**SOFT X-RAY SPECTROSCOPIC MEASUREMENTS
OF PLASMA CONDITIONS AT EARLY TIMES
IN ICF EXPERIMENTS ON OMEGA**

Semi-Annual Report
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Semi-Annual Report

SOFT X-RAY SPECTROSCOPIC MEASUREMENTS OF PLASMA CONDITIONS AT EARLY TIMES IN ICF EXPERIMENTS ON OMEGA

Since arrival of FY-99 funding in December, we have been preparing for our first series of experiments under this grant on the OMEGA laser facility, which just took place (for one day) on April 27, 1999. The campaign was successful and results will be included in the next progress report following analyses. For the first time, we fielded our Ten Inch Manipulator (TIM-) mounted flat-field, grazing-incidence extreme-ultraviolet (euv) spectrograph [1] with a four-channel gated-stripline microchannel plate (MCP) detector. This spectrograph covers the spectral range of 30-250 Å ($h\nu=50-400$ eV). As in a previous campaign of May 1998, where we used this instrument with time-integrated photographic recording, the spectrograph reached closer to the target than did the previous version mounted on the chamber wall; such that the sensitivity increased by at least a factor-of-10 for viewing weak spectral features.

Our analysis during this reporting period of the euv spectroscopic results from the October 1998 NLUF/OMEGA campaign of Mg X, XI and XII spectra from $n=3$ to $n=2$ transitions are shown in Fig. 1 versus time. The data plotted represent a composite between the three most sensitive striplines, delayed relative to each other, for a number of shots. The intended emphasis was on the early portion of the event while the laser intensity is rising to a peak. This measured euv history agrees with that from the x-ray streak spectrographic data shown in Fig. 2 from the same campaign, i.e., the peak period of emission being in the first 1.5 ns.

Besides euv spectral lines from the $n=3$ to $n=2$ transitions in magnesium, resonance lines from carbon and oxygen were recorded at early times (see prepulse discussion below), presumably originating from the stalks supporting the microballoon targets, which is inevitably irradiated by some of the 59 beams used. Also, an Al XIII Balmer- α feature was observed during the period of the laser pulse at a much lower level than that for magnesium, being from a very thin layer (125-Å). Appearing at a low level and with some overlap with others were spectral lines from neon and argon from the gaseous filling. These occurred at late times, extending to at least 10 ns, i.e., well after collapse and during final expansion. Those lines definitely identified were from $n=3$ to

$n=2$ transitions in the spectra of hydrogenic Ne X and in Ar IX-XIII, all with ionization potentials in the 420-1360 eV range. In fact, the normally intense spectral line from a 3d-2p "resonance" transition in Li-like Ne VIII (ionization potential =239 eV) was surprisingly weak. This indicates that even at late times the ionization stage and "temperature" are high in the "frozen-in" state during expansion, and that the recombination rate is fairly low.

In this analysis of data from the October 1998 campaign, we continued to find a prepulse in the euv emission at a level of about 1/4 that found in the May 1998 campaign, still as early as 10 ns prior to the beginning of the main laser pulse. These prepulse measurements were described in detail at the November 1998 meeting of the American Physical Society [2], and a copy of the abstract is attached. However, in this case, the euv spectral lines originated mostly from carbon and oxygen, with some continuum. This indicates that the magnesium overcoating was not significantly vaporized in this series, which is consistent with a more "normal" x-ray (and euv) spectral sequencing.

Returning to the x-ray streak spectrograph data shown in Fig. 2, notice that the more intense x-ray continuum emission during the main collapse ("bang") peaks at ~ 2.6 ns. This agrees very well with hydrodynamic modeling carried out at LLE by Dr. Jacques Delettrez (Fig. 3) which predicts a value of 2.5-2.7 ns to collapse, i.e., an example of code verification by experimentation.

During this period, we completed the analysis of data and prepared a manuscript [3] (first page of preprint attached) describing experiments carried out on the TRIDENT laser facility at the Los Alamos National Laboratory in September 1998, experiments partially supported by NSF. In that campaign, the results of which are quite relevant to the OMEGA experiments, we used two opposing beams (at 0.53 μm wavelength) onto slab targets, and recorded, using a time-gated x-ray crystal spectrograph, spectra from Mg, Al and Si. Digital recording from a CCD camera was used. We also were able to achieve spatial resolution along a direction normal to the target surface. With 170 J per beam in a 1 ns Gaussian pulse, focused to a diameter of 500 μm , we obtained a typical target irradiance of $9 \times 10^{13} \text{ W/cm}^2$; and hence we could simulate the OMEGA irradiance by using small focal spot sizes on TRIDENT. We observed line radiation from resonance transitions in hydrogenic and helium-like ionic species, as well as innershell satellite lines in the next lower species. We also observed K_{α} type transitions

at the target surface, which arose from the first few ionization species. Thomson scattering diagnostics provided us with temperature and density values useful in numerical modeling of the data and for future "calibration" of our temperature measurements on OMEGA.

Typical results are indicated in the spectral scans presented in Figs. 4 and 5 for silicon and magnesium, respectively. In the case of silicon, notable features include unusually intense (relative to nearby lines) well-displaced satellite lines arising from $2s^2-1s2p$ and $1s2s^2-1s^22p$ transitions in He-like and Li-like ions, respectively, which involve a two-electron process with one photon being emitted. They arise from interactions between the $2s^2$ and $2p^2$ configurations for the two cases. Various explanations for the apparent anomalous satellite intensities have been offered. The most likely candidate at present is opacity in the radiative transfer of the more intense dipole satellite lines. This has been confirmed tentatively for the lithium-like satellites by numerical modeling carried out by Dr. Ehud Behar of Hebrew University.

From the scan for magnesium shown in Fig. 5, one sees the n-to-1 resonance spectral series for both H- and He-like ions merging with the continuum emission when $n=6$ or 7. The Inglis-Teller relationship [4,5] indicates an electron density of $N_e \lesssim 3 \times 10^{21} \text{ cm}^{-3}$, close to the critical value for the $0.53 \text{ }\mu\text{m}$ laser wavelength. From the relative line intensities of the spectral series it is also possible to derive an electron temperature [6,7]. Further analysis of the transition region from lines to continuum is planned, including modeling with the CRETIN code, courtesy of Lawrence Livermore Laboratory.

A very useful aspect of the (mostly) magnesium targets on TRIDENT was our ability to reproduce irradiances as low as a few $\times 10^{12} \text{ W/cm}^2$ on two-sided layered planar targets consisting of $20\text{-}\mu\text{m}$ thick CH covered with $300\text{-}\text{\AA}$ of Al and finally a $2\text{-}\mu\text{m}$ thick Mg coating, simulating the surfaces of the spherical targets used at LLE. We were able to demonstrate that Mg XI and XII x-ray spectral lines are produced at measureable intensities at such an irradiance. This was a point in question in our prepulse measurements at that level of irradiance carried out at LLE in May 1998 and described in last year's final report.

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Fig. 1. Time history at early times from 10/98 euv spectral data.

Fig. 2. "Normal" x-ray streak spectrum (10/98 run) with reduced prepulse.

Fig. 3. LLE hydro-modeling by Dr. J. Delettrez of the October 1998 experiments (originally multicolored), showing the various zones of expanding Mg and Al (thin) and collapsing CH and compressing Ne/Ar. The full collapse occurs at ~ 2.7 ns, in agreement with the October 1998 x-ray streak spectrographic data. The laser pulse is also shown for time correlation, scaled according to the laser power. Shock effects on the internal region are not indicated.

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Fig. 4. Silicon spectrum obtained using the TRIDENT laser at Los Alamos National Laboratory.

Fig. 5. Magnesium spectrum obtained with the TRIDENT laser at the Los Alamos National Laboratory.