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Absolute Kα line spectroscopy for direct observation of laser-plasma coupling

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Absolute Ka line spectroscopy is proposed to study laser-plasma interactions. The Kα line emission from Mo was experimentally and theoretically studied using clean, ultrahigh-intensity femtosecond laser pulses. The absolute yields of Kα x-rays at 17 keV from Mo was measured as a function of the laser pulse contrast ratio and irradiation intensity. Significantly enhanced Kα yields were obtained by employing high contrast ratio at the optimum irradiance. Conversion efficiencies of 4.28×10^{-5} /sr, the highest values obtained to date, was demonstrated with contrast ratios in the range of 10^{-10} to 10^{-11}. By analyzing the Kα yield with simulations, we can find the laser absorption mechanism and quantitative information about the transfer efficiency of laser energy to hot electrons.

1. Introduction

Kα emission, as a main production of laser plasma interaction, has been widely used as diagnostics in the field of high-energy-density physics. It has long been expected to provide more quantitative information about the hot electron generation and transport in laser plasma interaction. In this way, we propose an absolute Kα line spectroscopy dedicated for quantitative measurement of hot electron generation and transport in the high-Z target. This method provides local information about the hot electrons propagating through specific materials.

In the present study, hard x-rays at 17 keV was generated from Mo targets. The target was irradiated by an intense laser pulse with an extremely suppressed leakage level. A two-staged preplasma was formed and several absorption mechanisms happens. The multi-mechanism absorption not only leads to a high transfer efficiency (TE) of laser energy, but also produce a multi-temperature hot electron energy distribution. As a result, the highest Kα conversion efficiency (CE) of 4.28×10^{-5} /sr was achieved [1].

2. Experiments and results

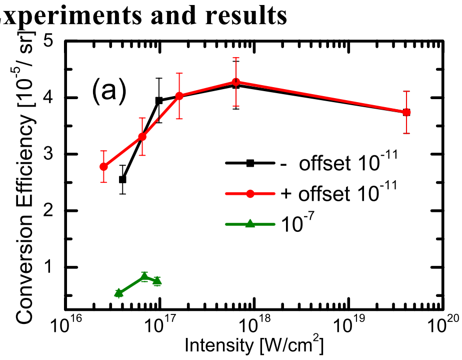

Fig.1. The conversion efficiency as a function of laser contrast and intensity.

Experiments were performed at J-KAREN laser facility at Japan Atomic Energy Agency, Kansai Photon Science Institute. This system delivered laser pulses at a wavelength of 800 nm. The effective pulse duration was 58 fs, which provided the peak power of 30 TW for a pulse energy of 1.8 J. With optical parametric chirped pulse amplifier (OPCPA) technology, the contrast ratio of this laser pulse could be enhanced to 10^{-10} and 10^{-11} [2,3]. The absolute Kα yield was measured by a calibrated CCD running in single photon counting mode. The conversion efficiency of Mo Kα as a function of laser contrast and intensity is shown in Fig. 1.

3. Transfer efficiency

According to D. Salzmann's model [4], the CE is a function of energy transfer efficiency and hot electron temperature T_h:

$$\eta_{K\alpha} = \frac{\eta_{TE}\, n_A\, \omega_{K\alpha} E_{K\alpha}}{4\pi T_h} \int_0^\infty dE \sigma_{K\alpha}(E) \times \int_0^d dx\, f_h(E_0, x) exp(-\frac{x}{\lambda_{x,mfp} cos(\theta)}) \quad (1)$$

where $\eta_{K\alpha}$ is the CE of Kα, which is experimentally measured. η_{TE} is the laser energy transfer efficiency. Assuming refluxing of hot electrons [5], the energy transfer efficiency can be derived from Eqn. (1). As shown in Fig. 2, by applying different power scaling laws for T_h, including Kruer's and Beg's [6,7], the transfer efficiency is estimated as a function of laser intensity with contrast of 10^{-10}. According to Beg's law, the TE in this experiment is about 20%.

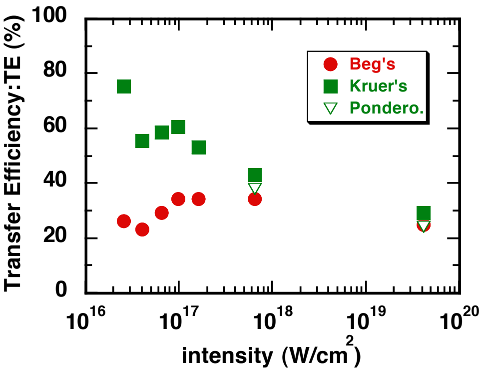

Fig. 2. Transfer efficiency.

3. PIC simulation

The preplama profile is estimated with a radiation hydrodynamic code, as shown in Fig. 3(a). The laser plasma interaction simulation is performed with a kinetic PIC code LPIC++ [8]. Figure 3(b) shows the time evolution of electron density. We can see, in the early stage, the front of laser pulse reaches the low density plasma and the electrons are pulled inside the high density region with ponderomotive force. Later, when the laser pulse propagates into the high density region, a part of the electrons are expelled into vacuum and gain energy from the electron field. This is so called vacuum heating (VH) process. Meanwhile, the behavior of **J**×**B** heating can be seen. The combination of 3 absorption mechanisms results in an enhancement of TE and consequently the Kα yield.

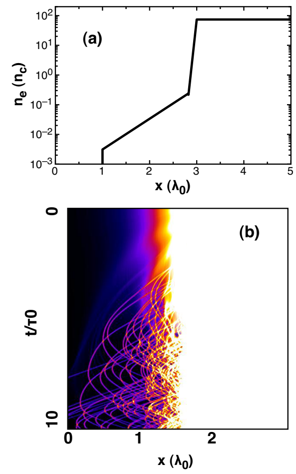

Fig. 3. Simulation profile: (a) Initial density profile; (b) time evolution of the electron density.

4. Conclusion

With quantitative Kα spectroscopy measurement, the behavior of laser plasma interaction with laser absorption and transfer have been experimentally and theoretically studied. The TE of laser energy to hot electron is estimated to be ~20%. This high value is due to a two stage sharp preplasma formed by the high contrast, high irradiance intensity laser pulse. Beside Mo, the Kα from Au and TE of cone-guide target have also been investigated in LFEX facility, the details will be given in the presentation.

Acknowledgments

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