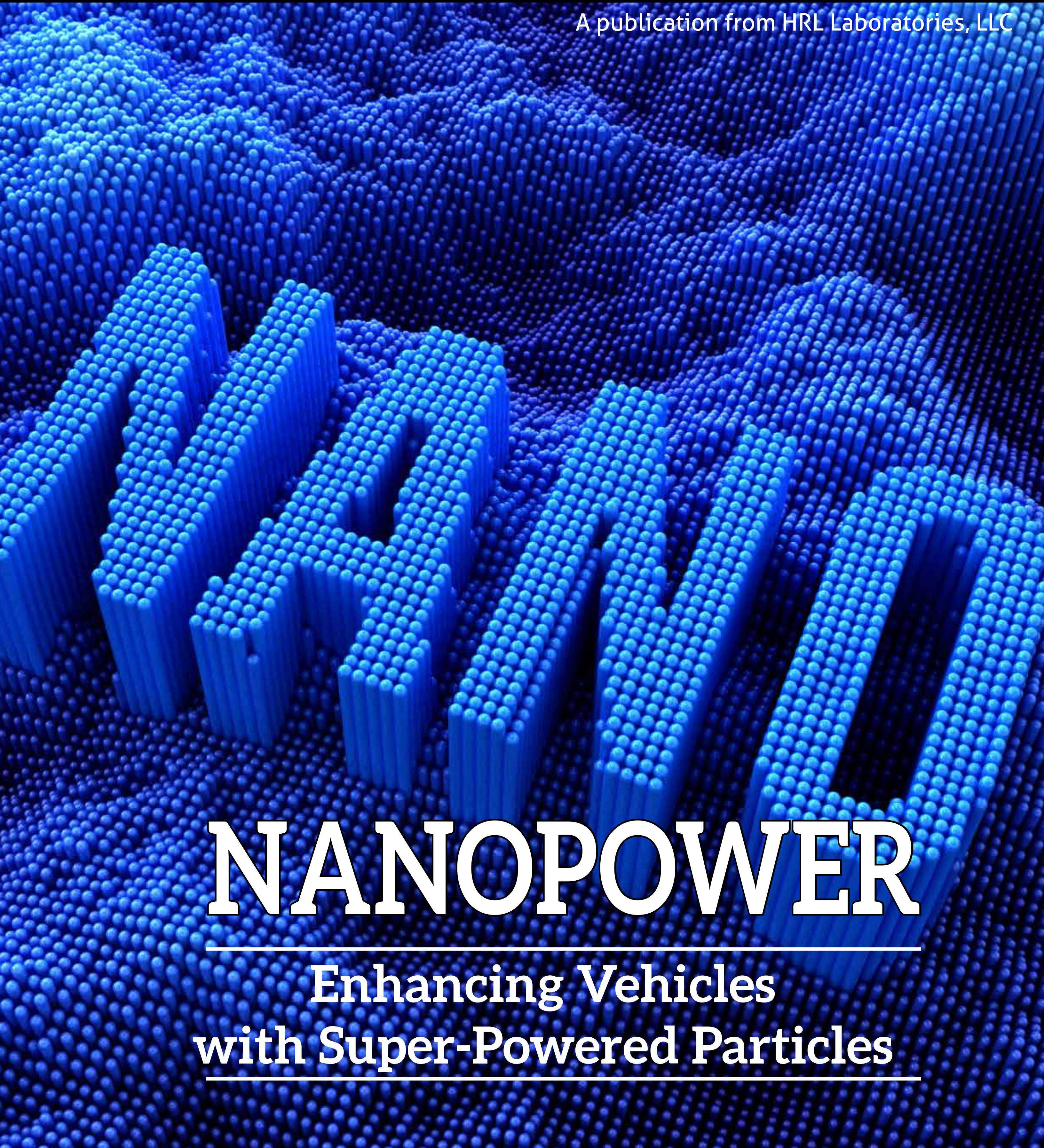
In this issue: HRL gets a corporate and campus facelift, new lab structure

ISSUE 03 - AUG 2018

HRL HORIZONS

A publication from HRL Laboratories, LLC



NANOPOWER

Enhancing Vehicles with Super-Powered Particles

HRL HORIZONS STAFF

Creative Director
Michele Durant

Technology Writer
Shaun A. Mason

Contributing Writers
Parney Albright
Leslie Momoda
Geoff McKnight

Photos
Bryan Ferguson
Julian Grijalva
Geoff Ramos
Getty Images

HRL HORIZONS Online
Bryan J. Ferguson

HRL HORIZONS
is a publication from HRL Laboratories, LLC's Multimedia and PR Department

Printed in the USA - August 2018

MS18223 - TICR 18-244

About HRL

HRL is the largest employer in Malibu, California with over 500 employees on our campus overlooking the Pacific from the Santa Monica Mountains. Although all HRL scientists and engineers are U.S. persons, 43% were born in other countries. Among them, 99% hold advanced degrees and 82% have doctorate degrees. Our diversity is a strength that enriches our organizational growth and development and ensures a breadth of perspectives from around the world with wide-ranging technical knowledge. Since 1960, HRL scientists and engineers have led pioneering research and provided real-world technology solutions for defense and industry. We are recognized for our leadership in physical and computer sciences, engineering research, and significant contribution to national defense.

CONTENT

HRL Laboratories, LLC, Malibu, California (www.hrl.com) is a corporate research-and-development laboratory owned by The Boeing Company and General Motors specializing in research into sensors and materials, information and systems sciences, advanced electromagnetics, and microelectronics. HRL provides custom research and development and performs additional R&D contract services for its LLC member companies, the U.S. government, and other commercial companies.

A WORD FROM Geoff McKnight

Acting Director,
Materials and Microsystems Laboratory

Nanotechnology, exploiting unique phenomena that occur in structures with dimensions measured in millionths of a millimeter, has been under development for over three decades. In electronics, top-down nanotechnology fabrication has enabled lower power, smaller, and higher performance computing that is responsible for many modern conveniences – the internet, cloud computing, smart phones, and smart factories to name a few. Many researchers have used these same electronics fabrication tools to demonstrate nanoscale-enhanced performance in sensors, optics, and electromagnetics. The power of nanotechnology will address important problems for society, but to date researchers have been largely unable to capture its full potential because sophisticated electronics microfabrication tools are unaffordable for applications with large physical dimensions – automobiles, airplanes, or buildings, for example.

HRL scientists in the Materials and Microsystems Laboratory (MML) are working on nanofabrication from the bottom up – using the tools of chemistry and materials science to realize nanostructured materials that can be fabricated affordably on large scales yet preserve performance and properties of the nanoscale. The key to this development is nanoscale material composition control in three dimensions. HRL's focus is on creating tools for precise dimensional control of many material types and functions that will enable nanotechnology advantages across a range of applications.

One key tool for scale-up of nanotech is self-assembly. Here, low-cost, highly uniform nanoparticles are the fundamental building blocks for previously unattainable properties in bulk materials. The critical challenge is the organized assembly of individual nanoparticles into bulk components. HRL's unique water-based methods exploit chemistry to control surfaces forces and drive consolidation. Combining this parallel mass assembly technique with the ability to change materials and properties during fabrication can enable coatings that efficiently cool cars or buildings and reduce energy consumption.

HRL is also using nanotechnology to solve critical challenges in additive manufacturing (3D printing). HRL researchers recently demonstrated a nanofunctionalization process that enables welding and 3D printing of traditional materials, such as aerospace aluminums, that could not be printed before. Using scalable processes, HRL researchers have been able to decorate microscopic powder with nanoscale particles that control melting and solidification in the 3D printing process.

In this issue of HRL Horizons we detail how HRL is exploring the future of materials design and fabrication, bringing the benefits of nanotechnology to large scale applications. ■

FACELIFT

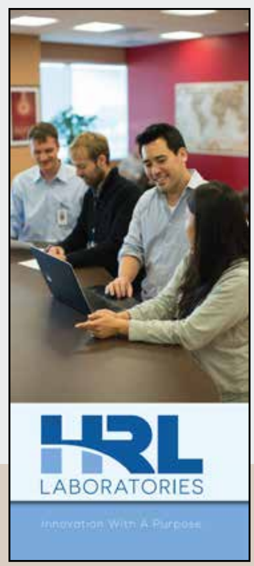
"Our reputation for excellence and innovation makes it easy and fun for me to talk to people about HRL," said CEO and President Parney Albright. "We felt that the 20-year mark was an opportune time to update our look to more accurately reflect our leading-edge approach to technology."

2017 marked the 20th anniversary of HRL Laboratories as a limited liability company. As part of the celebration, HRL premiered a new logo and branding campaign to better represent its research moving forward through the 21st century.

"Our new contemporary logo design is more in keeping with our status as a top research and development laboratory. Our attractive new color scheme reflects the beautiful natural setting of our campus overlooking the Pacific Ocean. We are among the elite scientific institutions, which should be reflected in the graphics we use to represent ourselves to the public. I think we've accomplished that very well," Albright said.

HRL's internet presence was also affected, with a completely new website design featuring new graphic elements. All signage, printed material, and promotional items were also rebranded with the new logo and color scheme.

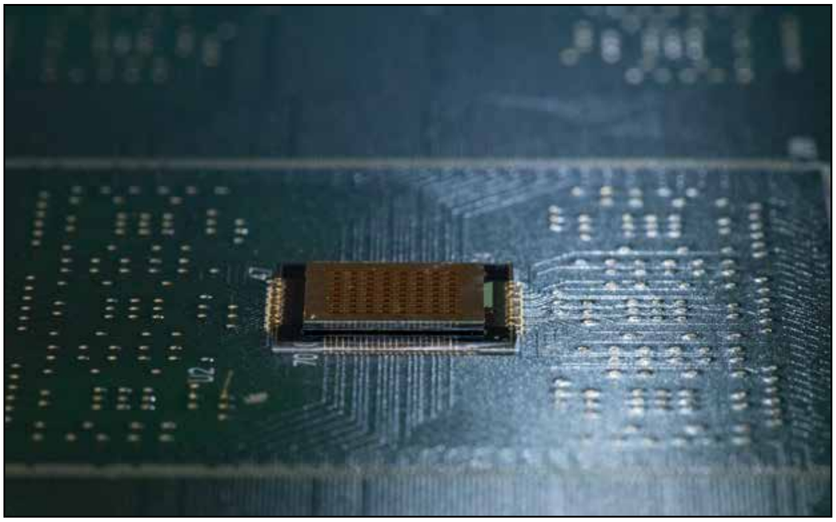
Among physical changes are an update of the HRL monument at the campus entrance on Malibu Canyon Road, a completely refurbished and redecorated employee dining center, and a redesigned and reconstructed common meeting area, The Hub, adjacent to HRL's library (detailed later in this issue).



Our corporate brochures, official website and intranet all benefited from the facelift and rebranding.

HIGHLIGHTS

A look at the year's biggest achievements and news



CASA Radar Detects Danger At A Safe Distance

HRL Laboratories developed a high-resolution, low-power radar antenna array (Coded Aperture Subreflector Array or CASA) that potentially can see weapons or explosives concealed on a person at tactically safe distances. With a CASA scanner, someone concealing a bomb could be detected while they were still far enough away to make a sudden detonation far less effective. The low power usage and scalability of the CASA array gives it versatility for many possible uses, from the aforementioned security scanners to being part of the eyes and ears of robots or autonomous vehicles.

New GaN MMIC Foundry Service Enables Custom Integrated Circuits

HRL launched a new shared foundry service, offering advanced millimeter-wave (mmW) gallium nitride (GaN) technology for fabrication of monolithic microwave integrated circuits through multi-project wafer runs. Eligible customers can design into HRL's cutting-edge mmW T3-GaN fabrication process. The resulting custom circuits, tailored for specific applications, cost much less than a dedicated foundry run.

Brennan Yahata and Zak Eckel

3D Printing Team Wins Awards

The HRL Laboratories additive manufacturing (3D printing) team was among the winners of the 2017 R&D 100 Award for their breakthrough in 3D printing high-temperature ceramics that was originally published in the January 1, 2016 issue of the journal *Science*.

The team also won the 2018 Silver Edison Award for their 3D-printed ceramic work. Often described as the Oscars® of innovation, the Edison Award recognizes the world's best innovations and innovators.

© Tsutsumida Pictures/UCLA Samueli

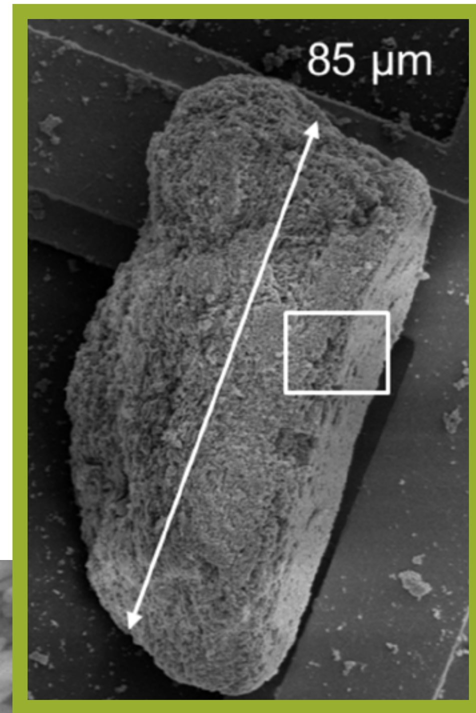
HRL Vice President Leslie Momoda Wins UCLA Engineering Award

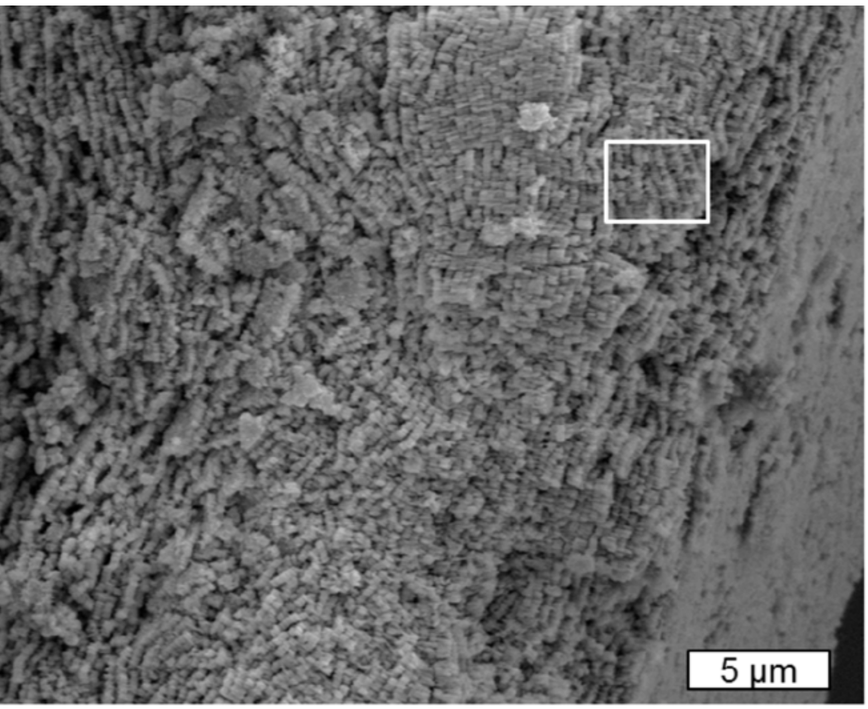
HRL Vice President Leslie Momoda won the 2018 UCLA Henry Samueli Engineering Professional Achievement Award, honoring the achievements of UCLA Engineering alumni in their chosen fields, including academia, industry, and entrepreneurship. The UCLA Henry Samueli School of Engineering and Applied Science seeks candidates with distinguished career accomplishments, contributions to the engineering profession, a history of mentorship, and notable service to the community and the profession.

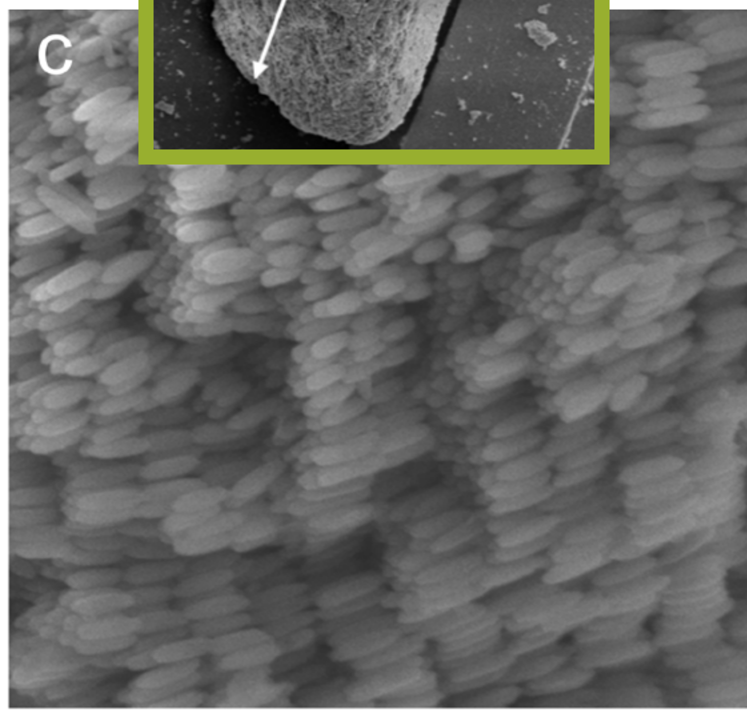
HRL's History of the Future Podcast Debuts

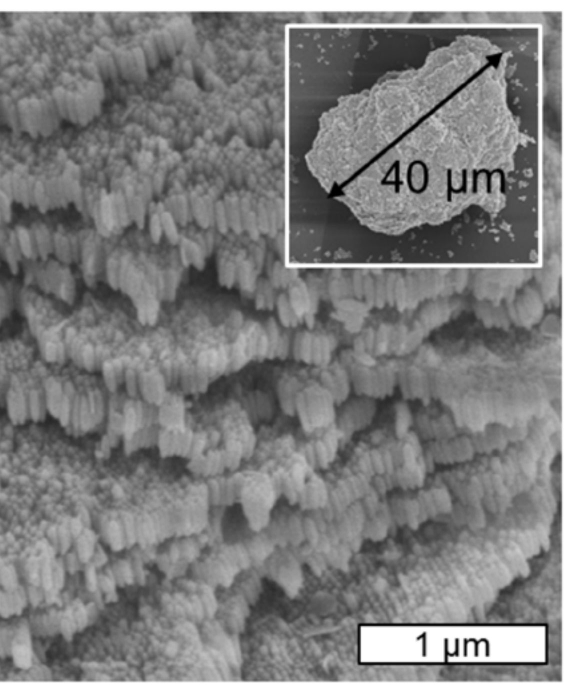
HRL launched its first podcast, *HRL's History of the Future*, focused on the famed facility's history and advancements in science and technology. The target audience for the program includes those interested in science and engineering, but who are not necessarily experts. Interviews with doctorate-level researchers are conducted by a non-scientist host with interview questions designed to appeal to the curiosity of students and the lay public. Guests include current and past HRL researchers as well as outside scientists whose research aligns with HRL's mission. *HRL's History of the Future* is available free on Libsyn.com and iTunes.

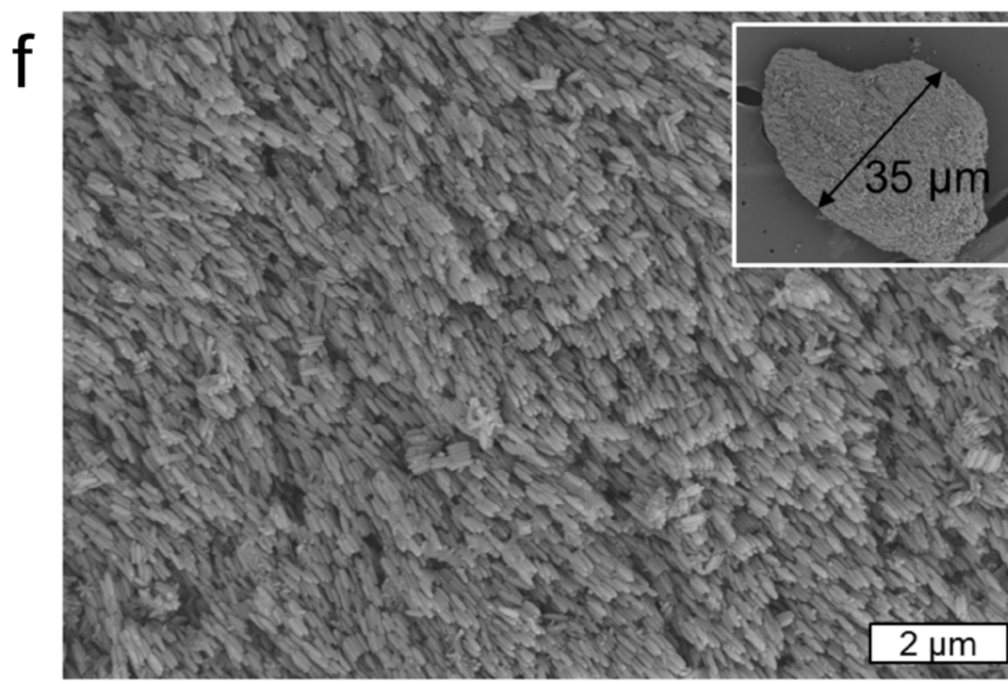
HRL Scientists Scale Up Amazing Magnetic, Optical, and Electronic Nanoscale Properties into Human Hands to Improve Daily Life











"It is a staggeringly small world that is below. . .Consider the possibility that we too can make a thing very small which does what we want— that we can manufacture an object that maneuvers at that level!"

– Richard Feynman,
There's Plenty of Room at the Bottom

1965 A reluctant Dr. Richard Feynman is greeted by colleagues with a red carpet arrival at HRL in Malibu after winning his Nobel Prize in Physics.

NANOPOWER

by Shaun A. Mason

Entering Feynman's World

In 1959, Nobel prize-winning physicist Richard Feynman gave a seminal talk entitled *There's Plenty of Room at the Bottom.* Later published as a paper by the American Physical Society, Feynman's presentation described a submicroscopic world in which there is plenty of room for writing the entirety of a 24-volume encyclopedia on the head of a pin and building an entire automobile that only a microscopic mite could drive. With astounding prescience, Feynman also forecasted computer microprocessors and structures built from individual atoms such as those we know today as nanowires.

The special materials and devices of that vanishingly small realm were first referred to as nanotechnology by Norio Taniguchi in 1974. The term gained more widespread notice in 1986 after the publication of K. Eric Drexler's book Engines of Creation: The Coming Era of Nanotechnology. Once a trope of science fiction, the tiny world-within-a-world that Feynman envisioned has been revealed to us step-by-step over the intervening decades since his talk. The special substances, properties, and devices enabled by contemporary nanotechnology—and the techniques needed to image, manipulate, and measure them—involve nearly every scientific discipline.

HRL Laboratories stands as a leader in technological advancements at the nanoscale. HRL researchers are striving to bring the sometimes strange and often wonderful powers of nanoparticles to scale sizes that allow human interaction with them. They are also developing techniques to bring production of nanomaterials to a scale of industrial manufacture.

Scaling Up Nanotechnology

Throughout engineering, electronics, materials science, and biology, technologies at the smaller-than-microscopic scales of atoms and molecules are being developed that scientists hope can benefit our world in startling ways. However, as with any growing technological field, not all successful experiments at this small level known as the nanoscale can be

Nanotechnology That Revolutionizes Metallurgy

Additive manufacturing (3D printing) metal parts begins with metal powder laid in a thin layer and scanned with a rastering laser. The laser melts the powder into a solid layer, repeating until the layers form the desired part. Until 2017, high-strength aluminum alloys could not be additively manufactured because of hot-cracking, which left metal layers weak and flakey like a biscuit. That year HRL researchers solved this age-old problem with a technique called nanofunctionalization, and for the first time were able to 3D print reliable parts made of high-strength aluminum. The method also makes previously unweldable alloys weldable, solving a problem as old as the metal itself.

HRL scientists were looking for a way to control how alloys melt and solidify that could be scaled up for additive manufacturing. They broke through with nanofunctionalization, in which aluminum powder grains are seeded with nanoparticles that control nucleation—the time of liquid-solid phase change—thus controlling metal solidification. That eliminated hot-cracking and the 3D-printed parts were solid, reliable, and accurately detailed. The team used big data analysis to find nanoparticles that worked for each kind of alloy they wished to print.

That made the technique usable for any metal, amounting to a reinvention of metallurgy, i.e., nanofunctionalization enables 3D printing and welding of any alloy.

"Being able to assemble and make hierarchical structures with these nanoparticles and microparticles is the key technology that enables metal solidification control," said team member Brennan Yahata. "The science behind that is the ability to look through the crystallographic databases and find the nanoparticle systems that work for each alloy."

"We're using atomic-scale phenomena to create micron-scale grains to make millimeter-scale features that are built into meter scale vehicle parts," said researcher Hunter Martin. "It's true optimization from the atomic to the vehicle scale."

Metal powder consistency is of crucial importance as the HRL team moves forward. "Repeatability between builds is a big issue," said researcher Julie Miller, "We are determined to make sure our powder is not a variable. The batch I made today is the same as the batch I made a month ago."

The future looks bright for nanofunctionalization. The HRL team is now exploring its myriad possibilities. "We're taking alloys that people want that are available at scale and rendering them printable," said researcher Jake Hundley. "There is already a market, scale, and ability to produce large volumes. Because we're nanofunctionalizing existing feed stock, we don't worry about material sources."

Martin also said that HRL is actively looking at how to scale up the process and get it into the marketplace. "We started out working with 1-gram vials of nanofunctionalized powder, now we're to the point that making hundreds of pounds is not unreasonable. To get into the market we will be thinking in metric tons, so we're contemplating physical space outside the laboratory setting where we can get this to our co-owners to be leveraged as a competitive advantage."

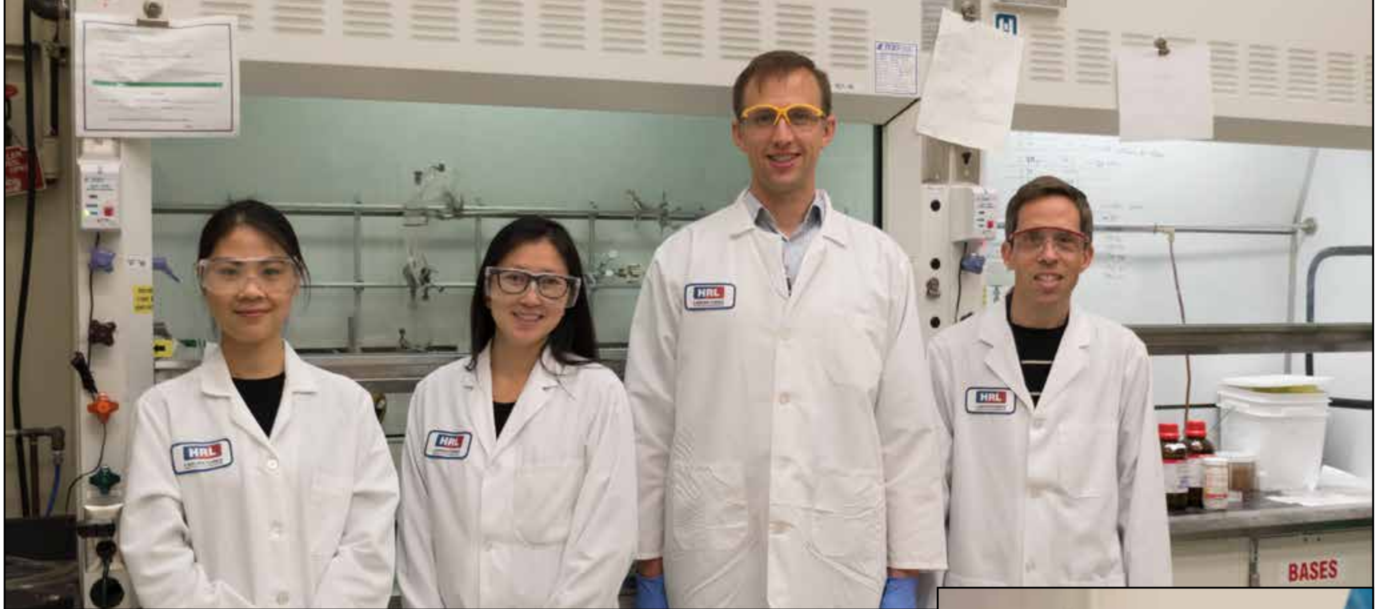
translated to levels that ordinary people can make use of.

"You see a lot of papers out there in which someone has made one nanoscale device or a collection of particles," said HRL researcher Christopher Roper. "These are often more of a scientific curiosity than something a million people could have in their pockets and interact with. What really excites me is asking how do we go from those initial curiosities that exhibit some interesting physical or chemical nanoscale properties to something on a scale that makes a difference in our macroscale world."

Bringing nanoscale materials and properties up to a scale that facilitates human interaction and benefit is the goal of HRL Laboratories' Scaled Nanotechnology team, of which Roper is a member. Accomplishing that goal, however, requires more than just making large amounts of small things.

"We're looking at more than just manufacturing nanomaterials," said team member Adam Gross. "Our long-term goal is to take advantage of nanostructured materials at vehicle scales. There is already a great deal of scalable manufacturing happening. You can make tons of nanotubes and hundreds of pallets of nanoparticles. However, what makes us different is that our mandate is to develop the ability to control how and where nanoparticles are distributed on a material's surface. We then will be able to exploit their special properties on a larger scale and ultimately make the process repeatable and low-cost. We're aiming for a method of selectively depositing nanoparticles on surfaces and then making larger discrete structures from them regardless of what material they are. If we can break out of previous 'one-trick pony' methods and accomplish this with a wide range of materials, the benefits to our LLC members and manufacturing in general will be significant."

Eventual applications of the HRL team's research could be nearly limitless. Nanoparticles with advanced optical and magnetic properties can potentially be



TOP: HRL SCALED NANOASSEMBLY TEAM. Left to right: Xin Guan, Shanying Cui, Christopher Roper, Adam Gross.

RIGHT: Magnetic nanoparticles in solution can be seen when drawn into a clump on the side of the tube by a scientist holding a magnet.

assembled for products such as special paint that keeps cars and airplanes cooler. They could also be used to develop powerful magnetic materials formed in ways that are currently not possible.

"At the start, nanoparticles are tantalizing because of optical, magnetic, thermal, or hardness properties that you cannot get from bulk materials, or that differ from bulk materials in beneficial ways," Gross said. "They can also be highly tunable based on size. This means we can adjust the desired properties by simply changing the size of the nanoparticles we use to form microstructures."

The relationship between microstructure size and adjustable properties is exemplified by an HRL experiment with spherical particles called Bragg reflectors. These are tiny spheres assembled from two different materials. The first material forms a ball of nanoparticles and the second material forms a shell around that ball. The result is that the combined materials form tiny mirrored spheres. The frequency or "color" of light a particular sphere reflects can be changed by adjusting the thickness of the sphere's shells. If the spheres are designed to reflect infrared light and are placed in a paint, any surface painted with it will reflect heat. If the painted surface is the outside of a car or airplane, the heat-reflective paint dramatically cools the vehicle.

Paints made with these reflective particles could be made in different colors simply by changing the particle size, which in turn would change the color of light reflected by the paint. The paint appears as a particular color to the human eye based on the light frequency that is reflected. This would eliminate the need for different pigments to be added to make different paint colors. Spheres formed by nanoassembled particles of the same material in different sizes would make different colored paints.

This is but one example of nanoscale properties scaled up to usable levels. Various nanoparticles have other properties such as magnetism or electrical conductivity that could also be exploited when scaled up.

Nanoassembly

Water-based nanoassembly is HRL's innovative method of building nanoparticles into larger microstructures that can be then be used at even larger scales, such as the reflective paint example. This fabrication method begins with nanoparticles of the desired material placed in water. The process is based on the electrical charge on the surface of each nanoparticle. Adjusting the surface charge draws them together in the water. Eventually, they pack themselves tightly together, self-assembling into larger microstructures.

"The driving force of nanoassembly is the interaction between the particles," said Shanying Cui, a key researcher on the water-based technique with the

Understanding the scale

Nanometer (nm) = 1 billionth of a meter A human hair is 80,000 to 100,0000 nanometers thick. A typical nanoparticle is 1-100 nanometers in length.
Micrometer (micron, µm) = 1 thousandth of a meter A human hair is 80 to 100 microns thick.
Nanotechnology Engineering, design, and manufacture of extremely small electronic circuits and mechanical devices built at the molecular level of matter. Specifically, science and technology for which dimensions and tolerances from 0.1 nm to 100 nm are critical.
Nanoparticle A three-dimensional bit of nanoscale material
Nanoscale Relating to or occurring on a scale measured by nanometers or microns
Scale up To increase in size or number according to a fixed ratio, such as a power of ten.

Scaled Nanotechnology team. "When particles have the same charge they will repel each other and disperse. However, particle interactions can be tuned to make the particles attract. By changing the pH in the water, the particles' charges can be changed—less positive or less negative as needed—until they have no charge. With no surface charge, the particles agglomerate, forming spheres in some cases, or stacked in layers onto a wafer substrate. We can manipulate how and where the nanoparticles join together."

The nanoparticles used in this assembly method can be made of metals, ceramics, semiconductors, or other useful materials. All these particles can assemble into larger micron-level spheres or layers on a substrate up to 100 microns thick. The technique applies to any nanoparticle with a pH-dependent surface charge and critically does not require organic ligands (carbon-based molecules) to be present on nanoparticles. It also enables selective placement of nanoparticles onto substrates to create patterns. This allows nanoparticles to be used to make optical elements on a chip that have not been possible before.

"Initially the technique did not work and we could form only very small assemblies of less than a micron across. Once we understood we needed a slower rate of pH change, the technique worked dependably," Cui said. "At that point we had microstructures of 50-100 microns across, which can be easily seen with a microscope and handled accordingly, while retaining the special properties the materials have at the nanoscale."

Because nanoassembly is done with water and requires no organic chemicals such as solvents or surfactants, it is done without elaborate equipment. This makes the technique very amenable to an industrial environment. One challenge is that water may oxidize some

E-BEAM LITHOGRAPHY BAY inside HRL's cleanroom. Inset: lithography engineer Stephen Lam dressed in cleanroom "bunny suit."

E-Beam: The *Sharpest* Tool in the Shed

The smartphones, tablets, computers, and other devices we depend on nearly constantly in modern life would not exist without nanoscale electronics. The processor chip in a current smartphone alone contains around 2 billion nanoscale transistors. Creating those transistors and many other nanoscale components requires special tools and a special place to do the work—the cleanroom.

The special standalone ventilation systems of the cleanroom remove nearly all particulate matter from the air inside. This is necessary to protect the very small parts made in the cleanroom from damage that could be caused by dust and other floating bits. Normal particles in the air that appear very small to human eyes can have the effect of a giant asteroid hitting the earth if they hit nanoscale components. A key tool for making nanoscale parts in the HRL cleanroom is the electron-beam (e-beam) lithography writer.

"E-beam lithography is the only process in our cleanroom capable of patterning nanoscale features today," said Fiona Ku, HRL cleanroom manager. "When working at the nanoscale, only very specific types of tools have the fine resolution needed."

Because of the wavelength of light, even a laser cannot be focused to a narrow enough beam to create the intricate patterns required for nanoscale lithography. An e-beam has a shorter wavelength than light and can be focused to write patterns in the electron-sensitive films used.

"If we really push the e-beam writer, we can focus it down to a spot 3 nanometers wide," said lithography engineer Stephen Lam. "That gives us a combination of very high resolution and extreme accuracy for writing on films that might be as thin as one molecule."

E-beam lithography also enables integrated circuit fabrication using materials that have very desirable properties at the nanoscale level. Those properties can be preserved in the circuit being made by laying down many layers of different materials. Each layer has a specific pattern and the patterns work together to make the integrated circuit.

"One of the long-standing materials that we work with in the cleanroom is gallium nitride or GaN," said Lam. "GaN is being used to make the next generation of transistors. That technology gets increasingly smaller, so the latest GaN transistors have very small features called gates with amazing lengths of only 20 nanometers."

Nanoparticles with advanced optical and magnetic properties can potentially be assembled for products such as special paint that keeps cars and airplanes cooler.

nanoparticles. The HRL team is solving that problem by coating those types of nanoparticles with a protective shell that is stable in water and does not interfere with surface charge or the self-assembly process.

Working at Macroscale with Nanoscale Benefits

"HRL's water-based nanoassembly method will enable us to use a very wide range of materials that would be very difficult to work with otherwise," Cui said. "It enables magnetic on-chip technologies that before would be extremely difficult because the materials used are not easily formed with other methods. With water-based nanoassembly we can self-assemble thin layers of those materials on a wafer, and in desired patterns, without difficulties such as having to evaporate them first, as some other methods require."

"There are two basic benefits to our experiments in this field," Roper summarized. "One is that there are certain properties that materials have at the nanoscale that they don't have at the macroscale. By assembling microstructures with nanoparticles we can keep and use those properties as the bits of material form larger structures that can be manipulated in the macroscale world. The other is that there are certain materials that you can only make at the nanoscale, and not at the macroscale. This assembly method enables us to make those materials and scale them up to that larger interactive level."

The HRL team's next steps will focus on assembling nanoparticles into microstructures with greater complexity. Nanoassembly with increased detail could make possible technologies, such as fine on-chip optical components on lidar detectors, using materials or architectures that cannot be made using current methods. It could also be used to make powerful magnets without the need for rare-earth materials.

High-throughput production will also be a priority, making what is now a batch process into a continuous process similar to what might be found in a chemical plant. This could be accomplished if the water-based nanoassembly that has been proven to work in a beaker is then done in water droplets. Billions of droplets could be made at faster rates, with each droplet creating an identical nanoassembly environment in which stacked nanoparticle structures are formed the same way.

With the water nanoassembly method proven in the laboratory, only imagination limits the extent of new substances that could become possible. Each day the effects of nanopower change our lives, from nanoelectronics in our phones to nanomaterials in our cars and planes, already exceeding Richard Feynman's personal vision, but continuing to show that there is indeed plenty of room at the bottom. ■

Lam said that using diamond for nanoscale devices is a good example of how e-beam lithography has enabled technology with desirable new materials due to its flexibility in the size of substrates it can write on. HRL scientists are the first ever to create a diamond-fin field-effect transistor, which requires a 100-nanometer lithographic feature that is not possible with other tools in the HRL cleanroom.

Using e-beam lithography with advances in vanadium dioxide—another new material—has helped HRL scientists successfully produce a nanodevice called a memristor, which is a fundamental building block for electronically mimicking biological brain cells. With scientists constantly improving computer power and energy efficiency, memristors could make possible a new wave of computer architectures that emulate the brain.

Planet HRL
Launches Efforts with Tree-Planting Event

Planet HRL—a new company-wide volunteer team open to all staff, friends, and family—enjoyed a sunny Saturday morning planting trees in the Santa Monica Mountains as part of Earth Day 2018. The planting event was sponsored by local nonprofit organization TreePeople. This inaugural effort by Planet HRL was organized by Chief Financial Officer Gary Lawrence. HRL's group met with other volunteers for a fun morning at Diamond-X Ranch in Calabasas, California. TreePeople staff and interns gave instructional presentations on proper tree planting—don't forget your gopher cage!—and tool safety and usage, then the fun work began.

Saplings of three indigenous tree species were supplied for planting by TreePeople: coast live oak, elderberry, and black walnut. The area chosen for the planting was a dry creek bed covered with an invasive grass. Team members raked the grass away and removed its roots from the soil in and around the holes they dug to plant the trees in. A truck was nearby with a brigade of buckets to supply plenty of water for planting. Two to three 5-gallon buckets were poured slowly on each tree to make sure the new saplings survived the initial shock of being

planted in the wild. All the planting holes had wire cages placed in them to protect the tree roots from the abundant native gophers, and the elderberry trees had wire cages placed around their tops as well to protect the leaves, a deer delicacy.

"We've been discussing a volunteer effort by HRL employees for a while now," said Lawrence. "I'm very gratified to see it come to fruition with a fun and helpful event. We'll be able to visit this site for years to come and watch these trees grow as a tribute to our efforts.

The turnout was to capacity for this event and we look forward to future opportunities for Planet HRL to bond and volunteer together. It makes us a stronger company and emphasizes our true strength, which is our people."

ELM

Enhanced Leverage Model

HRL's Enhanced Leverage Model Office Teams with Commercial Partners on Innovative Technologies

It's essential that HRL researchers experience how commercial research and development works, right down to the product level.

HRL Laboratories enjoys continuous success creating intellectual property (IP), conducting novel research, and developing and transitioning technologies for its corporate partners, General Motors and Boeing, and its extensive government clientele. This success has led to technological advances that make their way into products that make us safer, support national security, and improve our quality of life. The Enhanced Leverage Model (ELM) team builds on that success by leveraging HRL core competencies (see sidebar) on behalf of select commercial customers, through the positioning of HRL research and development services for engagements that will build advantage for the commercial customers and for HRL and its owners.

The ELM goal is to help identify appropriate commercial partners and leverage the suite of capabilities to meet a commercial partner's novel requirements. ELM is a proactive endeavor for HRL research managers to work collaboratively in the commercial space while gaining real-world experience developing products.

"Basically, our focus is to develop solutions rapidly that benefit outside entities we've chosen to work with based on their needs, and to further our mutual technical and strategic interests," said HRL researcher and current ELM officer Mohiuddin "Mohin" Ahmed. "Through ELM we devise agreements on solutions to be developed, investment commitment, ownership, and scheduling. Our people also get important exposure to commercial applications and methods. These are often very different from how we do things with our government customers. The companies we partner with get our expertise and technical abilities, they get to leverage our experience on the defense side, and they get a real product they need."

ELM officers often collaborate with HRL staff to identify potential commercial partners. In some instances, HRL's first contact with a commercial company is when they inquire about specific technology areas they've seen in HRL media reports, scientific publications, or patents.

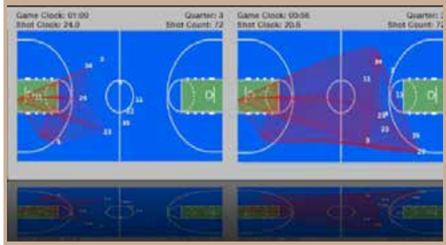
ELM engagement with a potential commercial partner begins with an evaluation of the company, examining key elements ranging from possible risks to how the companies align with HRL's core competencies. Research capability needs must align with the competencies of HRL's four laboratories. Another important factor for a commercial partner is the opportunity for HRL to grow with them through the creation or development of know-how that would otherwise not be available to HRL researchers (e.g., scaling production methods, rapid prototyping, and system or sub-system integration). Early development of creative solutions that could eventually benefit our LLC partners is very desirable. "One difference for ELM projects is that they are more product driven than many of our government projects. Product development is the discussion driver for an ELM project. It's never an open-ended research and development enterprise, but a focused program with a needed deliverable," Ahmed said.

Once a decision has been made to move forward with a particular commercial company, the ELM office insures all technical, contractual, and related requirements are met prior to work being initiated on a new engagement. New relationships require a clear and mutual understanding of expectations, such as IP sharing mechanisms and contractual deliverables and milestones. ELM is the spear tip of the engagement, insuring that technical activities begin with confidence toward successful outcomes. After a project is launched, the ELM team addresses any communication needs to keep the research running smoothly.

"I think it's essential that HRL researchers experience how commercial research and development works, right down to the product level," Ahmed said. "Such invaluable experience helps mature a researcher and positively affects how they do science. A holistic view from lower to higher research and development tiers benefits everyone and ELM is one way to get that training."

HRL Core Competencies

Parties interested in ELM partnerships can peruse HRL Laboratories' core competencies to find technologies that could potentially benefit them. The four different laboratories that compose HRL are Information and Systems Sciences (ISSL), Materials & Microsystems (MML), Microfabrication Technology (MTL), and Sensors and Electronics (SEL). Core competencies are broken down as follows:

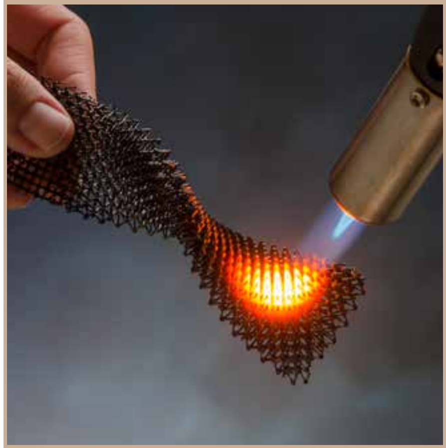


INFORMATION AND SYSTEMS SCIENCES

- Complex networks
- Cyberphysical resilience
- Brain-machine intelligence

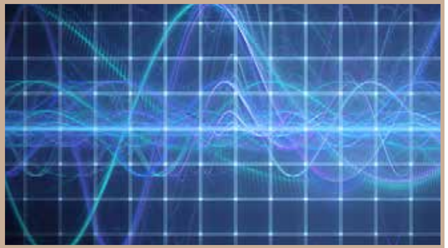
MICROFABRICATION TECHNOLOGY

- Epitaxial growth
- Metallization, dielectric, ALD, and CVD thin-film deposition
- Photolithography
- Electron-beam lithography
- Wet/dry etch and surface treatment
- Heterogeneous integration and post processing
- Metrology and electrical testing



MATERIALS AND MICROSYSTEMS

- Silicon and quartz MEMS
- Nonlinear mechanics
- Architected materials
- Metallurgy and ceramics
- Scalable nanotechnology
- Polymer and coating design



SENSORS AND ELECTRONICS

- Advanced apertures
- Infrared imaging
- Integrated mixed-signal solutions
- Integrated photonics
- Millimeter-wave subsystems
- RF GaN MMIC technology
- Nanoscale devices

> "Our goal is to help identify appropriate commercial partners and leverage the suite of capabilities to meet a commercial partner's novel requirements."

1988 ORIGINAL DINING CENTER

THE EMPLOYEE DINING AREA, although well maintained, had retained the same configuration since the building was inaugurated in 1988 and was showing the requisite wear that comes with many years of use and company growth. It was in need of a facelift. The space was redesigned with consideration given to the needs of current employees with room for an expanding workforce. The entire serving area was reconfigured and the dining area was gutted and rebuilt with new furniture and capabilities, including the convertible option of splitting the dining room ala hotel ballrooms.

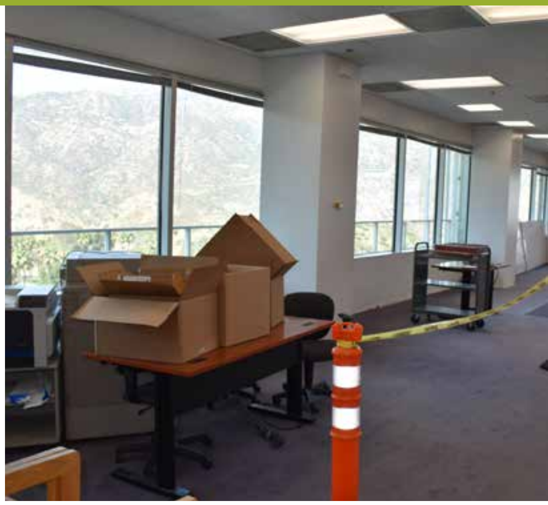
"I think it was a major success. Our staff has told us they love both spaces," said Michele Durant, Multimedia & PR manager, who redesigned the space. "We opened both rooms on the same day with a fun catered event. Cafeteria attendance has increased as a result. It's nice to see everyone using the newspace and it is a great perq to offer restaurant-quality food for our employees and their guests."

THE NEW DINING CENTER

More Than a New Coat of Paint
for HRL's Campus Dining Area & The Hub

HRL cherishes its architectural history and seeks to preserve it as much as possible. As a working facility, constant maintenance is required to keep support services for employees running smoothly. As part of the anniversary facelift of HRL, two very well-trafficked common areas were reconfigured and upgraded.

1988 ORIGINAL LIBRARY



THE HUB was originally the café built from half of the original 1988 library space. Over time the café became a comfortable casual space for meetings that did not require a conference room. The café's popularity led to it being easily crowded, as the furniture was not designed to accommodate large numbers. As even less library space was needed, it became feasible to expand and reconfigure the café into a larger, hipper space for casual small meetings.

The cheerful, bright, and colorful new design enabled more modern open seating and created a place for HRL interns to have a useful workspace. Because so many people were meeting in the previous space, pods were installed for casual meetings.

THE NEW HUB

5 New Tech Centers

Within HRL Laboratories are five new centers that focus on vibrant technologies to improve and hasten their development based on increased customer demands and industry needs. These centers create environments in which specific novel innovations can thrive and advance to the benefit of HRL and its owners.

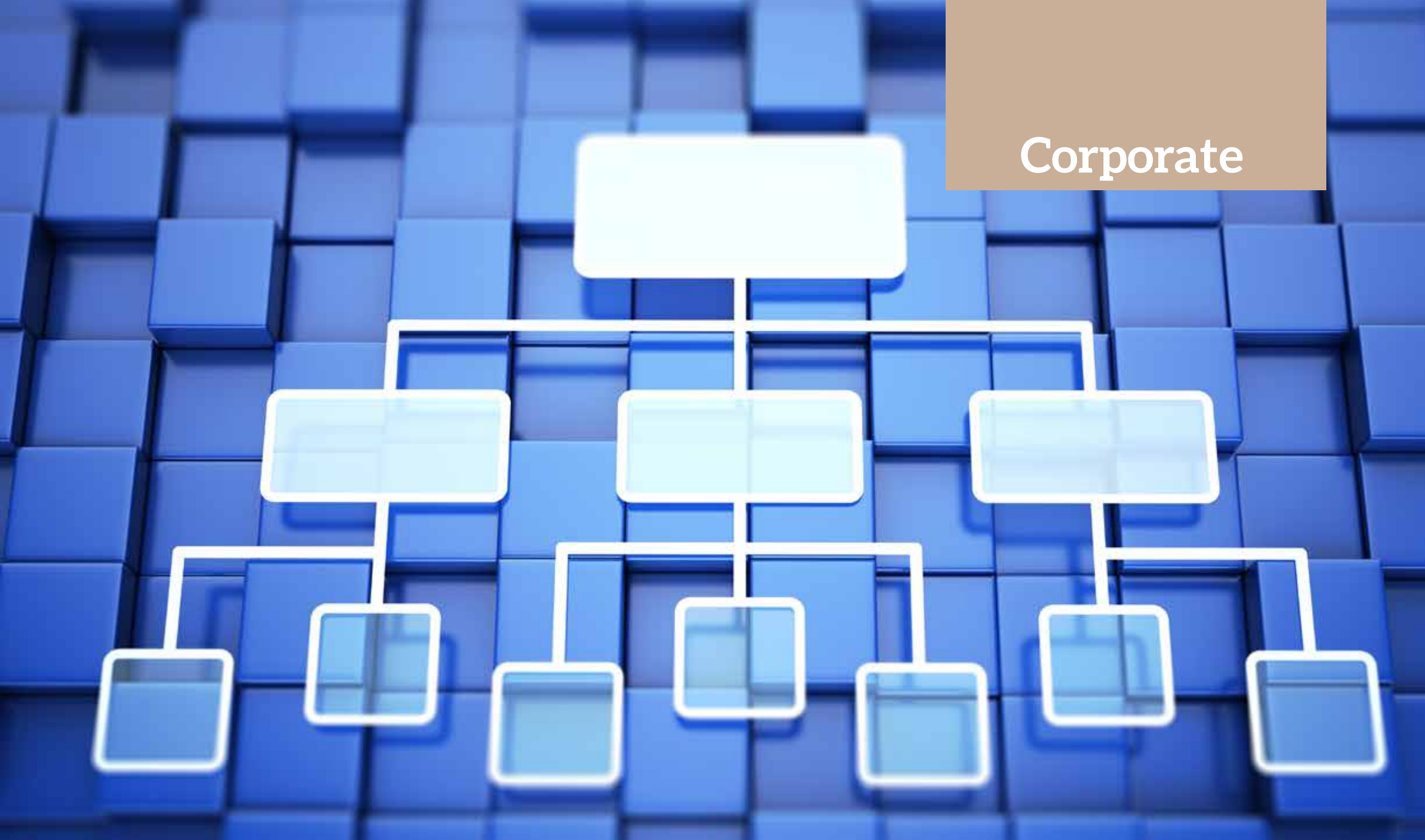
CENTER FOR ADDITIVE MATERIALS (CAM) aims to accelerate development of additive manufacturing (3D printing) processes for making high-performance materials. Additive manufacturing is being introduced to more industries every day. Having various materials available for 3D printing is a key to success in the current additive manufacturing revolution. CAM is dedicated to broadening that property space through processing innovations that enable 3D printing of established materials, new metal alloys, ceramics, and polymers. Quality control and part qualification is accomplished through in-situ sensing and data analytics.

CENTER FOR AUTONOMY COMPUTING (CAC) is dedicated to creating innovative algorithms and software for energy-efficient computing hardware on autonomous platforms. Research is focused on energy efficiency, system perception and control, and processing and analytics of subsequent data. New algorithms are also developed for autonomy functions that exploit unconventional computing hardware.

CENTER FOR COMPUTATIONAL NETWORK INTELLIGENCE (CCNI) develops innovative solutions in areas from vehicle health and machine intelligence to emerging interconnected human-machine and social systems. Computational theories and techniques are created to better understand, predict, and control evolving behaviors and phenomena in complex systems. Focus is on transitioning innovative technologies to products and platforms for HRL Laboratories' LLC partners and government clientele. Reproducible and generalizable research findings are CCNI's primary goal. An open science paradigm is in place to actively collaborate with researchers and practitioners from universities and industries.

CENTER FOR SECURE AND RESILIENT SYSTEMS (CSRS) develops novel tools and techniques for creation and analysis of complex systems capable of maintaining functionality in unpredictable adversarial environments. Building resilience and security techniques on firm theoretical foundations, CSRS draws from formal methods and logic, cryptography, distributed systems, graph theory, network science, and machine learning. These techniques are captured in new algorithms and tools used to build practical systems in multiple domains, including cyberphysical and heterogeneous distributed systems. With proper tools and frameworks, resilient systems can be made efficient and practical without increased cost or reduced performance. CSRS is committed to the broader research community, actively collaborating with academic and industry researchers.

CENTER FOR HUMAN MACHINE COLLABORATION (CHMC) explores whether there is a fundamental basis for human intelligence through research focused on understanding the brain's ability to learn, recall, and adapt to uncertainty. CHMC applies research by creating algorithms, tools, and systems to enhance learning, decision making, and intelligent behavior in machines.



New Technical Laboratory Structure

In January 2018, HRL Laboratories reorganized its technical laboratory structure to better vertically integrate key technologies.

The reorganization strengthens HRL's value to its LLC members and customers by consolidating sensor systems and supporting components projects into a single Sensors and Electronics Laboratory (SEL).

HRL's new structure improves coupling of system-level benefits with component features, alignment with our owners' strategies, and coordination of customer interactions. The change supports HRL's vision as a leading provider of revolutionary radio-frequency and electro-optical sensors throughout the world.

This was also an opportunity to strengthen HRL's wafer fabrication capability—the cleanroom and its supporting laboratories—by realigning them as the Microfabrication Technology Laboratory (MTL). This configuration is focused on engineering, prototyping, and production services for HRL researchers and external customers. MTL enables all researchers to access HRL's microfabrication capabilities and expertise through a matrix organizational structure.

Along with the SEL and MTL are the Information and Systems Sciences Laboratory (ISSL), developing breakthrough algorithms, architectures, and software-based systems to solve high-leverage problems with rapid solutions; and the Materials and Microsystems Laboratory (MML) creating differentiating technologies in advanced materials, coatings, structures, and microsystems from early-stage material innovations to vehicle/pre-production prototype-scale technologies for cost-effective implementation and production.

" The change supports HRL's vision as a leading provider of revolutionary radio-frequency and electro-optical sensors throughout the world. "

Awards

ALGORITHMIC TOOL KIT FOR ASSURED AUTONOMY

HRL will join DARPA's Assured Autonomy (AA) program with the Expressive Assurance Case Toolkit (ExACT) project, a set of mathematical tools to enable verification that any autonomous vehicle's guidance algorithms are correct and safe. Self-driving cars are a reality, although fully autonomous vehicles are still in their infancy. Developing safe and reliable autonomous vehicle technology beyond the testing stages and into the marketplace is potentially world changing, but only if the vehicles work as they are supposed to. Ensuring that autonomous vehicle systems perform as programmed without any unsafe behavior is the basis of DARPA's AA program.

DREAM PROJECT

HRL received an award from DARPA for the Dynamic Range-enhanced Electronics and Materials (DREaM) program. DREaM will develop the next generation of gallium nitride (GaN) transistors with dramatically improved linearity and noise figure at reduced power consumption. The new GaN transistors will be used in electronic devices that manage the electromagnetic spectrum from radio communications to radar. This will enable secure ultra-wideband communications with higher data rates, while reducing draw on the prime power sources of their eventual platforms, such as ships or aircraft.

DETECTING WEAPONS OF MASS TERRORISM WITH BIG DATA

HRL's proposed Complex Analytics of Network of Networks (CANON), is a set of software tools that will aim, with high confidence, to detect and warn intelligence analysts of weapons of mass terrorism (WMT) activity. Using integrated information from networks of massive amounts of intelligence data, CANON will be designed to find WMT activity at a level surpassing today's best practices. "WMTs can be known types of destructive weapons, but they can also be improvised from materials that are not alarming when purchased alone, such as the components of the bombs set off at the 2013 Boston Marathon. Despite being relatively small homemade munitions, the resulting atmosphere of terror they created has yet to dissipate at such public events," said Jiejun Xu, HRL's principal investigator for the Modeling Adversarial Activity (MAA) program.

STELLAR WILL ENABLE LIFELONG MACHINE LEARNING

HRL's project Super Turing Evolving Lifelong Learning ARchitecture (STELLAR) for DARPA's Lifelong Learning Machines (L2M) Program aims to develop a breakthrough machine-learning architecture that will enable autonomous artificial intelligence systems to remember mistakes, improve learning, and evolve over their lifetimes. The proposed system will continually improve performance and update its knowledge based on experience, without human supervision.

67 PATENTS ISSUED SINCE JANUARY 2018*

9,985,121 P-TYPE DIAMOND GATE-GAN HETEROJUNCTION FET STRUCTURE – Kenneth R. Elliot

9,984,326 SPIKING NEURAL NETWORK SIMULATOR FOR IMAGE AND VIDEO PROCESSING – Yang Chen, Yongqiang Cao, Deepak Khosla

9,981,240 DEVICES FOR CHARGE-TITRATING PARTICLE ASSEMBLY, AND METHODS OF USING THE DEVICES – Christopher S. Roper, Adam F. Gross

9,979,738 SYSTEM AND METHOD TO DETECT ATTACKS ON MOBILE WIRELESS NETWORKS BASED ON MOTIF ANALYSIS - Gavin D. Holland, Michael D. Howard, Chong Ding, Tsai-Ching Lu

9,978,149 SYSTEM AND METHOD FOR DOOR DETECTION FOR CORRIDOR EXPLORATION - Lei Zhang, Kyungnam Kim, Deepak Khosla

9,976,815 HEAT EXCHANGERS MADE FROM ADDITIVELY MANUFACTURED SACRIFICIAL TEMPLATES - Christopher S. Roper, David Page, Randall C. Schubert, Christopher J. Ro, Arun Muley, Charles Kusuda

9,976,039 SURFACE-STRUCTURED COATINGS - Michael H. Risbud Bartl, Alan J. Jacobsen

9,972,905 RECONFIGURABLE ELECTROMAGNETIC SURFACE OF PIXELATED METAL PATCHES - James H. Schaffner, Hyok J. Song, Keyvan R. Sayyah, Pamela R. Patterson, Jeong-Sun Moon, Alan E. Reamon, Keerti S. Kona, Joseph S. Colburn

9,822,835 TORSION SPRINGS WITH CHANGEABLE STIFFNESS - Andrew C. Keefe, Geoffrey P. McKnight, Sloan P. Smith, Christopher B. Churchill

*as of 7/26/2018

WHAT'S NEXT

by Leslie Momoda, Vice President

This issue emphasizes HRL Laboratories' continued commitment to development and implementation of advanced materials and processes.

Begun from our research heritage of laser crystals, advanced semiconductor growth, and device fabrication, HRL produces breakthroughs that impact the future of engineering. Our recent demonstrations of additive manufacturing of engineering-relevant ceramics and metal alloys are key innovations necessary to accelerate the application of these disruptive manufacturing technologies.

HRL is recognized as a pioneer in architected materials, producing the first scalable manufacturing process for ultralight-but-strong microlattice structures with customizable designs. In microelectronics, we produce industry-leading device performance from wide-bandgap and nanoengineered materials and develop the processing innovations to fabricate them in volume.

What's next at HRL is development of new materials and fabrication processes to transform next-generation systems with the engineering discipline to enable rapid transition from laboratory demonstrations to vehicle-scale implementations. Before we begin any project, our staff considers operational requirements such as manufacturing at scale, rate and cost, certification, reliability and maintenance, anti-counterfeit protection, and traceability. Experience has taught us that delaying these considerations invariably leads to approach redesign or potential project abandonment. We work the underlying physical models and simulations of new devices and structures for system function to accelerate adoption of promising technologies. Process modeling, multiscale modeling, polymer modeling, and new methods for in-process monitoring are all underway, often in collaboration with the nation's top universities and national laboratories. At HRL, our future is not just making new materials and processes but producing next-generation discriminators. ■

"What's next at HRL is development of new materials and fabrication processes to transform next-generation systems with the engineering discipline to enable rapid transition from laboratory demonstrations to vehicle-scale implementations."

...

HRL Horizons

HRL LABORATORIES, LLC
3011 Malibu Canyon Road
Malibu, CA 90265

www.hrl.com

LinkedIn.com/hrl-laboratories
Facebook.com/HRLlaboratories
Twitter.com/HRLLaboratories