NATIONAL ECONOMIC IMPACTS

from the National Nuclear Security Administration and Lawrence Livermore National Laboratory

CRADAs and License Agreements

SUCCESS STORIES

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National Nuclear Security Administration
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Success Stories

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Photo by George Kitrinos/Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory has been an incubator for innovation and economic benefit since its founding in 1952.

LASER SHARP

Laser peening technology revolutionizes metal manufacturing with fighter jet applications

In the mid-1990s, the world of lasers was booming, and the Lawrence Livermore National Laboratory in California was on the forefront. The federal lab had recently developed one of the largest high-powered lasers in the country, called Nova, and was in the process of developing a range of other high-power lasers to enable unique capabilities for printing computer chips and generating high resolution satellite imagery for the U.S. Air Force.

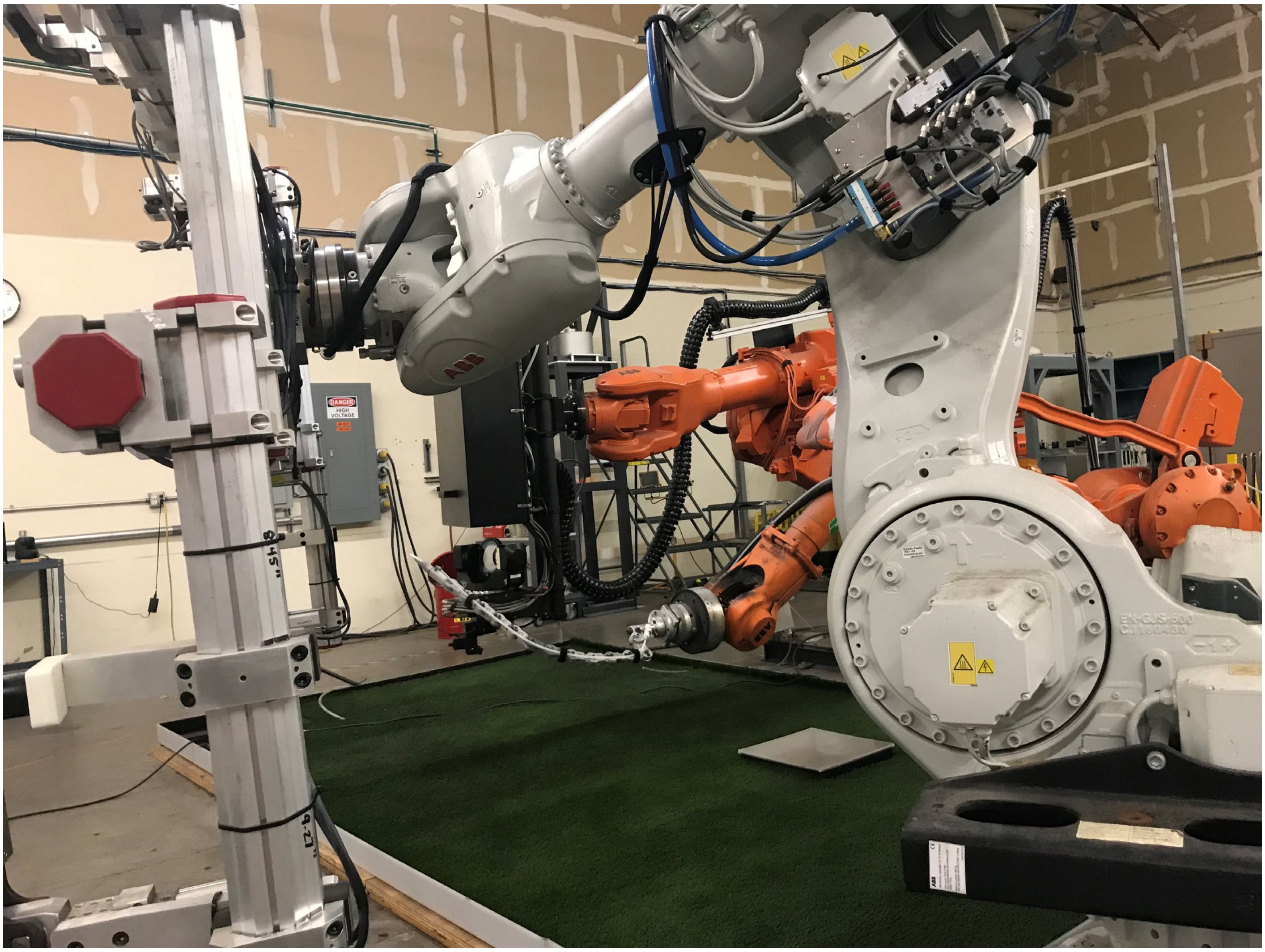
F35B Lightning II fighter jets prepare for takeoff.

Around that time, the Lab received a call from Metal Improvement Company (MIC), a New Jersey-based subsidiary of Curtiss-Wright Corporation specializing in metal surface treatments. MIC had been hearing about a new surface engineering process called laser peening that used lasers to impart beneficial residual compressive stresses into materials. But it needed both a laser capable of the processing as well as the expertise of researchers at Lawrence Livermore to further understand and refine the technique. The company proposed a Cooperative Research and Development Agreement (CRADA) between the two entities.

The resulting CRADA, in 1996, achieved a breakthrough in industrial laser capability and placed LLNL laser technology in an important industrial application. The original implementation of peening used hammers with a ball end to pound beneficial residual stress into metals—a technique that, due to the physics of plastic compression and the properties of metal, creates a crack resistant, longer lasting end product. In 1945, Henry Fuchs, the founder of MIC, introduced an advanced version of this technique, replacing hammers with metal shot that was blasted at the surface creating beneficial compressive stress. However, the advancement of lasers enabled a process that goes beyond shot peening in achieving a much deep level of compression and thus providing a greater effectiveness. This is what led to the collaboration with LLNL.

For its part, according to David Dawes, business development executive at LLNL, the lab provided laser and shock physics technology that was found almost nowhere else in the world.

"The innovation the Lab brought to the CRADA and subsequent licensed patents was the use of a high-pulse energy laser capable of sustained operation at relatively high repetition rates, and coupled this with the Lab expertise in the generation and propagation of high pressure shock waves. This was laser technology that could generate very intense pressure pulses while operating at rates meaningful for an industrial process," Dawes said. "The advanced laser design uniquely enabled firing with sustained high rate and beam quality



Three-robot system for laser peening large fighter jet structures: The foreground robot (cream colored) picks up and orients the structure for peening. The middle robot (orange with extension wand) delivers deionized water that tamps the laser peening plasma. The rear robot (orange arm holding black box) formats beam spot size, aspect ratio, and polarization for each peened spot while directing the spots on to target with 100 μm accuracy.

and the shock physics technology ensured that the pressure waves created the intended response without side effects."

The diffraction-limited beam quality, beam polarization, and LLNL expertise in image relaying were additional critical advances. With the use of relay optics and robotic arms, the developers could locate the laser remotely and propagate the beam with high quality into complicated work areas such as done currently, deep into the interior structure of the most advanced fighter jets.

As is often typical of revolutionary technologies, it took time to find a spin-out application. It was, in the words of Dr. Lloyd Hackel, a co-inventor of the peening laser technology while at LLNL and currently Vice President at Metal Improvement Company (a subsidiary of the Curtiss-Wright Corporation), a "solution looking for a problem." That problem emerged just a few years later when Rolls-Royce began experiencing fatigue issues with the fan blades on its commercial airline engines. Considering the engineering problem Rolls was having, Hackel said, the laser peening technology presented the perfect solution.

"With technical support provided by LLNL, MIC developed a solution to that problem," he said. MIC worked with Rolls-Royce on the blade peening application, laser peened half an engine set of test blades and in a full engine test, demonstrated that the laser peened blades lasted as much as 20 times longer than the un-peened blades. LLNL assisted in commercializing the laser peening process and to further demonstrate that components that were laser peened would last longer. The fan blade breakage problem that continues to trouble other engines was thus solved 20 years ago for the Rolls engines.

"What peening does is plastically deforms the metal, building a compressive field. With laser peening, unlike shot peening or roller burnishing, because we can apply each impact with a big footprint, laser peening creates plastic deformation in the metal that drives the compressive stress ten times deeper," Hackel said. "This deep depth translates into equivalently increased time before cracks initiate; we laser peen and get dramatic lifetime improvements."

Additionally, Hackel said, the CRADA helped fund high-quality research for a professor and a number of graduate students at the University of California-Davis. The work of those students continues to advance the world-wide lifetime and performance of systems.

Around 2003, MIC began working with the U.S. military laser peening components on F-22 fighter jets, and more recently on already-built F-35 B and C models.

"It was fundamental physics coupled into a practical application," Hackel said of the CRADA. "We had funding within the Lab via the Department of Defense to develop the laser for illuminating satellites and making x-rays, but having a commercial industrial company come to the Lab and recognize that we had unique technology and to apply it to an industrial application, is where the CRADA agreement enabled dual use."

Around 2003, MIC began working with the U.S. military, laser peening components on F-22 fighter jets, and more recently on already-built F-35B and C models, to prevent serious structural lifetime limitations. This work is solving a lifetime shortfall enabling these problems to be solved without adding even an ounce of weight to the aircraft. Structures for all new F-35B aircraft now come to MIC's Livermore facility for laser peening, resolving the problem less expensively before the aircraft are built.

MIC's commercial applications have included working on engines of Airbus and Boeing airliners, as well as gas turbines for GE and Siemens, and nuclear facility waste canisters. Components now come to the Livermore facility from Mexico, Italy, and other countries for the unique laser processing. Laser peening is slowly becoming ubiquitous, Hackel said, thanks in part to the company's modeling that can virtually simulate the results of the laser peening and quickly demonstrate to companies the technology's effectiveness. MIC went on to develop transportable peening systems that allow them to bring the peening capacity right to manufacturers' facilities.

"We are more and more transitioning from being a band-aid to being the industry standard, enabling higher performance and lighter weight right at the design stage," Hackel said.

The technology has further areas for growth, he added. Hackel is currently working on combining laser peening with annealing, which has shown promise for higher temperature performance of super alloys, additive manufactured (3D printed) metals, and ceramics that need to function under extreme temperature and stresses. Immediate applications are focused on the hot-running turbine section of jet engines and natural gas turbines as well as components for new sCO2 (Supercritical Carbon Dioxide) reduced greenhouse-gas free electric power generation. Both he and the researchers at LLNL recognize the importance of the CRADA program in getting the company to this point, as well as buoying both commercial and U.S. military equipment with advanced manufacturing capabilities.

"CRADAs have the great benefit of a protected environment to conduct a collaboration using the resources the Lab has, which is a world-leading set of resources, in a relatively simple way," Dawes said. "When we can engage with partners through a CRADA, it is a great agreement."

COMPUTER CRASHES

Software developed at Lawrence Livermore National Laboratory helps modernize the field of car crash simulations

Electric vehicles—whether hybrid, plug-in hybrid, or all-electric—are rapidly becoming a more common sight on American roads. According to the U.S. Department of Energy (DOE), a record 761,000 electric vehicles were sold in 2020, representing the fifth consecutive year of growth. The market share of these cleaner, greener cars is expected to reach almost a third by 2030, with Europe and Japan joining the U.S. as leading regions.

Given the growing demand, one concern from car makers and government agencies involves battery safety. Most electric vehicles use lithium-ion batteries, the same kind found in consumer electronics like cell phones and laptops. Traffic accidents and fire incidents can damage the lithium-ion battery, leading, in worst case scenarios, to fires and explosions.

To better understand the threat to occupants, responders, and those involved in post-crash operations, Livermore Software Technology Corporation (LSTC) worked closely with Ford Motor Company to create computational models of lithium-ion batteries. LSTC successfully adapted its core software technology, LS-DYNA, into an accurate, user-friendly, and cost-effective program for battery safety simulations. LS-DYNA is a multi-module software package capable of simulating complex, real-world problems for the automotive, aerospace, civil engineering, defense, manufacturing, nuclear, and biomedical industries.

"Modeling a car crash was one of the first and biggest applications of LS-DYNA, and since the automotive industry is developing more hybrid and electric cars, it was important to be able to see how a battery behaves during a crash," said Pierre L'Eplattenier, Senior Scientist at ANSYS, Inc., which acquired the Livermore, California-based company in 2019. "Now it is available to all car makers and is being used more and more, not just in the U.S. but also in Europe and Japan."

What makes LS-DYNA unique is that it can incorporate multiple aspects of physics—such as mechanics, electromagnetism, and thermal processes—into each simulation. To build up the electromagnetism module, L'Eplattenier and his colleagues got a much-needed helping hand from DOE's Lawrence Livermore National Laboratory (LLNL). In 2006, LSTC was awarded a Copyright License Agreement (CLA) to utilize FEMSTER Software, v. 2.0 technology from LLNL. FEMSTER was something called a finite element library, and it allowed LSTC to incorporate electromagnetic fields, electromagnetic forces, and current into LS-DYNA. A finite element library is a toolkit that provides fundamental building blocks for developing finite element algorithms.

"Without FEMSTER, I'm not sure we would have started an electromagnetism module in LS-DYNA at all. Bringing in FEMSTER was really a key part," said L'Eplattenier. "Now we have developed a lot of things on top of it, but for the roots as a starting point, this technology was very important."

LSTC itself began as a spin-off company from LLNL, founded by John O. Hallquist in 1987. At LLNL, Hallquist developed DYNA3D, a massive finite-element program that could model large deformations in metal and other stiff materials as a result of collisions and explosions. Finite-element programs break large domains into simpler parts—for example, dividing the sides of a building into many small triangles—in order to solve complex equations that arise in engineering and mathematical modeling.

After kicking off collaborations with the automotive industry, Hallquist decided to start his own company to commercialize a public-domain version of DYNA3D, which eventually became known as LS-DYNA.

"The fact that it did bending, folding, and collapsing of metal structures got the attention of the automobile industry. In the mid-1980s, John left LLNL to develop the code in the direction that the automobile industry needed," said Roger Werne, Senior Advisor for the Innovation and Partnerships Office at LLNL. "That code basically pioneered the entire field of automobile crash simulation. LS-DYNA was the original code that could do that, and it was really quite good."

"Most of the world doesn't realize how much of our day-to-day technology comes out of national labs."

Today, LS-DYNA is the primary crash analysis tool utilized by over 80 percent of the world's major automotive manufacturers. It has saved car makers like General Motors billions of dollars by eliminating the need for expensive collision testing with actual vehicles.

Early on, however, the program only took mechanical modeling into account. In the 1990s, thermal processes were added to the program to make it a true multi-physics simulation, followed by electromagnetism and fluid dynamics modules from 2004 onwards.

Licensing FEMSTER from LLNL served as the starting point for the electromagnetism code within LS-DYNA. FEMSTER saved L'Eplattenier and his colleagues significant amounts of time in terms of generating the foundation needed to use smaller elements—three dimensional shapes such as tetrahedrons, hexahedrons, and wedges—that make up the larger structure.

The CLA to utilize FEMSTER allowed LSTC to couple mechanical, thermal, and electromagnetic responses in battery safety simulations for electric vehicles, along with several other real-world problems. One of the more innovative of these applications was electromagnetic forming, a method for shaping aluminum that uses high-intensity pulsed magnetic fields to induce a current, generating a strong repulsive magnetic field in the aluminum. This extremely fast process can push the aluminum onto a shaped die, without being pressed mechanically..

"Magnetic metal forming allows the aerospace and automotive industries to replace a lot of parts that were previously made by steel with aluminum, which is much lighter," said L'Eplattenier. "At the time, LS-DYNA was the only code that could do these kind of magnetic metal forming simulations."

Another project, currently in progress, attempts to model the electrophysiology of the human heart. The propagation of electric waves in the heart triggers the contraction of the four chambers, two upper chambers (atria) and two lower chambers (ventricles). Simulations of this process, along with fluid dynamics of blood flow, can be used to study heart conditions like arrhythmia or the effects of medicine. Such a model could also help surgeons determine whether a procedure would be beneficial for a given patient.

All in all, LS-DYNA has enabled researchers, private companies, and government organizations to accurately simulate tests before building complete prototypes. ANSYS sells the program to several agencies of the U.S. government, including the DOE, National Nuclear Safety Administration, Department of the Navy, NASA, and the Federal Aviation Administration.

"That's one of the nice things about having a successful technology transfer with a start-up company that started up and continues to grow. When they have those connections and roots with a national lab, it's common for us to see them come back with other needs, as LSTC did with FEMSTER," said Charity Follett, Business Development Executive at LLNL. "Most of the world doesn't realize how much of our day-to-day technology comes out of national labs."

PIVOT POINTS

A CRADA with Lawrence Livermore National Laboratory supports molecular testing

The Rheonix Microfluidic disposable CARD cartridge, "a fully integrated microfluidic device in which DNA extraction, purification, amplification and detection are completely automated," allows for the processing of four patient test samples simultaneously.

After completing clinical trials for his company's molecular-diagnostics technology in 2019, and submitting an application to the Food and Drug Administration (FDA), Rheonix CEO Greg Galvin was eager to see the laboratory tests—called assays—applied in healthcare settings.

Then the pandemic struck.

Galvin, who has published 20 technical scientific papers and holds 58 patents, and his team at Rheonix in Ithaca, New York, adapted the technology (originally intended for sexually transmitted infection (STI) testing), to perform COVID-19 testing. The result, in April 2020, was one of the first COVID-19 molecular-diagnostic assays available in the U.S. under Emergency Use

Loading the Encompass Workstation from Rheonix

Authorization (EUA) by the FDA.

Today, Rheonix's two molecular-testing workstations—the Encompass MDx and Encompass Optimum™—are widely used around the country, for COVID-19 testing as well as non-clinical applications in the food and beverage industry.

"It was a pretty easy pivot," Galvin said of the quick transition from STI to COVID-19 applications.

The reason for the seamless conversion was the cutting-edge technology underpinning the systems, which was shaped through a 2004 Cooperative Research and Development Agreement (CRADA) involving Rheonix's predecessor company, Kionix, founded by Galvin in 1994, and the Lawrence Livermore National Laboratory. That agreement aimed to develop a portable cell maintenance system for rapid toxicity monitoring. After Rohm Co. acquired Kionix in 2009, Galvin started Rheonix, which utilized the technology developed from the CRADA to build new molecular-testing devices.

"It's not a causality type of story where one can point to, 'We did this under the CRADA that resulted in this particular invention that became this particular product,'" Galvin said. "It was more of an evolution. The CRADA was part of the ongoing technology development that ultimately became the products that Rheonix has brought to the marketplace today."

Rheonix says Encompass MDx and Optimum™ provide "a one-stop solution, from raw sample to result, for molecular testing needs today and in the future." Galvin noted that the two stations are "really the same instruments with distinct names." He added, "The only difference between them is the MDx is designed to run FDA-cleared assays for clinical applications and the Optimum is non-clinical," he said.

One of the Optimum's current non-clinical applications is pathogen testing for the brewing industry. Galvin said the traditional way of testing for contamination in beer is to grow cell cultures in Petri dishes for seven days. The Optimum’s assay can detect spoilage pathogens in five hours. Galvin said both small microbreweries and large global brands use the Rheonix testing systems.

The other non-clinical application is an assay that detects the presence of listeria in food-production facilities. Amid a proliferation of food recalls in recent years due to listeria outbreaks, the Optimum’s arrival to the marketplace is well timed. Galvin notes that he subscribes to an industry newsletter for food safety and sees something nearly every day about listeria.

“Getting into the food-testing industry has been challenging, but the need is very real,” he said.

On the clinical side, soaring demand for COVID-19 testing prompted Rheonix to scale up rapidly, which Galvin said will benefit the company as it seeks to expand the workstations’ approved uses, including plans to circle back to STI testing.

“We’re still doing a lot of COVID but also getting back to our original business plan,” Galvin said. “The pandemic forced us to grow much more quickly than we would have otherwise and enabled us to serve other aspects of the market. Just by virtue of manufacturing in high volumes for many months on end, you get a lot better at what you’re doing, more efficient, costs come down.”

Streamlining the workstations’ functionality is the disposable Rheonix CARD cartridge, a fully integrated microfluidic device in which DNA extraction, purification, amplification and detection are completely automated, allowing for the processing of four patient test samples simultaneously. The Rheonix CARD allows the workstations to test more samples in less time while reducing operator error and increasing accuracy.

“That’s where all the actual work happens,” Galvin said of the cartridges. “The workstation runs the analysis off of the CARD.”

The cartridges, which combined with reagents form the testing “kits,” also allowed for Rheonix’s major scale-up during the pandemic, in which capacity grew from 5,000 tests per week initially to 120,000 tests today.

“None of the molecular diagnostic companies could meet demand—labs had an instrument but couldn’t get enough of the kits to run the instrument,” Galvin said. “As we placed more and more instruments in hospitals, we made a conscious effort to produce enough of the kits to keep the instruments running.”

Galvin said smaller regional hospitals in rural areas have particularly benefited from the technology, giving them the ability to achieve accurate testing with quick results simply by placing a workstation or two in their facility. The workstations measure two by three by two feet and can fit on a standard lab table.

Among other degrees, Galvin holds a Ph.D. in materials science from Cornell University. And during his Ph.D. research, Galvin frequently collaborated with national labs, giving him an up-close view of federal research. In the years since, he has been involved in efforts through both CRADAs and the Small Business Innovation Research (SBIR) program. He says such government programs are invaluable for innovation in the U.S.

“Over the many years I’ve had a lot of different engagements with the government research enterprise,” he said. “CRADAs and related mechanisms are really important for getting the private sector to be able to tap into this vast knowledge base and technology development activity of the broader federal research ecosystem.”

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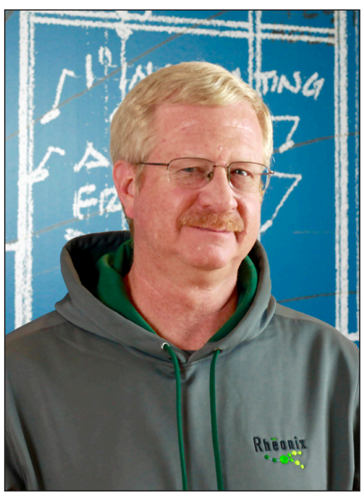


Greg Galvin

ROCK STAR TECHNOLOGY

A patent license agreement paves the way for affordable and efficient detection of nuclear materials

The U.S. Department of Homeland Security and other departments involved in the security of the United States have, for decades, acknowledged the importance of identifying nuclear radiation. Refining technologies that can readily detect and identify specific types of radiation has been an urgent need, not only in the interests of health and human safety, but also to enforce treaty compliance and nonproliferation agreements. Key to these technologies have been certain types of crystals whose qualities can be harnessed to emit light in the presence of radiation.

Lawrence Livermore National Laboratory (LLNL) in California has been a key player in the areas of crystal research and development. Initially propelled forward in this arena by Natalia Zaitseva, who joined LLNL in 1993, Zaitseva's pioneering work in the development of rapid growth technology for large-scale crystals led to improvements in the growth and production of crystalline stilbene, an organic material with potential applications in the world of radiation detection. Stilbene is a scintillator, a material that lights up when struck by high energy radiation. Importantly, stilbene can also distinguish between neutrons and gamma-ray radiation.

Given these properties, stilbene crystals have long been recognized as the perfect tool for nuclear material detection. Until recently, however, they were considered difficult to grow and prohibitively expensive for most uses. A recent Patent License Agreement (PLA) between LLNL and New Jersey-based Inrad Optics, promises to remove those barriers, offering a cutting edge, efficient detection tool, available to both government agencies and private industry.

Inrad Optics was founded in 1973 and

Stilbene crystals presented in their Inrad Optics housing.

Amy Eskilson

Candace Lynch

is an industry leader in crystal growth and precision fabrication of crystal optics. The company was granted a PLA with LLNL in 2016 to utilize solution-grown crystal technology for neutron radiation detection. This solution-growth method was revolutionary, according to Dr. Candace Lynch, director of crystal growth at Inrad Optics. Prior to its development, stilbene crystals were produced by melting material and cooling it to grow a crystalline solid, which proved slow and costly. This method, according to Lynch, "was not considered suitable for producing sufficiently large crystals of stilbene economically."

However, the solution- growth method licensed from Livermore "allows the material to be grown in considerably larger sizes in a cost-effective manner," she said.

Practically speaking, this has meant the company has scaled up the process to yield crystals which are large enough for most real-world applications. Inrad has been further refining the technique, studying the crystals they've produced and developing different form factors and packaging options to suit the varied needs of researchers.

Inrad was also able to take that initial PLA and spin it out into multiple Small Business Innovation Research (SBIR) awards, with the funding being used in an effort to further develop the processes for crystal growth and fabrication to commercialize solution-grown stilbene.

"Without those initial tests conducted under the PLA, we wouldn't have had a compelling SBIR proposal," Lynch said. "That was critical for us to take it from an idea to commercial execution."

"All of our stilbene work has centered on fast neutron detection, which is key for nuclear materials detection," added Amy Eskilson, President and CEO of Inrad. "Our mission is to have a commercial adoption.

"The use, nationally and internationally, has been really broad," she said.

In the U.S., stilbene crystals have shown promise for applications that use active interrogation to detect fissile material, such as vehicle and cargo scanning and testing of uranium in nuclear fuel assemblies. They have also been utilized by researchers at the Department of Energy and National Nuclear Security Administration facilities to develop next-generation methods for identification, imaging, characterization, and mass determination of fissile materials such as uranium oxide and plutonium.

Eskilson and Lynch both acknowledged the role played by the PLA, and later the SBIRs, in helping the company bring the state-of-the-art crystals to market.

"We probably would not have been able to pursue this very focused effort without these agreements," Eskilson said. "They were essential for us."

"We're motivated by the potential of this material to make a difference in people's lives and our national security," Lynch added. "And these partnerships have been instrumental along the way."

"We probably would not have been able to pursue this very focused effort without these agreements," Eskilson said. "They were essential for us."

CHIPS ON THE TABLE

A CRADA between the Department of Energy and multiple industry partners creates groundbreaking production capabilities for silicon chips

In scope and significance, the Department of Energy (DOE) extreme ultraviolet lithography (EUVL) program could be compared to the Manhattan Project during World War II. Both programs had monumental challenges that required a unique partnership between the U.S. government, U.S. industry, and foreign government partners. In addition, both programs were critical to U.S. national defense and economic interests.

DOE labs began research on EUVL technology in the early 1990s. At the time, semiconductor manufacturers were facing limitations in the manufacture of silicon chips. The prevailing technology was about to reach the threshold of the number of transistors that could be manufactured on a chip. EUVL was being explored as a replacement technology to break through the barrier on transistor density.

Why are smaller chips important? The smaller the chip, the more can be embedded on a wafer at minimal additional cost. More chips on a wafer mean greater speed and more functions packed into a smaller area which leads, in turn, to more computing power with less heat. These innovations would lead, in turn, to the development of smaller more efficient devices like cell phones and iPads. In the 1970s, a chip had thousands of transistors. Today there are chips with 20 billion transistors.

In the initial stages of EUVL research, DOE laboratories entered into a Cooperative Research and Development Agreement (CRADA) with several large U.S. chipmakers acting in collaboration. By 1996, three DOE labs—Lawrence Berkeley (LBL), Lawrence Livermore (LLNL), and Sandia National Laboratories (SNL)—provided funding estimated at $30 million, matched by contributions from eight participating firms, including Intel Corporation, to develop the EUVL technology. In a 1998 *Science & Technology Review* article, Don Sweeney, Livermore's EUVL program manager said, "Intel came to us because we are the world leader in technology for EUV lithography." He then continued, "Our work grew out of our national security mission, and our multidisciplinary workforce allows us to integrate the technologies needed for this project."

To help fund the EUVL research, Intel searched for more partners to help underwrite the cost. Their search led to the formation of the Extreme Ultraviolet Limited Liability Company (EUV LLC). Intel at the time was the majority shareholder in the LLC while Advanced Micro Devices, IBM, Infineon, Micron Technologies, and Motorola were shareholders. The LLC would serve as a CRADA partner with the DOE laboratories.

Under the LLC, the three DOE laboratories combined into a single unit, called the Virtual National Laboratory (VNL). Rick Stulen, a Sandia scientist and chief operating officer of the VNL, indicated that the labs decided to work together to provide a single interface for their corporate counterparts. In effect, the laboratories would channel all their interactions with LLC companies through the VNL. VNL work was to

The EUV Lithography system, shown here as a commercialized product, was created by a highly unusual collaboration between industry partners and the Federal government.

demonstrate proof of concept by building a fully functional prototype "engineering test stand."

Each laboratory brought unique contributions to the VNL. For example, LLNL supplied its expertise in optics, precision engineering, and multilayer coatings while SNL provided systems engineering, the photoactive polymer thin film exposed by the light, and the light source. LBL contributed its Advanced Light Source capability to generate EUVL light to characterize optics and resists at the nanometer scale.

According to David Attwood, LBL's point man on the project, there were many challenges for the laboratories and the companies to collaborate effectively, but mutual commitment to the project helped them succeed. "I've been in multi-lab projects before, but they just split up the tasks," Attwood said. "Here, everybody's working on everything..." He added, "The amazing thing is that this has engendered the attitude of a single program."

Jim Glaze, VNL's executive director, noted at the time that individuals and scientific teams involved in the project demonstrated exceptional willingness to cooperate across institutional boundaries. "A lot of people have been working very hard over the last few months to work out this agreement," he said.

Intel's Chuck Gwyn, general manager and program director of the LLC, said at the time, "When this project is completed, it could easily represent a paradigm shift in terms of the way in which complex development activities are approached."

In order to ensure the acceptance of EUVL as a global standard for next generation lithography, LLC members admitted ASML Holding N.V., a company based in the Netherlands, into the CRADA. The member companies realized the costs of developing an EUVL system were so great that commercial viability would require both U.S. and foreign sales. Jim Glaze, VNL director, said the agreement "was a necessary step to achieving international acceptance" of EUV technology.

Negotiations with ASML were led by Mary Egger, Deputy General Counsel, and Paul Gottlieb, Assistant General Counsel for Tech Transfer and IP (retired). "The agreement followed DOE guidelines with respect to U.S. manufacturing." Mr. Gottlieb continued, "DOE negotiations maximized the benefit to the US economy in light of the economic reality about where chips were manufactured at the time...The chips would be made available to US companies to use."

Gottlieb concluded, "That is the goal when you deal with these U.S. manufacture waivers. You take a look at economic reality and then you try to negotiate the maximum net benefit to the U.S. economy notwithstanding the political pressure."

Successful development of a production quality EUVL source will allow the semiconductor industry to reduce the cost of chips and thereby allow LLNL and the DoE/NNSA to more rapidly increase the computational resources that they can acquire.

ASML wasn't the only international company involved in the EUVL project. Early EUVL infrastructure work took place in Japan particularly on resists and mask blanks. European companies ASML, ZEISS, and TRUMPF also made significant contributions to the EUVL technology.

The LLC eventually licensed the EUVL technology to ASML for commercialization. Although the EUV LLC CRADA was initially funded for $250 million over three years, ASML spent more than $9 billion dollars over nearly 20 years to fully commercialize the technology, requiring optics redesigns, source approach changes, flexible illuminator development, and significant effort on vacuum chamber and components cleanliness.

The provisions of the CRADA gave the EUV LLC complete ownership of the EUVL IP developed within the program. The rights retained by the LLC were subject to retained government rights that included a royalty-free government license and certain requirements to promote U.S. manufacture of any new technology. The DOE retained the right to use the technology, royalty-free, for use in defense applications.

ASML developed six generations of tools to get to the production tool. The first EUVL machines for mass production were completed in 2017. The current generation of EUVL machines are roughly the size of a bus and cost $150 million each. Shipping the machine to customers requires 40 shipping containers, 20 trucks, and three Boeing 747s. ASML's senior vice president of technology, Jos Benschop, indicated that, as of January 2021, ASML had sold their 100th EUV machine.

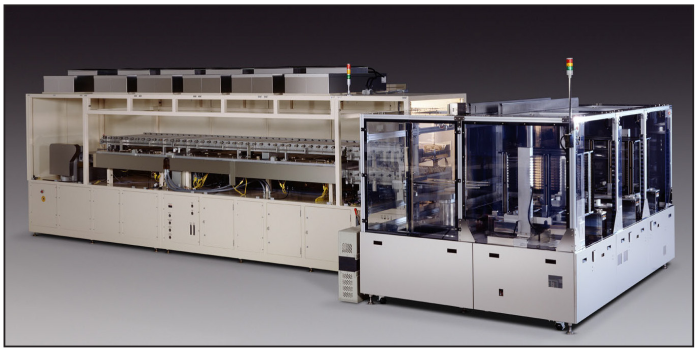
According to a LLNL report, successful development of a production quality EUVL source will allow the semiconductor industry to reduce the cost of chips and thereby allow LLNL and the DOE/National Nuclear Security Administration (NNSA) to more rapidly increase the computational resources that they can acquire.

The switch to EUV Lithography in manufacturing is predicted to broadly impact the entire semiconductor industry. According to World Semiconductor Trade Statistics, the semiconductor industry in 2021 is estimated at U.S. $527 billion worldwide.

Coherent Market Insights (CMI) reported the global EUV lithography tools and related technologies market was estimated at U.S. $4.6 billion in 2020 and predicted to be $29.6 billion by end of 2028.

FLAT-OUT BRILLIANT

A PLA with Lawrence Livermore National Laboratory expedited flat-panel display manufacturing



A process system developed from an LLNL patent license agreement facilitated the production of flat-panel displays.

In an age when everybody wants to have crystal-clear, high-resolution imagery on their cell phones, one company perfected a product to deliver just that, with an assist from the Lawrence Livermore National Laboratory (LLNL).

In October 2002, Photon Dynamics, based in San Jose, California, obtained the license, from LLNL, to commercialize a diffuse reflector technology. Photon Dynamics' patent license agreement (PLA) was awarded for the production of equipment and apparatuses used in manufacturing flat-panel displays.

"The technology that was licensed is basically a highly reflective diffuse reflector and long arc lamp," said Jeff Hawthorne, who took over as Photon Dynamics' CEO in 2003 and is today the CEO of OJVP Corp.

Displays are manufactured by patterning individual pixels on a glass substrate through a semiconductor process that involves thin layers of metals and oxides arranged photolithographically to create pixel circuits. Photon Dynamics' product included two different pieces of equipment. One was a horizontal system to transfer the sheets of glass substrate, while the second involved a cassette in which the sheets of glass were loaded into the machine by a robot.

Heating elements are needed to facilitate the process, and Photon Dynamics' product included two different kinds of arc lamps to heat the sheets of glass, deposited films, deposited silicon and metal films. The product applications were the crystallization of amorphous silicon to form polysilicon and to activate the silicon doping process.

Hawthorne said the products were initially promising for Photon Dynamics, with companies such as Sharp, Innolux, and Samsung using the products in their flat-display manufacturing processes. "There were a number of these systems that were manufactured and sold to these display manufacturers," he said.

Hawthorne emphasized that federal programs that spur tech transfer to the private sector play a significant role in entrepreneurship. The PLA, he noted, was instrumental in the success of the Photon Dynamics flat-panel display product. And while that product was later discontinued, elements of the experience demonstrate how a PLA can have far reaching effects, even beyond initial market return.

"Having this technology available and having it mature enough to put into a product really helped jump-start that product line," Hawthorne said. "The product was successful early on. The market unfortunately took longer to develop, which happens all the time with technology…(The PLA) saved years of development and uncertainty by being able to access that technology through the license. Trying to develop something from the ground up is a potentially riskier and much more costly process."

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