In this issue: Transparent Antennas, Environmental Sustainability and More

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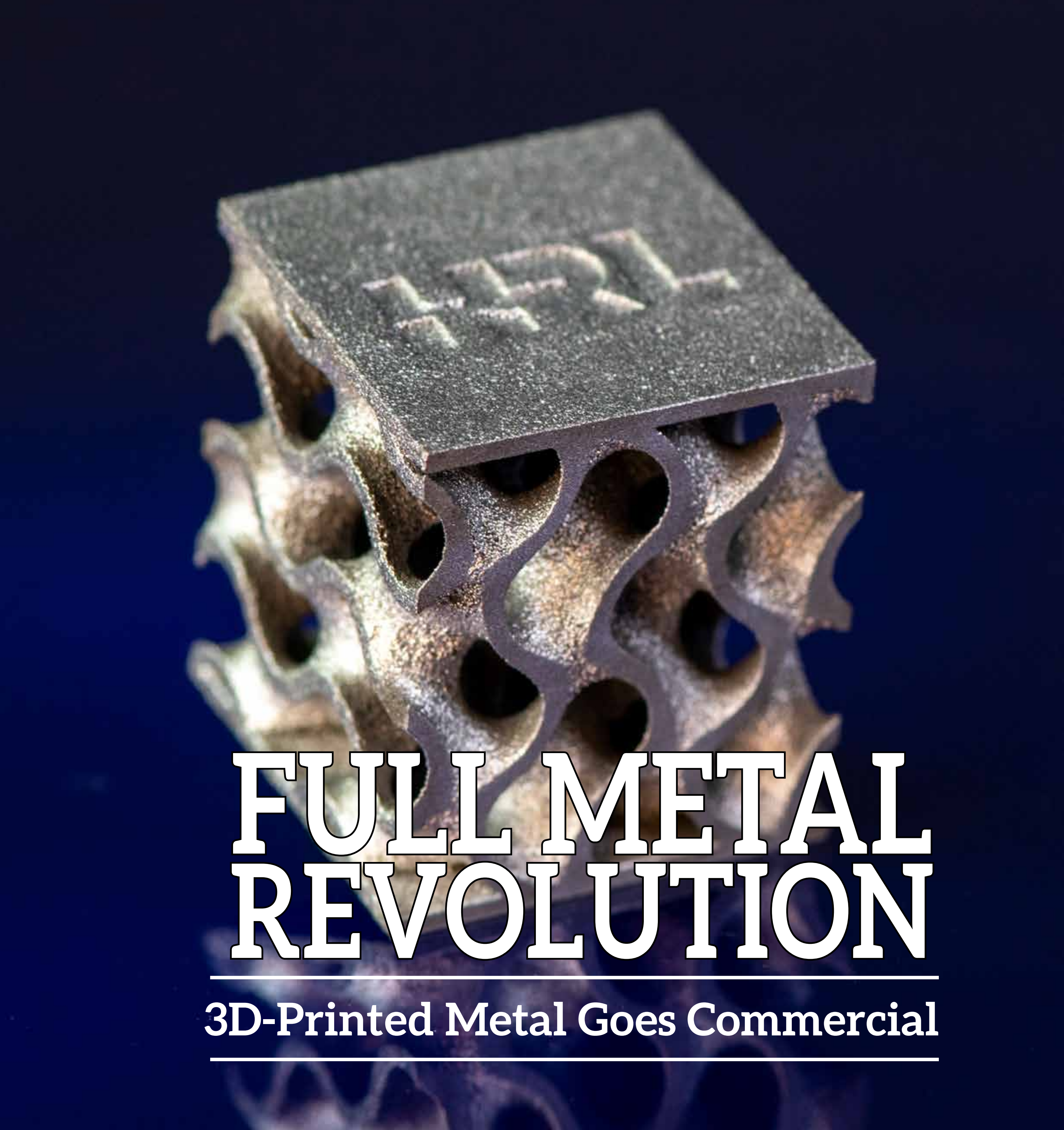

FULL METAL REVOLUTION

3D-Printed Metal Goes Commercial

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hAbout HRL

HRL is the largest employer in Malibu, California with over 500 employees on our campus overlooking the Pacific from the Santa Monica Mountains. All HRL scientists and engineers are U.S. personsand most hold advanced degrees. Our diversity is a strength that enriches our organizational growth and development and ensures a breadth of perspectives. Since 1960, HRL scientists and engineers have been recognized for their 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 electronics, information systems and sciences, materials and microsystems, and microfabrication technology. 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
Parney Albright

Chief Executive Officer

There is much to brag about at HRL Laboratories as the second decade of the 21st Century comes to a close. This issue of HRL Horizons features several of the quickly advancing technologies responsible for these bragging rights, from antennas to protective software systems. The feature story of the issue focuses on a technology—3D-printable high-strength alloys—that typifies the mission of HRL, in that it is relatively young, advancing rapidly, completely revolutionary, and provides the opportunity to put into practice a discriminating capability for our owners and customers. For the first time, parts that simply cannot be even designed (much less produced) under the constraints of more traditional metalworking technologies will be available in high-strength alloys—alloys that up to now could not be used with 3D printers. This opens up a whole new world of engineering design.

HRL's first large-scale foray in this arena has been with high-strength aluminum alloys, already positioning us as the world's leader. Of course the innovations will not stop there; HRL has a long tradition of follow-up and expansion of revolutionary innovations. Because the technique used to make these aluminum alloys printable can be applied to any other metal or alloy, our research continues toward new areas of 3D-printed, high-strength parts for cars, planes, and spacecraft, just to name a few.

I am excited to invite you into this new issue of Horizons to share the curiosity, innovation, and joy with which we push the limits of science, engineering, and technology. ■

HIGHLIGHTS

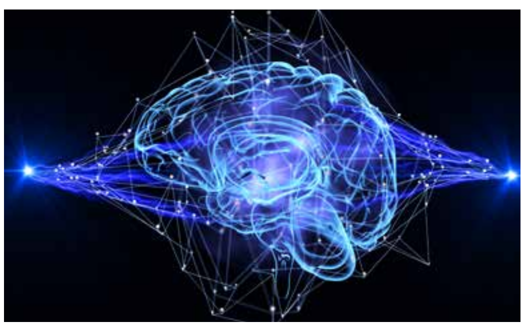
A look at the year's biggest achievements and news

SAVER Project to Build on Earlier Cold-Atom Success for Ultra-Precise Position, Navigation, and Timing

HRL was awarded the Swift Alkali Vapor Emitter & Regulator (SAVER) Project to build a key component for future cold-atom clocks and systems requiring ultra-precise position, navigation, and timing (PNT). Funded by the Defense Advanced Research Project Agency (DARPA), SAVER will build upon HRL's previous success with an atom source for cold-atom–based devices, such as portable atomic clocks.

"With our earlier cold-atom source we showed we could build a solid-state, electrically controlled way to regulate rubidium vapor pressure to cool down the rubidium atoms," said HRL's principal investigator Chris Roper. "With this new project we intend to do that faster and more intensely. Future PNT systems that use this type of technology could be orders of magnitude more accurate and function without GPS assistance. Also, industries that depend on precision timing, such as financial networks, could eventually benefit."

Sparse Associative Memory Emulates a Major Brain Function



HRL published *Sparse Associative Memory*, a paper describing a computer model of human associative memory that surpasses previous models in accuracy while avoiding the common problem of false memories that plagued earlier such models. HRL's model, Sparse Associative Memory or SAM, emulates the human brain's ability to learn and remember relationships between items based on recognizing patterns. The work was published online in the May 2019 issue of the journal *Neural Computation*.

Radar that Learns to Identify Objects

HRL researchers published a new framework for training computer deep neural networks to be able to classify synthetic aperture radar (SAR) images without a large labeled data set, solving the problem of SAR image identification when only a few labeled data were available. Usually installed in moving vehicles such as aircraft, SAR scans over objects to create two-dimensional images or three-dimensional reconstructions of objects, such as landscapes.

The paper, *Deep Transfer Learning for Few-Shot SAR Image Classification*, was published in the journal *Remote Sensing* on June 8, 2019. The authors included Mohammad Rostami, Soheil Kolouri, and Kyungnam Kim.

Kourosh Hadi of Boeing and Pamela Fletcher of GM Join HRL Board of Directors

HRL Laboratories, LLC, leadership and staff are pleased to welcome Kourosh Hadi, Boeing's Director of Commercial Airplane Product Development and Pamela Fletcher, Vice President of Global Innovation and Research & Development Laboratories for General Motors, to its Board of Directors.

"We are very excited and honored to welcome Pamela and Kourosh to the HRL Board of Directors," said HRL President and CEO Parney Albright. "Pamela's experience and expertise in electric and autonomous vehicle technology couldn't be a better fit with a large portion of our research here at HRL; and, with his extensive history with Boeing airplanes, Kourosh brings detailed technical knowledge as well as decades of senior leadership experience to the HRL Board."

In the search for vehicle technology that does not rely on fossil fuels and has little or no carbon footprint, hydrogen fuel cell technology satisfies many criteria.

ABOVE John Vajo (left) and Jason Graetz (right) discuss their hydrogen cell research in their laboratory.

Renewed Promise for HYDROGEN FUEL CELLS

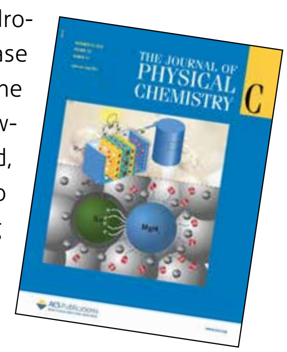
Most fuel-cell—powered vehicles are classified as zero emission, with water and heat as their only exhaust products.

A fuel-cell vehicle runs on electricity supplied from a reaction between stored hydrogen and oxygen taken from the air, with water as a byproduct. The fuel cell continuously powers electric motors for as long as the hydrogen fuel lasts. However, several significant challenges have limited widespread adoption of hydrogen as an alternative fuel platform. Current fuel cell systems rely on high-pressure compressed hydrogen in large, heavy tanks that can reduce trunk or back seat space.

HRL Laboratories has been researching ways to overcome hydrogen storage limitations for over a decade. One early advancement addressed the compressed hydrogen gas problem by storing the hydrogen as a solid, saving space without needing high pressure or very low temperatures. The hydrogen is released from the solid by heat and can then be used to generate electricity. A research team led by John Vajo found that they could reduce that heat by combining two different hydrogen storage powders. This was an important discovery, but further research revealed another obstacle to the system's practicality in a vehicle.

"When combining the powders, hydrogen emerges too slowly to be practical for most applications," Vajo said. "We think that the reaction is difficult because solid powder particles do not have much surface contact. Our newest technique is to combine the powders in a liquid called an electrolyte. Our hope is that the reaction rates increase when the particles are surrounded by the electrolyte."

"This idea came from our previous work on lithium batteries," researcher Jason Graetz said. "A liquid electrolyte enables lithium transport between electrodes in a battery, a function similar to the type of transport hydrogen storage powders need to sustain their reactions and release the hydrogen. Based on this understanding, we hoped that the appropriate electrolyte would facilitate transport in our powders and speed up hydrogen release. It seemed far-fetched, but it worked better than we thought it would. It also seems to work with several different types of materials. We're exploring further and we've tested 4 or 5 materials successfully."



The HRL team published their findings in *The Journal of Physical Chemistry.* ◆

In his laboratory at HRL (then called Hughes Research Labs) on **May 16, 1960**, Theodore Maiman (left) and his assistant Irnee D'Haenens (right) completed an experiment that changed the world forever—they activated the first successful laser.

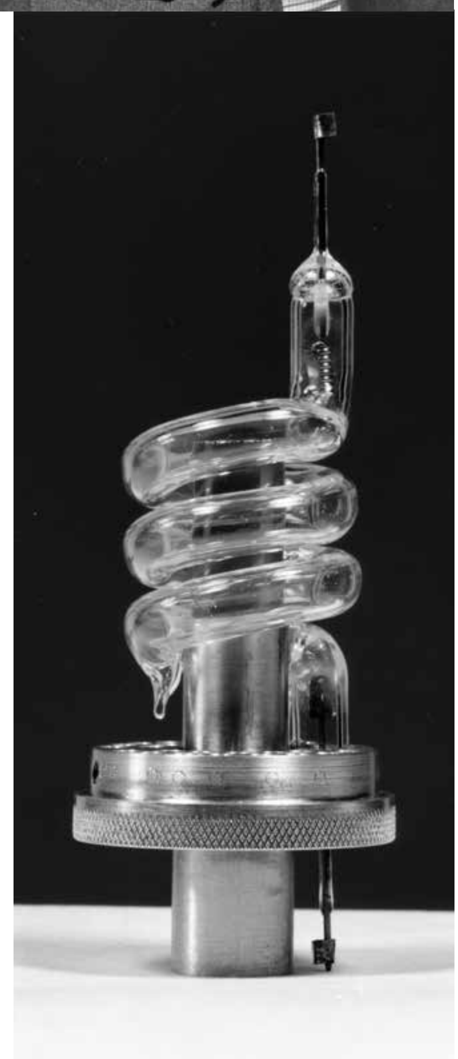
THE LASER TURNS 60

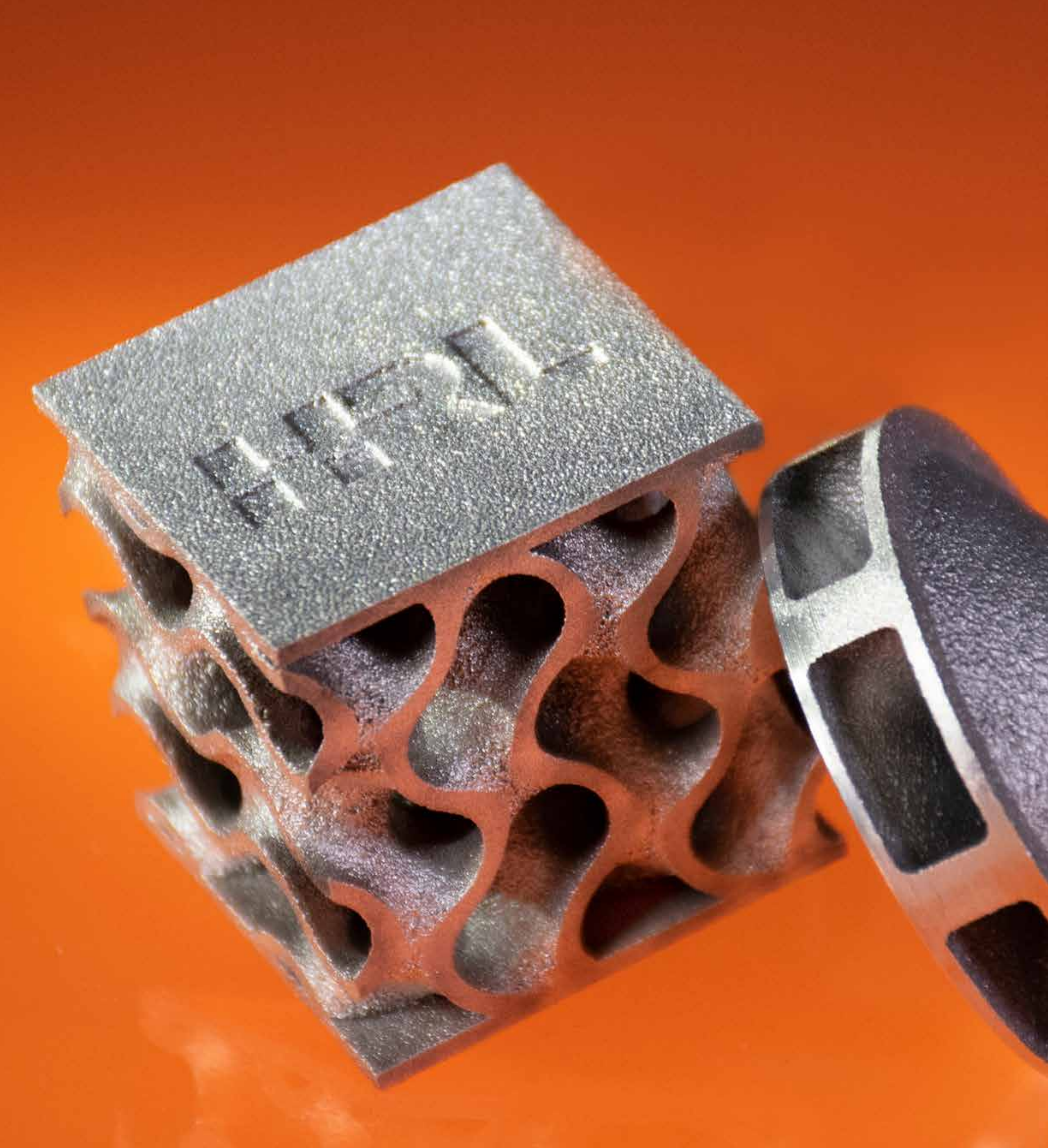
Although other scientists had theorized that light could be amplified by stimulated emission (the fundamental theory of which was developed by Albert Einstein), the community was skeptical of Maiman's approach, which was to use a flashlamp-triggered synthetic ruby crystal. When they activated the device on that day, the pulses of red light were so bright that D'Haenens could see them, despite his inability to distinguish the color red. With that experiment an entirely new capability was created that has had an enormous impact on commerce, national security, and research in nearly every field of endeavor.

Maiman's laser was a relatively small device that was elegant in its simplicity. While others were experimenting with much more complicated apparatuses designed to use chambers filled with gases such as helium and neon as the "lasing" material or gain medium, Maiman stood by his calculations that showed a ruby laser would work.

Originally LASER was the acronym derived from light amplification by stimulated emission of radiation, the term to describe the generation of coherent monochromatic photons into an intense beam of light. Coherence means here that each photon has the same phase—they all collectively march together in unison—as distinct from the incoherent light emitted by, for example, an incandescent light bulb or a light-emitting diode (LED)—and hence can propagate on a very narrow, intense beam. In contemporary language, the word "laser" is a household term for a tool that is used in super accurate range finders, in bar code readers, for engraving, cutting and welding, for communications, and for a myriad of other applications. In the years since Maiman's invention, lasers have become an integral part of our world.

Later describing the moment in his autobiography, Maiman said, "The output trace started to shoot up in peak intensity and the initial decay time rapidly decreased. Voila. This was it! The laser was born!" ◆





"Our goal is to provide the highest quality powder to HRL's LLC members in the aerospace and automotive industries, as well as other commercial customers" – Zak Eckel

FULL METAL REVOLUTION

Going Commercial With 3D-Printed High-Strength Aluminum

by Shaun A. Mason

An Era of Breakthroughs

Several recent breakthroughs in additive manufacturing have put HRL Laboratories at the forefront of this exciting technology. Also known as 3D printing, HRL has enabled this manufacturing method for two very different types of materials, high-strength metal alloys and ceramics. Both materials have properties that are highly desirable in aviation and automotive technology, as well as other engineered systems.

The first breakthrough came with the development of 3D-printed photopolymer-derived parts that were then converted into strong, light-weight ceramic. These ceramic parts are able to withstand temperatures up to 1700 degrees Celsius and can be made with the versatility and precision that characterize 3D printing.

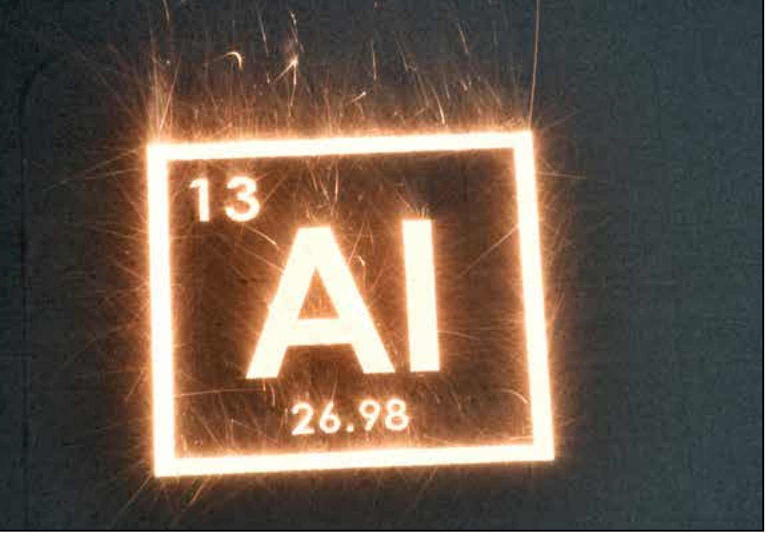
Wrought high-strength aluminum alloys typically used for structural applications have never been successfully 3D printed because the process requires the metal to be weldable.

World-First Registration of Printed Alloys

The Aluminum Association, which oversees alloy registration and product standards, launched a new registration system in February 2019 to cover additively manufactured alloys. The world-first registration in this system was HRL Laboratories' high-strength aluminum. HRL was granted registration number 7A77.50 for the aluminum powder used to 3D print the alloy and 7A77.60L for the manufactured alloy.

"Registration connects HRL to this alloy composition forever," said Hunter Martin, lead scientist on the alloy team. "The numbers will always track to HRL like a DNA signature. This came about because the Aluminum Association did not have a system in place to register alloys printed from powders or the powders themselves, so they created a new system to do it."

"Companies who want our powder for their 3D printers can ask for it by number as a true commercial alloy," said Zak Eckel of the HRL team.



HRL scientists solved the weldability problem and were able to successfully 3D print high-strength 2000, 6000, and 7000 series aluminum alloys for the first time. The 3D-printed parts prompted the Aluminum Association to create a new registration system for additively manufactured alloys. HRL Laboratories 3D-printed alloy was the first to be registered under said system (see sidebar). HRL's discovery was described in a paper in the journal *Nature* in 2017.

As happened with the invention of the laser at HRL back in 1960, rapid advancements in 3D printing have followed quickly since the advent of these breakthroughs. Development is underway of complex-shaped, heat-tolerant rocket engine parts, funded by NASA. HRL's 3D-printed aluminum feedstock powder is the thrust of a new commercialization effort.

Commercialization

As is common with breakthroughs, interest in the technology is widespread and has led to high demand for HRL's high-strength aluminum feedstock powder for additive manufacturing. Besides enabling never-before-printable parts in high-strength aluminum, the powder can be used with standard off-the-shelf additive manufacturing equipment without any modifications. Hence, HRL Laboratories launched HRL Additive, a commercialization effort for the production of printable aluminum powder.

"Certainly, the 7A77 feedstock powder could unlock the production of large-scale components produced via fusion-based additive manufacturing."

ABOVE HRL partner nTopology, makers of 3D engineering design software, designed this sample part to show the amazing intricacy possible with HRL's 3D metal printing technology.

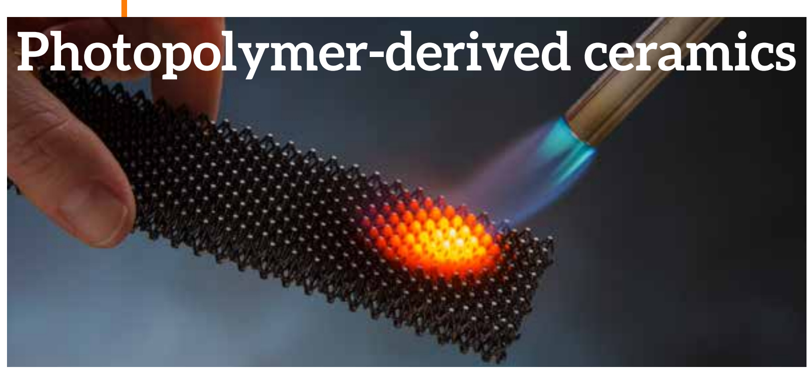
"Our goal is to provide the highest quality powder to HRL's LLC members in the aerospace and automotive industries, as well as other commercial customers," said Zak Eckel for HRL Additive. This way we guarantee that we can answer any question and help our customers find the best use of the material, allowing them some start up time before they lock in their own additive manufacturing process and scale up to commercial production quantities."

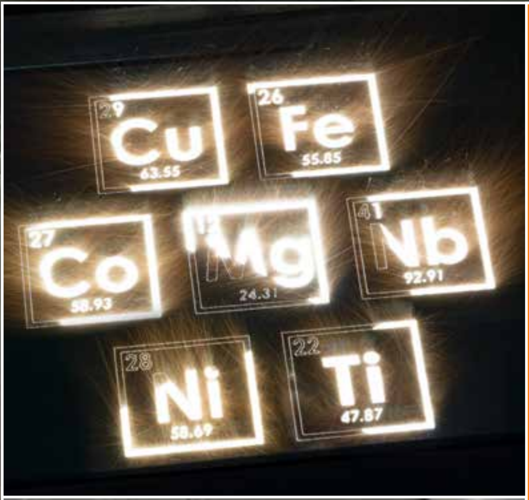
HRL Additive's plan for commercial powder production is testing the market to determine commercial demand and enabling HRL inventors to collect data about the marketplace.

"There have been many factors we never would have considered that have come up during our public interactions

Because ceramics have very high melting points, they are desirable materials for parts that must withstand extreme heat. That characteristic also makes them difficult to 3D print compared with metal or polymers. HRL has now developed technology to 3D print parts from liquid resin that is UV cured in stereolithography-based printers and subsequently converted to ceramic. "Ceramics cannot be cast and are difficult to mold or machine, so 3D printing is a real game changer as it enables complex shapes at low cost," said Tobias Schaedler of the HRL team.

Photopolymer-derived ceramics





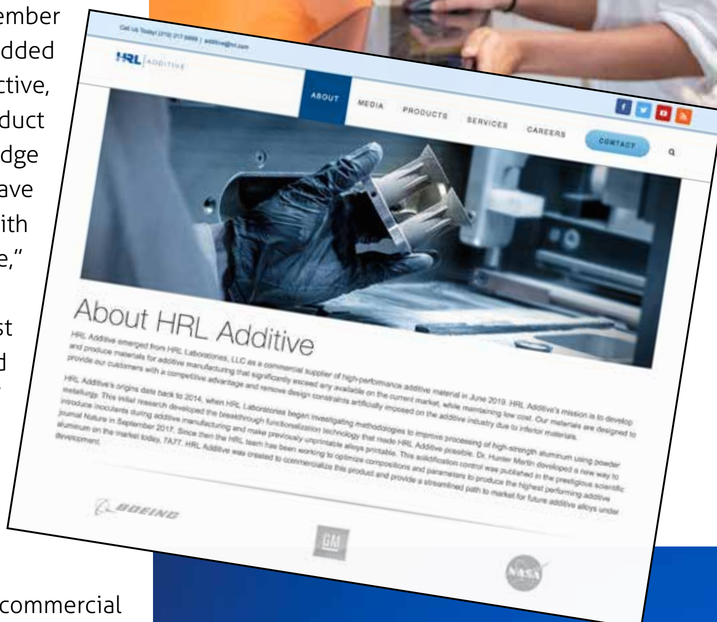
How is metal 3D printed?

Additive manufacturing, or 3D printing metal requires thin layers of metal powder to be precision-welded with a rastering laser to build up parts. Previous attempts to do this with high-strength wrought aluminum powders, such as those of the 2000 and 7000 series, always ended in brittle, cracked metal parts due to lack of control of nucleation, the microstructures that form as the molten metal solidifies. Having solved this cracking problem, the HRL researchers have revolutionized metallurgy with the additional discovery that their technique can be adjusted to enable 3D printing of multiple metal alloys that are commonly used in aircraft, automobiles, naval construction, recreational equipment and consumer devices.

While HRL has achieved enormous success with its printable high-strength aluminum powder—offering it on the commercial market—research continues on the 3D printability of other high-strength metals such as chromium, titanium, magnesium, and nickel.

STAFF AT WORK HRL researchers Darby LaPlant and Julie Miller oversee additive manufacturing of a high-strength aluminum part in HRL's 3D Printing Laboratory.

HRLADDITIVE.COM HRL Laboratories launched HRL Additive as the commercialization effort for their 7A77 3D printable, high-strength aluminum powder. Potential clients interested in purchasing the powder for their own alloys can initiate contact through the HRL Additive web site.



and sales that are reinforcing our research," said HRL team member Jake Hundley. "There is added value, from HRL's perspective, we get from selling our product because we're gaining knowledge we would not necessarily have been exposed to working with an outside vendor at this stage," Hundley said.

"We have a vested interest in the success of this alloy and this manufacturing process," said team member Hunter Martin.

First Commercial Sale Made to NASA

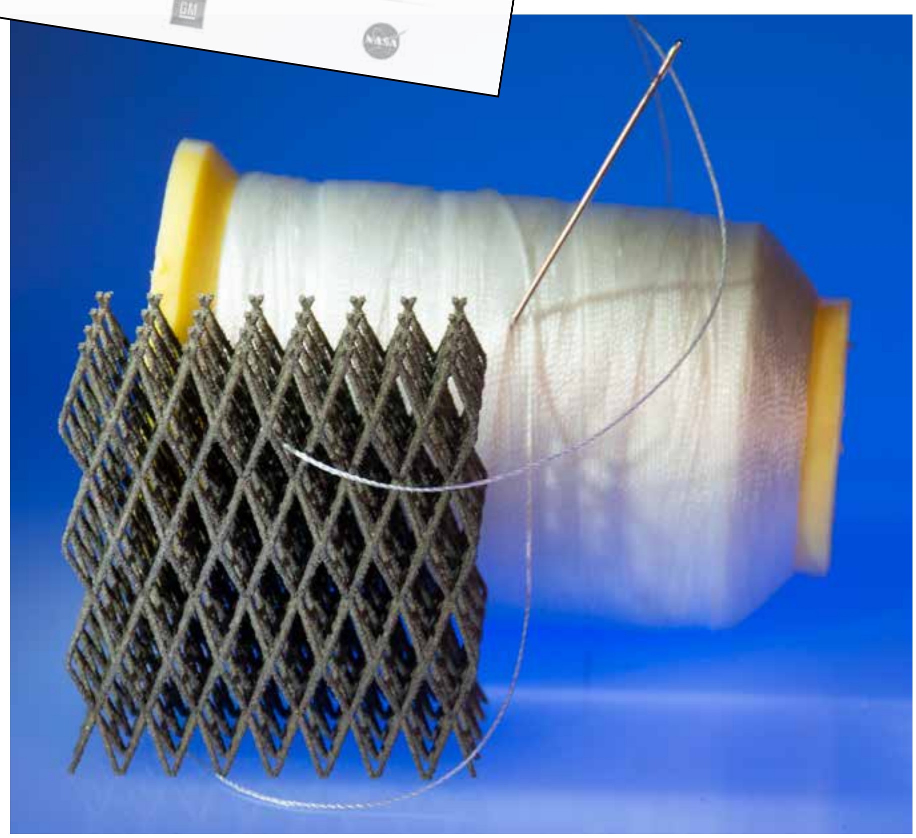
HRL Additive launched its commercial effort with an initial sale of 3D-printable powder to a very high-profile customer, NASA's Marshall Space Flight Center (MSFC).

The MSFC will first print parts for comprehensive testing and measurement over different length scales. If the initial testing shows that the printed parts meet all of NASA's rigorous standards, the 7A77 powder could be a significant part of aerospace-related assets produced at the large-scale advanced manufacturing facility NASA is planning.

"Certainly, the 7A77 feedstock powder could unlock the production of large-scale components produced via fusion-based additive manufacturing," said Omar Rodriguez of MSFC.

HRL Laboratories is expanding its commercial efforts and the HRL Additive portfolio with other printable alloys. ✤

AS THIN AS A THREAD
3D printed with strands as thin as common thread, this architected microlattice structure looks delicate, but is made of high-strength aluminum alloy and can support hundreds of pounds. HRL's aluminum powder enables additive manufacture with exactness of detail never before available in this alloy.



HOT WIRED INFRARED CAMERAS

HRL researchers are leading development of wafer-scale infrared focal plane arrays (FPAs) that will dramatically reduce the size and cost of infrared (IR) cameras.

The research has entered Phase III of the DARPA program Wafer-scale Infrared Detectors or WIRED.

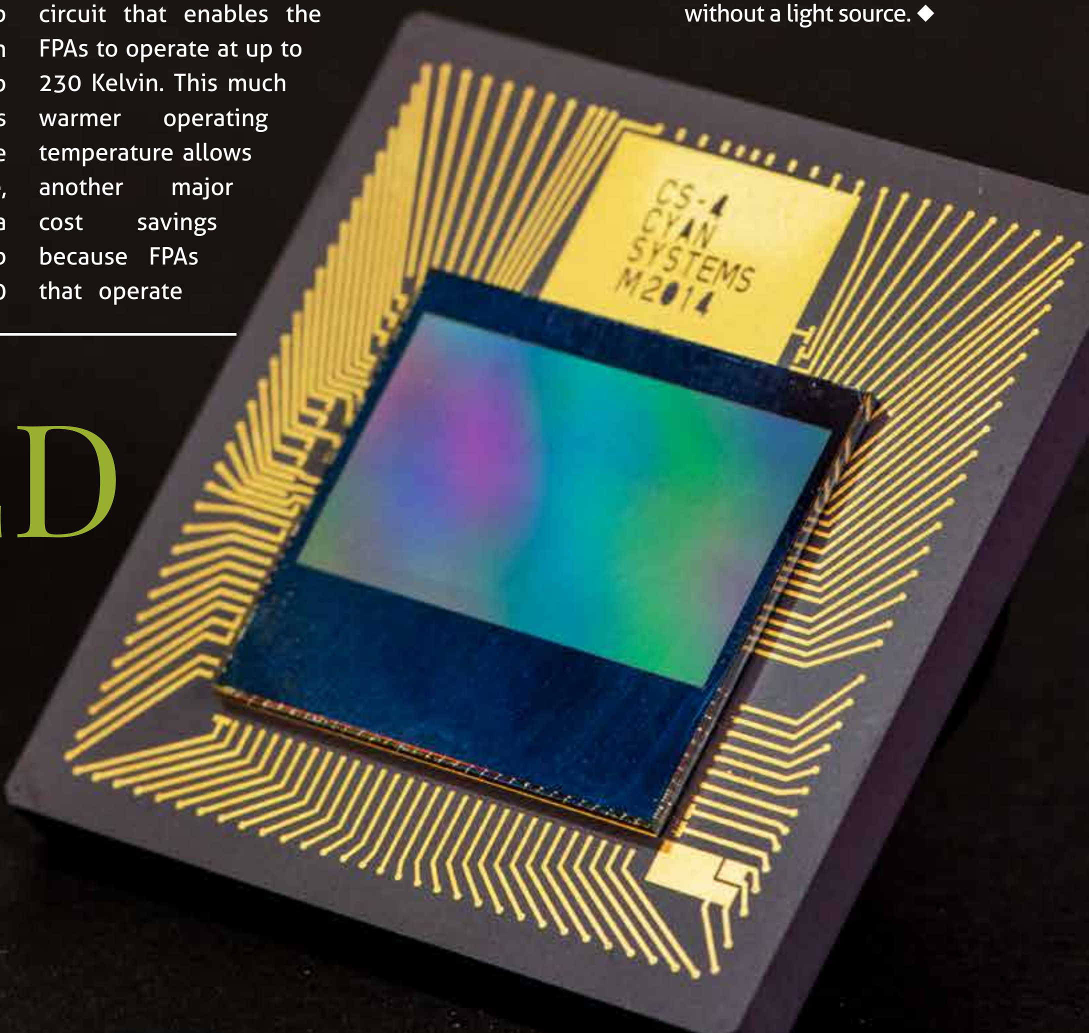
WIRED Phase III has two main goals. The first is to mature wafer-scale fabrication of FPAs, making them very low cost, high-yield technology that can be widely manufactured. The second is to reduce the high cost of cooling infrared cameras by leveraging advances in detector and read-out integrated circuit designs to build devices that perform at higher temperatures.

"The current industry practice is to process FPAs in series," said HRL's WIRED principal investigator Minh Nguyen. "That means that we might have several different IR detector array chips fabricated on one wafer that are then diced apart into individuals. Each chip has to be hybridized and integrated with a Silicon read-out integrated circuit chip to build one complete FPA. The process is repeated for each FPA, which is very time consuming and expensive. Furthermore, to work properly, each camera needs a bulky cooling apparatus that can keep the circuit very cold, around 77 to 120 Kelvin. These factors combine to make infrared cameras very costly."

HRL's approach is to process the entire integrated circuit with all its elements already combined on a wafer. This is a challenge because it requires mating two wafer materials—one silicon for readout circuitry, the other a III-V light-sensing material—that do not combine easily at full wafer scale. With the WIRED fabrication technique, the cost of each FPA is dramatically reduced.

"We've shown that our concept is feasible," Nguyen said. "Now we are working to make the technique practical on a multiple-wafer fabrication scale on wafers up to six inches in diameter. We also are implementing a new read-out integrated circuit that enables the FPAs to operate at up to 230 Kelvin. This much warmer operating temperature allows another major cost savings because FPAs that operate at this temperature can be cooled by smaller, less expensive thermoelectric coolers instead of the bulky and expensive cryo-coolers currently used. The resulting low-cost, compact IR cameras will be more accessible to consumers."

Thermal IR cameras use an imaging mode that is completely different from typical visible-light cameras. While visible-light cameras require a source of illumination, for example the sun or lights, thermal IR cameras can image an object from its infrared signature and do not require additional lighting. They also have better penetration through fog, smoke, and certain other media, and can reveal the temperature of objects. Thus, IR cameras enable secure surveillance without a light source. ◆



"The resulting low-cost, compact IR cameras will be more accessible to consumers."

MAN MACHINE

CYBER MIND MELD

Hybrid Forecasting Combines Machine Learning with Human Judgment to Predict Geopolitical Events.

HRL researchers have been exploring hybrid forecasting in which human forecasters join forces with specialized computer systems to predict such things as geopolitical events.

HUMAN FORECASTING is done by inviting diverse groups of people to answer questions about particular events. Forecasting groups are allowed to research the events and their answers are combined into a single forecast about a particular event, such as an election, a social upheaval, or a sporting event. Machine forecasting is done with mathematical tools such as algorithms applied to large amounts of data to make predictions about the behavior of the people the data describes.

HRL researchers have been exploring hybrid forecasting in which human forecasters join forces with specialized computer systems to predict such things as geopolitical events. The HRL system, called Machine-aided Analytic TRiage with Intelligent Crowd Sourcing—MATRICS—can help fill in gaps left by human or machine prediction systems alone.

Open-source intelligence gathering is the practice of collecting publicly available data to inform intelligence decisions. Volunteer groups that use open-source data to inform predictions can be surprisingly accurate in certain cases, but crowd-sourced forecasting also has human limitations.

Computer intelligence systems can analyze large amounts of data very rapidly to make predictions, but such systems also have shortcomings. The differences between human and computer forecasting abilities are interesting because the two skill sets complement each other. Humans' strengths are their imaginations, flexibility, and ability to select appropriate data sources. However, humans also can be blindsided by cognitive bias, work slowly, fatigue over time, and require motivation to continue. Computer intelligence is impartial toward data collected, can work continuously at high speed, and can scale up the amount of work done by orders of magnitude. It is rigid, however, in its analysis, can suffer from bias in its training data, experiences model drift—losing accuracy—if data changes over time, and can require several days to make a prediction if a large amount of data input is needed to train the software before a cold start on making a prediction.

"Computers can help people streamline tasks, organize their thoughts, and mitigate cognitive bias," said David Huber, leader of HRL's MATRICS team. "By the same token, people can help computer intelligence systems select data, adjust to corner cases and overcome the cold-start problem." ■

TOP HRL engineer Jae Song (center) is easily visible as he peers through several transparent antennas that have been applied to a car windshield held by fellow engineers Jim Schaffner (left) and Arthur Bekaryan (right). **RIGHT** An HRL transparent antenna slightly visible on a piece of Willow® Glass, which can be applied to a car window. The dark portion is an area of denser copper mesh where wires can be connected to the antenna.

As our society becomes more dependent on Wi-Fi connectivity, Bluetooth devices, cellular service, and GPS navigation, the demand for availability of all these technologies in our cars has skyrocketed. Because all these services use varied radio signals, meeting the demand for all of them requires more and more antennas, one for each type of radio signal to be transmitted and received. Most cars house this growing antenna population in a radome—known as a shark fin—mounted on the car's roof. With more antennas comes a larger shark fin, which could detract from styling of the car, along with the cost of making and equipping the antenna enclosure with all the different types.

With 5G cellular service on the horizon, cars will need even more antennas to offer all the services today's customer demands, just as more antennas were added to existing radomes to accommodate 4G LTE services several years ago. This led HRL engineers to consider alternative antenna materials and placement. Because glass is a very good electromagnetic material, engineers Jae Song and Jim Schaffner began thinking about how to use the abundant glass on a car as an antenna surface.

"We only lacked a good source of transparent conductors that could be attached to the glass to act as the antenna," said Schaffner. "We tried such things as silver nanowires, but ended up using a very fine copper mesh fabricated by Kodak with a roll-to-roll process that can produce the mesh antennas the way newspapers are printed."

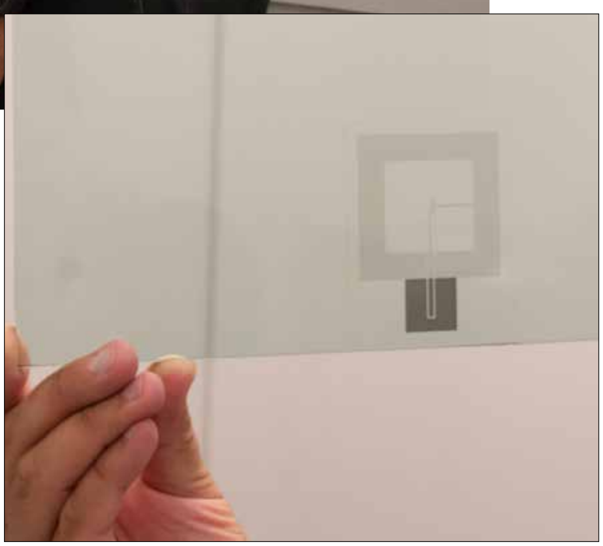
To apply the antenna mesh to the window glass, appliques are used that are backed by a very thin layer of glass called Willow® Glass, which protects the

Transparent Antennas Address Growing Connectivity and Reception

SMOOTH LINES & SMOOTH CONNECTIONS

mesh from solvents like window cleaners, or other possible destructive agents such as curious children. With windshields made with polymer layers to make them shatter-proof, the mesh can be placed as an extra layer during manufacturing.

"Copper mesh doesn't sound transparent," said Song, "but this is not an ordinary mesh. It is a very fine featured grid. With the strands approximately ten to twenty microns, about the thickness of human hair, when it's placed in a window, it is virtually invisible. We can see light up to 85% transparency and it has very good conductivity, the quality needed for an antenna that meets required standards for a vehicle." Because the copper mesh is already commercially available, manufacturing is easier and less expensive. The same method could work with other improved materials that might become available in the future.



> . . . this is not an ordinary mesh. It is a very fine featured grid. With the strands approximately ten to twenty microns, about the thickness of human hair, when it's placed in a window, it is virtually invisible.

With all of a car's antennas in the windows, there will be no need for a shark fin at all. By using a material that was already in the car and adding the antenna function, it expands the design space, appeasing designers who don't like bumps and ridges poking out of the body of an aerodynamically designed car. In this way, art and design aesthetics are improved by science and engineering.

Uses for transparent antennas can be expanded to aerospace, where aerodynamics are paramount. Any interruption to smooth air flow can cause drag, which, besides unwanted extra fuel consumption can also be a safety factor in controlling an aircraft.

"We're also pursuing non-vehicular applications, such as antennas in architectural windows in office buildings," Schaffner said. "With 5G, the wavelengths are so small that many more towers will be needed. However, if you can rent building space for antenna windows the signal could be boosted every 100 meters or so with no towers at all. This could help solve the current problem of phone reception in urban canyons." ■

CHESS
HACKING THE HACKERS

CYBERATTACKS like phishing emails are among the deceptions known collectively as social engineering. These and other techniques are used by criminals to gain enough personal or financial information to defraud their potential victims.

Bogus bank transfer requests are the largest of these types of threats. The average request from a cyberattacker is a startling $64,000, with the highest bogus request a truly frightening $950,000, according to PhishLabs *2019 Phishing Trends and Intelligence Report*. Because cyberattackers are getting more clever, detecting them is getting harder. Current approaches such as spam filtering are limited and often easily circumvented.

HRL Laboratories' approach to combatting such attacks is called Continuously Habituating Elicitation Strategies for Social Engineering Attacks (CHESS). This unique automated system does not attempt to block or discourage attackers, but engages with them to build trust by appearing to be a person willing to cooperate with them. With trust established, the system's counterattack strategy focuses on gaining enough information from the attacker to locate and identify them.

Funded by the Pentagon's Defense Advanced Research Project Agency (DARPA), CHESS is part of the Active Social Engineering Defense Program. The goal is to develop technologies that automatically elicit information from malicious adversaries to identify, investigate, and disrupt social engineering attacks.

HRL software tools based on multi-layer networks and network alignment algorithms enable the CHESS system to profile the attacker and extract hidden information. CHESS uniquely predicts an attacker's behavior and strategy by simulating their thought processes. The system then activates virtual bots that engage to countermand the attackers.

When deployed, CHESS will be part of an automated social engineering defense system that will engage an attacker as soon as a potential victim receives a phishing email. CHESS computes the likely trust between attacker and victim, then recommends countermeasures calculated to have the highest chance of engaging the attacker and obtaining the desired information. CHESS is currently undergoing rigorous testing by HRL scientists to fine tune and improve the system's algorithms for resilience and more effective defensive measures. ■

The average request from a cyberattacker is a startling $64,000, with the highest bogus request a truly frightening $950,000, according to the *2019 phishing trend and intelligence report*.

VIBRANT

Communication Through Earth or Sea

Despite the fact that everyone seems to be on their phones at all times, there are places where they do not work. Most of us have been in a vehicle that entered a tunnel, or walked into a building holding our phones and seen the reception bars disappear. Fewer of us have had the opportunity to use a phone underwater or in a cave, but the effect is the same. Our most commonly used radio frequencies do not penetrate significant distances into water, earth, or buildings.

This communications blind spot becomes particularly prominent in situations that require travel into difficult terrain or signal-deprived areas such as search and rescue missions or military operations. The ability to communicate anywhere on the planet, including these difficult areas, requires very low-frequency radio waves. Why not just equip soldiers, sailors, or firefighters with low frequency radios? The answer to that difficult question is what prompted the Defense Advanced Research Project Agency (DARPA) to initiate a program to solve the low-frequency radio problem: extremely low-frequency radio signals have very long wavelengths, which require massive antennas, often around 40 miles long.

DARPA launched the program A Mechanical Based Antenna, or AMEBA, to prompt research facilities like HRL Laboratories to tackle the engineering feat of creating a low-frequency antenna that was man-portable. In response to winning the DARPA contract, HRL engineers developed VIBRANT: VIBRational ANTtennas for Long Wave Applications.

"We created a high-power, electrically small magnetic transmitter for ultra-low frequency transmission by exploiting magnetoelastic materials," said HRL engineer David Shahan. "In this case these are electromagnetic rods in which the north and south poles switch back and forth within the rod when it is compressed. Compressing the rod by vibrating it very rapidly swaps the poles equally rapidly, enabling it send out a low-frequency radio waves as an antenna. Radio waves of this frequency would normally require antennas miles long, but our VIBRANT unit will fit in a backpack."

Equipped with VIBRANT antennas, divers will be able to send messages back and forth to each other or to submersible craft underwater. First responders of all stripes can maintain constant contact with support and navigation craft or each other no matter where they are underground, underwater, or in structures.

"We're helping solve a tough problem with VIBRANT," said Geoff McKnight, director of HRL's Materials and Microsystems Laboratory. "First responders and the military will make great use of this technology, but it also initiates new possibilities for many civilian uses. I'm sure that as our research progresses there will be uses for this device we don't even see yet. Frankly, that's what makes this work rewarding and fun."

"Radio waves of this frequency would normally require antennas miles long... But our VIBRANT unit will fit in a backpack."

LEADING THE CHANGE Gentry Jordan (left) and Melanie Zecca (right) oversee HRL's Sustainability efforts.

Our location is one of the features that sets HRL apart from nearly any other research and development facility.

HRL MAKES SUSTAINABILITY A PRIORITY

Our location is one of the features that sets HRL Laboratories apart from nearly any other research and development facility. Working in such a picturesque setting has many benefits and a special set of responsibilities. HRL's natural setting is as delicate as it is stunning, with an ecological balance that HRL strives to respect and maintain.

In keeping with that respect, HRL's Environmental Health & Safety Department (EH&S) is implementing a sustainability program to educate employees and implement conservation. The goal is to use conscientious waste segregation into categories that will divert waste to reduce HRL's landfill stream. Some landfill is unavoidable and necessary, but recycling and composting can divert significant waste from the environment.

Recycling glass, plastics, paper, and metal reduces our environmental footprint, and adds value to HRL's overall return on investment toward sustainability. Composting dramatically reduces the amount of food waste diverted to landfill, while producing reusable soil that will benefit the environment.

"We're committed to an environmentally sustainable future," said HRL environmental engineer Melanie Zecca. "As a company, we are very sensitive to our home in the mountains. Stewardship of our surroundings is a high priority of HRL's leadership. Our employees are also environmentally conscious and have made our recycling and composting efforts successful so far." EH&S has helped design signage and is creating instructional videos to reinforce diversion practices.

"When Melanie came to me with a plan for new recycling and trash bins, we decided to add compost bins as well," said Gentry Jordan, who supervises HRL's waste disposal and janitorial efforts for the Facilities Department. "Everything we use in the dining center, from pressed paper bowls and plates down to the wooden utensils is compostable. Paper hand towels are too, so we placed bins with compostable liners in HRL's restrooms. Most of our waste product is segregated and diverted from landfill. "

Zecca and Jordan are happy with HRL's diversion percentage, but both agree it could be even better. "Our goal for 2020 is to divert 70% of waste generated on site from going to landfill," Jordan said. "We're also developing incentive programs to encourage staff to recycle more." ◆

ExACT Solution for Autonomous Driving Safety

Autonomous vehicles are the promise of the future.

The traditional approach to ensuring safety requires rigorous testing and billions of driving miles. The goal is to confirm that the system will always work "well enough"—an impossible task due to time and cost constraints. Several self-driving car efforts all have examples of safety failures because of this drawback. HRL's Expressive Assurance Case Toolkit (ExACT) will help unlock the full potential of artificial intelligence (AI) by ensuring these vehicles are safe, because at present, they are just not safe enough.

Created under the DARPA Assured Autonomy Program and led by co-principal investigators Aleksey Nogin and Michael Warren, HRL's solution to reduce the amount of costly testing required is a toolkit of mathematical reasoning that can symbolically analyze the AI decision boundaries. ExACT can analyze AI-based systems to find and prevent safety failures. It is able to compute circumstances ahead of time that could cause negative outcomes.

In one test of ExACT, a simulation was run with an autonomous vehicle following waypoints on a high mountain road. Although the vehicle AI was not trained to drive in challenging environments, the vehicle maneuvered with relative safety. Within the simulation, ExACT was asked a simple question: would this neural network ever make a sharp turn left, off a cliff, when the next scheduled waypoint is on the right? Within a couple of seconds, ExACT finds a case in which this will happen. To observe those exact circumstances, we plug the scenario into our simulation and the vehicle drives off the cliff to validate the ExACT prediction.

Beyond determining that particular neural networks are unsafe, neural networks must be developed that are safe and the testing must be conducted with a real vehicle. For this testing, HRL worked with the US Army Combat Capabilities Development Command's Ground Vehicle Systems Center (GVSC) at Camp Grayling, Michigan to test ExACT on their autonomous M-RZR vehicle. The first challenge consisted of two tasks: 1) to develop a safe AI component that uses lidar to observe drivable ground and detect obstacles and 2) develop a safe AI component for driving a planned path. The initial set of solutions developed at HRL were taken to Camp Grayling for real-life testing.

IN ONE TEST OF ExACT, a simulation was run with an autonomous vehicle following waypoints on a high mountain road. Although the vehicle AI was not trained to drive in challenging environments, the vehicle maneuvered with relative safety.

The ExACT solution included safe neural networks, computer-checked proofs of safety and an additional dynamic assurance monitor that ensured that the real-world demonstration did not deviate from the mathematical model.

"We successfully validated our approach on a basic version of the GVSC challenge," Warren said. "As we continue scaling up our solution through 2022, we will focus on a more ambitious challenge from GVSC, developing a safe AI that drives the M-RZR on complicated terrain with the skill of a rally driver."◆

HRL AWARDS

HRL EMPLOYEE AWARDS

Each year HRL leadership awards outstanding work of our employees with awards in thirteen different categories. HRL scientists, engineers, administrative, and support staff awardees take home engraved glass statuettes and a monetary award, commemorating their achievements. Among this year's winners were:

HRL Chairman's Award – Jocelyn Hicks-Garner

The Chairman's Award is the highest recognition given to an individual by HRL to recognize multifaceted individual success. It can be for specific individual achievements in a given year or work spanning several years.

This year's recipient, Jocelyn Hicks Garner, embodied the very best of HRL with her vast program contributions, unflappable work ethic, and graceful communications. As a program facilitator and manager Jocelyn exemplified an important new HRL skill set critical to success in transitioning leading-edge technologies to programs and products. She was instrumental in capturing and executing several large efforts, resulting in successful launches of several major programs.

Outstanding Team Support Award

The HRL Outstanding Team Support Award recognized the most outstanding collaboration among HRL support staff members during the year. This year's Outstanding Team Support Award went to HRL's Equipment Support Group, whose members included Dennis Stephenson, Coy Winrow, Michael Brown, Tom Marshall, Gary D'Andrea, Juan Jeronimo, Keith Ferguson, Ron Lamm, Hussein Anton, Matt Hansen, Steven Kelly, Juan Hernandez, Tony Magana, Tony Pinedo, and Alberto Belmonte.

142 PATENTS ISSUED SINCE JANUARY 2019*

10,454,179 HOLOGRAPHIC ARTIFICIAL IMPEDANCE ANTENNAS WITH FLAT LENS FEED STRUCTURE – Adour V. Kabakian and Amit M. Patel

10,452,729 SYSTEM AND METHOD FOR USING NETWORK DATA TO IMPROVE EVENT PREDICTIONS – Matthew S. Keegan, Ryan F. Compton, Tsai-Ching Lu

10,451,951 PUSH-PULL PHOTONIC MODULATOR – Daniel Yap, Ryan Quarfoth, Troy Rockwood

10,446,305 MAGNETIC NANOCOMPOSITES AND METHODS OF FORMING MAGNETIC NANOCOMPOSITES – Adam F. Gross, John J. Vajo, Andrew P. Nowak, Eliana V. Ghantous

10,444,014 HIGH DYNAMIC RANGE GYROSCOPE – Logan D. Sorenson, Raviv Perahia, David T. Chang, Randall L. Kubena, Deborah J. Kirby, Hung Nguyen, Richard J. Joyce

10,442,935 COATINGS COMBINING OIL-ABSORBING AND OIL-REPELLING COMPONENTS FOR INCREASED SMUDGE RESISTANCE – Ashley M. Nelson, Andrew P. Nowak, April R. Rodriguez

10,424,608 FABRICATION OF POLYCRYSTALLINE SEMICONDUCTOR INFRARED DETECTOR – Terence J. DeLyon, Rajesh D. Rajavel, Sevag Terterian, Minh B. Nguyen, Hasan Sharifi

10,427,375 ARCHITECTED MATERIALS FOR ENHANCED ENERGY ABSORPTION – Jacob M. Hundley, Tobias A. Schaedler, Sophia S. Yang, Alan J. Jacobsen

10,430,587 SYSTEM AND METHOD FOR MAINTAINING SECURITY TAGS AND REFERENCE COUNTS FOR OBJECTS IN COMPUTER MEMORY – George Kuan and Aleksey Nogin

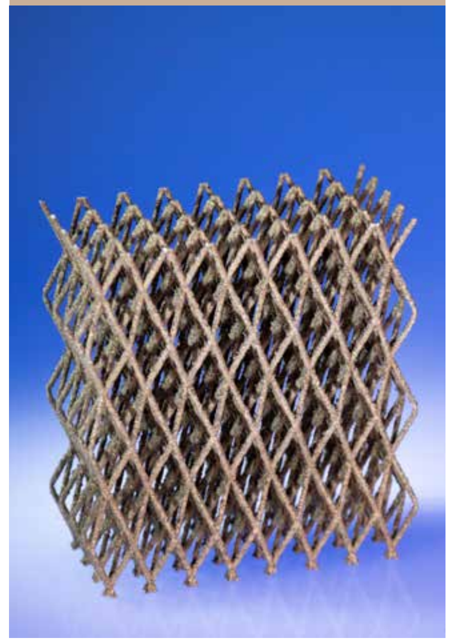
10,425,489 INFERRING NETWORK SERVICES AND THEIR DEPENDENCIES FROM HEADER AND FLOW DATA AND THE SWITCHING TOPOLOGY – Karim El Defrawy, Ian A. Maxon, Matthew S. Keegan, Tsai-Ching Lu

10,418,473 MONOLITHIC INTEGRATION OF GROUP III NITRIDE EPITAXIAL LAYERS – David F. Brown, Keisuke Shinohara, Miroslav Micovic, Andrea Corrion

*as of 12/09/2019

WHAT'S NEXT

by Leslie Momoda, Vice President



This *Horizons* issue gives you a glimpse of what HRL is doing to unlock the full potential of additive manufacturing (AM) technologies for future engineered systems. Besides developing advanced, application-relevant metal alloy and polymer-derived ceramic feedstocks to expand the suite of materials that can be additively manufactured, we are also exploring some novel materials made possible by the uniqueness of the AM process itself. Materials with controlled microstructure, engineered pores and non-equilibrium compositions are a few of the areas we are exploring. Also, the scaling of AM fabricated parts to industrially relevant quantities and the quality control required to transition these technologies from the lab to product are areas of investigation at HRL. By creating more tools for the AM toolbox, we can enable more applications of this disruptive technology. Currently HRL engineers are actively exploring new functionalities, enhanced performance and disruptive system designs that this expanded toolbox can produce.

Manufacturing, however, involves more than just the fabrication of parts –other key steps in the production path to a product such as design, finishing, joining, qualification, inspection and even cybersecurity are important. HRL has been involved in the manufacturing of semiconductor-based electronics for over 30 years and the scaling revolution that these technologies enabled, inspire and inform what is possible and what is needed in the next revolution. We haven't, therefore, limited our focus to just the creation of novel material feedstocks. We are actively working on other parts of a manufacturing value chain such as new joining technologies for dissimilar materials, novel in-process inspection techniques, machine vision for actively assessing parts and computationally relevant blockchain approaches for supply chain security. Understanding and addressing the key challenges in an entire production chain for a disruptive product is important to transitioning our cutting- edge technologies to the next-generation of engineered systems and is core to our mission. We look forward describing our advances in these key areas in future editions of *Horizons*.

"Besides developing advanced, application-relevant metal alloy and polymer-derived ceramic feedstocks to expand the suite of materials that can be additively manufactured, we are also exploring some novel materials made possible by the uniqueness of the AM process itself."

HRL Horizons

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