Also in this issue: HRL goes Green, Cleanroom Facts & A Look to the Future

VOLUME 1 ISSUE 1

HRL HORIZONS

THINKING DRONES

HRL Technologies Instill UAVs with Humanlike Brain Power

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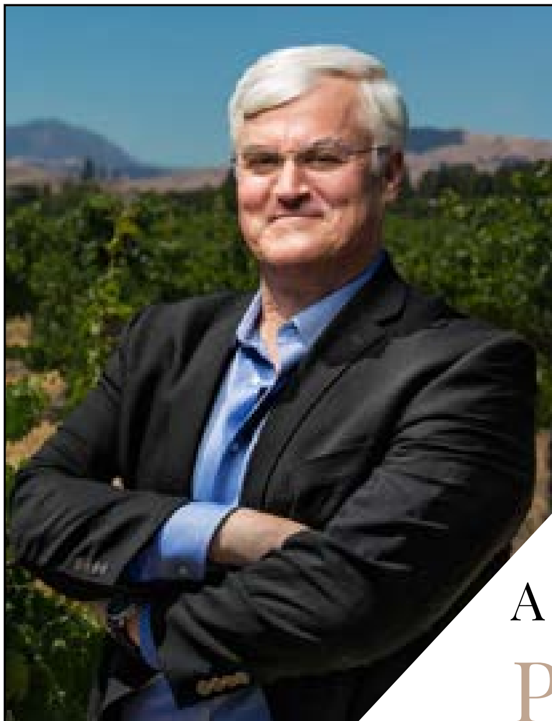
About HRL

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 world-class premier physical science and engineering research laboratories as well as our significant contribution to national defense.

HRL PHOTO COURTESY OF GEOFF RAMOS

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.



HRL PHOTO COURTESY OF GEOFF RAMOS

A WORD FROM PARNEY ALBRIGHT

HRL's mission is to develop and apply world-class science, technology and engineering that strengthens our LLC Members—Boeing and General Motors—and enhances the capabilities of our government and commercial customers. HRL decides what research areas to engage in by asking "Are we now, or can we be, among the best in the world on this topic?"

However, what distinguishes HRL's efforts from academic pursuits is that we ask a second question: "What is the use case?" Hence, HRL is all about solving practical problems with the innovations made possible by operating at the frontiers of science, technology, and engineering. HRL's size makes for an ideal incubator for creative ideas—our researchers can work across multiple disciplines, moving from concept through analysis and design to fabrication and testing, then on to next iterations, all in the same location.

At HRL we encourage collaboration and facilitate interaction between scientists to expand their knowledge, goals, and horizons. Our laboratories complement each other, easily integrating technology and discovery beyond their primary focus areas. Our engineers and researchers readily collaborate to achieve leading-edge products that are vastly greater than the sum of their parts. The range and diversity of our people is a unique strength of HRL.

Aside from famously developing the world's first working laser, HRL demonstrated the world's first ion propulsion engine; the world's lowest density structural material; the world's first (and only) neuromorphic learning chip; and has scored several "firsts" that transcend the boundaries of microelectronic science and engineering. The list of achievements is long, and as I hope will be clear with this inaugural volume of ***HRL HORIZONS,*** continues unabated.

HRL is on the most famous list of the best in the world, achieving a Guinness World Record

HRL researchers originally made headlines with a famous image of a metal microlattice structure resting atop an unaffected dandelion. Now the material has been vetted and confirmed by the Guinness book as having no peer among metals when it comes to weight. Made of nickel phosphorus, the microlattice is approximately 100 times lighter than Styrofoam®.

Lab Director Bill Carter said that there is no other material or product that enables the range of density in a manufacturing process with such relative ease and variation of material properties. Based on versatility and ease of customizable production, the potential uses of microlattice are many, including insulation, heat exchange devices, catalytic converters, airplane wings, energy-absorbent soldiers' helmets, and vehicle blast protection.

HRL Demonstrates the Potential to Enhance the Human Intellect's Existing Capacity to Learn New Skills

The study, published in the February 2016 issue of the journal *Frontiers in Human Neuroscience*, found that subjects who received brain stimulation via electrode-embedded head caps improved their piloting abilities. Video available on YouTube/users/HRl Laboratories

HIGHLIGH

A New Approach to Shock Absorption

Researchers in HRL's Sensors & Materials Laboratory developed an new approach that allows a vibration and shock isolation system to switch from stiff to soft at the push of a button. According to Principal Investigator Christopher Churchill, "This performance surpasses existing mechanisms by at least 20 times in speed and useful stiffness changes."

Video available on YouTube/users/HRl Laboratories

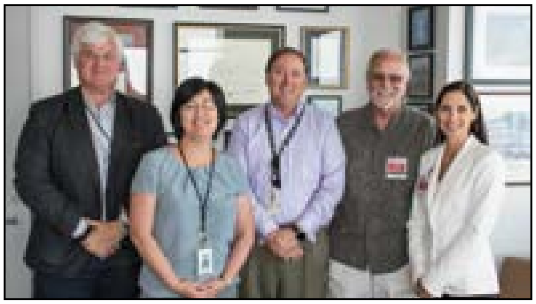
HRL STAFF ACHIEVEMENTS

• **Ashley Farhat** from HRL's Legal Team was appointed to the Department of State/Director of Defense Trade Controls, Defense Trade Advisory Group (DTAG). As such, she will have an opportunity to influence revisions to the International Traffic in Arms Regulations agency (ITAR) and build a network with DDTC and other export professionals.

• **Jeong-Sun Moon** from the Microelectronics Laboratory was selected to serve as Editor, Compound Semiconductors Devices on the Editorial Board of *IEEE Electron Device Letters.*

• **Minh Nguyen** (Sensors & Materials Laboratory, IR Dept) was elected to senior membership of SPIE, the international society for optics and electronics. SPIE Senior Members are honored for their professional experience and active involvement with the optics community and SPIE.

• **Rajan Bhattacharyya** from HRL's Information & Systems Sciences Laboratory was selected as one of 83 of the nation's brightest young engineers to take part in the National Academy of Engineering (NAE) 22nd annual *U.S. Frontiers of Engineering Symposium*, held in September of 2016.



In late June, HRL was honored to receive Reva Feldman, Malibu City Manager and Malibu Mayor John Sibert for a tour of our facility. (L to R: P. Albright, L. Momoda, R. Gronwald, J. Sibert and R. Feldman)

TS

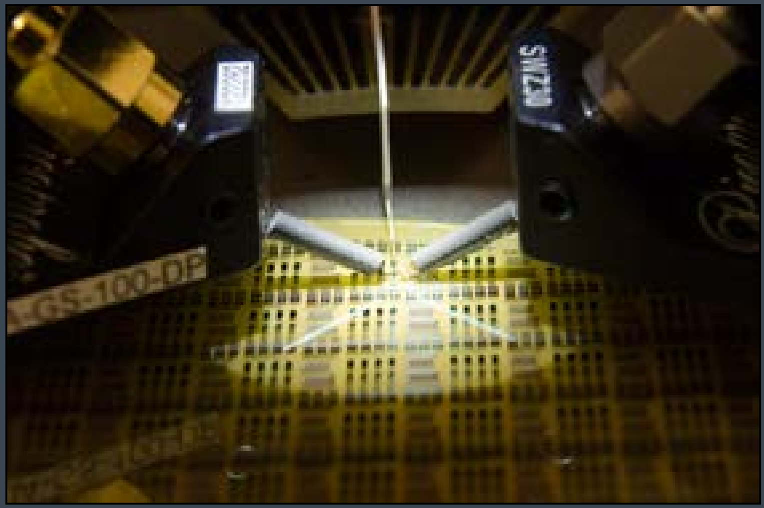
A look at the year's biggest achievements and news

BBC HORIZONS features HRL Technology on their show

Last Spring, a BBC team from the acclaimed science show HORIZONS came to HRL to inquire about the world's lightest metal—the HRL microlattice— and test HRL's record-setting microlattice impact absorber.

Bill Carter, director of HRL's Sensors and Materials Laboratory, showed the BBC crew the different forms of microlattice material, including the hollow nickel phosphorus lattice that holds the record for world's lightest metal and a version of microlattice able to float on the room's air currents. Carter answered many questions about the material, then supervised the event the BBC came for – the egg drop test.

Watch the episode at http://bbc.in/1RXa5oC



HRL Laboratories' Breakthrough May Pave the Way for Gallium Nitride to Supplant Silicon in Integrated Circuits

In February, Researchers at HRL Laboratories, LLC, achieved the first demonstration of gallium nitride (GaN) complementary metal-oxide-semiconductor (CMOS) field-effect-transistor (FET) technology, and in doing so established that the semiconductor's superior transistor performance can be harnessed in an integrated circuit. This breakthrough paves the way for GaN to become the technology of choice for power conversion circuits that are made in silicon today.

Above and below stories videos available on YouTube/users/HRl Laboratories

Breakthrough achieved in Ceramics 3D Printing Technology

HRL researchers achieved a milestone in 3D printing technology, demonstrating an approach to additively manufacture ceramics that overcomes the limits of traditional ceramic processing and enables high-temperature, high-strength ceramic components. Senior Chem. Engineer Zak Eckel and Senior Chemist Chaoyin Zhou invented a resin formulation that can be 3D printed into parts of virtually any shape and size. The printed resin can then be fired, converting it into a high-strength, fully dense ceramic. The resulting material can withstand ultrahigh temperatures in excess of 1700°C and exhibits strength ten times higher than similar materials.

THINKING DR

...This on-board intelligent perception enables real-time decisions about what action the machine takes based on situational circumstances such as "have I been here before?"

HRL Technologies Instill UAVs with Humanlike Brain Power

ONES

Written by Shaun A. Mason

HRL Laboratories, LLC has a rich history of cutting-edge aviation engineering and technology, including a leadership position in the current drone revolution. HRL scientists are at the forefront of unmanned aerial vehicle (UAV) technology in several areas that will benefit UAV users from the military, industry, and the general public.

The requirements for national defense and other uses of UAVs engage all four laboratories at HRL: Information and Systems Science (ISSL), Microelectronics (MEL), Sensors and Materials (SML), and Advanced Electromagnetics (AEL). HRL remains a world leader in developing artificial intelligence algorithms, microcircuitry, antennas, and sensors needed for a new generation of autonomous UAVs.

These drones are a new paradigm of small machines that can think and learn in real time, emulating the human brain in memory and power consumption. They need no pilots to find their destinations, avoid obstacles, and recognize their surroundings.

HRL labs explores interrelating technologies that extend the capabilities and uses of UAVs beyond what was thought possible a few years ago. Drones will continue to affect our lives and change the world and HRL technology will continue to change and improve drone technology.

Thinking Fast

Small UAVs have capabilities inherent in their size that enable a wide range of missions not approachable by larger military drones. HRL engineers are developing technology for these vehicles to accomplish complex missions independent of global positioning system (GPS) guidance, enabling operation in GPS-denied areas.

Based on a DARPA call for drones that fly on their own with the speed and characteristics of birds, the HRL team began research on high-speed autonomy. They began by determining what capabilities a UAV needs to fly through an unknown building, avoid doors and walls, remember where it has been, and electronically map its path. Such a vehicle needs cameras, sensors, electronics, and programs full of algorithms that analyze data gathered from many sources for instant decision-making.

Understanding visual scenes as a human does is key to robotic autonomy. "Once you understand the obstacles, walls, doorways, corridors, etc., the path planning or control aspect of autonomous navigation is less difficult," said Deepak Khosla, senior scientist in HRL's ISSL. "We have a series of algorithms that work okay if you say 'take this path,' but for the machine to understand the scene the way humans do is a bigger challenge."

"Smart perception" is the focus of HRL's research on these systems. The researchers developed algorithms and software able to make sense of the environment and perform complex tasks using dozens of visual cues at every location the robot enters. This on-board intelligent perception enables real-time decisions about what action the machine takes based on human situational circumstances such as "have I been here before?"

"Our algorithms are neuromorphic, meaning they are biologically inspired. Our goal is to make the drone brain emulate human perception, with the ability to see and remember rooms and quickly decide which action to take.

Because the human brain only uses 30 watts of power, 15-20 of which is used solely by the visual cortex, we build electronic brains that also use low power. This makes much smaller, more agile drones possible," Khosla said.

The input data for the autonomous drones comes from a variety of sensors, including monocular cameras, sonar, and the Kinect 3D depth sensor from an XBox gaming unit, which uses a camera combined with an infrared projector to determine how far away an object is from the unit. Visual cues include appearance, color, texture and depth information.

For UAVs with only one camera and no Kinect sensor, thus no depth perception, the drones use looming detection—a method that emulates insects and some birds—to determine the approach of an obstacle. As an object looms in front of the drone, it begins to grow larger in the drone's vision. The drone calculates the nearness to the object by how fast the object grows in its view. When a predetermined percentage of its view is taken up by the object, it identifies the object or person as an obstacle to be avoided.

To stay centered in a corridor without hitting walls, the drone has an algorithm to calculate the vanishing point of the corridor, then uses sonar to sense the walls on either side and use its vanishing point reference to stay between them.

Recording the visual cues and localizing its route through a building to create a digital map is called odometry. The drone can navigate in and out of a building safely by using odometry to make efficient decisions in real time. The subsequent map can be used in many ways, including informing the guidance

ADVANCED ELECTROMAGNETICS ADDED TO THE MIX

HRL's Advanced Electromagnetics Lab (AEL), which specializes in antennas and optics, has developed several core technologies that will be key to better UAV autonomy.

Antennas for communication links, radar, and lidar need to be as small and light as possible while enabling superior capability. Two especially relevant technologies are thin-film antennas and electrically small antennas. HRL researchers in the AEL who are focused on these areas are making advances that continue to improve UAV performance.

Antennas made from polyimide films, such as DuPont Kapton®, are amazingly light, paper thin, and can be used for such applications as GPS guidance. With low SWaP as a major concern in UAV design, switching out heavier metal stick antennas for highly efficient thin film would lead to significant weight reduction. Recent research also has been published on improving performance of thin-film antennas made from various transparent conductive films including indium tin oxide (ITO), fluorine-doped tin oxide (FTO), and silver coated polyester film (AgHT). Antennas that are transparent can be placed nearly anywhere in or around a UAV airframe without obstructing cameras and sensors, greatly expanding the design possibilities.

By utilizing technology such as non-Foster circuits, antennas that are normally large can be made smaller by a factor of 10, vastly reducing the SWaP of a UAV. With electrically small antennas, efficiency is increased by adding a circuit to the antenna that makes it resonate on the level of a larger antenna at fractions of weight and size. For example, the frequency for GPS is approximately 1.5 GHz. A conventional GPS antenna needs to be half a wavelength long—15-20 cm—and made of metal. An electrically small antenna can be a tenth of that size, reducing the weight of the antenna material proportionately. This type of antenna is dramatically lighter and smaller for UAV use.

of additional drones or familiarizing first responders with the layout of a building they must enter.

Emulating Brain Structure

Improving the capabilities of UAVs with such tools as scene recognition software requires hardware that reduces UAV size, weight, and power (SWaP). Lowering the power consumption of a UAV requires increasing its power efficiency. To get the most computing from the least amount of power consumption, HRL researchers like MEL's Jose Cruz-Albrecht are studying the most efficient computer—in terms of computing power per watt of energy consumed—the human brain. By emulating the brain's structure, they can build microprocessors that emulate the brain's unparalleled ability to compute with low power usage.

The human brain contains about 100 billion brain cells called neurons. Neurons are connected to each other by synapses, minute junctions that form networks to carry electrical signals throughout the brain. Each neuron has an average of 7,000 synapses, totaling roughly 1 quadrillion (10^{15}) synapses throughout the whole brain. Despite this mind-boggling number of electrical impulses traveling through the brain's neural networks at all times, the entire brain consumes only 20-30 watts of power to function, less than a 60-watt light bulb.

"We make microprocessor chips that mimic portions of the biological brain. Our chips have groups of electronic

AUTONOMOUS SWARMS can be deployed from various mothership craft without revealing the location of the initial launch platform. Small, gliding jammer drones with virtually no radar cross section can operate undetected in very close proximity to target installations.

ON-BOARD CAMERA'S VIEW during test flight of an autonomous quadcopter UAV. Without human pilotage, the drone navigates a hallway by calculating the vanishing point as its target (green and blue circles) and avoids walls with sonar (blue wavy lines). HRL-developed neural chips and neuromorphic algorithms to enable this type of thinking drone.

neurons interconnected with gain elements we call synapses," said Cruz-Albrect. "We can provide input to some neurons, which are connected to others by the synapses, to create another layer of electronics to analyze the input before the signal leaves the chip."

These synapse chips work at the biological speed of the brain and can process imagery from a variety of sensors. Their unique design enables the computing power needed to handle the large amount of data input and analysis required by drone autonomy algorithms, while still using very low power. Thus, room recognition software and other autonomous drone capabilities can be enabled in smaller, lighter drones with synapse chips.

While some parts of the brain are versatile and have many functions, some parts work in specific ways. With vision, for instance, the eye takes in light information and transmits it through the optic nerve to the brain where it is translated into an image. Cruz-Albrecht's team is also producing customized chips for specific tasks. For example, sensor data is analyzed with one chip deciding what in the scene is important, such as moving objects versus stationary objects or background. Another chip then identifies the important objects as people, cars, or obstacles, and yet another possible chip decides in real time what action to take regarding the object. Thus, the drone can avoid obstacles, determine destinations, or engage targets on its own as the situation demands.

"They are undetectable on radar and even visually look more like a bird than a drone. Because they drift randomly in the swarm they are hard to target."

Drone Swarms

The military UAVs most familiar to the general public look like slightly smaller versions of conventional airplanes and are powered by normal propeller or jet engines. Aircraft such as the Predator drone have proved invaluable to US defense and strategy. They routinely conduct remote missions that in the past would have endangered pilots and ground troops. Yet despite advancing technology, these relatively large UAVs have limitations in certain strategic situations.

Electronic warfare systems, especially those that jam enemy communications and radar, work best in proximity to their targets. This is because the effective range of a jammer decreases quickly in proportion to distance. Traditional jammers are operated at comparatively far distances from enemy installations. That distance causes path loss, or weakening of the jamming signal, and requires large amounts of energy to overcome.

Equipping drones to jam enemy radar and communications seemed a possible solution, but to equip larger Predator-type UAVs with bulky jamming equipment increases the craft's radar cross section (RCS) making it much more vulnerable to attack. For a jammer to be made compact, its range is necessarily very limited, requiring that it be very close to target installations to work. For a large drone, that proximity is fatal.

In response to the needs of drone-borne electronic warfare, US defense organizations are researching a different paradigm from the traditional Predator-like drones—swarms of much smaller aircraft called microdrones. An engineless microdrone glider with virtually no radar cross section could carry a light electronic payload very near an enemy installation without detection. The length of jamming time and overall jamming power supplied by one microdrone would not be enough by itself, but a swarm of tens or hundreds of them equipped with powerful microelectronic technology could glide in and surround enemy radar and communications with a veritable cloud of jamming signals. With no propulsion and a small amount of electronics composing the entire vehicle, microdrones can be made cheaply and be disposable on the battlefield if need be. Microdrones also require autonomy, with onboard electronic navigation to reach their targets without remote pilotage, and room for additional electronics to add functions, such as jamming capability.

For each microdrone in a swarm to be equipped with a jammer, the electronics have to be compact, have high output with low energy consumption, and be able to manage heat dissipation and terminal management. Microdrone swarms need advances such as jamming technology that fits on a chip.

Known for its integrated circuit expertise, HRL Laboratories is ready to handle these challenges. HRL engineers are developing technologies to enable chip-based microjammers including: high-speed semiconductors (40-nanometer T-gate gallium nitride technology) to obtain high efficiency (> 40%) over the very wide bandwidth necessary to jam radar and communications; HRL's unique multichip integration technology with embedded thermal heat spreaders; and low-profile reconfigurable antenna design. HRL is a world leader in microwave/millimeter-wave monolithic integrated circuit design using gallium nitride wafer technology for making very efficient broadband circuitry able to handle microjammer terminal issues. With some microdrones small enough to fit in an outstretched palm, many can be deployed without detection, and HRL's powerful microelectronics can improve their guidance and autonomous flight stability.

HRL ELECTRICAL ENGINEER JOSE CRUZ-ALBRECHT holds a neural chip he designed that contains 576 neurons with synapses that have Spike Timing Dependent Plasticity (STDP). Emulating brain structure on such chips enables drone autonomy algorithms while dramatically lowering SWaP.

The broad frequency range needed to jam most radar, cell phone, and radio communication frequencies is 2 to 18 Ghz, which is achievable by microjammers in proximity with their target with a transmission that lasts approximately 60 minutes. Other possible capabilities of swarm payloads are wireless reprogramming, wireless recharging, and collaboration between drones to complete larger missions.

"The advantages of small attritable or disposable glider drones are many," said Hasan Sharifi, HRL research scientist on the MEL team. "They are nearly undetectable on radar and even visually look more like a bird than a drone. Because they drift randomly in swarms they are hard to target." Swarms offer much more precise electronic attack with less collateral damage because the microdrones are able to fly so close to their targets without detection. Microjammers also have very small electronic signatures compared with large traditional jammers.

Drone swarms can be deployed from piloted or larger drone aircraft using devices that release the swarm a safe distance from the mothership -- or by missiles launched from ships or submarines -- without revealing launch platform position.

The Road Ahead

As with all advancing technology, HRL inventions and discoveries have applications that go beyond the initial projects that give birth to them. Technologies that reduce SWaP and enable humanlike thought in small UAVs can be translated to other areas of robotics and autonomy with limits set only by the imaginations of scientists and engineers.

Advancements such as chip-scale lidar sensors, alane fuel cell systems, and more electronically efficient nanomaterials lie on the horizon, promising new generations of UAVs with performance enhancements far beyond current capabilities. Where these technologies will have the most impact cannot be predicted fully, as new uses develop over time. Whatever direction robotic autonomy takes, HRL will strive to be at the forefront to guide its use to the benefit of all. ■

HRL GOES GREEN

HRL Laboratories began strategizing three years ago to build a new system of on-site power generation to run parallel with the existing power grid.

Building 254 Installation
It took a giant crane to install the first 5 microturbines on its Bldg 254 pad.

On the Scene
Rian Orgliano supervised the electrical installation for HRL

This cogeneration system will provide constant reliable power to keep research equipment running every day around the clock. It will provide backup power that is essential to keeping research from being disrupted by grid power dips or unexpected failures.

As a leading-edge physical science and engineering research and development facility, HRL remains sensitive to the local ecosystem of its Malibu, California community. Thus, HRL explored eco-friendly power generating methods with the smallest possible impact on the environment.

After extensive planning and construction, the final design comprises

Building 250 Capstone C1000

We installed a Capstone C1000 microturbine, which is actually five microturbine units working in conjunction.

Roger Gronwald

The Cogen Project has been championned by HRL's CFO, Roger Gronwald, who has worked diligently to bring it to life.

one generator unit for each of HRL's two buildings. Each unit has five natural-gas-fueled microturbine generators that combine to produce 1 megawatt of electricity continuously regardless of grid condition.

An additional benefit of this system is that waste heat from the generators will be collected and used to power chillers that will fulfill HRL's constant need for process cooling water.

"Generating power on site is advantageous because it eliminates electrical transmission loss, which is heat that emanates from the wires used to transfer the electricity from its source to the end user," said Roger Gronwald, HRL's Chief Financial Officer and Controller. "Our cost savings from the project based on power bill savings and HRL's overall carbon footprint reduction are estimated at 20 million dollars over 20 years."

The project began powering up in steps beginning late July 2016. The generators will run in a grid-parallel configuration, which means HRL will obtain all it's power from the on-site generators up to their capacity, then draw from the grid after that point. This will greatly relieve strain on the local power grid.

"We installed a Capstone C1000 microturbine, which is actually five microturbine units working in conjunction. The advantage with this generator is that if there is maintenance needed we can stop one turbine for repair without shutting down the whole system. We can continue generating 800 kilowatts of power during the repair," Gronwald said.

"This is especially important because every 10 years or so they have to do a major service replacing the units, so we can do that one generator at a time without power interruption."

Gronwald said that HRL used the largest generator possible given the constraints of the baseline power threshold of the building. It was also important to have maximum reuse of the waste heat. The two megawatts of combined power is the most that could be generated within the constraints.

"All of the power is being generated by natural gas, so we're comparing the efficiency of this unit to off-site natural gas generation. By utilizing the waste heat through the heat recovery unit and the absorption chiller we boost the overall system efficiency to about 70%," Gronwald said. "Even the best systems out there that utilize the waste heat for a steam cycle to add additional power generation run at maybe 60%, so just the difference in efficiency means that we going to get more power with less natural gas. That translates to annual net savings of about 4300 tons of CO_2 and 30 tons of NOX emissions. We're proud of this significant reduction in greenhouse gasses. I think more companies like ours will be trying to convert to on-site power and I encourage people to get creative, there are solutions out there." ■

"Our cost savings from the project based on power bill savings and HRL's overall carbon footprint reduction are estimated at 20 million dollars over 20 years."

A LOOK INSIDE

A WORLD-CLASS CLEANROOM

The advancement of ever smaller electronics since the 1950s has required work and fabrication space that is free of dust and other airborne particulate matter.

"Researchers and engineers can fabricate and build electronics down to the vanishingly small level of nanotechnology, where one dust particle can destroy or disable an expensive circuit."

Many attempts were made in the 50s to create fabrication environments that carefully controlled air particles. From their inception these high-tech enclosed areas were known as cleanrooms. In 1960, Willis Whitfield, a physicist at Sandia National Laboratories, designed a cleanroom system with continuous airflow through filters. Whitfield's system constantly replaced impure air and captured particles at an unprecedented rate, thus achieving the first modern cleanroom.

Most cleanrooms are actually facilities that contain many rooms of large workspace area with their own water and ventilation systems sealed off from the systems of their parent buildings. Cleanrooms are rated according to the particle count per cubic foot or meter of air. Within cleanrooms, researchers and engineers can fabricate and build electronics at nanometer scales, where one dust particle can look like a boulder and destroy or disable an expensive circuit.

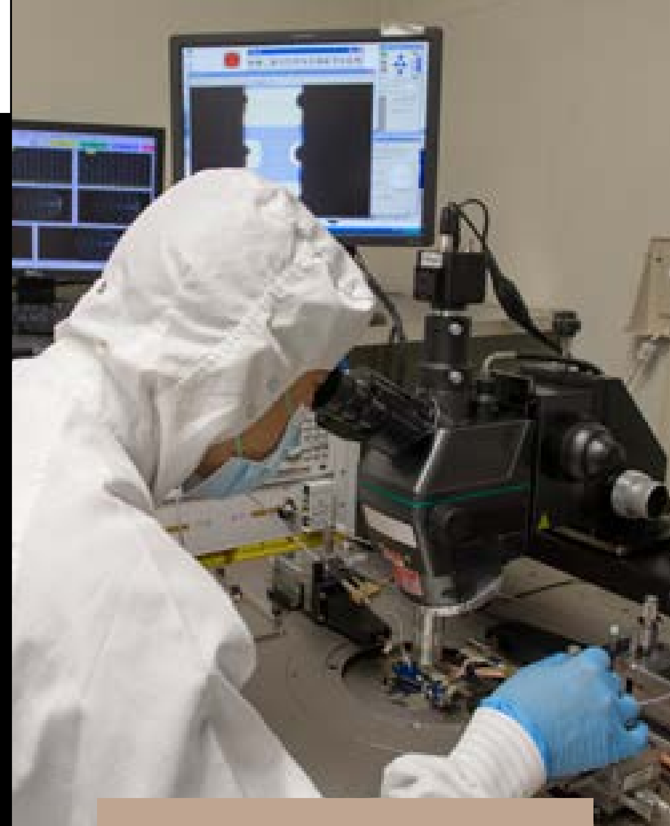
The HRL cleanroom facility is rated according to the International Standards Organization at level 4 (ISO 4), which means it can contain no more than 83 1 μm particles per cubic meter and none greater than 5 μm.

The cleanroom remains the cornerstone of semiconductor fabrication and nanotechnology at HRL. The technical staff are experienced in device design, research, and process development. HRL also collaborates with government and commercial customers to develop emerging technologies and fulfill pilot production manufacturing needs.

Other facilities at HRL that are essential to fully functional wafer fabrication of various semiconductors include:

- Atomic Layer Deposition (ALD) tools for dielectrics and metals
- Dry etch tools for semiconductor materials, dielectrics, and metals
- Metal deposition by sputtering, evaporation, and plating
- Stepper and contact photolithography tools.

The cleanroom also houses some of HRL's ten different epitaxial growth tools.



HRL's cleanroom has some unique features

- 100 keV electron-beam lithography tools able to create elements of very small electronic circuitry that are under 10 nanometers in size, approximately ten thousand times smaller than the width of a human hair;
- an FC300 die bonder for integration of different types of semiconductors onto various substrate materials, which enables specialized device design and improved performance in electronics, optoelectronics, and infrared focal arrays;
- US Department of Defense Trusted Foundry accreditation, designating HRL as a trusted provider guaranteeing the US Government access to leading-edge microelectronics services at a domestic facility.

World record performance is not unusual in the HRL cleanroom

Some recent accomplishments enabled by our wafer fabrication capabilities include:

- world-record linearity (OIP3/Pdc) from a broadband gallium nitride monolithic microwave integrated circuit amplifier
- world record noise figure from a Ka-band gallium nitride monolithic microwave integrated circuit
- demonstration of a high-performance 2.4 megapixel, 5μm pitch, mid-wave infrared camera
- demonstration and quantified atomic-scale abruptness in silicon/silicon germanium heterostructures
- demonstration of gallium nitride complementary metal oxide semiconductor integrated circuit technology.

> "Our cleanroom remains the cornerstone of semiconductor fabrication and nanotechnology at HRL. The technical staff are experienced in device design, research, and process development."

IP & AWARDS

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Here are the September highlights

PATENTS ISSUED SINCE JANUARY 2016

9,443,089 SYSTEM AND METHOD FOR MOBILE PROACTIVE SECRET SHARING • El Defrawy, Karim; Lampkins, Joshua D.

9,443,189 BIO-INSPIRED METHOD AND APPARATUS FOR FEATURE DETECTION WITH SPIKING DYNAMICS • Chelian, Suhas E.; Srinivasa, Narayan

9,444,001 LOW COST, HIGH PERFORMANCE BARRIER-BASED POSITION SENSITIVE DETECTOR ARRAYS • Sharifi, Hasan; Rajavel, Rajesh D.; De Lyon, Terence J.; Yap, Daniel

9,445,739 SYSTEMS, METHODS, AND APPARATUS FOR NEURO-ROBOTIC GOAL SELECTION • Payton, David W.; Daily, Michael J.

9,449,177 GENERAL PROTOCOL FOR PROACTIVELY SECURE COMPUTATION • El Defrawy, Karim; Baron, Joshua W.

9,449,259 OPPORTUNISTIC CASCADE AND CASCADE TRAINING, EVALUATION, AND EXECUTION FOR VISION-BASED OBJECT DETECTION • Cheng, Shinko Y.; Owechko, Yuri; Medasani, Swarup

9,449,833 METHODS OF FABRICATING SELF-ALIGNED FETS USING MULTIPLE SIDEWALL SPACERS • Regan, Dean C.; Shinohara, Keisuke; Tang, Yan; Micovic, Miroslav

9,450,022 MEMRISTOR DEVICES AND FABRICATION • Wheeler, Dana C.; Hussain, Tahir; Royter, Yakov; Wang, Eason F.

9,450,597 HARDWARE BASED COMPRESSIVE SAMPLING ADC ARCHITECTURE FOR NON-UNIFORM SAMPLED SIGNAL RECOVERY • Ahmed, Mohiuddin; Rao, Shankar R.; Ng, Willie W.

9,450,938 INFORMATION SECURE PROACTIVE MULTIPARTY COMPUTATION (PMPC) PROTOCOL WITH LINEAR BANDWIDTH COMPLEXITY • Lampkins, Joshua D.; El Defrawy, Karim; Baron, Joshua W.

9,453,604 HOLLOW POROUS MATERIALS WITH ARCHITECTED FLUID INTERFACES FOR REDUCED OVERALL PRESSURE LOSS • Maloney, Kevin J.; Roper, Christopher S.

AWARDS HIGHLIGHTS

WAFER-SCALE INFRARED DETECTORS

DARPA awarded HRL funding to research wafer-level direct integration of infrared detector material with Readout Integrated Circuits (ROICs) to drastically reduce cost and increase speed of infrared camera production. "Time-consuming, conventional die-level serial processes will be replaced with streamlined wafer-level processes," said Dr. Rajesh Rajavel, manager of HRL's infrared detector team.

"STAMP" LEARNING INTO THE BRAIN

HRL received 2 years of DARPA funding to develop a man-portable system to boost learning during waking and memory consolidation during sleep to increase a person's ability to quickly integrate and accurately recall information. The project builds upon previous HRL research that showed effectiveness of transcranial direct current stimulation in accelerating practical learning, and understanding the underlying neural mechanisms.

NEXT-GENERATION INERTIAL SENSOR TECHNOLOGY

DARPA has awarded HRL $4.3 million to develop vibration- and shock-tolerant inertial sensor technology that meets future system accuracy needs without utilizing GPS. "The ATLAS project will deliver a comprehensive approach to breaking performance and cost, size, weight, and power barriers that prevent robust, GPS-independent, military positioning, navigation, and guidance," said Dr. Logan Sorenson, Principal Investigator and Research Staff Member in HRL's Sensors and Materials Laboratory.

WHAT'S NEXT

by Leslie Momoda, Vice President

BETTER DRONES and MORE

While this inaugural issue of *HRL Horizons* highlights many of HRL's current capabilities in support of UAVs, we continue to develop new technologies to expand the future mission spaces for these platforms. With coming improvements in information control and autonomous decision making, drones will be the nodes in highly mobile, robustly redundant, rapidly configurable network-based systems. These will integrate advanced communications, power supply, payload delivery, intelligence, surveillance, and reconnaissance.

To enable small craft navigation in GPS-denied areas, we are working to break the tradeoff between miniaturizing position, navigation, and timing devices and positional accuracy through new physical sensing mechanisms and improvements in microelectromechanical device design. Our goal is highly accurate and stable chip-scale navigation devices that can be readily mounted on small UAVs.

Technologies to further decrease vehicle weight and cost are being developed, such as engineered feedstocks to allow additive manufacturing of metal alloys and high-temperature ceramics, enabling printing of complex high-performance parts on demand. HRL has also pioneered design and rapid fabrication of micro-architected materials that maximize structural performance with very low weight analogous to printable bird bones. HRL's novel, self-structuring coatings repel debris, extending drone mission space through icing environments and insect-infested conditions.

To realize autonomous navigation and decision making, HRL is enhancing its work in brain-inspired, neuromorphic hardware and software. HRL has been one of the pioneers in the area of low power, sensory processing through the development of neuromorphic chips and software algorithms. We continue to push these frontiers by incorporating contextual learning, enabling quick decisions in very complex situations. High-performance electronic materials and algorithms will also enable drone operation in contested environments.

HRL is researching technology to make vehicle software resistant to cyberattack as well. Methods under development will automatically authenticate users and identify intrusions, harden software control systems against attack, and potentially allow completely safe computing in a cloud environment.

Lowering size, weight, power, and cost will enable many new types of on-vehicle sensors. HRL has been one of the early demonstrators of non-Foster—based antenna systems that act electrically big in a small package. We also have advanced designs for conformal antennas across a wide frequency range, eliminating the "porcupine" look of multi-antennaed vehicles. We have made similar advances in infrared and multispectral regimes using HRL's semiconductor materials design and growth technologies combined with chip-scale device integration technologies for photonics.

Nestled in the mountains of Malibu, HRL's world-class facilities enable our workforce of scientists, engineers, and support staff to succeed daily as we meet the growing demands of our customers. ■

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HRL Horizons

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