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X-RAY CONVERSION PHYSICS

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ABSTRACT

We have performed a series of experiments to study the physics of the conversion of 0.35-μm laser light to soft x-rays in high-Z materials. The efficiency of soft x-ray and M-band radiation production as a function of laser intensity (5×10^{13} to 3×10^{15} W/cm^2) was measured. At fixed intensity 5×10^{14} W/cm^2, the time-resolved and time-integrated thermal x-ray ($E < 1.5$ keV) conversion efficiency increased with the laser pulse length for up to 4-ns-long pulses on gold targets. The effects of material opacity were examined by making targets of mixtures of gold and beryllium to vary the density of the strongly radiating gold in the target. These experiments demonstrate the effects of material opacity on both thermal and M-band x-ray production. These experiments were performed with large laser spots and greater than 1 kJ of 0.35-μm laser light using the Nova laser. These experiments have expanded our understanding of our ability to computer model the interaction of high intensity laser light with high-Z plasmas.

Continued research interest at LLNL has been the study of laser interaction with high-Z plasmas. Understanding production and the spectral content of the x-ray emission from these high-Z plasmas provides an exacting test of our understanding of radiation hydrodynamics. On previous lasers at LLNL we have experimentally investigated the wavelength dependence of x-ray production from laser-irradiated Au disk plasmas.[1-3] These early experiments were performed using Gaussian shaped laser pulses. More recently on the Nova laser we have measured the intensity dependence of the x-ray production using 0.35-μm light with 1-ns square pulses.[4] These experiments using pulses with rise times of only 100 ps could not be as well understood as the previous experiments using Gaussian pulse shapes. We have performed additional experiments, reported here, to better understand the dynamics of the x-ray production process.

The major features of the experiments are the use of longer pulse lengths, as well as time-resolved x-ray production and time-resolved x-ray imaging to better study the dynamics of the plasma. Experiments were also performed using targets made of low concentrations of Au dissolved in Be and small dots of Au embedded in CH. Results of these experiments will not be discussed due to length constraints.

The experiments were performed using a single beam of the Nova laser. Pulses of 0.35-μm light having energies up to 2 kJ irradiated the disk targets with intensities of $2 - 5 \times 10^{14}$ W/cm^2. All of the pulses had approximately 100 ps rise and fall times with a approximately constant intensity central region. Nominal laser spot sizes varied between 400 and 500 μm.

The time dependence of the instantaneous efficiency for conversion of laser light to x rays is shown in Fig. 1 for three pulse lengths. The x-ray flux is measured using an x-ray streak camera having six broad band channels spanning the range from 100 eV to 1.5 keV.[5] The six channels were absolutely calibrated by comparing the integrated signals from the channels to x-ray diode signals having similar x-ray response. The incident laser time history was measured using an optical streak camera normalized to incident laser calorimetry. The time history of the optical and x-ray streak cameras have been correlated to 50 ps using an optical fiducial.

Two different time dependences can be noted in the instantaneous conversion efficiency. For times less than about 500 ps the instantaneous efficiency rises rapidly from zero to about 0.6. This

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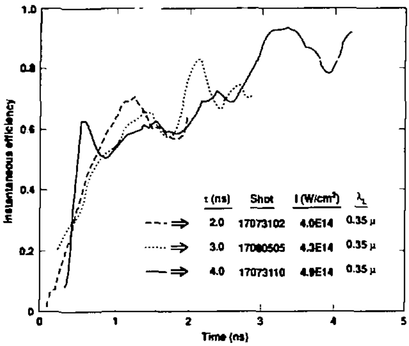

Fig. 1. The time dependence of the instantaneous conversion efficiency is measured for three pulse lengths. The incident laser intensity is 5×10^{14} W/cm^2 of 0.35-μm light.

rapid rise occurs while the plasma is establishing electron conduction gradients in the overdense region where calculations indicate that most of the x-ray production occurs in high-Z targets.[3] After 500 ps the instantaneous efficiency increases gradually until the end of the laser pulse. Values greater than 0.75 are observed for the longer pulses. The data also shows smaller scale modulation. This modulation coincides with fluctuations in the laser pulse intensity. Since the plasma has finite heat capacity, it does not respond instantaneously to fluctuations in laser intensity.

Time integrated spectra are shown in Fig. 2 taken using 100-ps pulses (2a) and 3-ns pulses (2b). The qualitative difference between the two spectra is the enhanced emission in the region around 250 eV for the 3-ns pulse. The pulse length study indicates that emission in the 250-eV region increases monotonically with respect to energies around 700 eV as the pulse length increases from 100 ps to 4 ns.

To better understand the origin of the enhanced emission around 250 eV, we time-resolved the 250-eV emission using a pinhole and x-ray streak camera. Results are shown in Fig. 3 for a 4-ns pulse focussed to a 500-μm spot on a Au disk. The results show an intense emission the size of the laser spot emitting for the duration of the laser pulse as indicated by the dashed lines. In addition low intensity wings are observed to spread laterally as indicated by the solid line. Images at 700 eV show the intense emission the size of the laser spot, but the expanding lower intensity wings are not observed.

Based on the imaging results we have developed an empirical model for the pulse length dependences of the integral x-ray conversion efficiency. We assume that the experimental conversion efficiency from the laser spot is the measured efficiency for 1-ns pulses. The increase after 1 ns is due to the lateral spreading of the cooler region whose brightness is derived from the 240-eV time-resolved imaging.

Figure 4 compares the results of this empirical model with the measured pulse length dependence of the x-ray conversion efficiency. The model qualitatively explains the data although there appears to be a slight enhancement in the

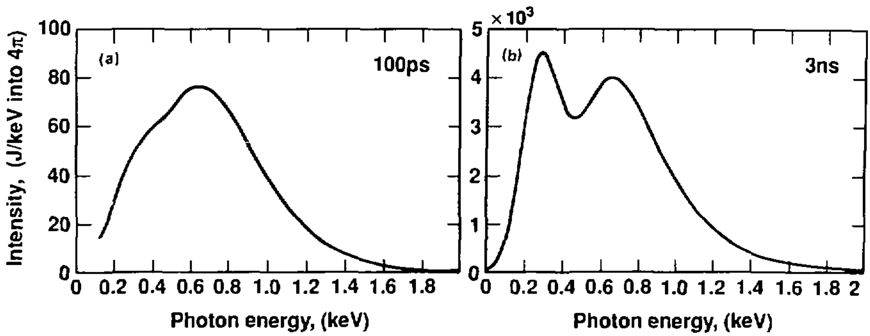

Fig. 2. Time-resolved spectra are shown for 100 ps (a) and 3 ns (b) pulses.

Fig. 3. A time-resolved image of 250-eV x-ray emission from a Au disk shows lateral spreading of the emitting region.

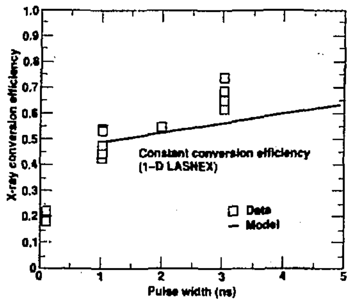

Fig. 4. Pulse length dependence of the integrated x-ray conversion efficiency is compared with an empirical model assuming lateral spreading of low-energy x-ray emission.

conversion efficiency above that explained by the model.

The cooler expanding plasma appears to be produced primarily by radiation heating the outer regions of the disk. Coronal expansion should produce a harder spectrum than observed in the outer regions. This feedback of the radiation into material heating may also explain some of the differences in conversion efficiency observed between disks and spheres. The spheres are usually illuminated nearly uniformly. Any radiation emitted laterally would be heating already hot matter which would enhance the radiation efficiency. We could speculate that a similar enhancement may also be occurring on a smaller scale for smoother beams with ISI causing the enhanced conversion efficiency. Of course these speculations need to be confirmed by experiments.

In summary, we have furthered our data base on high-Z x-ray production in laser-produced plasmas. Long pulse experiments indicate that lateral spreading due to radiation conduction is more important than previously believed. In addition other experiments using diluted targets and finite mass targets, which have not been discussed here, have also aided in our better understanding of the interplay between radiation and hydrodynamics in high-Z plasmas.

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