian Stewart and Oak Nelson

The plasma physics group at Columbia University has recently published a series of three articles describing essential considerations for a new tokamak designed to demonstrate net fusion energy gain by producing 140MW of fusion power. Tokamaks are toroidal devices that confine plasma inside of them with strong magnetic fields. The recent work by Columbia concerns the design of a new machine called SPARC, will be operated by Commonwealth Fusion Systems (CFS) and is currently under construction in Devens, Massachusetts. This research highlights computational and collaborative strengths of the Columbia plasma program.

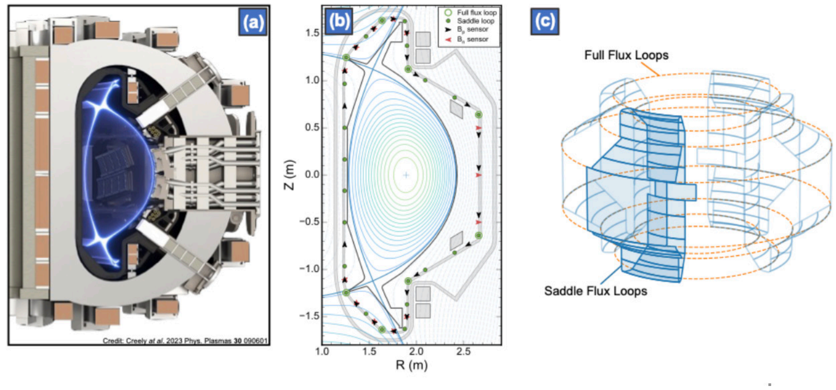


Figure 1: (a) Cross section of one half of the SPARC tokamak, (b) diagram of the magnetic sensor locations on the vacuum vessel wall with the contours of the plasma equilibrium shown in blue and (c) a three dimensional view of the flux loop sensors defined in the study.

Measuring the Magnetic Field: New research, published by Columbia researcher **Ian Stewart** in collaboration with CFS and the Massachusetts Institute of Technology (MIT) has identified the key areas where magnetic sensors need to be placed in order to control the shape and geometry of the plasma in the future SPARC experiment [1]. These magnetic sensors are small loops of wire that track the change in flux to measure the magnetic field at various locations around the tokamak. A cross section of SPARC and the layout of the optimized magnetic sensor set from the publication are shown in Figure 1.

Determining the plasma location and shape using magnetic sensors is fundamental to the success of tokamaks like SPARC that rely on magnetic control to maintain a stable, high-performance plasma. This study determined where sensors should be placed and how many sensors are necessary to measure the plasma shape via a process known as equilibrium reconstruction. These general methods can be extended for use in the design of other future fusion experiments, which will have limited space and budgets to construct and install these types of critical sensors.

Ensuring Vertical Stability: Tokamak plasmas are often stretched vertically in order to maximize the volume of plasma available for fusion power production. However, there is a delicate balance between how stretched a plasma can be before it becomes subject to a vertical instability which can lead to loss of plasma confinement.

In order to assess this phenomenon on the SPARC machine, Columbia researcher **Oak Nelson** worked closely with scientists at MIT and CFS to model the response of the magnetic equilibrium to active control coils. This analysis, recently published in *Nuclear Fusion* [2], devises strategies and constraints on the control system that will allow operators to ensure safe operation of SPARC as it pursues its performance goals.

Catching Relativistic Electrons: Relativistic electrons are a phenomenon unique to plasma physics. An electron moving through a hot plasma in the presence of a strong and sustained electric field can quickly be accelerated up to speeds approaching the speed of light. These conditions can occur during tokamak events characterized by a quick termination of the current flowing through the plasma. The resulting beams of relativistic electrons have the potential to severely damage the walls of future tokamaks if they are not properly handled.

To mitigate the effects of these electrons on SPARC, Columbia researchers **Alexander Battey** and **Chris Hansen** explored the potential addition of a mitigation coil to the SPARC design in a stand-alone work [3]. The coil (depicted in Figure 2 alongside a similar design for the DIII-D tokamak in San Diego) is a helical conducting structure placed within the tokamak that conducts large currents in the presence of strong electric fields. This will create a large three dimensional magnetic field which is capable of quickly dispersing the relativistic electrons to prevent wall damage.

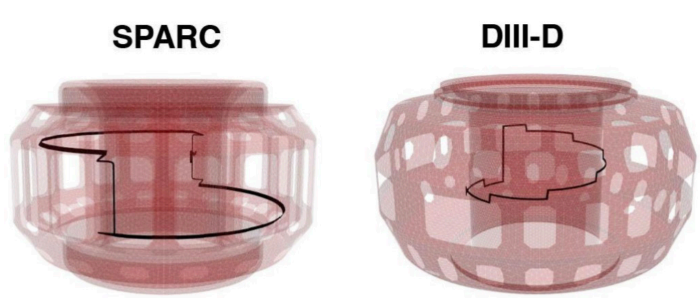


Figure 2: Mitigation coils designed to control relativistic electrons for the SPARC and DIII-D tokamaks.

Dive Deeper: The work described in this article is the subject of three publications, listed below, appearing in the journal *Nuclear Fusion*. Columbia Plasma Lab members are working on further related studies, particularly focused on the pursuit of clean and sustainable fusion energy.

References

[1] https://iopscience.iop.org/article/10.1088/1741-4326/acf600/meta

[2] https://arxiv.org/abs/2401.09613 (to be published with *Nuclear Fusion* soon)

[3] https://iopscience.iop.org/article/10.1088/1741-4326/ad0bcf/meta

In Memoriam: Professor *Emeritus* Daniel N. Beshers

Daniel Beshers (1928-2024)

The Columbia Engineering community mourns the loss and celebrate the life of Professor Emeritus Daniel N. Beshers

Professor Emeritus Daniel N. Beshers, age 95, died peacefully in his sleep on January 4, 2024.

He was born August 13, 1928 in Chicago, IL, to Hugh Monahan Beshers and Caroline (Newson) Beshers. His early childhood was spent mostly on Aruba, where Hugh, a civil engineer, helped to build and run an oil refinery. Daniel had two younger brothers, James and Eric, both deceased. When he was 12 the family settled in Washington, DC, where he attended junior high and Woodrow Wilson high school.

Daniel attended Swarthmore College (BA in Mathematics, 1949) and the University of Illinois at Urbana-Champaign, where he earned an MS (1951) and PhD (1955) in Physics. He spent one year at the Office of Naval Research Laboratory in Washington DC, and then moved to Columbia University in New York as an Assistant Professor of Applied Physics and Applied Mathematics in the Henry Krumb School of Mines, specializing in Metallurgy. He spent the rest of his career at Columbia, being promoted to Associate Professor with tenure in 1965 and Full Professor in 1970.

He advised a number of graduate students and was known for his demanding yet rewarding classes. He retired as a member of the Department of Applied Physics and Applied Mathematics in the School of Engineering and Applied Sciences.

In 2008 he was awarded the Zener Medal by the International Conference on Internal Friction and Mechanical Spectroscopy (ICIFMS) for "remarkable scientific achievements in the field of anelasticity, mechanical spectroscopy and the study of condensed matter with acoustic methods". His final co-authored paper was published when he was 89 years old.

An obituary featuring details from his personal and family life can be found at **https://rb.gy/5oddcl**

We'd love to hear from you, APAM Alumni!

Please send your news to

apam@columbia.edu

Read more alumni updates online at:

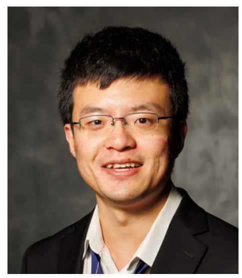
www.apam.columbia.edu/alumni-reports

Welcome Marri Davis - New APAM DA

We are thrilled to announce that **Marri Davis** is the new APAM Department Administrator! In her role, she will work closely with the Chair and will be responsible for the overall administration, operations and financial management of the Department. She will provide active, hands-on leadership for academic administration and financial activities, and will also supervise APAM's Finance Analyst, Administrative Services, and Student Services team.

Marri joins us from NYU's Steinhardt School where in her most recent role, she served as the Director of Faculty Affairs overseeing human resources across eleven departments. Over the years she has worked in various roles within the Steinhardt School, including eight years as the Department Administrator in Applied Psychology. In this role she managed administration, budget, and spearheaded the implementation of the online programs for Mater's students. She has Bachelor of Arts in Photography/History from Bennington College, and two Master's degrees at NYU in Photograph and Educational Psychology.

Changmin Shi '19 Named Top Under 30 Chinese-American Elite

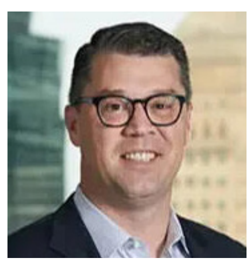


Changmin Shi

Changmin Shi, (MS 2019, Materials Science & Engineering) was named in the 2024 'Top Under 30 Chinese-American Youth Elite List' in recognition of his contributions to innovation, entrepreneurship, and professional growth. This recognition is considered the highest honor for young Chinese professionals in America and he has been featured in the *Los Angeles Post, People's Daily, Chinanews,* and *China Daily*.

Dr. Shi is currently a Postdoctoral fellow at Brown University and his research focuses on developing safe high-energy density batteries and novel thermal management materials. He has published 16 papers in top journals of the *Nature* series and in materials and metallurgy fields, applied for two US patents, and received honors and awards 16 times.

In Memoriam: Cory Cates, PhD '06



Cory Cates (1974-2024)

The APAM Department is very sad to announce that **Cory Cates** (PhD 2006, Plasma Physics) passed away on May 6, 2024.

Following his PhD at Columbia, Cory worked at Credit Suisse for eight years and then became the Chief Information Officer of Longevity Holdings in 2013, where he was responsible for technology and analytics. He is survived by his wife of 28 years, Kari Jo Harris Cates, and their children Nathan, Henry, Caroline, and Betsy.

Cory's advisor, Prof. Michael Mauel stated, "He was my PhD student and was the first to demonstrate active feedback control of "resistive wall modes" in a tokamak. It was very important work, and Cory was a clear-thinking scientist who was devoted to his loving family".

A full obituary for Dr. Cates can be found at:
https://www.clintonfh.com/obituaries/cory-cates

Photos and tributes can be found at:
https://everloved.com/life-of/cory-cates/

In lieu of flowers, please consider a gift to City Seminary of New York.

(Student & Department News, continued)

Student Report: Princeton Fintech and Quant Conference

by Yuqi Zhang

On April 6th, I attended the Princeton Fintech and Quant Conference, thanks to the APAM Department for bringing this valuable opportunity to my attention. The event featured insightful lectures and panel discussions from leaders in trading, banking, and technology, enriching my understanding of both the industry and academia in the field I am passionate about.

The conference was an incredible networking opportunity, allowing me to connect with experts and industry leaders who shared insights that have significantly shaped my future plans. I was particularly excited to meet several Columbia alumni who provided guidance and shared their experiences, which were immensely helpful and have strengthened my network. This experience not only broadened my industry knowledge but also highlighted the strong support system available through our networking resources.

Hansen Featured at Fusion Energy Week

Dr. Christopher Hansen was featured in an online panel during Fusion Energy Week, May 6-10, 2024. Dr. Hansen is a research scientist in the Applied Physics and Applied Mathematics department at Columbia University. His group develops and applies validated physics-based numerical simulations and fast data-driven models using machine learning. While Dr. Hansen group's work is primarily computational, it prioritizes a close coupling to experimental investigations to provide trustworthy models for design and control applications. The tools and methods developed by this group are currently applied to the design of new prototype fusion reactors and the understanding, improvement and control of present and future devices.

Jim Andrello and the Newly Renovated Applied Physics Teaching Lab

by Michael Mauel

Since the founding of our department, both undergraduate and graduate students in Applied Physics have planned, executed, and reported experiments in the Applied Physics Teaching Lab. This year, we had our highest student enrollments, and students conducted twelve weeks of experiments in a newly renovated laboratory space. **Jim Andrello** (pictured on the right), who manages and maintains the Applied Physics Teaching Lab, worked with the Staff of the Fu Foundation School of Engineering and Applied Science and designed the new laboratory space.

New lab benches, new lighting, new safety features, and new lab utilities were made compatible with twelve project lab stations. Student teams conducted experiments to measure the speed of light, the concentration of semiconductor dopants, the supersonic speed of plasma shock waves, critical properties of superconductors, high-vacuum technology, and Paschen's law. Besides instructing all of our applied physics students on safe laboratory techniques, Jim is manager of the Plasma Physics Laboratory and chief research technician on the HBT-EP Tokamak.

Contributing Authors

Katayun Barmak, Alexander Battey, Columbia Engineering, Columbia Engineering Magazine, Columbia News, Columbia Quantum Initiative News Allison Elliot, Holly Evarts, Katie Luna, Meeri Kim, Michael Mauel, Ellen Neff, Oak Nelson, Carlos Paz-Soldan, Ian Stewart, Michael Weinstein, Yuqi Zhang

Photos/Images

Katayun Barmak, Eileen Barosso, Columbia Engineering, Columbia Engineering Magazine, Carlos Paz-Soldan, Svitlana Samoilina, Yuqi Zhang

Contact Us

We'd love to hear from you and stay connected! Follow us on social media and please send your news and updates to **apam@columbia.edu**

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