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SOFT X-RAY EMISSION FROM Fe AND Cu LASER PRODUCED PLASMAS

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ABSTRACT

We studied X-ray emission from laser plasmas produced by irradiating Fe and Cu targets at 1μm wavelength and intensity on target up to 1.2 10^{13} W/cm^2. Laser pulse lengths were either 3 ns or 20 ns. X-UV conversion efficiency was measured versus laser intensity and pulse duration. The comparison with similar data obtained using near-UV laser sources is discussed. X-UV spectra are also presented.

Laser produced plasmas are interesting sources of soft X-rays, potentially competitive with synchrotrons in a wide range of applications. They have been already successfully applied to X-ray microscopy, microlithography, radiobiology, EXAFS.

To these purposes the most widely used laser systems are Nd and KrF. Generally speaking the X-ray pulse length is comparable with the laser pulse length, $t_X \approx t_L$. KrF lasers, due to their shorter wavelength, give a deeper laser plasma coupling and consequently a higher laser light to X-ray conversion efficiency $\eta = E_X/E_L$. Here E_L and E_X are the laser pulse energy and the energy emitted by the plasma in the soft X-ray region of the e.m. spectrum. However laser plasmas produced by KrF lasers of relatively long (tens of nanoseconds) pulses give X-ray pulses with $t_X < t_L$, so also limiting [1] the efficiency. This makes interesting to study X-ray emission of plasmas produced with Nd lasers at different pulse durations. This kind of study is also interesting from the point of view of interaction physics, because non linear phenomena are expected to be stronger at longer wavelength. In this context we also performed measurements on thin foil targets, a better condition to understand phenomena involved in X-ray emission[2].

In this report we characterize the X-ray plasma sources obtained from thick metallic targets irradiated by Nd laser light. It will be evident that the parameters of those sources make them interesting for applications.

Fe and Cu targets were irradiated with focused 1.06 μm laser light in a spot of about 60 μm at intensities up to 1.2 10^{13} W/cm^2. Two different laser pulse durations have been used: 3 ns and 20 ns FWHM. The laser beam was focused with a 20 cm focal length lens on a rotating target rods so that fresh metal surface was available each shot. The incidence angle was 45^0, also to avoid dangerous reflections back to the laser system. Targets were put in a vacuum chamber filled with 1 torr He to reduce debris coating of the focusing lens.

In order to measure the X-ray intensity, a P-I-N silicon diode was used at 45^0 to the laser beam, whose line of view was normal to the target surface. The diode was filtered with a 12 μm Al foil, which stopped visible light and defined the allowed spectral range. We measured η versus both laser intensity I_L and pulse length t_L. An important finding was that with 20 ns laser pulse still $t_X \approx t_L$, differently from KrF laser generated sources, which showed a definite X-ray pulse shortening in this case[1]. Besides η was found to increase with pulse length. As a net result the conversion efficiency was found to be higher with 20 ns than 3 ns Nd laser pulses. Another different result from KrF to Nd irradiation was that in the latter case we measured about the same conversion efficiency for Cu and Fe. Differently in previous measurements with UV laser light, $\eta(Fe) \approx 3\ \eta(Cu)$ was found[3].

As long as the irradiation with 20 ns pulses was found to be more efficient, we discuss some detail of data obtained in this configuration. Efficiency was varying from 0.1% at

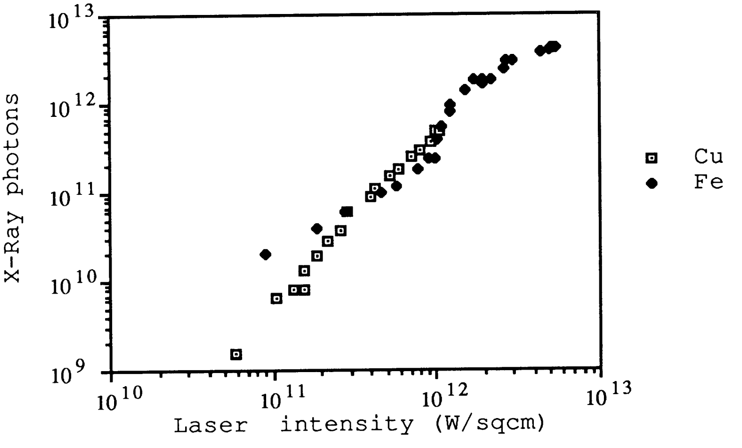

Fig.1 Flux of X-ray photons for Cú and Fe targets versus laser intensity, 20 ns pulses, measured at 45^0 from the laser axis, normally to the target surface. The plot was obtained from experimental data and normalized for 1 cm^2 sample put 10 cm from the plasma.

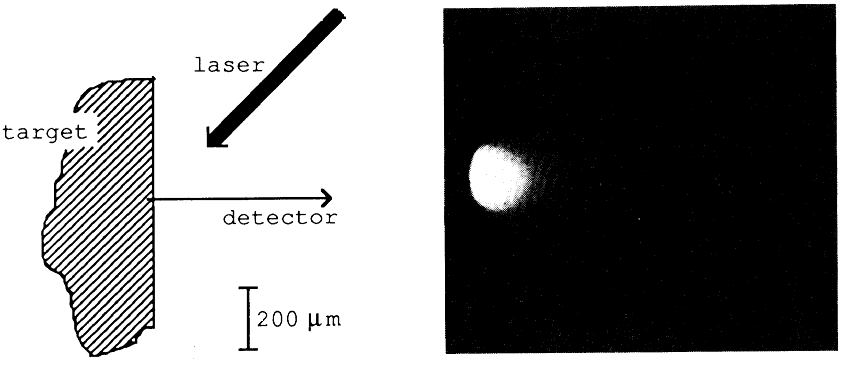

Fig.2 A pin-hole camera image of the X-ray source. Target: Fe; laser intensity: 5 10^{12} W/cm^2.

$I_L = 10^{11}$ W/cm^2 to a maximum value of 5% at $I_L = 4\ 10^{12}$ W/cm^2. At higher intensities η was slowly decreasing (down to 4%).

In Fig.1 we see the X-ray signal as a function of laser intensity in terms of both X-ray flux (in units of photons/cm^2) and source brightness for each laser shot and photon energy ≈1keV. The X-ray flux was calculated for a sample detector put at 10 cm from the source along its symmetry axis which is the direction of maximum emission. A cosθ angular distribution was assumed, accordingly with that one usualy observed in this kind of experiments, in order to estimate the total emission and the conversion efficiency. The sharp increase in the flux, a "threshold-like behaviour", is due to the L-shell character of the X-ray emission of Cu and Fe, as discussed in ref.[1]. In correspondence to the highest values of I_L, where efficiency is decreasing, the X-ray flux still shows a slow increase.

A pin-hole camera was used to image the X-ray source. Fig.2 shows a typical picture obtained with a 10 μm pin-hole and a 13 μm Be filter. The line of view was at 45^0 in a vertical plane. Fig.2 evidences that the source is very small as shown by the scale reported in the figure.

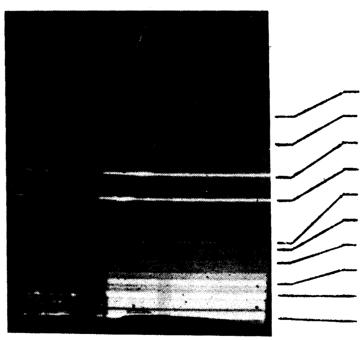

Fig.3 A typical Cu L-shell spectrum.

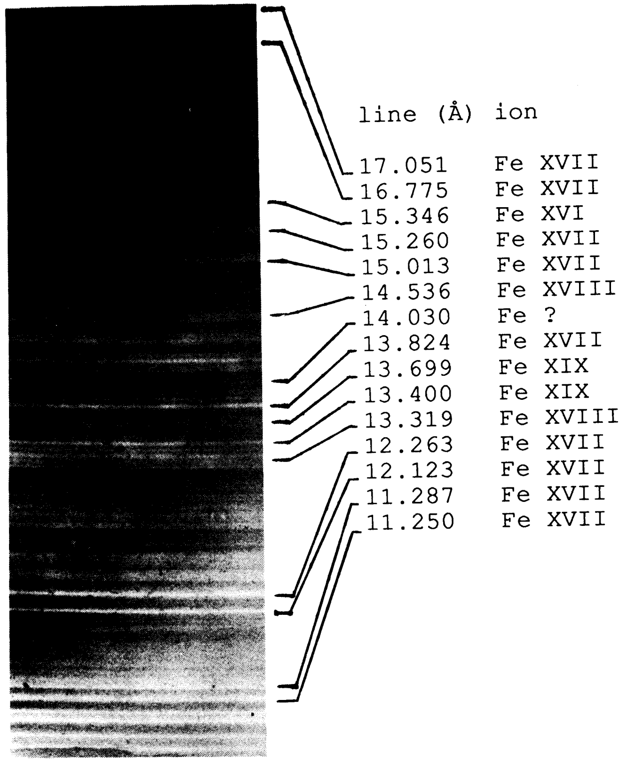

Fig.4 A typical Fe L-shell spectrum.

The small size is very important in many applications. It also causes the X-ray flux to increase as the reciprocal squared distance for any practical distance of utilization.

We recorded Cu and Fe X-ray L-shell emission spectra at at $I_L = 4\ 10^{12}$ W/cm^2 using a flat crystal spectrometer filtered with 13 μm Be. A KAP crystal was used, with 2d = 26.6 Å. Our spectra, showed in Figs. 3 and 4 are not very different from those recorded in analogous conditions with an UV laser (see ref.[4] for Cu and ref.[5] for Fe spectra respectively). We observed that ionic species contributing to spectra are Fe XVI to Fe XIX for iron , Cu XX and Cu XXI for copper. Our spectra are centered at $h\nu \approx 1.2$ keV for Cu and $h\nu \approx 0.9$ keV for Fe due to the higher atomic number for copper.

Both were recorded using X-ray Kodak DEF films, which where also used for the pin-hole pictures. Since conversion efficiency was rather high, a single laser shot was sufficient to record a spectrum and/or a pin-hole image.

In conclusion we can say that our experiment confirms laser generated plasmas as simple and relatively cheap means to obtain high soft X-ray fluxes (up to $3\ 10^{12}$ X-UV photons/cm^2 per laser shot at working distance). In this respect they are an attracting alternative to synchrotron machines. Our measurements seem to suggest the use of Nd laser as X-ray source drivers at least for pulse duration of tens of nanoseconds, where KrF driven sources are affected by pulse shortening.

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