L-shell emission from high-Z solid targets by intense \((10^{19}\text{W/cm}^2)\) irradiation with a 248nm laser

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Abstract: Efficient (1.2% yield) multikilovolt x-ray emission from Ba(L) (2.4 – 2.8\AA) and Gd(L) (1.7 – 2.1\AA) is produced by ultraviolet (248nm) laser-excited BaF\(_2\) and Gd solids. The high efficiency is attributed to an inner shell-selective collisional electron ejection.

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1. Introduction

Much effort has been expended recently in attempts to develop an efficient coherent x-ray source suitable for high-resolution biological imaging [1,2]. To this end, many experiments have been performed studying the x-ray emissions from high-Z materials under intense (>10\(^{18}\text{W/cm}^2\)) irradiation, with the most promising results coming from the irradiation of Xe clusters with a W (248nm) laser at intensities of 10\(^{18}\) – 10\(^{19}\text{W/cm}^2\) [3,4]. In this paper we report the production of prompt x-rays with energies in excess of 5keV with efficiencies on the order of 1% as a result of intense irradiation of BaF\(_2\) and Gd targets with a terawatt 248nm laser. The efficiency is attributed to an inner shell-selective collisional electron ejection mechanism in which the previously photoionized electrons are ponderomotively driven into an ion while retaining a portion of their atomic phase and symmetry. This partial coherence of the laser-driven electrons has a pronounced effect on the collisional cross-section for the electron ion interaction [5].

2. Experiment

The laser system used in the experiments is a Ti:Sapphire/KrF* hybrid system. The system produces pulses with an average energy of 400mJ and temporal duration of 230fs. The beam is focused with an f/2 parabolic optic for a resultant focal intensity of 10\(^{19}\text{W/cm}^2\). The spectra were recorded using a mica-crystal von H\(\ddot{a}\)mos spectrograph in 3rd order. The targets used were a BaF\(_2\) optical flat, and a 100 \(\mu\)m thick Gd foil.

Figure 1 shows the recorded Ba(L) spectrum. As can be seen from the figure, the double-peaked structure characteristic to the 3d\(\rightarrow\)2p transition is present, with charge states ranging from 29+ up to 38+. In addition, the Ba spectrum displays the prominent characteristic solid state transitions \(L_{\omega}, L_{\pi}\) and \(L_{\rho}\) from weakly ionized (0 – 10+) Ba atoms. Figure 2(a) shows a similar spectrum recorded for Gd(L).
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Fig. 1. Ba(L) spectrum, produced by intense irradiation (10^{19} W/cm^2) of a BaF\textsubscript{2} target. The peak has a charge state of 38\textsuperscript{+} as labeled on the plot.

Fig. 2 (a) Gd(L) Hollow atom spectrum + characteristic line spectra. The peak has a charge state of 40\textsuperscript{+} as labeled on the plot. (b) Gd(L) characteristic line spectra only.

To illustrate the efficiency of the x-ray yield, a calibrated diamond photoconductive semiconductor device (PCD) was used with the BaF\textsubscript{2} target. A signal from this detector is shown in Figure 3. The signal shown in the figure corresponds to a total energy of \sim 4.9mJ, assuming a uniform 2p distribution. Since the total laser energy on target was 400mJ, this translates into a conversion efficiency of 1.2\%!
Fig. 3. Diamond PCD signal of the L-shell radiation from BaF$_2$. The trace shows a rise time of ~150ps for the detector. The calibration of 160μA/W corresponds to an energy of ~4.9mJ of energy, assuming a 2π radiation distribution.

3. Theory

The shell selective collisional ionization theory, as outlined in reference [5], predicts that for L-shell emission, the 2p vacancies are generated by collisions with photoionized 4p electrons. According to current above threshold ionization (ATI) theory, a laser intensity of $1.4 \times 10^{19}$W/cm$^2$ is required to ionize the entire 4p subshell in Gd. The two Gd spectra (Fig. 2) were taken with laser intensities differing by a factor of 1.6. The lower intensity failed to produce the ionized plasma spectrum, while the upper intensity yielded the desired result. This data then provides a means of estimating the peak laser intensity, in this case producing a value of $1.4 - 2.3 \times 10^{19}$W/cm$^2$.

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5. References