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Long-distance Guidance of Fast Electrons with Fine Wires Irradiated by Intense Femtosecond Laser Pulses
高強度短パルスレーザー照射極細ワイヤーによる高速電子の長距離誘導

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We have studied the characteristics of fast electrons emitted from fine (10-μm diameter) wires irradiated by a femtosecond laser pulse with intensity of approximately 1.0×10^{19} W/cm^2. We have found the property that the electrons emitted from a metal wire are self-guided to the axial direction of the wire, and in this paper we demosntrated 150-mm length guidance of fast electrons from the laser focal spot to the wire end. 400-keV electrons are guided along the wire in space of the diameter of 3.5 mm. Furthermore, we have confirmed that the emitted electrons have directionality over 100 mm even after leaving the wire end.

1. Introduction

Fast electrons can be generated and accelerated by the interaction of intense short pulse lasers with solid-density targets and have potential for fast electron beam sources, which have been extensively studied for applications such as electron diffraction [1,2], particle acceleration [3,4], and fast ignition fusion [5]. To develop high-intensity and directional electron beams, laser generated electrons affected by the characteristics of the laser and target have been intensively studied.

Many experiments have been performed to generate collimated beams using various targets. For planar target experiments [6,7], for instance, an electron beam emission along the surface of a metal foil target has been observed. This directional beam emission is interpreted by the static electric and magnetic fields generated on the target surface [6].

We have been studying characteristics of fast electrons emitted from metal wires irradiated by intense femtosecond laser pulses. We have demonstrated that the electrons emitted from a wire are self-guided along the wire direction, using tungsten wires with diameter of 300 μm [8]. To investigate the physical mechanism of self-guiding along the wire in more detail and the feasibility of higher directionality, we have performed experiments of electron transport along a rather long and fine wire (tungsten wires with diameter of 10 μm).

2. Experiment

Laser pulses used are delivered from a Ti:sapphire chirped-pulse amplification system is used. The central wavelength is 800 nm, the pulse duration is 160 fs and the pulse energy is 250 mJ. The laser pulses are focused with an f/3.5 off-axis parabolic mirror to a spot of 3 μm × 4 μm, resulting in the peak intensity of approximately 1.0×10^{19} W/cm^2. The laser pulse is p-polarized and is irradiated on a tungsten wire with diameter of 10 μm at an incidence angle of 45°. Imaging plates (IPs, Fujifilm FDL-UR-V) are used to detect fast electrons. The IPs have high sensitivity in the energy range from 40 to 1000 keV. The experiments are performed in a vacuum chamber with pressure of 0.02 Pa.

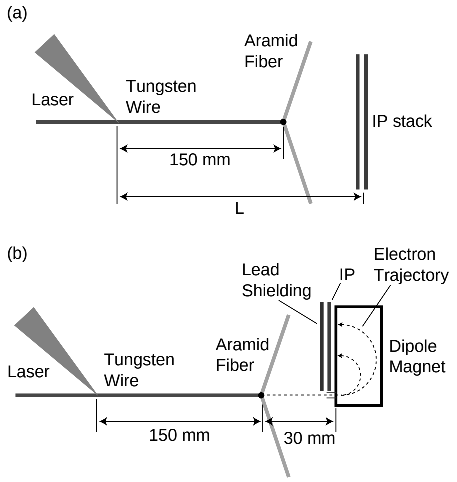

Fig.1 (a) Experimental setup to observe emitted electrons using stacked IPs. (b) Experimental setup to observe the energy distribution of electron beam along the wire and through a 0.5-mm aperture.

Figure 1(a) shows the experimental setup to observe the emitted electrons. L is the distance from the laser focal spot to double-layer stacked IPs. An aramid fiber of diameter 14μm is connected to the end of the tungsten wire with adhesive. When L is 150 mm or less, a hole with diameter of 1 mm is made in stacked IPs to pass the wire through it. Figure 1(b) shows the setup to observe the energy distribution of the electron beam, using a spectrometer composed of a 0.1-T dipole magnet and an IP. The diameter of the incidence aperture of the spectrometer is 0.5 mm.

3. Results

Figures 2(a),(b) are typical single-shot images of the second layer IP with L = 150 mm, L = 250 mm. On the second layer, electrons with energies higher than about 400 keV can be detected. The FWHM of central part intensities of the images in Fig. 2(a) and (b) are 3.5 mm × 3.5 mm and 2.0 mm × 2.0 mm, respectively. The number of electrons per unit solid angle through the aperture is about 2.8×10^{11} /sr at L = 30 mm. This value is ten times higher than that obtained by a planar target with a 2.0×10^{18} W/cm^2 laser [6]. The electron beam is clearly guided to the wire direction. A ring with diameter of 28mm can be seen in Fig. 2(b). This ring may be due to the influence of adhesive at the end of tungsten wire. A typical energy distribution of the emitted electrons is shown in Fig. 2(c). The distribution has a peak around 50–100 keV.

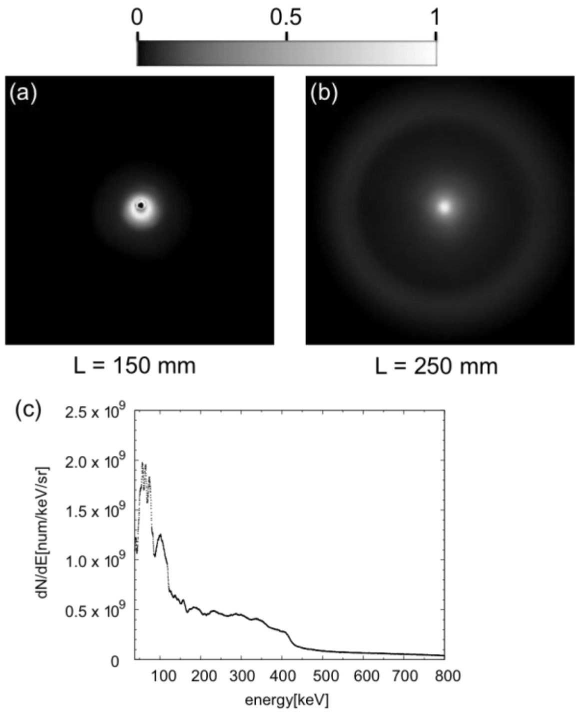

Fig.2 (a) and (b) Typical single-shot images of electron emission obtained on the second layer IP with L = 150 mm, L = 250 mm, respectively. The color scale is set independently for images for maximum contrast. The actual dimension of the images are 35 mm × 35 mm. Center black spot seen in (a) is a hole with diameter of 1 mm is made in the IP. (c) Typical energy distribution of electrons.

Tokita *et al*. has reported the interpretation for the directivity of the emitted electrons as follows [8]. The electric field in outward radial direction is generated as a result of the interaction of an intense laser pulse with the wire. The field vanishes within tens of picoseconds. The field decelerates the electrons emitted from the wire, consequently some electrons are pulled back to the wire or are guided along the wire-axial direction. The guided electrons propagate in spiral trajectories along the wire with the balance between the centrifugal force by the spiral motion and the electrical force by the laser generated field. However, it seems that the electric field lives in rather long time as much as tens of picoseconds because the emitted electrons are guided over a few hundred millimeters.

4. Conclusion

We have demonstrated that fast electrons emitted from a fine wire irradiated by intense femtosecond laser pulses are guided along the wire over a few hundred millimeters.

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