REAR SIDE K-SHELL X-RAY EMISSION FROM Al FOIL TARGETS

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The K-shell spectra and the intensity of the X-ray emission from the rear side of laser-irradiated Al foils were studied for various target thicknesses. Comparison of front and rear side X-ray intensity gives evidence of high X-ray transmission through the target. The application of rear side emission as a debris-free X-ray source is discussed.

In most of the applications of laser-produced plasmas as soft X-ray sources, the production of debris during target ablation must be carefully controlled, since the debris may damage the sample and the filters used in typical experiments. A He or Ne atmosphere has been introduced in some experiments in order to solve this problem[1]. Also the laser light scattered or reflected from the target may be a nuisance for applications.

The use of the X-ray emission from the rear side of a foil target as a debris-free soft X-ray source has been recently proposed by D.Giulietti et al.[2] and subsequently by Hirose et al.[3]. In these papers it was observed that for an Al foil target, several microns thick, irradiated by a laser pulse of a few nanoseconds duration, laser burnthrough does not occur and thus the target acts as a shield for debris and laser light. On the other hand, anomalously high X-ray transmission through the foil was observed, the X-ray emission intensity from the foil rear side being comparable to the intensity from the front side. Consequently, such technique could result suitable for application purposes.

X-ray transmission through laser-irradiated targets was experimentally investigated also in some papers[4,5,6] mostly devoted to the study of radiative target preheating in laser fusion and of the dense matter equation of state. However, only few authors investigated the X-ray spectrum of the rear side emission, despite the fact that, as discussed below, valuable information on the dynamics of energy transport in the target[7] can be acquired by accurate spectral analysis of such a radiation.

In this paper we analyze K-shell spectra of the rear side emission from laser-irradiated Al foils. The comparison of front and rear side spectra for various target thicknesses gives evidence of ionisation burnthrough and strong increase of the X-ray transmittivity. The X-ray yield of rear side emission is also measured.

The experimental set-up is the same as described in our previous work[2]. A 3 *ns*, 1.064 *μm* laser pulse was focused on Al foil targets in a 60 *μm* focal spot at an intensity of $2 \cdot 10^{13}$ $W\,cm^{-2}$. Front and rear side spectra in the 5-8 Å spectral region were obtained using a Bragg spectrometer equipped with a PET crystal ($2d$=8.742 Å). Each spectrum shown in this paper was taken with a single laser shot.

Fig.1a shows a representative front-side K-shell spectrum from a 6 *μm* target, consisting of resonance and satellite lines and He-like recombination continuum. For comparison, a rear-side spectrum obtained in the same conditions is shown in fig.1b. The two spectra are quite similar, showing that very efficient X-ray transmission through the 6 *μm* foil takes place in this spectral window. Fig. 1c shows a rear-side spectrum from a 3 *μm* target, filtered through a second 3 *μm* Al foil placed about 1 *cm* behind the target. Although incomplete on the long wavelength side, this latter spectrum shows strongly attenuated emission lines with respect to the spectrum in fig.1b. Finally a rear side spectrum from a 13 *μm* target is shown in fig.1d: in this spectrum the lines are weaker with respect to the preceding spectra but they are still clearly distinguishable. In contrast, no lines were distinguished from the background in a rear side spectra from a 6 *μm* target, filtered through a second 6 *μm* foil.

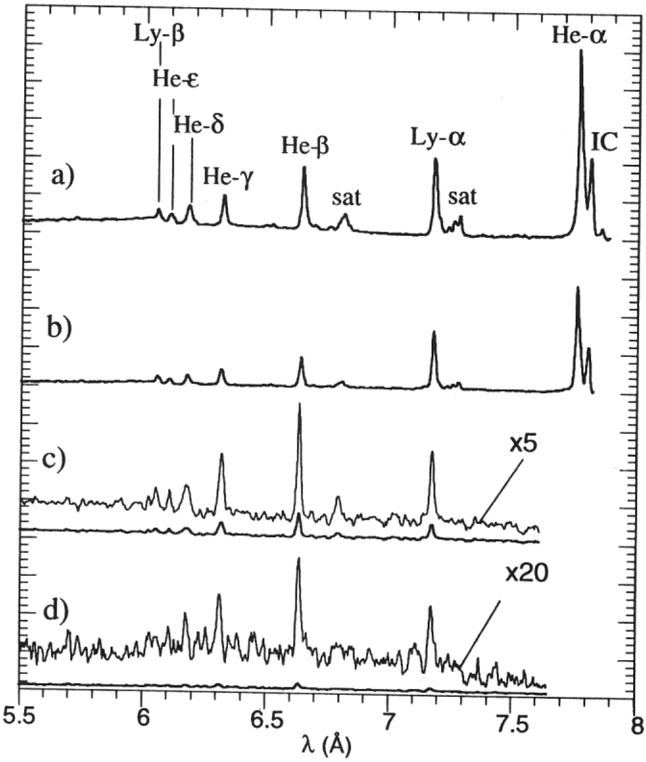

Fig.1: Al K-shell spectra from a) 6*μm* target front side; b) 6*μm* target rear side; c) "3+3"*μm* target rear side; d) 13*μm* target rear side

Fig.2 shows the ratio between line intensities of the rear-side spectrum 1b and the front-side spectrum 1a. The transmittivity of various thicknesses of "cold" Al is also shown for comparison. From fig.2 it is evident that the transmittivity of the laser-irradiated ("hot") Al foils is definitely higher than the transmittivity of "cold" foils of the same thickness, which is low due to the Al K edge at λ=7.96 Å. It is noticeable that the transmittivity appears considerably higher for the resonance lines than for the dielectronic "satellites" near the He-β and Lyα lines. We believe that this effect is due to the fact that resonance lines are strongly absorbed in the front side coronal plasma, while absorption is negligible for the satellite lines. For this reason the ratio between the intensities of a resonance line and a neighbouring satellite may depend upon the line of view. Thus only the optically thin satellite lines and the Intercombination (IC) line intensities are considered in order to estimate the X-ray transmittivity of the target backside. From fig.2 we find a transmittivity of about 30% at $\lambda \approx 7$ Å. A similar analysis for the 13 μm foil target gives a transmittivity of roughly 5%. Our results can be compared with those of Hirose et al.[3] who analysed rear side L-shell spectra in very similar experimental conditions. From their spectra, a 20% transmittivity can be estimated in the 20-100 Å range for a 7 μm Al target.

In order to estimate the laser ablation depth of the target we used the 1-D lagrangian hydrodynamic code MEDUSA[8], which takes thermal and shock wave energy transport mechanisms into account. According to simulations the ablation depth is expected to be about 3 μm in our experimental conditions and thus it cannot account for the observed foil transmittivity. Furthermore we observe that 1-D simulations are likely to overestimate the ablation depth due to an overestimate of the plasma temperature[2].

Hence the high X-ray transmission must be attributed to a decrease of the Al X-ray absorption in the target backside. Among different processes which may lead to a lower X-ray absorption efficiency, 2-D rarefaction of the target, as suggested by Ng et al.[6], is not expected to play a dominant role in our experimental conditions. In fact, in our case, the

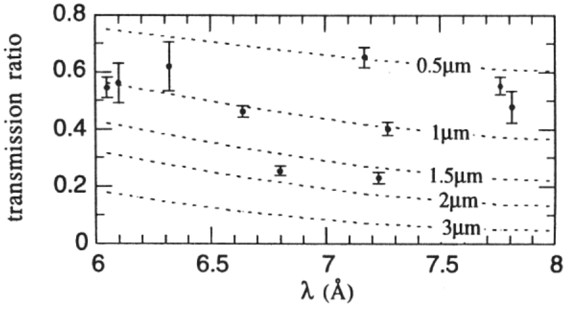

Fig.2: transmission ratio between line intensities of spectra 1b) and 1a). The transmittivity of various Al thicknesses is also reported (dashed lines).

laser spot size is much larger than the target thickness and thus expansion of the high density region is expected to exhibit a 1-D behaviour. Suprathermal electron transport is also expected to be negligible since the irradiation intensity is low. Thus, we attributed the anomalously strong X-ray transmission to ionisation burnthrough driven by radiative transport. This explanation was firstly suggested by Duston et al.[7] who simulated experimental conditions very similar to the present ones. In that model the ionisation generated by radiation transport causes the Al photoionisation edges to shift towards shorter wavelengths, thus opening X-ray "transparency windows" which move from the red to the blue side of the spectrum.

According to the ionisation-bunthrough model, from the rear side spectra we can estimate the ionisation in the target backside. In fact, since the transmittivity of the foil target at the IC line wavelength (λ=7.81 Å) is similar to that of a "cold" 1 μm foil (fig.2), at about 1 μm from the target rear face the solid Aluminium must have become "transparent" to this line. Thus, in this region ionisation must have reached the Al^{3+} stage for which the K edge (λ=7.76 Å) lies below the IC line. We have assumed that the transmittivity of ionised Aluminium is obtained from that of neutral Aluminium by simply shifting the absorption edge and then interpolating the mass absorption data between the two edges. If we assume Local-Thermodynamic Equilibrium (LTE) in the dense target, then, according to Saha equation, the rear side temperature corresponding to Al^{3+} ionisation stage is about 25 eV. These results are in reasonable agreement with other experiments[3,9] and simulations[7], altough different laser and foil parameters were used.

The time-integrated front and rear side X-ray intensity was measured using an X-ray P-I-N diode. The diode spectral sensitivity had its maximum for $\lambda \approx 7$ Å. The spectrally integrated intensity of the X-ray emission from the rear side of the 6 μm and 13 μm targets resulted about 0.1 and 0.02 times the intensity of the front side emission, respectively. According to these values, rear side emission could provide a debris-free X-ray source without a dramatic decrease of the X-ray intensity. Moreover the laser light conversion efficiency into X-rays, which is low for Al, could be increased by coating the Al target front side with a thin layer of some high conversion efficiency material.

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