Building Nova: Industry Relations and Technology Transfer

A continuing technology transfer effort has characterized the Laboratory's development of progressively more powerful laser systems. The recent completion of the Nova laser is an example of a successful, long-term, major collaboration between Laboratory researchers and industry that has advanced the frontiers of laser technology and produced benefits far beyond the original expectations.

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Since the early 1970s, when laser research and development were taking shape at LLNL, technology transfer has been an integral part of the Laboratory's laser program. During these years, the needs of a burgeoning laser technology steadily pushed forward state-of-the-art boundaries and placed stringent demands on an industrial complex not yet ready to meet the exacting specifications of laser designers. Our laser program made an active commitment to work hand in hand with U.S. industry, and this cooperation of researcher and manufacturer, born of necessity, has matured into a symbiotic arrangement with benefits far exceeding the original expectations.

Now, as then, this collaboration is a two-way exchange: a means of passing to U.S. industry a developing piece of technology and a means by which industry can give the research community high-quality components at affordable prices. The success of the Laboratory's laser systems, from the early Janus and Argus lasers to the more recent Shiva and Nova lasers, attests to the productiveness of a close interaction between research facilities and industry.

Although technology transfer has been a long-standing practice at the Laboratory, it was formalized by Congress for all national laboratories with the passing of the Stevenson-Wydler Technology Innovation Act of 1980. The spirit of the Act is to increase industrial innovation and to stimulate the economy of the United States by the transfer of technology from federally funded national laboratories to domestic industry. Emphasis is not on a net outflow of technology from laboratories to industry but rather on an exchange of innovative practices and ideas. At LLNL, our Technology Transfer and Exchange Office facilitates and monitors technology transfer activity between industry and

the Laboratory and reports to the Department of Energy. In addition, a Technology Transfer and Exchange Policy Committee comprising associate directors, senior managers, and representatives from various programs establishes Laboratory policy on technology transfer and related issues.

For the Nova laser system, about 75% of the total funds spent went to industry. Contracts for more than $1 million were awarded to 25 companies, for $100 000 to $1 million to 79 companies, for $10 000 to $100 000 to 224 companies; more than 977 companies received contracts for less than $10 000.

The interaction between LLNL and the industries that took part in building the Nova laser illustrates the three basic ways by which we transfer technology. The first way is to transfer an entire package of several diverse technologies to industry, the second is to provide industry with specific technical knowledge in a fairly narrow area, and the third is to join with industry to develop a technology. In each case, we may use any or all of the following methods:

- We work directly with suppliers; for the Nova project, we had research, development, and production contracts with companies.
- We have specific technology transfer meetings, relating, for example, to power conditioning, coating damage, KDP finishing, and plasma shutters.
- We provide limited consulting in the form of meetings, tutorial sessions, and specific consulting tasks.
- We present papers at conferences, teach short courses, and publish in technical journals.
- We provide, in the Laser Program Annual Report, an extensive source of information to industry, universities, and other laboratories.

Transferring a Complete Technology Package

A dual effort is required to transfer a complete technology package from the Laboratory to industry: an effort to move the technology out of the Laboratory and an effort by a receptive company to acquire the technology. The company must have a sufficient market to justify its efforts and a commitment to keep the technology up to date. A good working relationship between the two organizations is essential for success.

Our first step when making such a transfer is to present a formal technology transfer symposium. We provide legal notification in the *Commerce Business Daily* and notify all interested companies with whom we have dealt in the past. Our first such meeting was in 1975 and was associated with the Shiva laser system. In the past few years, we have carried out a number of complete technology transfers (see Table 1).

One example will illustrate the difficulties in effectively transferring and using a technology, even when the receiving organization is very skilled and qualified. When Bell Laboratories, an outstanding technical organization, desired to duplicate our laser oscillator for their research program, it took them a year to fully absorb this technology: "We received more than 250 drawings from Livermore for the oscillator and glass amplifiers alone. We ordered over 2000 separate parts, had our machine shop fabricate literally hundreds of precision mechanical parts for over 200 drawings and then spent months assembling them. Altogether, we made four trips to Livermore, two trips to Stanford, spent two months ordering parts and 2.5 man-years building the system" (Ref. 1).

Other organizations interested in building such a system can look forward to considerable cooperation from the Laboratory but should be prepared for the considerable effort and time it takes to acquire new technology.

Transferring Specific Technical Information

It is usually easier to transfer specific technical information than an entire technology package because specific information fills a certain need and because the interaction between the Laboratory and the company lasts a shorter period of time, making the task simpler. The benefit to the company is usually a product that is improved or costs less. Some examples are

Table 1 Examples of transfer of an entire technology package.

Technology	Recipient	Comment
Shiva laser system	ILC Technology, Inc., plus many others	Formal technology transfer meeting; ILC has sales of ~$10M based upon this technology
Short pulse oscillators	ILC Technology, Inc., Sylvania, University of Rochester, Bell Laboratories, SLAC, AWRE, China	Several generations of development sales by ILC
Planar triodes	Pulse Sciences Enterprises	Company formed on the basis of this technology
Praxis	BBN, System Cognition, Fermi Lab, Lockheed, Science Applications	System Cognition formed on the basis of this technology; language being used by others; several invited papers
Absorbing glass calorimeters	Apollo Laser, Scientech	Commercial product
Laser system architecture	Naval Research Laboratory, KMS, Rutherford	Linear chains with spatial filters
Streak cameras	Cordin	Produced commercial product
Laser glass handbook	Many	Standard reference in optical industry
Shiva pulsed power	Many	Formal technology transfer

Table 2 Examples of the transfer of specific LLNL technology.

Technology	Recipient	Comment
Electropolish cleaning	Alliance Tool Corp.	Used on Shiva and now a money-making service
Welding space frame	Rigging International	Used on Shiva
Clean-room techniques	Many	Ongoing; many articles/ UCRLs and 15 short courses
Vacuum technology	Many	Several formal meetings
Silver plating of reflector	Many	Being used on Nova
Diamond turning of KDP	Many	In process for Nova
High-pressure freon cleaning	Many	Used on Shiva, Novette, and Nova
Ring electro-Pockels cells	Cleveland Crystals, Lasermetrics, and Inrad	Now standard commercial product
Standards for optical material	Many	Becoming accepted standard
Vibratory stress relief	Hefrecht	Used on Shiva
Welding with minimum distortion	Weldon General Tool	Being used on Nova

electropolishing parts, cleaning parts, space-frame welding, clean-room technology, vacuum technology, silver plating, diamond turning of KDP, and small specific technology transfer bits, shown in Table 2. In general, this transfer has been to our suppliers, but clean-room and vacuum technologies have been transferred to many organizations.

Developing Technology Jointly

The most beneficial and easiest transfer takes place when the Laboratory and a company work together, sharing the costs, to develop a technology. Generally, we either sponsor the research and development within the company or work with the company in association with prototype or production orders. Such jointly developed technology is of long-lasting national benefit because it results in significantly enhanced capabilities for the company. The following examples illustrate this.

Large KDP Crystals

With the Nova laser, we convert the initial frequency of the laser light to shorter wavelengths by means of harmonic conversion, achieved with large, pure crystals of KDP (potassium dihydrogen phosphate). We worked with three companies (Cleveland Crystals, Inrad, and Lasermetrics) to advance the state of the art of crystal growing from the production of small, apple-sized crystals to the growth of a KDP crystal weighing several hundred pounds and standing about a metre tall (Fig. 1). We procured these crystals from two of the suppliers, Inrad and Cleveland Crystals, for use on the Nova laser system. (See Ref. 2 for additional information about harmonic conversion.)

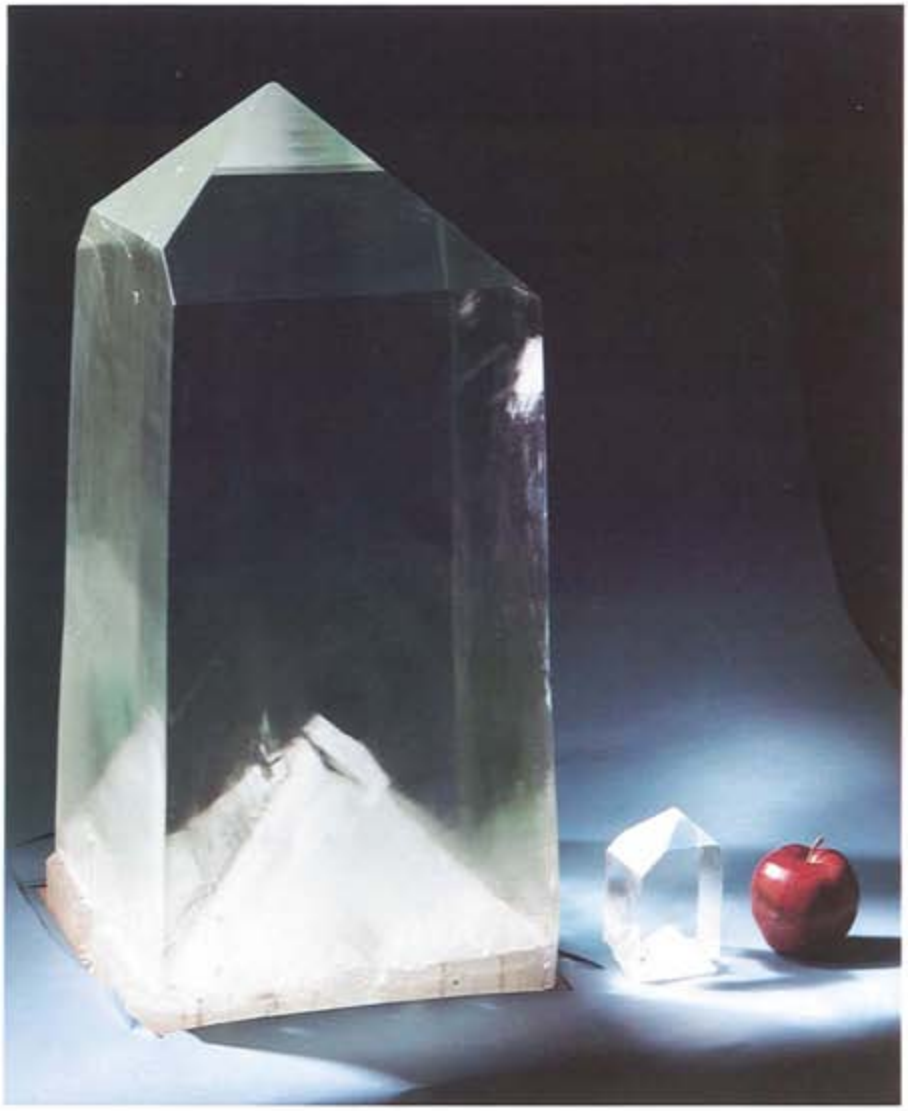
High-Quality Optical Materials

The successful operation of any laser depends on the accurate reflection or transmission of the light beam, and this is highly dependent on the optical components of the laser—the lenses and mirrors that direct, transmit, or focus the beam. For the Nova laser, in which the initial light pulse is amplified to a 74-cm-diam beam and then focused down to 250 μm, such factors as high or low reflectivity, damage resistance, and optical transmission assume prime importance for all optical components. The goal is maximum energy delivered to the target. Therefore, the numerous and large optical materials must be both of high quality and relatively inexpensive.

We worked with industry to produce large optical materials that would be of the same high quality as smaller ones. For this, we required three types of optical material: BK-7, a high-quality borosilicate glass similar to that used in eyeglasses; fused silica, a very high-quality optical material; and neodymium-doped laser glass. Schott Optical and

Fig. 1

Size comparison of KDP crystals from the apple-sized crystal on the right to a boule large enough to yield a 27-cm^2 crystal for Nova frequency doubling. This demonstrates remarkable advancement in the making of solution-grown KDP crystals. Until a few years ago, the largest KDP crystals were about 2.5 cm in diameter. We worked with manufacturers to increase the size of crystal boules and to determine optimum potential sizes for crystal arrays for Nova's 74-cm output apertures. One factor limiting the availability of large crystals is their slow growth rate: 1 to 2 mm per day. For instance, a crystal boule 30 cm wide on a side takes 9 to 12 months to grow, a rate of growth that represents both a risk and a cost liability. Our goal was a system with the potential of increasing the growth rate of KDP by a factor of two to four.



Hoya Optics supplied the BK-7 glass. Because we bought about 45 pieces of glass of the size shown in Fig. 2, low price was important. We obtained the second optical material, fused silica (used to transmit the Nova third harmonic, 0.35-μm light), from Corning Glass and from Heraeus. Again, we worked with both companies to ensure the delivery of the required large sizes at high quality and reasonable price. We procured the third material, neodymium-doped laser glass, from two companies, Schott Optical and Hoya; the latter has opened a plant in Fremont, California, to produce laser glass and other precision optical materials.

Optics Polishing

Another example of collaboration involved the flat-lapping or polishing of large optics pieces a metre or so in diameter. Conventional polishing techniques for such large pieces would have been very costly. Responding to this need, two companies, Zygo Corporation and Eastman Kodak, built large flat-lapping machines similar to those used for polishing smaller units. The resulting scaling up of technology produced high-quality parts in larger sizes at lower prices or, as needed, numerous small pieces. Figure 3 shows the Zygo and Kodak flat-lapping facilities. The Laboratory paid for the machines, and the companies designed the machines and provided all the support facilities. The Laboratory's needs have top priority for use of the machines, but commercial uses also are possible. For example, Kodak also makes optical parts for copiers with its flat-lapping machine.

Fig. 2

Rough-cut BK-7 turning mirror blanks (1.2-m-diam) manufactured by Schott Optical. This company's advances in the manufacture of massive melts of BK-7 glass have played a significant role in making Nova a cost-effective laser. For example, Nova includes 98 massive mirrors, some of which have very high homogeneity to transmit the beam to diagnostics instruments. In addition, Nova laser chains include two BK-7 lens blanks (the output spatial-filter lens and the diagnostic objective lens) with a clear aperture of 77 cm. The borosilicate for all these components came from one continuous melt. Schott Optical also developed apodizers that are made by fusing a cylindrical section of index-matched, copper-doped BK-7 glass into a clear BK-7 substrate.

Optical Coatings

The reflectivity level of an optical piece is determined by the type of coating applied to it. Nova, being a large optical system, requires special optical coatings. To obtain them, we paid for the construction of large coating chambers at both Optical Coating Laboratories, Inc. (OCLI) and Spectra-Physics (see Fig. 4). The Laboratory paid for the design and

(a)

(b)

Fig. 3

In 1981, Zygo Corporation and Eastman Kodak completed construction of large flat-lapping machines for finishing the large Nova mirrors: (a) Zygo's 4.1-m-diam machine, and (b) Kodak's 3.6-m-diam machine. Finished mirrors are produced at a combined rate of six per month. This is a significant accomplishment, in view of the sizes of these mirrors, which range from 60.4 to 109 cm in diameter and weigh from 55 to 446 kg. All are high-precision mirrors having reflected wave-front distortions $\lambda/10$ over the clear apertures and transmitted wavefront distortions $\lambda/8$. Each machine features a Fizeau interferometer with an 80-cm aperture for the frequent checking of parts during the manufacturing process.

fabrication of the chambers, and the companies paid for installation and housing. Laboratory needs have the first priority, but the companies also use these chambers to make optical coatings to meet commercial and Department of Defense requirements. These two chambers mark a significant advance in precision-coating capability in the U.S.

(a)

(b)

Fig. 4

(a) Nova coating chamber with a 3-m diameter at Optical Coating Laboratories Inc., can coat optical materials for either high-reflecting or antireflecting properties. (b) The Spectra-Physics coating chamber is cryogenically pumped, a unique feature in the coating industry. The coatings are difficult to produce because of the tight tolerance (1%) required for the film thickness. Both companies have been able to produce polarizer coatings on large substrates, to Nova specifications, with excellent production yields. Each has also produced a variety of mirror coatings on substrates ranging from 60.4 to 94 cm in diameter. Five Nova coating designs have been produced, and three different sizes of mirror substrates (some of which are transmitting, for diagnostic purposes) have been successfully coated.

In addition, we assisted in developing, for both the BK-7 and fused silica optics, antireflecting coatings that are not easily damaged by laser beams. Schott Optical developed (and we licensed) a neutral-solution process to produce antireflecting surfaces on large BK-7 lenses. LLNL, Corning, and Westinghouse developed a coating technique called solution gelatin (sol-gel) to provide a similar low-reflectivity coating for fused silica.

Summary

LLNL's technology transfer effort during the construction of the Nova laser system was motivated by our desire to acquire at affordable prices state-of-the-art components for our large laser systems. Our exacting requirements made demands on the capabilities of our suppliers that necessitated a close collaboration aimed at improving and extending existing technologies. The result of this technology transfer effort was that the required hardware was provided on schedule and within specifications, and there was a concomitant significant increase in the technology and production capability of U.S. industry.

Key Words: laser—Argus, Janus, Nova, Shiva; Stevenson-Wydler Technology Innovation Act of 1980; technology transfer.

Notes and References

1. R. H. Storz, "Technology Transfer: A Case History," *Laser Focus* (September 1981), pp. 65–66.
2. "Laser Fusion with Green and Blue Light," *Energy and Technology Review* (UCRL-52000-82-8), August 1982, pp. 18–29.