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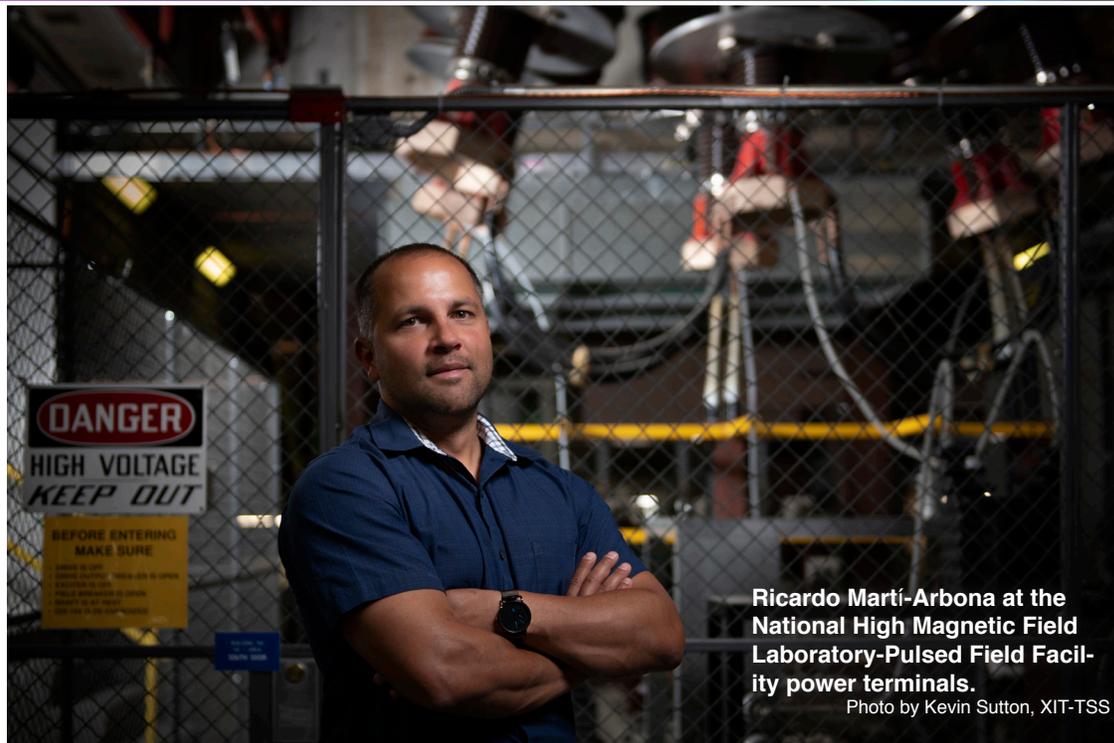
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Ricardo Martí-Arbona at the National High Magnetic Field Laboratory-Pulsed Field Facility power terminals.

Photo by Kevin Sutton, XIT-TSS

## Ricardo Martí-Arbona

### *Introducing MPA's new process and safety coordinator*

By Madeline Bolding, ALDPS Communications

As a scientist with 20 years of research experience, Ricardo Martí-Arbona knows how to observe, develop and test a hypothesis, and draw conclusions from the process. As safety and process coordinator for Materials Physics and Applications (MPA) Division, he will apply the principles of the scientific method to make it easier for his colleagues to perform their research.

"My parents modeled what it's like to empower people, and that's what I want to do but for scientists," said Martí-Arbona, who grew up in Puerto Rico, the son of education administrators.

Martí-Arbona, who has a PhD in chemistry from Texas A&M University, joined the Lab in 2007 as a postdoctoral researcher in Bioscience Division. In 2011 he became a staff scientist on the Biochemistry and Structural Biology team in Bioenergy and Biome Sciences (B-11). Most recently he

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His background in science taught Martí-Arbona independence and problem solving and his interest in safety has taught him unique lessons in teamwork.”

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## From Chris's desk

Over a decade ago, as part of my work in the Superconductivity Technology Center, I was fortunate to work with Dr. David Reagor on his underground radio project. We performed field tests of the low-frequency, through-the-earth communications system in Farmington, N.M., at the BHP Billiton coal mine (see photo at left). The radio system consisted of two identical sets of H-field antennas and electronics packages. One set was positioned inside the mine in selected tunnels, 100-300 feet below the surface, and the other was positioned on the surface. Dave and I would then take turns being in the mine and on the surface and test the communications capabilities of the system.

While we were working there, several safety-related observations caught my attention. One was the attention to detail by the staff and organization in ensuring that we had the proper equipment, safety briefings about our equipment, and suitable escorts. Another observation that particularly stood out to me was something that happened as the group of us was walking, in our gear, from the parking lot to the change room. As we were nearing the building, there was a mine worker unloading equipment from his truck who noticed that we would be walking close to his toolbox and a few tools near it on the ground. I recall that the tools were out of our direct walking path but still near it. As we approached, he stopped, addressed us, pointed to his equipment on the walkway and said something to the effect, "Please watch out for the tools." That was a simple observation and gesture on his part, but it impressed me with his alertness and willingness to say something and look out for his fellow workers.

Here at LANL, and in MPA Division in particular, as we continue to improve our security and safety performance, it is critical to improve our safety culture. Recently, at least in ALDPS, we've had some events that we could have been handled better, events in which our co-workers were either compromised or injured, and we've had some situations in which we've performed very well. We are a learning organization and are continuing to do better and better.

The notion of looking out for one another is critical to our success. In unsure situations it is okay, and in fact encouraged, to question something that appears amiss and to pause work if necessary and take a fresh look. The worker at the mine exemplified that behavior by alerting us to his tools.

It is a pleasure to be associated with MPA. I'm impressed with the diversity and quality of the research and staff. Thank you for continued support, contributions, and dedication.

*Acting MPA Deputy Division Leader Chris Rose*

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*The notion of looking out for one another is critical to our success. In unsure situations it is okay, and in fact encouraged, to question something that appears amiss and to pause work if necessary and take a fresh look.*

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## From George's desk

I was having a conversation with some colleagues recently where we were reflecting upon our careers and the often unexpected paths we have found ourselves traversing. In fact, it seems fairly rare that one finds oneself doing exactly what his or her younger self envisioned. In my experience, remaining open to unanticipated opportunities has often led to the best experiences of both my professional and personal life.

Over the course of my professional career, I have always been involved in research in the field of applied energy. In graduate school (and as an undergraduate) I was interested in the field of CO<sub>2</sub> capture from power plant flue gas, commonly called carbon capture, utilization, and storage. When I came to the Lab, I switched to the nuclear field, focusing on developing separations processes for advanced nuclear fuel cycles and the processing of special nuclear material. What started out as a postdoc in a new area to bridge the gap to academia turned into a career. I have worked extensively over the years with the Science Program Office, particularly with the Civilian Nuclear Energy Program Office, and I currently serve as the interface for LANL with the DOE Office of Nuclear Energy Fuel Cycle R&D Program for the area of separations and waste forms.

Since I joined MPA nearly five years ago, I have had the opportunity to be exposed to a whole different side of the Lab than I had previously experienced. I have had a lot of fun learning about the diverse, new, cutting-edge research performed in MPA and discussing with many of you possibilities for applying these new technologies in the applied energy field. We have had some success with this, such as using additive manufacturing to design and print new separation contactors (featured in the latest issue of *1663*) and using acoustics sensors for safeguards and structural health monitoring in high-temperature molten salt environments for next-generation nuclear reactors. I have also recently re-engaged in several projects funded by the Office of Fossil Energy (DOE-FE), Applied Energy Program Office here at LANL, in the areas of rare-earth recovery from coal waste streams and once again in the field of CO<sub>2</sub> capture. It turns out that a lot of the separations research LANL has been developing for the nuclear area has a lot of overlap with research needs at DOE-FE, and its program managers have been excited to leverage this expertise here at the Lab. The interest by this new sponsor has re-invigorated some of our researchers here at the Lab and has provided potential for significant new growth in the coming years.

While I have not been actively engaged in DOE-FE projects for the last 14 years here at LANL, many of the same faces are still involved in the programs at DOE headquarters, and they are happy to see a familiar face involved in the new projects. One of the best parts of our Lab is the multidisciplinary research and the ability to interact with colleagues from nearly every scientific discipline. So if you have an idea you think might work in an area you aren't familiar with or maybe you have an idea that you think could apply to an area of research you aren't active in anymore ... it is never too late! Call up your program office or talk with your group managers. We would be happy to help facilitate those conversations. If you are interested in the applied energy area, feel free to contact me. I am always happy to have a conversation about how to better solve our energy problems.

*MPA-11 Deputy Group Leader George Goff*

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*... if you have an idea you think might work in an area you aren't familiar with or maybe you have an idea that you think could apply to an area of research you aren't active in anymore ... it is never too late! Call up your program office or talk with your group managers. We would be happy to help facilitate those conversations.*

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*Marti-Arbona cont.*

served as the group's scientific operations lead, a role that allowed him to develop a holistic view of how to perform science safely. When the opportunity arose for him to contribute to safety and process improvements for an experimental organization as diverse as MPA, he jumped on it.

At Los Alamos Martí-Arbona has served on several safety and security committees and learning teams, receiving awards for his efforts that have improved mission operations while reducing the group's environmental impact. For example, he helped a B-11 lab to become the first from any DOE laboratory to earn certification by My Green Lab, a non-profit organization considered to set the standard for laboratory sustainability best practices across North America. As a B-11 team leader he worked with specialists in facilities, purchasing, construction, and safety regulation to install a liquid nitrogen plant to generate the large volumes of cryogenics that scientists use for instrumentation, sample preparation, and storage. The project, which reduced costs and the environmental impact of shipped nitrogen, received a 2018 NNSA Sustainability Award Honorable Mention. He has contributed to housekeeping, recycling, and energy-saving improvement projects, and the procurement and installation of energy-efficient, dependable freezers that expand scientific capabilities, work for which he received a Laboratory 2018 Patricia E. Gallagher Environmental Award. He is the recipient of a 2019 Department of Energy Sustainability Award for the Sustainability Champion category and a Laboratory WESST Star Award for his continual support of the environment, safety, and security at the Lab.

One of Martí-Arbona's first MPA projects is essential to the success of the Lab's mission-focused science, technology, and engineering. He is working with engineers, internal safety professionals, and contractors to coordinate the disassembly of LANL's 1.4 billion-watt power generator in preparation for its rotor to be shipped off-site for repairs.

Using his experience in science and safety, Martí-Arbona anticipates logistical and safety issues for the project, including compliance with environmental regulations, operation of the crane that will be used to lift generator components, and transportation of the 230-ton, 69-foot-long rotor to Virginia.

His background in science taught Martí-Arbona independence and problem solving and his interest in safety has taught him unique lessons in teamwork. Since 2016 he has volunteered as an auxiliary Hazmat emergency responder, regularly meeting with emergency responders, designing mock emergency scenarios, and suiting up for training.

"In (an emergency) call, you assess who has the strengths for each part of the scenario," he said. "We all have skills that are not specifically within our job description, so I try to differentiate between people's interests and maximize on their capabilities." With a foundation in science, skills in safety, and an inclination to help others, Martí-Arbona's new position with MPA maximizes his unique capabilities for the good of the team.

## Ricardo Marti-Arbona's favorite project

**Who:** R&D researchers paired with warfighters at the 823d RED HORSE (Rapid Engineer Deployable Heavy Operations Repair Squadron Engineers) Squadron U.S. Air Force Air Combat Command

**What:** The Scientists in Motion program

**When:** 2018

**Why:** The program allows R&D scientists to experience a simulated chemical, biological, radiological, nuclear, and high-yield explosive operational environment to better understand how a warfighter serving on the front lines would use the tools available.

**The "ah-ha" moment:** Warfighters need to be prepared for a lot of situations while only carrying a limited number of supplies. Rather than having plastic gloves ready, they may use a trash bag to protect themselves from a biohazard. Understanding their limitations helps the scientists visualize how to smooth the transition of novel technologies into the war zone to achieve our ultimate goal—bringing soldiers home safely.

## MPA staff in the news

### *Millie Firestone inspires future scientists at National Science Bowl*

Millie Firestone presented her perspective on the promise of nanotechnology to middle and high school students competing in the 2019 National Science Bowl in Washington DC.

In “Next steps and challenges in translating nanoscience to nanotechnology,” Firestone (Center for Integrated Nanotechnologies, MPA-CINT) discussed the nanoscience landscape and the creative process inherent in synthesizing scientific concepts into usable devices. Her perspective comes from her own research and her relationship between the nanoscience research centers at Argonne and Los Alamos national laboratories.



**National Science Bowl speakers, left to right: Todd Satogata (Jefferson Lab), James Glownia (SLAC National Accelerator Laboratory), Pat Dehmer (DOE Office of Science, retired), Millie Firestone (LANL), Jeff Sims (SLAC), Anne Marie March (Argonne National Laboratory).**

Photo by Dennis Brack, National Science Bowl®, Department of Energy, Office of Science

A team-based knowledge competition begun by the DOE in 1991, the National Science Bowl features students answering questions in the categories of biology, chemistry, energy, mathematics, physics, and earth and space science. This year approximately 500 students advanced to the National Science Bowl.

At the event, scientists from DOE facilities volunteered to share their research with the students to inspire curiosity and demonstrate fulfilling scientific careers. Other speakers included Todd Satogata (Jefferson Lab), James Glownia (SLAC National Accelerator Laboratory), Pat Dehmer (DOE Office of Science, retired), Jeff Sims (SLAC), and Anne Marie March (Argonne National Laboratory).

Firestone, who received her PhD from Northwestern University, helped establish the Center for Nanoscale Materials at Argonne National Laboratory. At CINT she served for five years as a leader for its Soft, Biological, and Composite Nanomaterials Thrust, in which she worked toward under-

standing and mimicking biological processes to design new ways to store and transduce energy. She works to bridge fundamental nanoscience with the Laboratory’s mission science.

*Technical contact: Millie Firestone*

### *Hou-Tong Chen co-chairs international optical terahertz research conference*

Hou-Tong Chen (Center for Integrated Nanotechnologies, MPA-CINT) co-chaired the 8th international conference on Optical Terahertz Science and Technology (OTST), held recently in Santa Fe, N.M. As co-chairs, Chen and his CINT colleague Igal Brener (Sandia National Laboratories) established the conference’s technical program.



Chen is a fellow of the American Physical Society and the Optical Society of America, holds three patents in the fields of terahertz science and metamaterials/metasurfaces, serves as a topical editor for *Optics Letters*, and is on the editorial board of *Scientific Reports*.

Founded in 2005, OTST is held every two years and provides a forum for scientists to discuss research performed with optical techniques to access the terahertz spectral range. The conference featured talks and poster presentations covering advances and perspectives in optical terahertz generation and detection, material science, imaging and sensing, studying and generating energy, biological studies, and quantum systems. It included an introductory workshop for students and researchers new to the field.

### **Program featured LANL-led session, invited talk, CINT overview**

Rohit Prasankumar (MPA-CINT) served on the program committee. Associate Laboratory Director for Physical Sciences Antoinette Taylor gave an invited talk, “Few-layer metasurfaces: fundamentals to applications.” She and Prasankumar chaired separate sections of the session on terahertz spectroscopy and excitation of quantum systems. Nicholas Sirica (MPA-CINT) spoke on “Ultrafast photocurrents in the Weyl semimetal TaAs,” and Prashant Padmanabhan (MPA-CINT) presented a poster on “Magneto-plasmonic manipulation of THz transmission and Faraday rotation using graphene micro-ribbon arrays.”

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MPA staff cont.



This year's conference attracted more than 200 attendees from across the globe, including speakers from Canada, Japan, Germany, the United Kingdom, South Korea, Denmark, Switzerland, France, Italy, and China. The event was sponsored by the Laboratory's Center for Nonlinear Studies and Center for Integrated Nanotechnologies and 13 international industrial sponsors.

Technical contact: Hou-Tong Chen

### *Jacob Spendelow recognized for leadership by DOE's Hydrogen and Fuel Cells Program*

Jacob Spendelow (Materials Synthesis and Integrated Devices, MPA-11) received a 2019 Annual Merit Review Award for his work in fuel cell research and development from DOE's Hydrogen and Fuel Cells Program. The award committee cited Spendelow for outstanding leadership demonstrated in conducting the fuel cell project "Advanced electrocatalysts through crystallographic enhancement." Spendelow led a large team of scientists from Los Alamos National Laboratory, State University of New York Buffalo, Brown University, University of Pennsylvania, and EWII Fuel Cells.

Spendelow and his team developed new intermetallic platinum-cobalt (PtCo) catalysts with atomic-level ordering that stabilizes Co atoms within the catalyst nanoparticles. This reduced the leaching rate of Co and maintained high Co content even after durability testing. The key innovation in 2018 was the development of a new synthetic method that enables simultaneous achievement of small nanoparticle size (<4 nm) and a high degree of ordering. Previous efforts to develop intermetallic PtCo nanoparticles were limited by excessive particle growth that occurs during the ordering process. By avoiding this particle growth, the Los Alamos catalyst maintains high surface area and high catalytic activity while exhibiting improved durability. The catalysts achieved a mass activity of 0.6 A/mg<sub>PGM</sub> after 30,000 voltage cycles, with a loss of only 40% after 30,000 cycles, exceeding DOE targets for catalyst performance and durability.

Spendelow joined the Lab as a Director's Postdoctoral Fellow in 2006 and became a staff member in 2008. He received his PhD in chemical engineering from the University of Illinois at Urbana-Champaign. He has served as a science advisor and a program manager at the DOE Fuel Cell



**Jacob Spendelow (left) receives his award from Dimitrios Papageorgopoulos, program manager of the fuel cells program, at the Annual Merit Review and Peer Evaluation Meeting in Annapolis, M.D.**

Technologies Office in Washington DC, where he managed R&D projects related to polymer electrolyte membranes, catalysts and supports, and reversible fuel cells.

Technical contact: Jacob Spendelow

### *Sandip Maurya receives Postdoctoral Distinguished Performance Award*

Sandip Maurya (Materials Synthesis and Integrated Devices, MPA-11) is the recipient of a 2018 Los Alamos Distinguished Performance Award. He was recognized for "outstanding levels of creativity, personal dedication, and technical acumen related to the development of alkaline fuel cell systems."

Maurya's work has helped sustain and grow the Lab's reputation in the areas of high-temperature polymer fuel cell and redox flow battery R&D. His work has the potential to significantly impact new fuel cell technologies.

Maurya, who earned a PhD in environmental science and engineering from Gwangju Institute of Science and Technol-



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MPA staff cont.

ogy, is mentored by Yu Seung Kim and Rangachary Mukundan (both MPA-11).

Established in 2001, Postdoctoral Distinguished Performance Awards recognize outstanding, unique contributions by Lab postdoctoral researchers that result in a positive, significant impact on the Lab's scientific efforts and status in the scientific community. Other 2018 recipients were Osman El-Atwani (Materials Science in Radiation and Dynamics Extremes, MST-8) and Lukasz Cincio (Physics of Condensed Matter and Complex Systems, T-4).

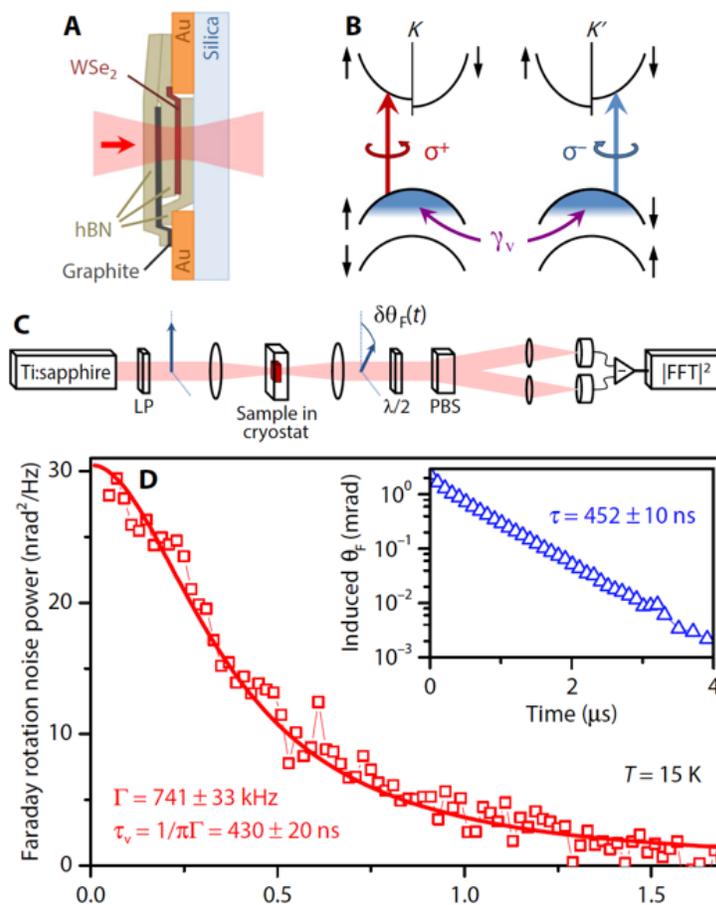
Technical contact: Sandip Maurya

## Using light to 'listen' to electron scattering for the nascent field of valleytronics

Scientists have long wanted to improve on the means by which conventional electronics use a binary system to store and transmit information that is based on an electron's charge. Including additional physical parameters, or degrees of freedom, could improve computational speeds, efficiency, and information security. For example, one approach that has been studied over the past two decades is to exploit an electron's spin degree of freedom. Storing information whether an electron is oriented "spin-up" or "spin-down" (or indeed, in some quantum-mechanical superposition thereof) forms the basis of the research field known as "spintronics."

In the recently discovered family of atomically-thin transition-metal dichalcogenide semiconductors (e.g., a single monolayer of  $\text{MoS}_2$  or  $\text{WSe}_2$ ), it is also possible to store information in an electron's *momentum* state. That is, whether an electron resides in one or the other of two inequivalent energy minima, or "valleys," in the material's band structure (formally, at the  $+K$  or  $-K$  points of the material's Brillouin zone in reciprocal space). Crucially, in these new two-dimensional semiconductors it is particularly easy to access specific valleys using circularly-polarized light. This new valley-based degree of freedom forms the basis for the nascent field of "valleytronics."

In a recent report published in *Science Advances*, Los Alamos researchers and their external collaborators measured an important parameter for the field of valleytronics: the time it takes for an electron to scatter from one valley to another. This timescale will be a limiting factor for future device applications based on valley degrees of freedom. Importantly, this was accomplished not by using conventional pump-probe methods, which are necessarily perturbative and which are therefore associated with various fundamental limitations. Instead, the team employed an innovative means of using an optical probe to passively "listen" to the intrinsic fluctuations of the electrons as they scatter back and forth between the two valleys, a random process that always occurs even under conditions of strict thermal equilibrium.



(A) **Sample:** A single  $\text{WSe}_2$  monolayer is electrically gated. (B) **Band structure and circularly-polarized optical transitions** of hole-doped monolayer  $\text{WSe}_2$ . Even in thermal equilibrium, resident holes spontaneously scatter between  $+K$  and  $-K$  valleys, giving a randomly fluctuating valley polarization noise. (C) **To detect valley noise,** a linearly-polarized probe laser is focused through the sample. Spontaneous thermodynamic valley fluctuations impart Faraday rotation fluctuations on the probe laser, which are detected using balanced photodiodes. (D) **The valley noise power spectrum.** Its Lorentzian line shape indicates an exponentially-decaying valley relaxation time scale  $\tau_v = 1/\pi\Gamma = 430$  ns. Inset: Valley relaxation measured separately in a perturbative pump-probe experiment, showing good agreement.

Thanks to the fluctuation-dissipation theorem, this spontaneous "valley noise" can be used to infer the truly intrinsic valley scattering and relaxation time scales.

The work was performed as part of an ongoing Laboratory Directed Research and Development Exploratory Research program. Lead author Mateusz Goryca (National High Magnetic Field Laboratory-Pulsed Field Facility, NHMFL-PFF) is a LANL Director's-funded postdoctoral researcher, and all data were taken at the National High Magnetic Field Laboratory at Los Alamos, using structures assembled in the group of longtime collaborator Xiaodong Xu at the University of Washington.

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Using light cont.

The work supports the Laboratory's Energy Security mission and its Materials for the Future science pillar by uncovering the parameters essential to designing next-generation devices.

Researchers: M. Goryca (NHMFL-PFF), N. P. Wilson (University of Washington), P. Dey (NHMFL-PFF) X. Xu (University of Washington), S. A. Crooker (NHMFL-PFF).

Reference: "Detection of thermodynamic 'valley noise' in monolayer semiconductors: Access to intrinsic valley relaxation time scales," *Science Advances* 5, eaau4899 (2019).

Technical contact: Scott Crooker

## Precisely imperfect films advance quantum information science

*Localized strain defects lead to single-photon emission*

All-optical quantum computing and quantum information technologies rely on the ability to controllably emit a single photon. Recent studies have observed single photons originating from defect structures in two-dimensional (2D) materials, causing postulation that non-uniform strain fields govern quantum emission in these materials. However, important aspects remain unclear, including the mechanism responsible for this phenomenon and how generally these conclusions can be applied.

Toward understanding the phenomena at work, Los Alamos materials scientists and collaborators have designed a 2D material with highly spatially localized and well-separated defects that become effective emission sites. Their research paves the way for larger-scale quantum materials, where future in-depth studies looking at the role of mechanical deformation in creating these quantum emission sites may enable a route to control quantum optical properties using strain. *Appl. Phys. Lett.* published the work.

The team created a thin, highly uniform crystal film of a material that previously was shown to randomly emit single photons. They then created an array of ultrasharp silicon di-

oxide tips and laid the thin film on top. The change in shape as the material formed around the tip of the peaks created considerable strain, and the material produced single-photon emission at the apex of the tip. These emissions had exciton lifetimes much longer (one order of magnitude) than those intrinsic to the film, a significant step toward quantum memory.

This work was supported by the LANL Laboratory Directed Research and Development Program (Award No. 20190516ECR), a National Science Foundation CAREER grant (Program Manager José Lage) awarded to Pettes, and a user proposal at the Center for Integrated Nanotechnologies. Materials characterization was performed at the Ion Beam Materials Laboratory, one of Los Alamos's core research facilities.

The work supports the Laboratory's energy security mission area and its Materials for the Future science pillar, particularly its Emergent Phenomena science theme, by pursuing predictive understanding of single-photon emission to enable the controlled design and creation of new materials and devices.

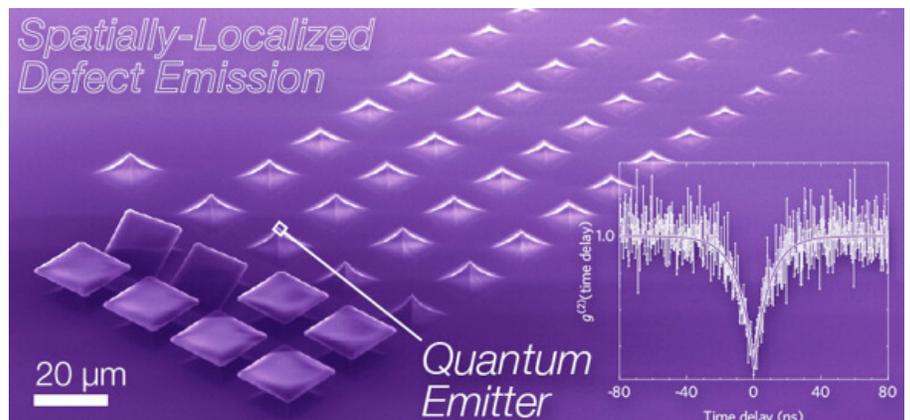
Future work studying interactions that underlie quantum emission onset, stability, and quenching in 2D materials will benefit from the Dynamic Mesoscale Material Science Capability, an experimental facility concept for simultaneous characterization of microstructure and response at the mesoscale.

Researchers: W. Wu (University of Connecticut); C. K. Dass and R. Hendrickson (Wright-Patterson Air Force Base); R. D. Montaño (University of Connecticut and University of Arizona); R. E. Fischer (University of Oregon); X. Zhang, T. H. Choudhury and J. M. Redwing (The Pennsylvania State University), Y. Wang (Materials Science in Radiation and Dynamics Extremes, MST-8), and M. T. Pettes (Center for Integrated Nanotechnologies, MPA-CINT).

Reference: "Locally defined quantum emission from epitaxial few-layer tungsten diselenide," *Appl. Phys. Lett.* 114, 213102 (2019).

Technical contact: Michael Pettes

**Scanning electron micrograph of a thin crystalline sheet of WSe<sub>2</sub> laid over an array of silicon dioxide. The tips induce strain in the crystal material and promote single-photon emission. Inset shows Hanbury-Brown Twiss interferometry measurement proving quantum emission.**

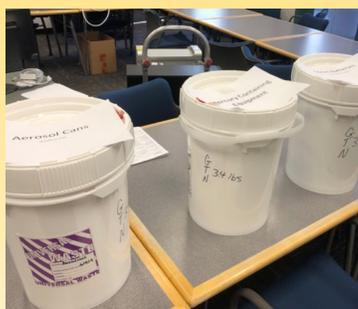


# HeadsUP!

## Tidiness in small, medium, and large packages

The Materials Science Complex was the site of a recent whirlwind housekeeping day. Over just two hours, residents delivered items ranging from desks and chairs to batteries and bulbs.

Organizing and managing the effort were Mario Santestevan (Materials Science and Technology, MST-DO), Monica Maes (Condensed Matter and Magnet Science, MPA-CMMS), Nix Mattson (Property Management, OS-PM), and Jon Roberson (Waste Management Services, EPC-WMS) who ensured all items are being processed properly.



The haul included the following.

- 30 monitors
- 2 microwaves
- 2 pelican boxes of peripherals
- 4 printers/scanners
- 2 TVs
- 1 vacuum
- 16 power supplies
- 3 oscilloscopes
- 1 box of office supplies
- 6 boxes of binders
- 5 cabinets
- 10 chairs
- 3 desks
- ~20 burn boxes
- 2 bins recycle paper
- 14 computers/laptops
- 4 ccd cameras
- 5 vacuum systems
- Various batteries and bulbs



## Celebrating service

Congratulations to the following MPA Division employees celebrating recent service anniversaries:

Andrea Schmidt, NHMFL-PFF.....	15 years
Vivien Zapf, NHMFL-PFF .....	15 years
Richard Sandberg, MPA-CINT .....	10 years
Helen Lu, NHMFL-PFF.....	5 years
Jonathan Reynolds, MPA-11 .....	5 years
Andre Spears, MPA-11 .....	5 years

## MPA Materials Matter

Materials Physics and Applications

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To submit news items or for more information, contact Karen Kippen, ALDPS Communications, at 505-606-1822, or [aldps-comm@lanl.gov](mailto:aldps-comm@lanl.gov).

For past issues, see [www.lanl.gov/org/ddste/aldps/materials-physics-applications/materials-matter-archive.php](http://www.lanl.gov/org/ddste/aldps/materials-physics-applications/materials-matter-archive.php)



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