L-shell emission from high-Z solid targets by intense (10^{19} W/cm²) irradiation with a 248nm laser

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Abstract: Efficient (1.2% yield) multikilovolt x-ray emission from Ba(L) (2.4 – 2.8Å) and Gd(L) (1.7 – 2.1Å) is produced by ultraviolet (248nm) laser-excited BaF₂ 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 ($>10^{18}$ W/cm²) irradiation, with the most promising results coming from the irradiation of Xe clusters with a UV (248nm) laser at intensities of $10^{18} - 10^{19}$ W/cm² [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 BaF₂ 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} W/cm². The spectra were recorded using a mica-crystal von Hámos spectograph in 3rd order. The targets used were a BaF₂ optical flat, and a 100 μm 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→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_α, L_{β1} and L_{β2} 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_2 target. The peak has a charge state of 38^+ as labeled on the plot.

Fig.2 (a) Gd(L) Hollow atom spectrum + characteristic line spectra. The peak has a charge state of 40^+ 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_2 target. A signal from this detector is shown in Figure 3. The signal shown in the figure corresponds to a total energy of $\sim 4.9 \text{mJ}$, 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 BaF₂. 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 2*p* vacancies are generated by collisions with photoionized 4*p* electrons. According to current above threshold ionization (ATI) theory, a laser intensity of 1.4×10^{19} W/cm² is required to ionize the entire 4*p* 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/cm².

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