The Evolution of the Nanowire Array under the Influence of Prepulse of Intense Femtosecond Laser and Its Consequences on the Kα Production

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The quasi-monochromatic K_α source based on the intense ultra short pulse laser is one of the attractive research topics in the short pulse laser applications. Using relatively simple setup, it is possible to produce bright hard x-ray line emission from several keV to a few tens keV with sub-ps pulse duration[1] and ～10 micrometer source size[2]. This ultra short x-ray flash has great potentials in a variety of applications, such as biomedical imagines [3-4] and ultra fast probing of atomic structures [5]. It is also developed as a novel backlighter for the pulsed radiography of high energy density physics [6-7].

The K_α emission is excited in the dense target by the fast electrons generated during laser plasma collective interaction. Previous works have presented the detailed studies on the K_α emission with both non-relativistic [8] and relativistic [9] lasers. The high conversion efficiency (η_k) of laser to K_α emission is an important subject in the research for the purpose of applications. The high conversion efficiency of laser to fast electrons and appropriate electron spectra are essential in achieve this goal. The solid targets with nano structure surface have been proved to be effective in enhancing the laser absorption and the x-ray production in the moderate laser intensity. For the high laser intensity, the simulations[10] show the similar enhancement. However, the inherent prepulse of short pulse laser may modify the surface structure before the main pulse impinges on the target. There [11]is very few detailed study on the evolution of the nano-structured target under the influence of prepulse of intense femtosecond laser and its consequences on the Kα production. We performed the detailed comparison studies on the K_α yields of nanowire array targets (NWAT) and the bulk copper targets (BT) on the high contrast terawatt Ti:sapphire laser. We found the ratio (η_r) of the K_α yields of the NWATs over foils changed in a complicated way with the laser intensity increasing from 2×10^{15}W/cm^2 to 1.8×10^{18}W/cm^2. The observed complicated behaviour of the η_r was the results of the transform from the regime of the enhancements of the laser field due to the surface nanostructure at low laser intensity to the regime controlled by the laser prepulse at high intensity. PIC and MC simulations reproduce the experimental results quite well.

1. EXPERIMENTAL DETAILS

The experiments were performed on the high contrast terawatt Ti:sapphire CPA laser at the Shanghai Institute of Optics and Fine Mechanics (SIOM), delivering up to 200 mJ on target in infrared (800 nm), p-polarized pulses of 60 fs duration. The laser beam was focused on the target with the f/5 off-axis parabola at the incident angle of 16 degree. The 44% laser energy was contained within the 8 x 11 μm^2 laser focus (FWHM). The highest available laser intensity was 1.8 x 10^{18}w/cm^2. The contrast in the ps range measured by a third order auto-correlator is shown in Fig. 1. Except the pre-pulse at 3 ns ahead of the main pulse and having a contrast of 10^{-6}, the ASE background was about 10^{-11}. The pedestal began at about 100 ps and the contrast was better than 10^{-9} till 30 ps and rose to 10^{-5} at 2 ps ahead of the main pulse. As shown in Fig. 2, two CCD cameras working at single photon counting mode were employed to measure the hard x-ray spectra, both at 45° to the target normal. The deflecting magnets were installed to avoid the hitting of fast electrons on the CCD. The fluence of hard x-ray photons was adjusted by choosing the appropriate Cu filters.

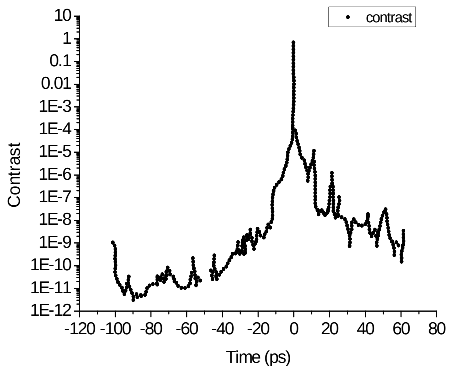

Fig. 1 The contrast measured by the third order auto-correlator

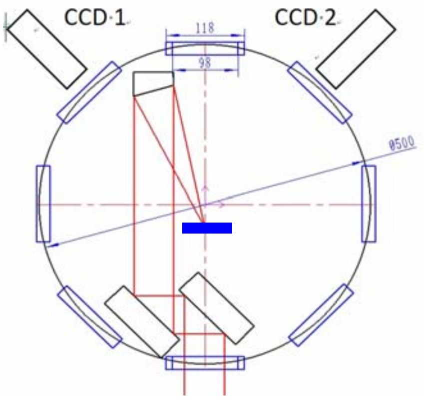

Fig. 2 The schematic of experimental setup.

2. EXPERIMENTAL RESULTS

Two types of copper targets were used in the experiments. The first is the 81 μm thick copper foils. The second is the nanowire array targets (NWATs). The NWATs consist of the array of tightly packed thin cylindric copper wires (φ230 nm × 1.4 μm) deposited on the 70 μm copper substrate. The Fig. 3 is the SEM pictures of the NWATs. In the experiment, the laser intensities on the target surfaces were varied between 2×10^{15}W/cm^2 and 1.8×10^{18}W/cm^2 by moving the target towards the parabola from the focus.

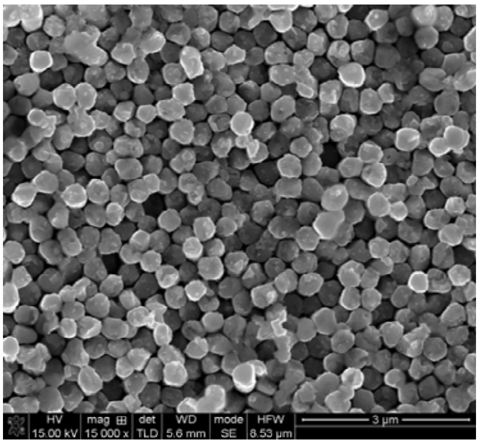

Fig. 3 The top view picture of the NWATs

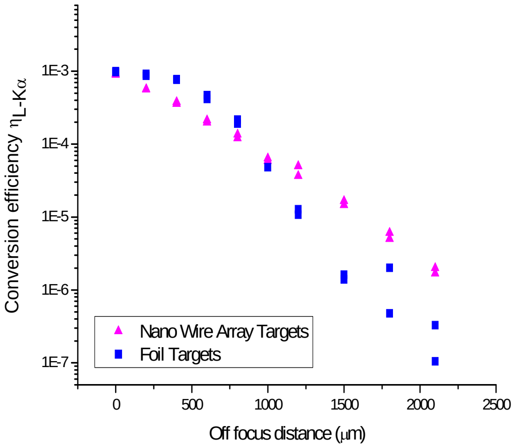

Fig. 4 The measured η_k for foils and NWATs

The measured K_α conversion efficiency (η_k) is shown in Fig. 4 for the two types of targets. The ratio of the K_α conversion efficiency of the NWATs to foils changed in a complicated way when the laser intensity increased from 2×10^{15}W/cm^2 to 1.8×10^{18}W/cm^2. When the laser intensity changed between 2×10^{15}W/cm^2 and 7×10^{15}W/cm^2, the η_k of the NWATs was about an order of magnitude higher that that of foils. When the laser intensity reached 1×10^{16}W/cm^2, the η_ks of the NWATs and foils were identical. When the laser intensity continued to grow from 1.5×10^{16}W/cm^2 to 1×10^{18}W/cm^2, the η_k of the NWATs was about half of that of foils. When the laser intensity finally reached 1.8×10^{18}W/cm^2, the η_ks of the NWATs and BTS became identical again, with the laser to K_α conversion efficiency (4π) reaching the maximum of 1×10^{-3}.

3. SIMULATIONS AND DISCUSSIONS

The 1-D hydrodynamic (MULTI) simulation with the measured laser contrast shown the scale length of the preplasma was less than 25 nm when the laser intensity was less than 7×10^{15}W/cm^2. The NWATs were basically kept their initial surface shape when the main pulse arrived. The 2-D particle in cell (PIC) simulations were performed to obtained the fast electron spectra for the NWATs and foil targets. Fig. 5 shows the typical spectra for the two types of targets. The fast electron production of the NWATs is substantially higher than that of foils. The spectra in Fig. 5 were further put into the MC codes (MCNP) to obtain the K_α yields. The MC simulation shows the K_α yields of NWATs is a factor of 5.62 larger than that of foils, which is in good agreement with the experimental results. The complicated behaviours of the K_α yields for the laser intensity between 1.5×10^{16}W/cm^2 and 1×10^{18}W/cm^2 may be caused by the different preplasma for the two types of targets. The further hydrodynamic and PIC simulation will be carried out to clarify the detailed physical scenario.

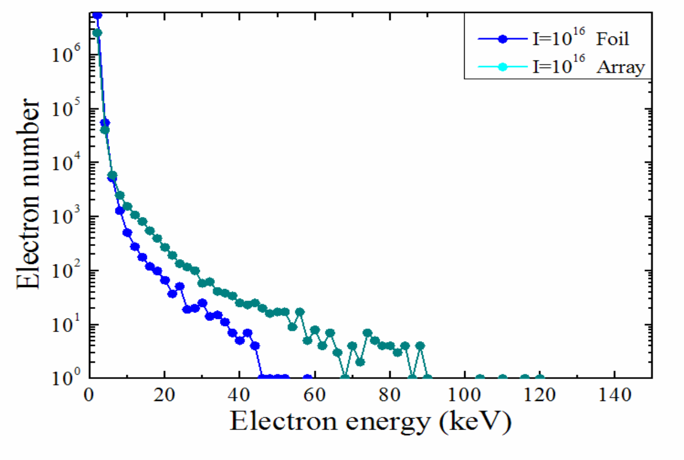

Fig. 5 The electron spectra from the 2D-PIC simulation

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