18pB-1

Guidance of electrons generated and accelerated by the interaction of an intense laser pulse with a foil using a metal wire

高強度レーザーと薄膜との相互作用により発生・加速される電子の金属ワイヤーを用いた長距離誘導

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We have experimentally demonstrated that fast-generated and accelerated by the interaction of an intense short pulse laser with a foil are guided along a metal wire which is set perpendicularly to the foil with a gap. Experimental results show that electromagnetic field may exist around the wire and contributes to the guidance of electrons. The wire would not be charged up by the laser irradiation because the wire is separated from the foil. It is considered that the electromagnetic field is the surface electromagnetic wave, which is generated by the laser-foil interaction.

1. Introduction

Fast electrons generated and accelerated by the interaction of intense short pulse lasers with solid-density targets have attractive characteristics such as point source, high brightness, and short pulse. This electron beam sources have been extensively studied for applications such as electron diffraction [1,2], particle acceleration [3,4], and fast ignition fusion [5]. To put the laser accelerated electron sources into practice with higher performance as electron source, it is necessary to improve emission directivity.

We have reported that electrons accelerated by the interaction of intense short pulse lasers with metal wires are guided along the metal wire and the directivity is greatly improved [6,7]. The particle trajectory simulation reproduces the results with assuming a radial electric field. This field is considerable to be (1) electromagnetic waves propagated along the wire surface [8] or (2) a electro static field produced by charge of the wire. We are studying the physics of this phenomenon in more detail. In the present study, we aim to confirm the presence of an electromagnetic wave propagating through the wire surface.

2. Experiment

The present experiments are done with the T6-laser, Kyoto University (Ti:sapphire chirped-pulse amplification system). The central wavelength is 800 nm, the pulse duration is 40 fs, and the pulse energy is 400 mJ. Laser pulses are focused with an f/3.5 off-axis parabolic mirror resulting in a peak intensity of 3.5×10^{19} W/cm^2. Laser pulses with p polarization is irradiated onto an aluminum (Al) foil target of 11 μm at an incidence angle of 45° . A tungsten wire with diameter of 300 μm and length of 150 mm is placed perpendicularly to the foil. The foil and the wire are not contact, but with a gap of 50 μm. Imaging plates (IPs, Fujifilm FDL-UR-V) are used to detect fast electrons generated by the interaction of the laser pulse with the Al foil. The IPs have high sensitivity to electrons of the energy range from 40 to 1000 keV. Figure 1 shows the experimental setup to observe the emitted fast electrons. L is distance from the wire to the IPs. The experiments are performed in a vacuum chamber with pressure of 0.1 Pa.

It is considerable that the wire is not charged, because it is isolated from the foil, and then an electromagnetic surface wave works if the electrons are guides along the wire.

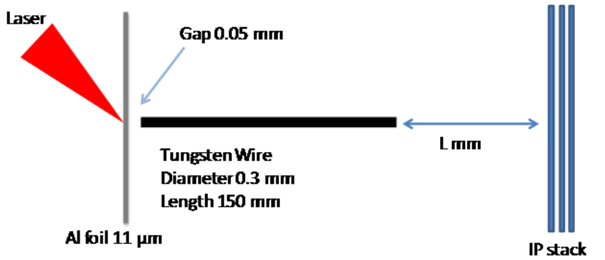
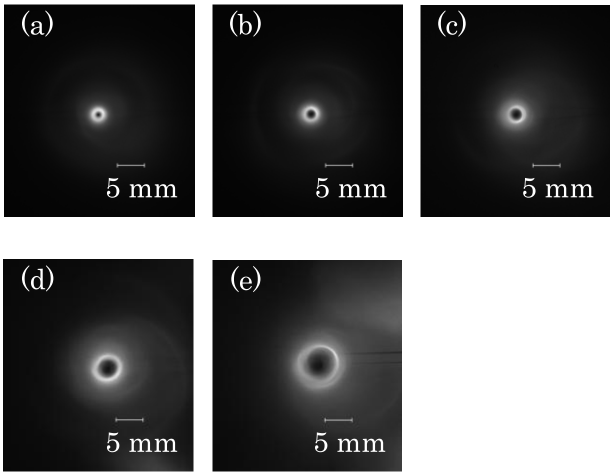


Fig. 1 Experimental setup to observe emitted electrons using stacked IPs.

3. Result

Figures 2(a), (b), (c), (d), and (e) are typical single-shot images of the first layer IP with L = 1, 10, 20, 50 and 100 mm. Electrons are distributed in a ring shape at IPs. The diameter of the ring on the first IP increases with L. These experimental results suggest that the electron beam is clearly guided along the wire at least over 100 mm.



(f)

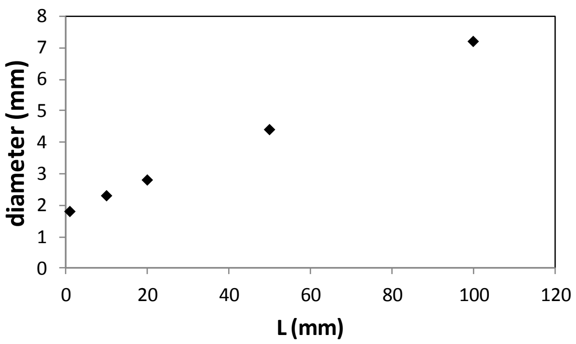


Fig. 2 (a), (b), (c), (d) and (e) Typical single-shot images of electrons emission obtained on the first layer IP with L = 1, 10, 20, 50 and 100 mm. The color scale is set independently for maximum contrast. (f) The diameter of the ring as a function of L.

S. Tokita *et al.* has reported that the electric field in outward radial direction of the wire can guide electrons [6]. Our experimental results show guidance of the electrons to the wire direction. This means that some electromagnetic field present around the wire to control the motion of electrons. Because there is the space between the Al foil target and the wire, the wire would not be charged by the laser irradiation. It can be considered that that electromagnetic field is formed by a surface electromagnetic wave which generated by the laser-foil interaction.

4. Conclusion

We have demonstrated that fast electrons generated and accelerated by the interaction of the intense short pulse laser with the Al foil can be guided by using a metal wire, which is placed with a gap on the back surface of the Al foil target. It is the first demonstration to separate the functions of electron generation/acceleration and guidance.

Acknowledge

This work was supported by a Grant-in-Aid for Challenging Exploratory Research (Grant No. 25600138), a Grant-in-Aid for Scientific Research (S) (Grant No.23226002), a Grant-in-Aid for Young Scientists (B) (Grant No. 26800280), the MATSUO FOUNDATION.

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