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NIF Optics and Photonics

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Teaming Up to Harness the Power of Light

Not many government construction projects have spawned a whole new industrial capability to support them—but that's what was needed to build the Department of Energy's National Ignition Facility, usually shortened to NIF.

Now nearing completion at Lawrence Livermore National Laboratory, NIF is the world's largest and highest-energy laser. It's also the biggest optical instrument ever built; the stadium-sized facility houses some 7,500 meter-sized optics and about 30,000 smaller optics, all working together to focus the intense energy of 192 giant laser beams on a tiny hydrogen target the size of a BB. NIF's goal is to compress and heat the target to the point where the hydrogen nuclei fuse and "ignite" in the world's first controlled thermonuclear reaction—releasing more energy than the laser energy required to initiate the reaction.

NIF is an experimental cornerstone of the National Nuclear Security Administration's Stockpile Stewardship Program for maintaining the safety and reliability of the nation's nuclear deterrent without nuclear testing. NIF also will provide the scientific basis for fusion's long-term potential as a clean, safe and virtually boundless energy source; and it will enable unprecedented research in astrophysics, materials science and a variety of other disciplines.

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Laser Bay 2, one of NIF's two laser bays, was commissioned on July 31, 2007

NIF experiments already have demonstrated that its lasers are capable of producing the energy levels needed to achieve ignition. When construction is completed in March of 2009, additional experiments will enhance understanding of the processes that are required to ensure fusion. A careful course of research, using many different diagnostic techniques, will be followed along the path to the first attempts at ignition in 2010.

To get to the verge of this historic scientific breakthrough, the NIF project had to overcome a wide variety of research and development, technology and engineering challenges—not the least of which was procuring the optical components needed to build the lasers.

Not Exactly Off-the-Shelf

"You don't go to the Yellow Pages to find the kind of optics we needed," says NIF's Erik Storm, a veteran of LLNL's laser programs. "They just didn't exist when we started (in the mid-1990s). We basically had to go out and work with the optics industry to create a worldwide large optics fabrication capability."

And fabricating the optics was just the beginning. NIF's optical specifications also required state-of-the-art measurement and coating techniques and new methods for amplifying the laser beams to the needed energy levels.

Working in tandem with major optics vendors such as SCHOTT North America, Inc.—Advanced Optics, Hoya Corp. USA, Cleveland Crystals, Inc., Kodak, ITT, Zygo Corp., Tinsley Laboratories, Spectra-Physics and the University of Rochester's Laboratory for Laser Energetics, the NIF scientific and engineering team made order-of-magnitude improvements in manufacturing precision large optics, including continuous-pour glass, rapid-growth crystals, optical coatings and new finishing techniques that can withstand NIF's extremely high-energy lasers.

"We look at these suppliers as partners," says Ed Moses, LLNL Principal Associate Director for NIF and Photon Science. "Through the entire development and pilot-production period we shared in the technology development with them to reduce the risk of achieving production capability for quality and rate.

"Generally, once they reach that capability we have a cost basis for their production, and then we go on to regular contracts."

"I felt very strongly that American industry could do a very large portion of what we needed if we provided the technology development, scale-up monies, and so forth," adds John Emmett, former LLNL associate director of laser programs.

"And we really enforced that, and developed a whole series of first-rate industrial organizations that have supported the Laboratory from our earliest laser projects all the way through NIF."

Ribbons of Glass

A classic example of such public-private partnerships is the production of NIF's laser glass, the material that amplifies the laser light to very high energy. NIF's laser glass is a phosphate glass that contains a chemical additive with atoms of neodymium. The NIF laser system uses about 3,070 large plates of laser glass, each about two inches thick, three feet long and about half as wide. If stacked end-to-end, the plates would form a continuous ribbon of glass 1.5 miles long.

To produce this laser glass quickly enough to meet construction schedules, NIF used a new production method developed in collaboration with SCHOTT, of Duryea, Pennsylvania, and Hoya, of Fremont, California, that continuously melts and pours the glass. Once cooled, the glass is cut into pieces that are polished to the demanding NIF specifications. The continuous-pour process, which won a 2001 R&D 100 Award, produces high-optical-quality glass 20 times faster and five times less expensively than had been possible using previous one-slab-at-a-time batch-melting technology.

“In the case of both Hoya and SCHOTT, they did the machine and design engineering and came up with all the chemicals we’d have to buy,” says LLNL chemist Jack Campbell. “Livermore bought the equipment they needed and they built a plant with all this Livermore-furnished equipment. This had never been done before at this scale.

“We didn’t know if it would work—you have to have a lot of patience with your partner and yourself, and there are some pretty bleak times,” Campbell says. “It took about five years to develop the process and build the plant until it was ready to go. The first couple of runs were far from satisfactory but we persisted. When you have partners who work with each other and trust each other, you know that you can succeed.”

The fabrication of melted and rough-cut blanks of laser glass amplifier slabs needed for NIF construction (3,072 pieces) was completed in 2005. The amplifier slabs are neodymium-doped phosphate glass manufactured by SCHOTT North America, Inc.—Advanced Optics and Hoya

Corp.USA. Here an employee at Hoya inspects a sheet of glass as it moves down the assembly line.

Along with NIF, the French Commissariat à L'Energie Atomique (CEA), which helped fund the research and development effort, will use slabs from the continuous-pour process for its Laser Megajoule, a NIF-like laser facility now under construction near Bordeaux, France. In addition, both SCHOTT and Hoya are applying several new technologies developed for the process to the manufacture of other optical glasses, including the most common optical glass, BK-7, in large sizes. BK-7 is commonly used to manufacture optics for cameras, binoculars and precision optical instruments. Other aspects of the process are being used to improve the manufacture of glass used in digital cameras, hard-disk-drive substrates, liquid crystal displays, projector lenses and telecommunication devices.

Fast-Growing Crystals

Another crucial material in NIF is potassium dihydrogen phosphate (KDP) crystal, which is used in the beamlines for frequency conversion and polarization rotation. NIF laser beams start out as infrared light, but the interaction of the beams with the fusion target is much more favorable if the beams are ultraviolet. Passing the laser beams through plates cut from large KDP crystals converts the frequency of their light to ultraviolet before they strike the target. KDP is also used in NIF’s optical switches, which allow laser beams into the amplifiers and then rotate their polarization to trap the beams in the amplifier section. The trapped laser beams can then increase their energy much more efficiently during multiple passes back and forth through the energized amplifier glass.

This potassium dihydrogen phosphate (KDP) crystal, weighing almost 800 pounds, was produced through a newly developed rapid-growth process that takes only two months, as opposed to two years using conventional methods. Each crystal is sliced into 40-centimeter-square crystal plates. More than 500 of these plates are needed for NIF.

For NIF's optics, about 500 large slices of KDP were needed. Using traditional crystal growing methods, it would have taken more than two years to grow crystals with the required large sizes. In the early 1990s a fast-growing method, pioneered in Russia and perfected at Livermore, produced high-quality crystals at the required size in just two months. In addition, the size of the rapid-growth crystals is large enough that more plates could be cut from each crystal, so a smaller number of crystals were able to provide NIF with the same amount of KDP. LLNL also teamed with Cleveland Crystals to improve the quality of deuterated KDP produced by CCI's own technology. Cleveland Crystals upgraded its facility in order to perform the entire process, from growing crystals weighing up to 1,500 pounds through finishing. Both the rapid-growth crystal technology and the optical switch won R&D 100 awards.

Helping Grow the Industry

The results of LLNL optics R&D also include optical surfaces and coatings of extraordinary quality and optical characterization metrology of unprecedented precision. "If you look at the final focusing optics," says Moses, "between Corning, Heraeus, Tinsley and Zygo, we are making glass that has the highest surface quality." NIF's final optics, which convert the laser beams' wavelength from infrared to ultraviolet and condition and focus the beams for the final stage of their trip to the NIF target, will play a key role in the facility's success in achieving its goal of creating a miniature sun in the laboratory.

By transferring LLNL technology and collaborating closely with vendors on new technology development, LLNL has reshaped the technology infrastructure and stimulated significant growth in the precision optics industry. "Since we started, we have actually increased the large-scale optics production capability in the world by a factor of five," says Moses."

Sidebar: Lasers, Lasers and More Lasers

Lawrence Livermore National Laboratory (LLNL) does vital research in a wide variety of disciplines—from chemistry and bioscience to nuclear nonproliferation and homeland security—and the science of lasers and photonics has been tightly woven into the Laboratory's research portfolio almost since the first laser was created in 1960.

For most of the last four decades, Livermore has been home to the world's highest-energy lasers, from the two-beam, ten-joule Janus laser in 1974; to Nova, which operated at Livermore from the mid-1980s through the 1990s and produced 30 kilojoules of energy and 25 terawatts of power; to the present-day National Ignition Facility (NIF), a giant, 192-beam facility that will be able to generate 1.8 million joules of ultraviolet laser energy and 500 terawatts of power when it's completed in March of next year. (A joule is the amount of energy required to lift a small apple one meter against the Earth's gravity). NIF's powerful lasers will focus on a tiny hydrogen-filled target, heating and compressing it until a nuclear fusion reaction takes place. The self-sustaining reaction will result in the long-sought goal of fusion research: *energy gain*—the release of more energy than the laser energy required to initiate the process.

Today, of course, lasers are everywhere—in DVD players and supermarket scanners, in medical clinics and tattoo parlors, and they are even used to stimulate lightning in thunderclouds. But in the late 1950s, when the first papers describing "light amplification by stimulated emission of radiation" were published, the shortsighted dismissed the technology as "a solution in search of a problem."

Not Livermore. Immediately after the laser was invented in 1960, LLNL scientists recognized the possibility of using laser light to ignite a fusion "micro-explosion" and create conditions similar to those in the core of the sun, triggering a controlled thermonuclear, or nuclear fusion, reaction—the same reaction that powers the sun and stars. They also realized this would be a significant step toward making fusion a commercially viable source of electricity. Their research, based on nuclear weapons codes, was largely classified until then-LLL Director John Nuckolls spelled out how it might be done in a seminal article in the journal *Nature* in 1972.

Once the door was opened to unclassified laser fusion research, Livermore's laser program took off and hasn't looked back. Working closely with industrial partners in the optics, semiconductor, defense and manufacturing industries, LLNL scientists have made remarkable strides in fabricating optics and finding new ways to use "the power of light" for both research and practical applications. As a result, LLNL's laser programs have captured 52 R&D 100 awards for innovative technology since 1978.

Lasers also play a key role in the Laboratory's national security missions. Besides supporting the National Nuclear Security Administration's Stockpile Stewardship Program, the NIF and Photon Science Directorate is developing next-generation laser-based defensive systems, such as the solid-state heat-capacity laser and the tailored-aperture ceramic laser. LLNL also is developing technologies such as an extreme X-ray source to detect nuclear materials in transportation systems to enhance homeland security.

Technology advances from LLNL's R&D and from collaborations with industrial partners will continue the tradition of spinning off Livermore research into new products in the marketplace. Much commercial technology already has grown out of research for

NIF, including silicon monolithic microchannel high-powered laser diode packages, optics finishing techniques, laser peening, fiber laser technology and multilayer dielectric diffraction gratings for improved efficiency of high-power lasers.

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