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Back-Side Emission from Filtered Gold Targets

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ABSTRACT

An investigation of the rapid rise time of incoherent x-ray emission from targets heated by an ultra-short pulse (USP) high-intensity optical laser was conducted for use as the x-ray source for inner-shell photo-ionized (ISPI) x-ray lasing. Previous studies considered front-side x-ray emission; however, ISPI x-ray lasing requires a filtered x-ray source. Modeling using the hydrodynamics/atomic kinetics code LASNEX of a 40 fs USP driving laser with an intensity of 10^{17} W/cm^2 incident on a flat target of thin Au layered on a Be filter is presented. The filter has a modest influence on the x-ray emission of the Au via conduction cooling but has a large effect on the backside spectrum by removing low energy x rays as the Au emission passes through the filter. The use of such a filtered source is shown to provide the needed x rays to achieve high gain in C at 45 Å.

Keywords: ultra-short pulse, x-ray source, inner-shell photo-ionized

1. INTRODUCTION

Within the last 5 years there have been major advances in obtaining high optical intensity through chirp pulse amplification. Pulse duration as short as 20 fs^{1,2} and powers $> 1 \text{ PW}$, with longer pulse duration ($\sim 500 \text{ fs}$), have been demonstrated.³ These lasers yield intensities as high as 10^{20} W/cm^2 and can be used to generate near solid-density high-temperature plasmas. The plasma emits high energy x-rays which can be used as an incoherent x-ray source or to pump an x-ray laser.

In this paper we will present modeling results of back-side emission from filtered gold targets heated by an ultrashort pulse high intensity laser. We show that this emission can be used to pump an inner-shell photo-ionized x-ray laser or produce a short pulse of incoherent high energy x rays. In section 2 results from modeling are presented showing the fast risetime of the high energy x rays. In section 3 we discuss the inner-shell photo-ionized x-ray lasing scheme. This scheme promises both a short wavelength and a short pulse source of coherent x rays with high average power. In section 4 we present our conclusions.

2. X-RAY SOURCE

An investigation of x-ray emission from targets heated by an USP high-intensity optical laser was conducted using the hydrodynamics/atomic kinetics code LASNEX.⁴ As seen in Fig. 1 a high intensity short pulse laser is incident on a thin Au target layered on a Be filter. The USP laser is absorbed by the Au creating a near-solid density plasma. The laser-produced plasma emits a broadband of x rays. However, by the use of a filtered source we are able to reduce the flux of low-energy x rays creating a short duration high-energy x-ray pulse with a rapid risetime. This x-ray source can be used by itself or to pump an inner-shell photo-ionized x-ray laser.

In Fig. 2 we show typical spectral results from a 40 fs USP driving laser with an intensity of $1.0 \times 10^{17} \text{ W/cm}^2$ incident on a flat target of thin (200 Å) Au layered on a $0.5 \mu\text{m}$ Be filter (see Fig. 1). An investigation of x-ray emission from targets heated by an USP high-intensity optical laser was conducted using the hydrodynamics/atomic kinetics code LASNEX.⁴ When we model this system, the energy is deposited in a self consistent manner by solving the wave equation for the laser electromagnetic field⁵ and the atomic kinetics and x-ray emission are calculated with an average-atom atomic model that includes spin-orbit coupling. Figure 2 shows the effect of filtering and the $0.5 \mu\text{m}$ Be filter reduces the x-ray flux at the carbon K-edge (280 eV) by 75% where filtering is not desired. However, this

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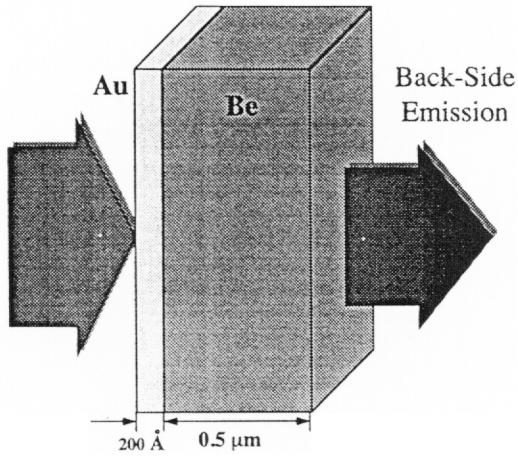


Figure 1. A high-intensity USP driving laser is incident on a flat target of thin Au layered on a Be filter, the resulting filtered back-side emission is a short pulse of high-energy x rays.

filtering is needed to sufficiently reduce the low-energy x rays which can L-shell ionize filling the lower-laser state of a carbon ISPI x-ray laser.

The density profile of the Au at time of maximum USP driving laser intensity is shown in Fig. 3 along with the energy deposition rate. The majority of the absorption takes place at half-solid density. The corresponding electron temperature is shown in the plot on the right. A temperature gradient is seen across the Au. At later time, before maximum x-ray emission ~ 100 fs, the Au heats uniformly and heats a small portion of the Be filter (~ 100 Å at time of maximum x-ray emission).

As seen in Fig. 2 the emission from the front side of the target is greater and the emission from the back side. By use of a filtered target we are able to reduce the flux of low energy x rays and retain a majority of the high-energy x rays. In Fig. 4 the time dependent intensity is shown. The USP driving laser intensity is shown to precede the back-side x-ray emission by ~ 50 fs and have a conversion efficiency of 0.8%. The emission of the x rays is shown to be ~ 100 fs in duration and consist mainly of x rays above 0.5 keV. Whereas emission below 0.5 keV is significantly reduced.

3. X-RAY LASING IN CARBON AT 45 Å

Inner-shell photo-ionization (ISPI) x-ray lasing is a very attractive approach to short wavelength lasing ($\lambda < 50$ Å). In this approach, an incoherent x-ray source with a fast risetime is used to selectively ionize inner-shell electrons of the lasant material. The scheme was originally proposed by Duguay and Rentzepis⁶ but problems of collisional ionization associated with the relatively long pulse optical lasers available at that time caused x-ray lasing to never be realized. More recent work done by Kapteyn⁷ and Strobel, et al.⁸ concentrated on very short wavelengths, $\lambda \leq 15$ Å, where x-ray lasing has not been demonstrated. We present results, using the conventional ISPI scheme, for C at 45 Å as a representative low-Z element where lasing can be tested using current high energy USP lasers. Lasing at 45 Å requires less energy, at least an order of magnitude less than for 15 Å.

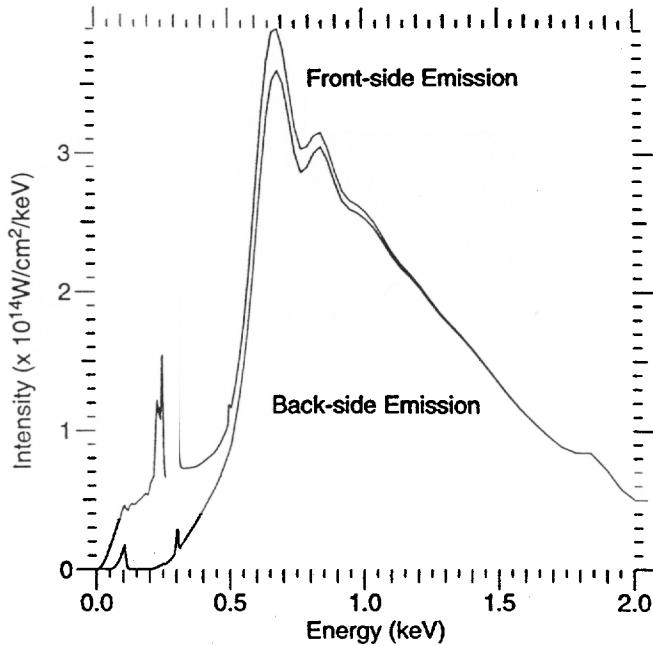


Figure 2. The spectral front-side and back-side emission is shown at time of maximum x-ray emission. The effect of filtering can be seen in the reduction of x-ray intensity below 0.5 keV. The maximum intensity is between .5 and 1.0 keV.

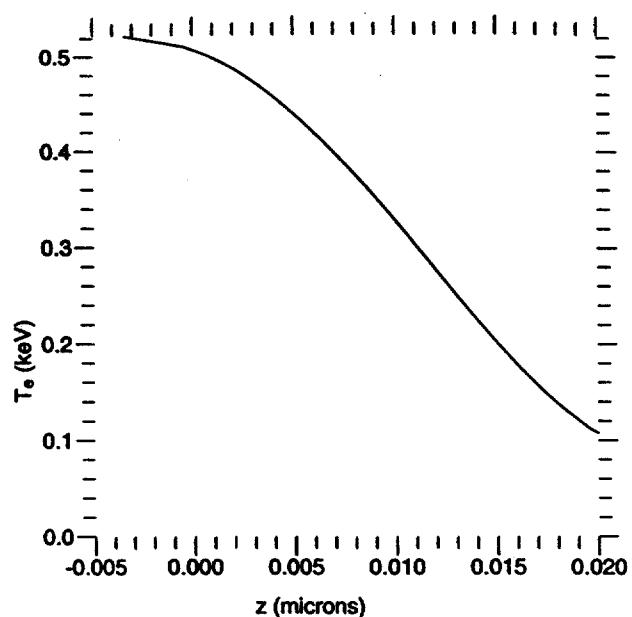
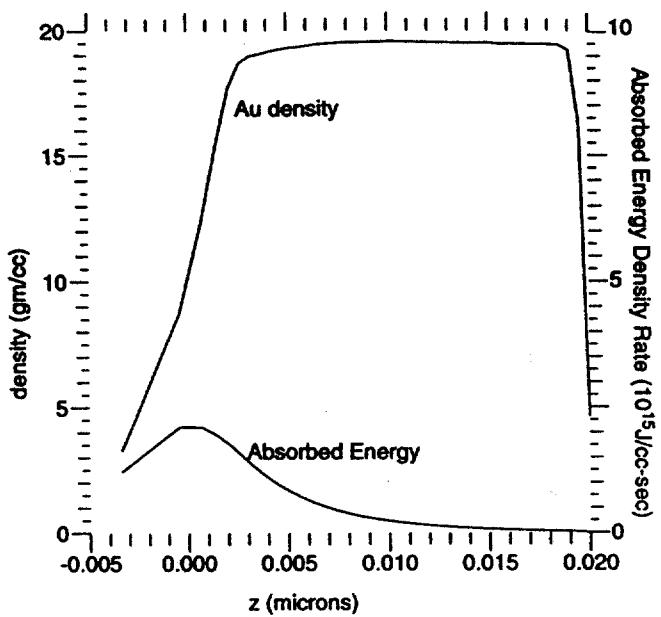


Figure 3. Density and absorption of the 200 Å Au target is shown at time of maximum incident laser intensity and the associated electron temperature for a $1.0 \times 10^{17} \text{ W/cm}^2$, 40 fs USP driving laser incident on a flat target of thin (200 Å) Au layered on a $0.5 \mu\text{m}$ Be filter.

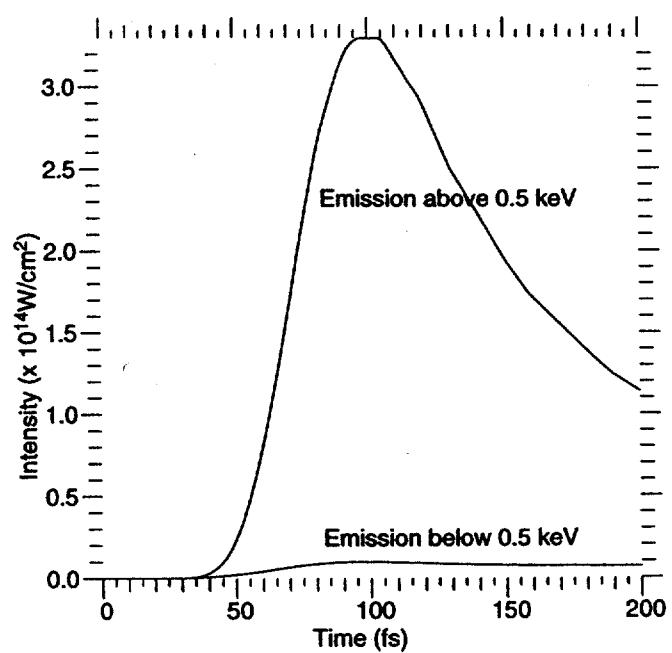
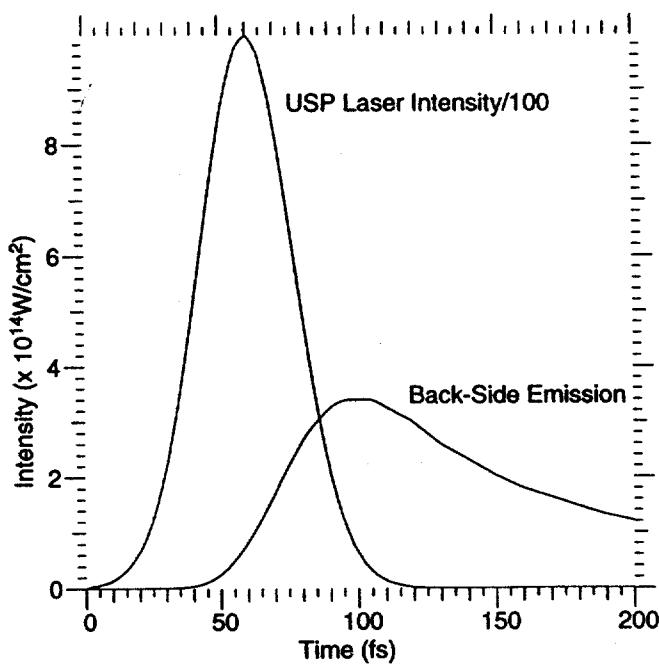


Figure 4. The rapid risetime of the filtered source is shown. The effect of filtering can be seen in the reduction of x-ray intensity below 0.5 keV.

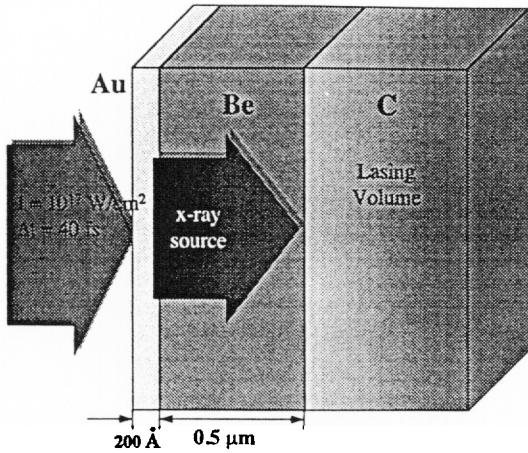


Figure 5. The required large flux of x rays is obtained from a high Z target heated by a high-intensity ultrashort-pulse laser. The incoherent filtered x-ray source creates a population inversion in the low density C resulting in x-ray lasing at 45 Å.

Figure 5 shows our proposed x-ray laser target with a line focused laser beam incident on a high-Z material. This laser produced plasma emits a broad spectrum of x rays. A high-pass x-ray filter is required to remove low energy x rays, which would lead to significant L-shell ionization, prior to the x-ray source being incident on the low density C. Modeling shows that a driving laser of intensity 10^{17} W/cm^2 , 40 fs FWHM, incident on a flat target composed of 200 Å Au layered on a 0.5 μm Be filter is sufficient to produce a large gain-length product. For a $10 \mu\text{m} \times 1\text{cm}$ line focus, a carbon density of $1.2 \times 10^{20} \text{ cm}^{-3}$, a peak gain of 15.6 cm^{-1} is found. In Fig. 6 we show the gain as a function of time along with the time dependent filtered intensity of the x-ray source. Collisional ionization to the lower-lasing levels limits the duration of lasing to ~ 50 fs FWHM. Due to the USP nature of the ISPI x-ray laser a traveling wave pump is needed to achieve a large gain length. In this manner output in a single direction is achieved and the length of the laser is only dependent on the driving laser and tolerances in the optical system. Since the lasing is on a time scale of 50 fs this requires tolerances in the wavefront on the order of 15 μm.

The use of flat targets offers the absorption of only a fraction of the incident energy (17%), yet with the use of structured targets one can achieve nearly complete absorption. Structured targets can be composed of grooves, clusters or cylinders. All these have approximately 100% absorption of the incident energy with high x-ray emission. Cluster targets, e.g., gold-black, are inexpensive but hard to model due to their fractal properties and there are issues of slower risetimes associated with potential low density emission.⁹ Grooved targets, in general, are expensive but easy to model. A third choice is a two-dimensional lattice of cylindrical absorbers where work done by Marjoribanks, et al.¹⁰ shows high x-ray conversion efficiencies for such structured targets. By the use of a structured target a modest reduction in energy driving laser can be used making ISPI x-ray lasing in carbon.⁹

4. CONCLUSION

X-ray emission from the back-side of a filtered target of thin (200 Å) Au layered on a 0.5 μm Be filter heated by a 40 fs FWHM high-intensity, 10^{17} W/cm^2 optical laser has been shown to produce a short pulse (88 fs FWHM) of high-energy x rays with a conversion efficiency of 0.8%. Our calculations show that a driving laser with a pulse duration of 40 fs, a $10 \mu\text{m} \times 1\text{cm}$ line focus, and energy of 4 J gives a gain length of 15.6 in C at 45 Å or an effective gain length of 10 accounting for absorption. We demonstrate that such a short duration for the optical driving pulse

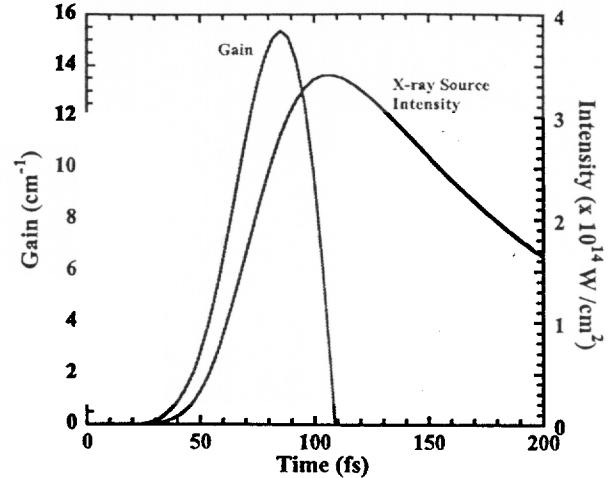


Figure 6. The gain as a function of time along with the time dependent optical USP laser intensity divided by 100 and the filtered intensity of the x-ray source are shown.

is required to control collisional filling of the lower laser state. Optical lasers with the required attributes and with repetition rates of order 10 Hz are becoming available, making this approach realizable in the near term.

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