Proton Radiography of Intense-Laser-Irradiated Wire-Attached Cone Targets

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***Abstract*—Measurements of extreme electrostatic and magnetic fields are of interest for the study of high-energy-density plasmas. Results of proton deflectometry of cone–wire targets that are of interest to fast-ignition inertial confinement fusion are presented.**

***Index Terms*—Fast Electron, fast ignition, intense laser-target interaction, proton radiography.**

FAST-IGNITION (FI) inertial confinement fusion [1] uses a high-energy high-intensity laser pulse (ignitor laser pulse) as an external heat source to initiate ignition in the compressed fuel. The imploded plasma core is heated by high-energy (megaelectronvolts) electrons generated in the interactions between the ignitor pulse and a guiding cone. The cone is considered to enhance the energy coupling from the ignitor pulse to the plasma core. For FI, the fast electron generation inside the cone is crucial and has been studied using a cone-wire-type target [2]: a wire attached to the tip of a cone. To date, the cone-wire targets have been used to benchmark simulation codes as a comparison with experimental observations of K-shell X-ray emissions from the wire. The cone-wire targets are heated and charged in a short time scale by the fast electrons. Spatial and temporal profiles of electrostatic and magnetic fields excited around the target reflect the fast electron properties in the target. Proton probing [3] provides a good diagnostic tool to extract information about the fields and, consequently, electron dynamics.

In this paper, we present a proton radiography study of the field excitation around the cone-wire targets. A Cu wire (40 μm in diameter and 1 mm long) was attached to the tip of a Au cone (cone opening angle of 40°, 1.5 mm long from its tip to another end, and 20-μm-thick wall). An intense laser pulse with energies up to 800 J in 10-ps duration from the OMEGA EP laser [4] was focused into the cone. The peak laser intensity was $\sim 10^{19}$ W/cm^2. The proton beam was generated by another intense laser pulse, which had the energy of $\sim$300 J in 1 ps, in the interaction with a 50-μm-thick gold foil (2 mm by 2mm). The gold foil was placed at 10 mm from the cone-wire target in the direction perpendicular to the wire axis. Two-dimensional spatial profile of the proton beam was recorded with a multilayered radiochromic film (RCF) with filters. Protons deposit their energy dominantly at the Bragg peak; therefore, each layer of RCF observes protons with a small energy spread [5]. Since the timing when the proton reaches the cone-wire target depends on its energy, the temporal evolution of fields can be observed with the multilayered RCF. In the experimental configuration with ten layers of RCF, the time window of radiography was $\sim$200 ps with the best temporal resolution of $\sim$10 ps. The image magnification was nine with the RCF placement at 80 mm from the cone-wire target. Two types of fields can be excited around the wire: the azimuthal magnetic field and the radial electric field by the fast electrons propagating along the wire. In the experimental configuration, the deflection by the azimuthal magnetic field is parallel to the wire (i.e., protons are shifted in the horizontal direction on the RCF). The electric field splits protons up and down. The field strengths can be estimated with the deflection distance of protons with known energies, as determined from the RCF layer.

Proton deflection in the vertical direction around the wire was clearly observed in the experiment, as shown in Fig. 1. Fig. 1(a) shows the schematic of the experimental setup. The images in Fig. 1(b)–(d) were recorded on the fifth (15 MeV), second (7 MeV), and first (5 MeV) layers of RCF (energy of protons), respectively. Fig. 1(b) shows the proton radiograph of the cone-wire target before the laser interacted with the cone. The inset shows the view of the cone-wire target from the Au foil target. The vertical deflection around the wire in the images in Fig. 1(c) and (d) indicates the existence of electrostatic field on the wire surface. The electrostatic field at $\sim$100 ps after the injection of interaction pulse is estimated to be few tens of kilovolts per micrometer with the image of 5-MeV protons [Fig. 1(d)]. A deflection around the cone target and mounting stalk is also

Manuscript received December 1, 2010; revised May 19, 2011; accepted June 11, 2011. Date of publication August 4, 2011; date of current version November 9, 2011. This work was supported by the U.S. Department of Energy under Contracts DE-FG52-09NA29033 (NLUF), DE-FC02-04ER54789 (FSC), and DE-FG02-05ER54834 (ACE).

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Digital Object Identifier 10.1109/TPS.2011.2160291

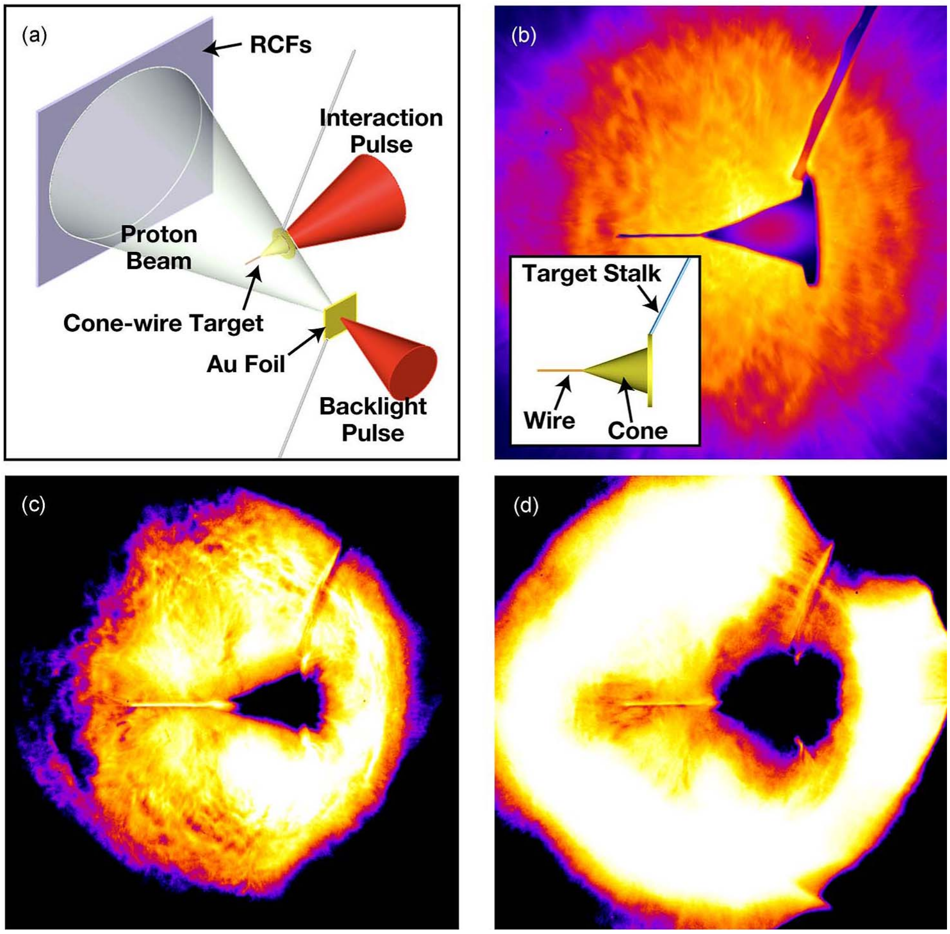

Fig. 1. (a) Schematic of experimental setup. Radiographs of cone-wire targets taken with proton beams with energies of (b) 15 MeV, (c) 7 MeV, and (d) 5 MeV. The images with 7- and 5-MeV protons represent the field properties at ~80 and ~130 ps, respectively, after the timing when the image was taken with 15-MeV protons. The inset in (b) shows the view of the cone-wire target from the Au foil.

seen, likely due to the net charge. Focusing of the proton beam is found at the edge of the cone wall and its brim. It can be caused by the field enhancement due to the sharp structure of the target.

In summary, we have used proton deflectometry to assess the electrostatic and magnetic fields around the cone–wire targets, which may be useful when studying the fast electron dynamics in cone–wire targets.

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