Laser-produced plasma He-alpha source for pulse radiography

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Through the use of time and space integrated kiloelectronvolt (keV) spectroscopy, we investigate the thermal emission of plasma, which produces strong line emission from the titanium K shell (He-α at 4.7 keV and H-α at 4.9 keV), created by laser. In order to optimize the conversion efficiency enhancement on titanium foils, the experiment is conducted under a variety of laser-driven intensity conditions. The X-ray emission intensity at 4.7 keV is measured and compared with prediction. The experimental result demonstrates that the solid Ti target laser-produced plasma (LPP) source has X-ray emission at 4.7 keV, which are all generated from electronic transitions in Ti ions at pulse width of 2.1 ns or 30 ps, the crudely evaluated He-α X-ray intensity appears to slightly increase with laser intensity enhancement, and the pre-pulse effect increases the conversion efficiency of the He-α X-ray. In addition, a 90-μm-thick Ti foil as a filter is used to transmit He-α X-ray at near 4.7 keV, creating a quasi-monochromatic transmission and greatly reducing the lower- and higher-energy background.

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X-ray radiography is an important tool for diagnosing the dynamics, symmetry, stability, and size of a laser-driven implosion[1−4]. In general, bright X-ray pulses are desired to map the implosion history of one or more regions of a multilayered target[5]. The requirements on the probing X-ray photon energy, spatial resolution, and signal-to-noise ratio (SNR) needed to yield quantitative measurements from radiographic images are derived from the planned high-energy density (HED) experiments. Although X-ray lines emitted from laser-produced plasmas are the most practical means of generating these high intensity sources[6−8], we do not currently have a firm understanding or a model that predicts K-α X-ray source parameters[9] for experimental conditions of interest. We have performed several experiments on the SHENGUANG II facility to understand He-alpha source and to test radiography concepts. In this letter, we try to understand if a short, bright burst of X-rays can be made, and to determine the conversion efficiency from laser light into X-ray photons for reasonably X-ray backlighting sources. While studying physics issues such as X-ray conversion efficiencies, source sizes, spectral bandwidths, and dependencies on laser intensities, we are trying to optimize the source towards workable high-energy radiography levels.

The experiment was performed on the SHENGUANG II Laser Facility. Figure 1 gives a schematic view of the experimental chamber. The planar solid target of titanium (Z = 22) is illuminated by a frequency-doubled beam of the 9th beam Nd-glass laser system (wavelength 0.53 μm, pulse width of either $\tau_{\rm L} =\sim 2.1$ ns or $\tau_{\rm L} =\sim 30$ ps (full-width at half-maximum, FWHM), at a focal spot diameter of $\sim$ 300 μm), with an average variety of intensity spanning from $\sim 0.8 \times 10^{15}$ to 5×10^{15} W/cm^2. We present the results derived from spectra taken with a flat crystal spectrometer (pentaerythritol (PET) crystal, $2d = 0.876$ nm), aiming at the expanding plasma in the horizontal plane of the driven laser, 45° from its axis. These data are time and space integrated near along the density gradient perpendicular to the target plane. A filter is positioned in front of the detector film. The spectra are recorded on Kodak SB-392 non-screen film and the conversion from optical density to intensity is done.

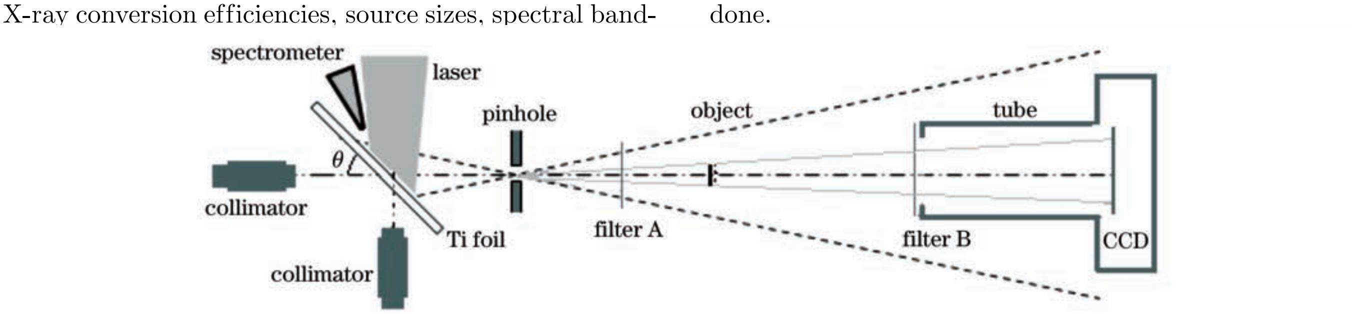

Fig. 1. Sketch of experimental arrangement. CCD: charge-coupled device.

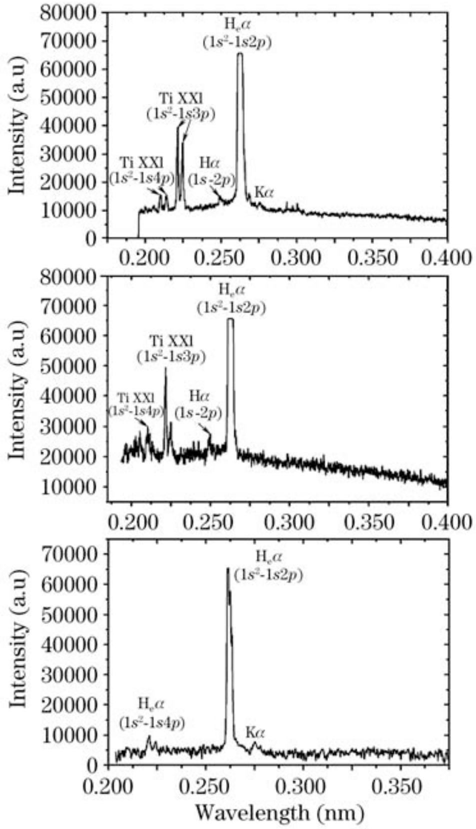

Fig. 2. Titanium K X-ray spectra from a laser-irradiated solid target. (a) Without pre-pulse, laser energy $E_L = 95.76$ J, $\tau_L = 2.23$ ns, with a 30-μm-thick Al filter; (b) with 0.1 pre-pulse, $E_L = 77.86$ J, $\tau_L = 2.208$ ns, with a 35-μm-thick Al filter; (c) without pre-pulse, $E_L = 49.47$ J, $\tau_L = 30$ ps, with a 20-μm-thick Al filter.

Figure 2 shows the typical titanium kiloelectronvolt (keV) spectra taken from the flat crystal spectrometer. Results are time and space integrated along the direction perpendicular to the target plane. Each spectrum consists of the bremsstrahlung continuous emission and the characteristic spectrum. It exhibits a high electron temperature. Figures 2(a)—(c) illustrate the lines considered in these measurements. Noted in each spectrum are the energy limits over which the photon yield has been integrated. In all cases this includes the bulk of the line emission that could be useful for a relatively narrow band X-ray imaging device (relative energy band $\Delta E/E \sim 0.1 - 0.2$). In particular, this includes the He-like resonance and Li-like satellite lines for Ti (~ 4.7 keV). The number of He-alpha photons is deduced by integrating this line. At present, the X-ray photon number is only crudely assessed in that the conversion from optical density to intensity cannot be still absolutely calibrated. At the pulse width $\tau_L = 30$ ps and the laser intensity explored ($\sim 3 \times 10^{15}$ W/cm^2), there is insufficient plasma temperature generated, as well as insufficient time available to produce a species of plasma ions (mainly He-like Ti) for radiating K X-rays[10,11]. Figure 2(b) shows the He-like Ti K X-ray emission data. It leads us to speculate that the He-like line is produced by both the thermal electrons and supra-thermal electrons present in the laser-heated plasma.

In order to probe the thick substrate layer, and differentiate the small thickness variation, a high SNR of the probe light will be needed for the lowest transmitting object in the image. Considering the narrow spectral bandwidth[12] of the Ti K-shell emission, a thick Ti foil as a filter was used to transmit He-α X-ray (at 4.7 keV), creating a quasi-monochromatic transmission and greatly reducing the lower- and higher-energy background. Figure 3 presents the image with a 90-μm-thick Ti foil as a filter to transmit He-α X-ray (at 4.7 keV).

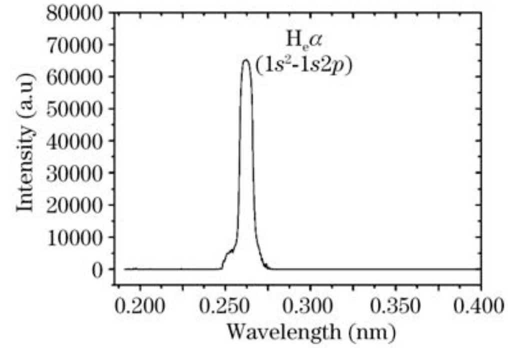

Fig. 3. Titanium keV spectral reconstruction result with a 90-μm-thick Ti filter. No pre-pulse is used, $E_L = 504.28$ J, $\tau_L = 2.21$ ns.

In summary, the pre-pulse effect increases the conversion efficiency of the He-α X-ray. At the pulse width of 30 ps, a species of plasma ions (mainly He-like Ti) radiating K X-rays was found. The conversion efficiency of the He-α X-ray appears to slightly increase with laser intensity. A 90-μm-thick Ti foil as a filter was positioned in front of the detector film to transmit He-α X-ray at near 4.7 keV, creating a quasi-monochromatic transmission and greatly reducing the lower- and higher-energy background. This method for reconstructing the Ti K-shell emission spectra has been tested for X-ray radiography.

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References

1. J. A. King, K. Akli, R. A. Snavely, B. Zhang, M. H. Key, C. D. Chen, M. Chen, S. P. Hatchett, J. A. Koch, A. J. MacKinnon, P. K. Patel, T. Phillips, R. P. J. Town, and R. R. Freeman, Rev. Sci. Instrum. **76,** 076102 (2005).
2. X. Wen, W. Hong, Y. Gu, Y. He, C. Tang, and J. Wang, High Power Laser and Particle Beams (in Chinese) **19,** 1373 (2007).
3. I. Uschman, E. Förster, H. Nishimura, K. Fujita, Y. Kato, and S. Nakai, Rev. Sci. Instrum. **66,** 734 (1995).
4. J. Workman, J. R. Fincke, P. Keiter, G. A. Kyrala, T. Pierce, S. Sublett, J. P. Knauer, H. Robey, B. Blue, S. G. Glendinning, and O. L. Landen, Rev. Sci. Instrum. **75,** 3915 (2004).
5. J. Dong, S. Fu, J. Xiong, R. Wang, X. Huang, H. Shu, Y. Gu, and Z. Wang, Acta Opt. Sin. (in Chinese) **28,** 604 (2008).
6. D. Boschetto, G. Mourou, A. Rousse, A. Mordovanakis, B. Hou, J. Nees, D. Kumah and R. Clarke, Appl. Phys. Lett. **90,** 011106 (2007).

7. D. L. Matthews, E. M. Campbell, N. M. Ceglio, G. Hermes, R. Kauffman, L. Koppel, R. Lee, K. Manes, V. Rupert, V. W. Slivinsky, R. Turner, and F. Ze, J. Appl. Phys. **54,** 4260 (1983).
8. L. Qi, Z. Li, Q. Ni, and B. Chen, Opt. Prec. Eng. (in Chinese) **13,** 272 (2005).
9. L. Xie and S. Zhu, Acta Opt. Sin. (in Chinese) **28,** 392 (2008).
10. M. Nantel, A. Klisnick, G. Jamelot, P. B. Holden, B. Rus, A. Carillon, P. Jaeglé, Ph. Zeitoun, G. Tallents, A. G. MacPhee, C. L. S. Lewis, S. Jacquemot, and L. Bonnet, Phys. Rev. E **54,** 2852 (1996).
11. J. Wu, W. Zhang, X. Shao, Z. Lin, and X. Liu, Chinese J. Lasers (in Chinese) **35,** 445 (2008).
12. Y. Li, X. Hou, J. Bai, J. Yan, C. Gan, and Y. Zhang, Acta Opt. Sin. (in Chinese) **28,** 1623 (2008).