Executive Summary

The fiscal year ending September 1999 (FY99) concluded the second year of the cooperative agreement (DE-FC03-92SF19460) five-year renewal with the U. S. Department of Energy (DOE). This report summarizes research at the Laboratory for Laser Energetics (LLE), the operation of the National Laser Users' Facility (NLUF), and programs involving education of high school, undergraduate, and graduate students for FY99.

Progress in Laser Fusion

A principal mission of the University of Rochester's Laboratory for Laser Energetics is to study the direct-drive approach to inertial confinement fusion (ICF). During the past year we have made a number of advances in our understanding of direct-drive ICF through the use of the OMEGA facility and the use of our computational and theoretical capabilities. A major part of the LLE program is directed toward developing the potential for direct drive for an ignition demonstration on the National Ignition Facility (NIF) under construction at the Lawrence Livermore National Laboratory (LLNL).

Long-scale-length plasmas with parametric relevance to the NIF have been produced and characterized on the OMEGA system (pp. 1–11). On the basis of these experiments we have concluded that stimulated Raman scattering (SRS) and stimulated Brillouin scattering (SBS) are unlikely to cause unacceptable losses or produce unacceptable preheat through instabilities on NIF-scale targets.

We have modeled the stability of self-focused filaments in laser-produced plasmas. A wave-equation treatment of the laser light combined with self-consistent filament equilibrium simulations indicates that only very small filaments, where one waveguide mode is propagating, may be considered to be stable. When two or more waveguide modes can propagate, the filament tends to break up within tens of microns (pp. 191–196).

Direct drive requires high uniformity of irradiation. The article beginning on p. 12 describes our efforts using a number of beam-smoothing techniques to achieve increased uniformity on the OMEGA system and our projections for the uniformity that will be available on the NIF. We believe that on OMEGA the rms uniformity will be in excess of 99% (averaged over 300 ps) when beam-smoothing enhancements are completed for the facility. For the NIF, we project an even higher degree of uniformity using these same techniques.

Our study of hollow-shell implosions on the 60-beam OMEGA system (pp. 82–91) yielded information about target performance as a function of laser-irradiation uniformity and temporal laser pulse shape. We have found that pulse-shaped implosions place more stringent requirements on power balance and initial target-illumination uniformity. As improvements in laser drive are made, we expect higher neutron yields and higher areal densities than those obtained in these experiments.

In another set of experiments we investigated target performance enhancements when smoothing by spectral dispersion (SSD) was used to improve illumination uniformity. Time-integrated UV equivalent-target-plane imaging was used to compare two-dimensional SSD beam-smoothing rates to theoretical predictions for the 0.2-THz system on OMEGA (pp. 149–155). This work supports our confidence that larger-bandwidth SSD systems will produce enhanced smoothing.

Embedded titanium layers in spherical targets were used to determine the areal density of compressed shells. Target performance enhancement with the SSD beam smoothing is characterized using this method (pp. 139–148). A pinhole-array x-ray spectrometer captures core images below and above the *K* edge of titanium. The results are compared with two-dimensional *ORCHID* simulations.

The implementation of broadband smoothing on OMEGA with two-dimensional SSD is discussed beginning on p. 197. The article describes issues relevant to the architecture choices made during the design phase of the project, as well as measurements conducted to verify the laser bandwidth and ensure that FM to AM conversion is minimized.

The effect of temporal pulse shape on laser imprint and beam smoothing has been studied (pp. 203–208). Preimposed modulations on planar-foil targets were used to calibrate the mass equivalence of features imprinted by the laser, and the resulting growth rates are compared to numerical simulations.

A number of hydrodynamic instabilities arise in laser-driven implosions. While it is not possible to eliminate these instabilities, every effort must be made to limit the amount of implosion degradation they could cause. We have developed an analytic theory of the ablative Richtmyer–Meshkov instability. The principal result of this research (pp. 30–35) is that the instability exhibits a stabilizing mechanism due to the dynamic overpressure of the blowoff plasma with respect to target material.

While the effect of hydrodynamic instabilities on the performance of ICF targets is well known, techniques are required to characterize the sources of nonuniformities that can seed these instabilities. One such source is the surface roughness of the inside of the DT cryogenic fuel. Our numerical investigation of characterization of thick cryogenic-fuel layers using convergent beam interferometry (pp. 131–138) indicates that this optical technique can be used to isolate the surface under investigation and resolve the perturbations at the relevant level.

The nonlinear evolution of broad-bandwidth, laser-imprinted nonuniformities in planar targets accelerated by 351-nm laser light with beam-smoothing techniques was studied using throughfoil radiography. The saturation of three-dimensional perturbations produced by laser imprinting was observed and compared to those predicted by the Haan model (pp. 156–173). Modeling laser imprint in ICF targets is discussed in theoretical work (pp. 185–190) where the model describing the evolution of laser imprint shows that growth is determined by the velocity and acceleration perturbations generated by the laser-beam nonuniformities. Thermal smoothing inside a hot plasma corona suppresses only the acceleration perturbation, while the mass ablation suppresses both velocity and acceleration perturbations. The model predicts that directly driven NIF targets will remain intact during the implosion when the laser is smoothed with 1-THz SSD used on our current point designs.

In planning for direct-drive ignition on the NIF we have conducted a theoretical analysis of direct-drive NIF targets (pp. 121–130). We established that specifications required on the NIF ensure a successful direct-drive ignition demonstration using a baseline direct-drive target design. Independent calculations conducted by the Lawrence Livermore National Laboratory have confirmed these calculations.

Diagnostics Development

The evolution of ever-increasing sophisticated diagnostics to measure ICF events has been remarkable to observe over the last 20 years. As experiments become more complex and quantitative, diagnostic instruments must meet significant challenges to measure many details required for a comprehensive understanding of the underlying physics in ICF. As the National program prepares for an ignition demonstration on the NIF, all of the participating institutions are developing the required diagnostics. Similarly, as our understanding of directly driven targets increases with our use of OMEGA, more and better diagnostics are constantly in demand.

A novel charged-particle diagnostic has been developed that performs simultaneous ρR measurements of the fuel, shell, and ablator regions of a compressed ICF target, consisting of an inner DT-fuel region, a plastic (CH) shell, and an ablator (CD), by measuring the knock-on deuteron spectrum (pp. 17–25).

LLE continues the productive collaboration with our colleagues at MIT and LLNL to develop charged-particle magnetic spectrometers. We have demonstrated on OMEGA the diagnostic capability of two of these spectrometers. As an initial application, the simultaneous measurements of the fuel areal density, shell areal density, and fuel temperature have been carried out using D^3He-filled imploding capsules (pp. 93–96). Our initial experiments demonstrated the ability to carry out these measurements at fuel ion temperatures of 3 to 6 keV, fuel areal densities in the range of 10 to 20 mg/cm^2, and shell areal densities in the range of 40 to 60 mg/cm^2. Measurements like these can be applied to the parameter region characteristic of cryogenic-fuel capsules on OMEGA. In future experiments, we will extend such measurements to higher fuel and shell areal densities and validate these techniques on cryogenic-fuel targets.

Laser and Optical Materials and Technology

We have designed and tested an efficient, bulk-phase modulator operating at approximately 10.5 GHz, which can produce substantial phase-modulated bandwidth with modest microwave drive power (pp. 53–61). This modulator is the cornerstone of the 1-THz UV bandwidth operation for OMEGA. The resonator design employs an adapted form of cutoff-waveguide coupling and velocity matching to yield a simple, high-Q microwave design with practical clear-aperture dimensions suitable for applications in a 2-D SSD system. The design is scalable to other frequencies by simply changing the electro-optic crystal dimensions. The measured microwave performance of the modulator agrees well with performance predicted from fully anisotropic, three-dimensional numerical simulations.

Flexible modeling tools are required to simulate the generation and propagation of two-dimensional SSD pulsed laser beams. The Waasese code was developed to simulate the ideal and nonideal behavior of the many optical components that comprise the SSD driver line, including their relative positions (pp. 62–81). The code predicts measurable signatures that function as diagnostic tools since they are associated with particular optical components. Minimizing any amplitude modulation in the driver line will ensure the safety and lifetime of OMEGA optics by circumventing the effects of small-scale self-focusing. The code has proved to be an indispensable modeling tool for the OMEGA laser, and its inherent flexibility will provide a means to enhance its capabilities to model other laser propagation issues such as nonlinear propagation, on-target uniformity, amplifier gain, scattering losses, and pinhole clipping.

Laser-fusion experiments require precise control of the temporal profile of optical pulses applied to targets. While OMEGA has had a pulse-shaping capability for some time, the demands on the precision, flexibility, and repeatability of the optical pulse-shaping system have increased. To meet the new requirements, an aperture-coupled stripline electrical-waveform generator has been designed. The model we have developed (pp. 97–104) allows one to produce accurately shaped optical pulses suitable for injection into the OMEGA system. The model requires the solution of the telegraph equations using the method of characteristics.

A measurement technique has been developed that enables the complete characterization of electronic devices having any dynamic temporal and spectral frequency response, such as the photoconductive microwave switches on the OMEGA pulse-shaping system (pp. 105–113). The technique is a superset of a form of input–output relationships called the scattering or *S* parameter; this technique can also be applied to any microwave or millimeter-wave device whose properties vary rapidly, such as photoconductive attenuators, phase shifters, and directional couplers.

High-peak-power lasers for fusion applications, such as OMEGA, must constantly deal with optical damage in many components. We have studied the damage to the fused-silica spatial-filter lenses on the OMEGA laser system (pp. 114–120). LLE has implemented a plan to maintain the quality of OMEGA optics that includes frequent inspection and *in-situ* cleaning of optics. With the establishment of safe operational damage criteria, laser operation has not been impeded. The implications, morphologies, possible causes, and ongoing long-term experiments of spatial-filter lens damage are discussed in the article.

Because of its excellent homogeneity and low-intrinsic absorption properties, fused silica remains the preferred material for high-power laser applications over a wide wavelength range. Deciding when to replace spot-damage-afflicted fused-silica optics or, in the case of inaccessible space-based lasers, predicting the useful service life of fused-silica optics before catastrophic, pulsed-laser-driven crack growth shatters a part has recently become simpler. We report results from stress-inhibited laser-crack propagation and stress-delayed damage-initiation experiments in fused silica at 351 nm (pp. 26–29). The damage-initiation threshold was observed to increase by 70% when a modest amount of mechanical stress was applied to the fused-silica optic. Research is underway presently to determine the ramifications of these findings for large-aperture systems, such as OMEGA. In related work (pp. 174–179), we have obtained experimental results on stress-inhibited, laser-driven crack growth and stress-delayed laser-damage-initiation thresholds in fused silica and borosilicate glass (BK-7). The use of different loading geometries providing uniaxial and biaxial stresses shows that the biaxial stress configuration offers superior efficiency in raising the laser-damage-initiation threshold by up to 78% and arresting crack growth down to 30% relative to stress-free conditions.

We have measured the output signal-to-noise ratio (SNR) of a Nd:YLF regenerative amplifier and have found that our measurements are in excellent agreement with the predictions of a simple theoretical model (pp. 209–212). The model includes amplified spontaneous emission and noise injected into the amplifier.

Magnetorheological finishing (MRF) is a novel and recently commercialized process for figuring and polishing plano, convex, and concave optics (both spherical and aspherical) from a wide variety of optical materials. We discuss the development of new magnetorheological fluids to extend the finishing technique to two soft, single-crystal, optical materials: CaF_2 and KDP (pp. 213–219). Material-removal functions are characterized through analysis of polishing spots generated on a new research platform at the Center for Optics Manufacturing.

Advanced Technology

Rose bengal is a dye used in photodynamic therapy. Photodynamic therapy is a treatment in which the combination of a dye, light, and oxygen causes photochemically induced cell death. We present what we believe to be the first study of a triplet state of rose bengal that is produced by 1064-nm excitation of T_1 (pp. 36–47). The triplet-triplet absorption cross section was measured between 825 nm and 1100 nm. The state was further characterized using two-step laser-induced fluorescence to determine its thermalization rate, lifetime, and quantum yield of reverse intersystem crossing. Similar two-step laser-induced fluorescence measurements were made of the triplet excited by 632-nm light.

We have measured the picosecond response of optically driven YBaCuO (YBCO) microbridge and Josephson-junction integrated structures (pp. 48–52). Single-picosecond switching of a high-temperature-superconductor Josephson junction was observed, and the junction turn-on delay time was measured. These findings provide confirmation of the potential of YBCO for ultrafast optical and electrical transient detection and processing.

Charged particles interacting with an oscillating electromagnetic field will seek regions of low intensity. We have observed electron trapping in an intense single-beam ponderomotive optical trap (pp. 180–184). Thomson-scattered light from the electron trap was enhanced through the use of a novel trapping focus of the laser. The scatter distribution is compared with simulations for ordinary and trapping-focus beams.

Laser Facility Report

FY99 was a very productive year for the OMEGA system. We recorded 1207 shots on target for experiments for LLE, LLNL, LANL, and NLUF users. This is the second fiscal year where we have used an extended shot schedule (12 h/day, 3 days/week). Many of the shots took advantage of the 1-h cycle time for OMEGA. During FY99, a number of major system modifications were made; these modifications are discussed beginning on p. 222. Most notably, improved individual-beam uniformity resulting from an upgrade of the 2-D SSD system was achieved (see the article beginning on p. 197). We have also added second tripler frequency-conversion crystal assemblies to 13 of the 60 beams. These additional triplers allow efficient frequency conversion for laser bandwidths up to 1 THz. This is the first stage of a project to modify all 60 beams to be able to use 1-THz SSD in future experiments.

In preparation for cryogenic-target experiments, the upper and lower pylons of the cryogenic target handling system were installed on OMEGA. The system will be fully activated in FY00.

National Laser Users' Facility (NLUF)

Beginning on p. 223, we report on FY99 NLUF experiments. During the year, significant progress was made on several NLUF projects. A total of 144 OMEGA target shots were dedicated to the NLUF program during FY99.

In addition to NLUF-supported programs, several direct- and indirect-drive experiments, also coordinated through the NLUF manager, were carried out on OMEGA by groups from LLNL and LANL. These experiments are conducted for both ICF research and research in support of the Stockpile Stewardship Program. This program was formally initiated by the FY94 Defense Authorization (PL 103-160) to "*establish a stewardship program to ensure the preservation of the core intellectual and technical competencies of the United States in nuclear weapons*." Since the Nova laser at LLNL was decommissioned in May 1999, the National laboratories are making increased use of the OMEGA facility.

Thirteen proposals were submitted to NLUF for FY00. A DOE technical evaluation panel reviewed the proposals and recommended approval of seven proposals for funding. The accepted proposals are summarized in Table 80.VIII on p. 225.

Education at LLE

As the only university major participant in the National ICF Program, education continues to be a most important mission for the Laboratory. Graduate students play a significant role in LLE's research activities and are participating in research using the world's most powerful ultraviolet laser for fusion research on OMEGA. Fourteen faculty from five departments collaborate with LLE's scientists and engineers. Presently 42 graduate students are pursuing Ph.D. degrees at the Laboratory. The research interests vary widely and include theoretical and experimental plasma physics, laser–matter interaction physics, high-energy-density physics, x-ray and atomic physics, nuclear fusion, ultrafast optoelectronics, high-power-laser development and applications, nonlinear optics, optical materials and optical fabrication technology, and target fabrication. Technological developments from ongoing Ph.D. research will continue to play an important role on OMEGA.

One hundred thirty-three University of Rochester students have earned Ph.D. degrees at LLE since its founding. An additional 63 graduate students and 20 postdoctoral positions from other universities were funded by NLUF grants. The most recent University of Rochester Ph.D. graduates and their thesis titles are

D. Jacobs-Perkins	*Design, Analysis, and Implementation of an Ultrafast Electro-Optic Electric-Field Imaging System*
V. Smalyuk	*Experimental Investigation of the Nonlinear Rayleigh–Taylor Instability in CH Foils Irradiated by UV Light*
R. Ejnisman	*Studies with Ultracold Atoms*
A. Chirokikh	*Stimulated Brillouin Scattering Experiments on OMEGA*
M. Currie	*Ultrafast Electro-Optic Testing of Superconducting Electronics*
R. Giacone	*Spatiotemporal Evolution and Nonlinear Kinetic Simulations of Stimulated Brillouin Scattering*
J. Bromage	*Creating Rydberg Electron Wave Packets Using Terahertz Pulses*
P. Rudy	*Manipulation of Laser Cooled Atoms Via Dynamical Optical Potentials*
E. Alfonso	*Chemistry and Processing of Polymer Shells*
B. Conger	*Polarized Photoluminescence from Nematic and Chiral-Nematic Films*
P. Rodney	*The Photophysics of Ionic Semiconductors at Low Temperatures: Silver Bromide, Silver Iodide, and Cuprous Oxide*

Approximately 50 University of Rochester undergraduate students participated in work or research projects at LLE this past year. Student projects include operational maintenance of the OMEGA laser system, work in the materials and optical-thin-film coating laboratories, programming, image processing, and diagnostic development. This is a unique opportunity for these students, many of whom will go on to pursue a higher degree in the area in which they have participated at the Laboratory.

LLE continues to run a Summer High School Student Research Program (pp. 220–221) where this year 12 high school juniors spent eight weeks performing individual research projects. Each student is individually supervised by a staff scientist or an engineer. At the conclusion of the program, the students make final oral and written presentations on their work. The written reports are published as an LLE report. One of this year's participants, Aman Narang of the Harley School, has been named a semifinalist in the 1999 Intel Science Talent Search for his summer project. His research topic was "Analysis of the 3ω SSD spectrum of an OMEGA laser beamline"; he was supervised by Dr. W. Donaldson.

In 1999, LLE presented its third William D. Ryan Inspirational Teacher Award to Mr. John Harvey of Honeoye Falls–Lima Senior High School. Alumni of our Summer High School Student Research Program were asked to nominate teachers who had a major role in exciting their interest in science, mathematics, and/or technology. The award, which includes a $1000 cash prize, was presented at the High School Student Summer Research Symposium. Mr. Harvey, a mathematics teacher, was nominated by Jeremy Yelle and David Rae, participants in the 1997 program. "I have never met another teacher that was so passionate for what he teaches, and communicates himself well enough to get even the most complicated of ideas into the simplest of minds," wrote Yelle in his nomination letter. Mr. Rae added, "Mr. Harvey must also be recognized for his dedication to students after the books have closed and the homework has been passed in."

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