Executive Summary

The fiscal year ending September 1998 (FY98) concluded the first 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 the education of high school, undergraduate, and graduate students for FY98.

Progress in Laser Fusion

To evaluate the direct-drive approach to laser-driven inertial confinement fusion, we are planning to use the 30-kJ, 351-nm, 60-beam OMEGA laser to drive cryogenic solid DT-shell capsules that are hydrodynamically equivalent to the ignition/gain capsules planned for use on the National Ignition Facility. This year, in preparation for the cryogenic experiments, we conducted measurements of core and pusher conditions in surrogate capsule implosions (pp. 100–112). Measurements of the effects of imprint and unstable growth at the ablation surface have been carried out using the burnthrough technique, and target behavior during the deceleration phase has been investigated using Ti-doped shells surrounding an Ar-doped D_2 fill gas.

Other experiments have characterized an x-ray radiographic system for measuring mass modulations in planar laser-driven targets. Using the known sensitivity, resolution, and noise characteristics of this system, we have formulated a Wiener filter that reduces noise, compensates for detector resolution, and facilitates measurement of perturbations imprinted on targets by laser nonuniformity (pp. 242–250).

A soft x-ray microscope (E < 3 keV) with high spatial resolution (~3 μm) has been characterized and used for initial experiments on the OMEGA laser system (pp. 92–99). We report on details of the testing, calibration, and initial use of this microscope for studying the hydrodynamic stability of directly driven planar foils.

To increase the uniformity of drive on fusion targets, we have expanded the pulse-shape bandwidth of OMEGA's driver line from approximately 3 GHz to over 5 GHz by using a novel scheme that takes into account the transient carrier dynamics of the photoconductive switches used in the pulse-shaping subsystem (pp. 225–231). In complementary work to improve uniformity, we have performed calculations of near-field intensity modulations in high-intensity laser beams due to self- and cross-phase modulation between the orthogonally polarized laser beams emerging from KDP wedges placed into the OMEGA laser beamlines (pp. 232–241). Such wedges produce a reduction in the far-field speckle nonuniformity by polarization smoothing and are not expected to be a significant source of intensity modulation under expected operating conditions.

Based on previous extensive theoretical work, our theorists describe a simple procedure (pp. 20–31) to determine the Froude number *Fr*, the effective power index for thermal conduction ν, and the ablation-front thickness L_0 of laser-accelerated ablation fronts. These parameters are determined by fitting the density and pressure profiles obtained from one-dimensional numerical simulations with analytic isobaric profiles. These quantities are then used to calculate the growth rate of the ablative Rayleigh–Taylor instability using the theory developed by V. N. Goncharov *et al*., Phys. Plasmas **3**, 4665 (1996).

The use of systematic perturbation methods to derive formulas for the Landau damping rates of electron-plasma and ion-acoustic waves produced formulas far more accurate than the standard formulas found in textbooks (pp. 113–119).

The simultaneous forward and backward stimulated Brillouin scattering (SBS) of crossed laser beams is described in detail beginning on p. 189. We have obtained new analytical solutions for the linearized equations governing the transient phase of the instability and the nonlinear equations governing the steady state. These solutions show that backward SBS dominates the initial evolution of the instability, whereas forward SBS dominates the steady state.

Calculations of the damping of localized plasma waves have been made using a new physical approach that is linear in the wave field and avoids introducing complex particle velocities (pp. 200–211). The simplicity of this approach is obtained by invoking the time-reversal invariance of the Vlasov equation. This greatly simplifies the calculation of Landau damping of plasma waves in an infinite medium and “transit-time damping” of plasma waves localized in general geometries.

We have found a plausible explanation for observations of stimulated Raman scattering (SRS) that have been at odds with theoretical predictions (pp. 251–263). By calculating the collisionless damping rate of plasma waves confined within a small cylinder, we have found that plasma waves confined within small-radius filaments damp much more slowly than plane plasma waves in a homogeneous plasma. Predictions using these corrected rates, rather than rates obtained using the usual Landau theory for plane waves in homogeneous plasmas, provide a viable explanation of the anomalous SRS observations.

The indirect-drive approach to inertial confinement fusion involves laser beams that overlap as they enter the hohlraum. Because a power transfer between the beams adversely affects the implosion symmetry, it is important to understand the mechanisms that make such a power transfer possible. In a previous article [LLE Review **66**, 73 (1996)] we described a two-dimensional analysis of the power transfer between beams with top-hat intensity profiles in a homogeneous plasma. In the article beginning on p. 32, the calculations of the power transfer between crossed laser beams made possible by an ion-acoustic wave are extended to include three dimensions and arbitrary intensity profiles.

Diagnostics Development

A nuclear diagnostic for measuring the areal density of ICF targets is described in the article beginning on p. 15. This diagnostic is obtained by the addition of ^{3}He to the fuel and is based on the energy loss of the 14.7-MeV D-^{3}He proton in the target. This diagnostic will extend our ability to measure areal density to the high-density regime expected for cryogenic DD targets on OMEGA.

Development of the sweep deflection circuitry for the OMEGA multichannel streak camera, aided by a computer simulation model, is reported (pp. 6–14). Good agreement between the model predictions and measurements shows that using the model is an efficient means for conducting initial design, performance optimization, and correction of performance deficiencies for these cameras.

By placing a pinhole array in front of a flat-crystal x-ray spectrometer, we have developed a diagnostic technique with the ability to obtain simultaneously a large number of two-dimensional images over a wide range of photon energies at a high degree of spectral resolution. The article (pp. 182–188) presents images of Kα fluorescence pumped by core radiation, delineating the compressed, cold shell, and pumped by suprathermal electrons, showing that ~1% of the laser energy preheats the target.

Laser and Optical Technology

We have developed a new electrical waveform generator based on aperture-coupled striplines (pp. 1–5). The waveform generator is capable of producing shaped electrical waveforms with 50- to 100-ps structure over a 1- to 5-ns envelope at voltage levels suitable for OMEGA pulse-shaping applications. The design is a significant simplification over existing technology and offers many performance enhancements.

In an effort to identify an inexpensive shielding material to protect valuable laser optics from various forms of debris, we have screened perfluorinated polymer pellicles from various vendors. The optical-performance results of these tests (pp. 38–44) yielded the highest 351-nm-laser–damage thresholds ever recorded at LLE for 0.6-ns pulses.

Subsurface damage induced by microgrinding of glass is an important feature of the resulting surface that must be removed in any subsequent finishing operation. Analysis shows (pp. 45–49) how the depth of subsurface damage can be estimated from the measured surface roughness, how it can be correlated to the near-surface mechanical properties of the glass, and how ground-surface quality depends on the type of grinding process employed.

Polishing abrasives that have been bound in a solid matrix can offer several potential advantages over loose-abrasive processes for finishing optics. Research has established the various criteria for a successful bound-abrasive polisher, and we report results for six compositions used on a CNC generating machine to polish optical glass (pp. 50–58).

Our in-house development, scale-up, and manufacture of 60 continuous distributed phase plates with high laser-damage resistance (pp. 71–91) has been a great success. Inert ion beams were used to etch a continuously varying pattern into the surface of fused silica to form these devices.

High efficiency and good beam quality are potential advantages of the end-pumped solid-state lasers over the side-pumped ones. We describe the successful use of a transport fiber to end-pump a Nd:YLF laser, overcoming issues related to the astigmatic nature of the high-power, quasi-cw diode laser pumping source (pp. 120–124).

Using a single-beam *Z*-scan technique, we have determined values for the self-phase modulation coefficients in a KDP crystal at wavelengths of 1.053 μm, 0.527 μm, and 0.351 μm. The cross-phase modulation coefficients between 1.053 and 0.527 μm, measured by a two-color *Z*-scan, are also given (pp. 125–130).

A new model relates brittle material mechanical properties and grinding abrasive properties to the value of surface roughness that results from the cold working process (pp. 131–138). Surface roughness as measured by white-light interferometry can be used to establish an upper bound to the level of subsurface damage induced by grinding.

A series of experiments demonstrate a new scheme for converting the infrared light of OMEGA to the third harmonic in the ultraviolet over a bandwidth that is significantly wider than has been previously attainable (pp. 151–158). This innovative scheme, employing a second tripling crystal in addition to the doubler-tripler pair currently in use, was proposed by a scientist at Lawrence Livermore National Laboratory and adapted to the OMEGA system. Wider bandwidths on OMEGA will allow the use of broadband beam smoothing with faster smoothing times than have been employed until now.

We have made ultrahigh-dynamic-range measurements of high-contrast pulses using a second-order autocorrelator (pp. 159–170). This device is capable of measurements with dynamic ranges of up to ~10^{12} at a time resolution of ~50 fs, the highest dynamic range yet achieved for measurements with this degree of time resolution.

During the year we developed a highly stable, diode-pumped Nd:YLF master oscillator for the OMEGA laser system (pp. 213–218). This new master oscillator produces either single-frequency *Q*-switched pulses or cw radiation for the OMEGA pulse-shaping system. The switchover between these two regimes requires no laser realignment. The new master oscillator is completely computer controlled and has been operating continuously in OMEGA for six months without operator intervention.

A negative-feedback–controlled regenerative amplifier has been part of the OMEGA laser system for the past two years. The negative feedback makes the energy output of the regenerative amplifier stable and insensitive to the variations in pulse energy. This amplifier's long-term output energy stability is the highest ever demonstrated for a millijoule-level laser system, either flashlamp pumped or diode pumped (pp. 219–224).

Advanced Technology

Despite angle dependence and polarization selectivity, the color of cholesteric liquid crystal (CLC) polysiloxane films can be quantified by standard colorimetry. A new fractured form of the film called "flakes" makes it possible to use the Center of Gravity Color Mixing Principle to predict the chromaticity of CLC color mixtures. Our results show how a complete color gamut can be produced by layering CLC films, mixing CLC's physicochemically, and mixing CLC flakes (pp. 59–70).

The optical and physical properties of polymer liquid crystal flakes, alone and embedded in carriers, have been explored (pp. 139–149). These materials have applications as color coating, polarizing paints, and inks.

Results from two ion-beam analysis techniques—Rutherford backscattering spectroscopy and nuclear resonance analysis—have been used to provide an accurate method for determining the complete elemental composition of capsules and target materials used at LLE (pp. 171–181). These new sources of information are more expansive than other analytical techniques in use, and the data are needed for interpreting the results of our experiments.

Laser Facility Report

We report on substantial improvements made to the OMEGA facility this year. The operations time has been extended to meet increased demand for shots, both by LLE scientists and by scientists from the Lawrence Livermore National Laboratory and the Los Alamos National Laboratory. Improvements in the laser system (including system modifications to increase the uniformity of drive on the target) and the experimental area are described in the article beginning on p. 266. The extended shift operations produced an increase in the average number of shots/shot day from 5.2 to 9.8, with an increase in the average number of shots/week from 17 to 26. During the FY, 882 total target shots were taken.

National Laser Users' Facility (NLUF)

Beginning on p. 268, we summarize progress and experiments conducted by others as part of the National Laser Users' Facility. Since 1979, we have operated OMEGA for users under this program. During FY98, in addition to NLUF-supported programs, scientists from the National laboratories have conducted stockpile stewardship and indirect-drive laser experiments on OMEGA.

Fifteen proposals were submitted to NLUF for the next year (FY99). The table on p. 269 summarizes the principal investigators along with their affiliation and the proposed experimental programs that were approved by the Department of Energy Technical Evaluation Panel.

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 34 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 of our recent Ph.D. recipients, E. Korenic, was awarded the Glenn H. Brown prize from the International Liquid Crystal Society for one of the four best theses of liquid crystals in the world since 1994.

One hundred eighteen University of Rochester students have earned Ph.D. degrees at LLE since its founding. An additional 48 graduate students were funded by NLUF grants. The most recent University of Rochester Ph.D. graduates and their thesis titles are

V. Goncharov	*Self-Consistent Stability Analysis of Ablation Fronts in Inertial Confinement Fusion*
W. Grice	*Interference and Indistinguishability in Ultrafast Spontaneous Parametric Downconversion*
E. Turano	*Spatiotemporal Evolution of Stimulated Raman Scattering Driven by Short Laser Pulses*
B. Ucer	*Ultrafast Carrier Dynamics in Thin Porous Silicon Films*

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. 264–265) where this year eleven 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.

In 1998, LLE presented its second Inspirational Science Teacher Award to Mr. David Crane of Greece Arcadia High School. Alumni of our Summer High School 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. Crane, a chemistry teacher, was nominated by Robert Dick, a participant in the 1991 program. (Mr. Dick is presently a Ph.D. candidate in Computer Science at Princeton University.) Mr. Dick writes that Mr. Crane's "academic competence, curiosity, and enthusiasm toward teaching allow him to motivate students who would otherwise fall through the cracks. Mr. Crane attracted students who wouldn't typically take difficult science courses."

Robert L. McCrory
Director