A Modified Technique for Laser-Driven Magnetic Reconnection

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For over a decade, numerous experimental and computational studies have investigated magnetic reconnection in high-energy-density plasmas.[1–3] An improved understanding of the reconnection theory and its application to extreme astrophysical environments and controlled fusion motivates these studies. One method for driving reconnection uses the collision between two laser-produced plasmas at the surface of a solid target. As the plasmas expand, the oppositely oriented Biermann fields are forced together and reconnect. In all previous studies, the plasmas were generated up to several laser-spot diameters apart, allowing time for the plasmas to expand and the Biermann fields to grow before colliding and forcing reconnection at their outermost edges.

In this work, a modified technique for driving reconnection is proposed and demonstrated. Two high-energy laser pulses were focused to 2×10^{14} W/cm^2 and pointed one laser-spot diameter apart on the surface of a thick plastic foil. The closer spot separation minimizes the time for plasma expansion before the interaction occurs and allows the largest magnetic fields at the edge of each laser spot to interact and reconnect. Proton radiography was used to demonstrate the technique by mapping the changes in magnetic connectivity at the target surface. The data show where the magnetic fields are located, where they are transported to, how they merge and reconnect, and where they reside post reconnection.

Figure 1 shows the experimental setup carried out on the OMEGA EP Laser System. Two long-pulse beams with a 351-nm wavelength were focused on the surface of a 5×5-mm^2, 50-μm-thick plastic foil. Each beam delivered 2 kJ of energy in a 2.5-ns square pulse focused to an 820-μm-diam focal spot. The laser intensity was 2×10^{14} W/cm^2 and each laser beam included distributed phase plates. The main target interaction was probed with an ultrafast proton beam. The protons were accelerated from a 20-μm-thick Cu foil mounted inside a plastic tube facing the main target. The Cu foil was irradiated at normal incidence with

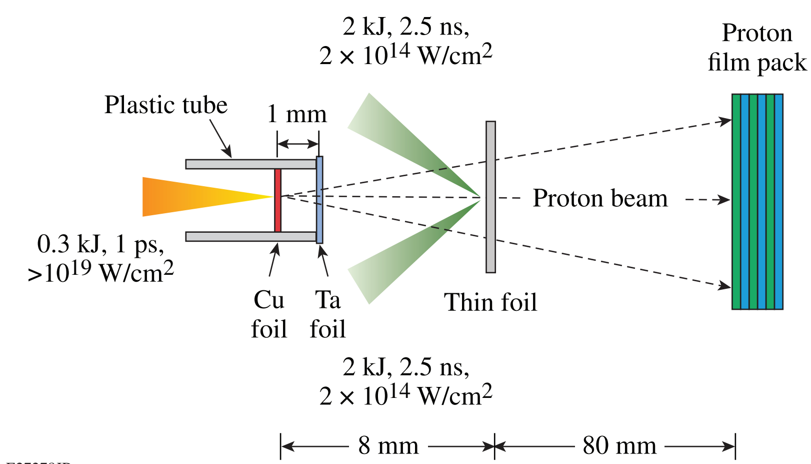

Figure 1
Experimental setup.

a 0.3-kJ, 1-ps pulse of 1.053-μm light at focused intensities above 10^{19} W/cm^2. A proton beam with energies up to several tens of MeV was accelerated by target normal sheath acceleration. To protect the rear surface of the Cu foil from the coronal plasma and x-ray preheat generated by the long-pulse interaction, a 5-μm-thick Ta foil was used to cap the end of the plastic tube. A filtered radiochromic film detector stack was used to measure the proton beam after it traversed the main target interaction.

Figure 2 shows proton radiographs of a series of two-beam interactions with a laser-spot separation of one focal-spot diameter (~820 μm). The laser pulses were co-timed. Data are shown at eight different times between $t = t_0 + 0.17$ ns and $t = t_0 + 1.97$ ns. Each time interval was measured on a different shot. The images were generated with 29-MeV protons. At $t = t_0 + 0.17$ ns [Fig. 2(a)], the radiograph shows a pair of dark rings consistent with two distinct Biermann fields at the edge of each laser focal region.[4] These dark rings remain continuous and physically separate at $t = t_0 + 0.27$ ns [Fig. 2(b)]. The plasmas have begun to merge at $t = t_0 + 0.37$ ns [Fig. 2(c)], and the detected proton flux at the intersection point is diminished. Over the next 800 ps, the inner dark rings progressively transform into a continuous oval-like pattern [Figs. 2(c)–2(f)]. This changing pattern is consistent with a transition from two isolated Biermann fields into a single global magnetic field that surrounds the laser focal regions. Post reconnection, the change in magnetic connectivity is sustained and the dark oval pattern is measured at $t = t_0 + 1.47$ ns [Fig. 2(g)] and $t = t_0 + 1.97$ ns [Fig. 2(h)].

The work described here uses a simple but crucial modification to the conventional laser-driven reconnection geometry that has significant physical implications. Compared to the original laser-driven reconnection technique, the geometry modifies where, when, and how magnetic reconnection occurs. The interaction between the neighboring plumes occurs earlier in time, the distance the largest magnetic fields must be transported before the reconnection layer forms is reduced, and the driven-reconnection process is less perturbed by plasma accumulation at the midplane. Most notably, the geometry allows for field-line reconnection

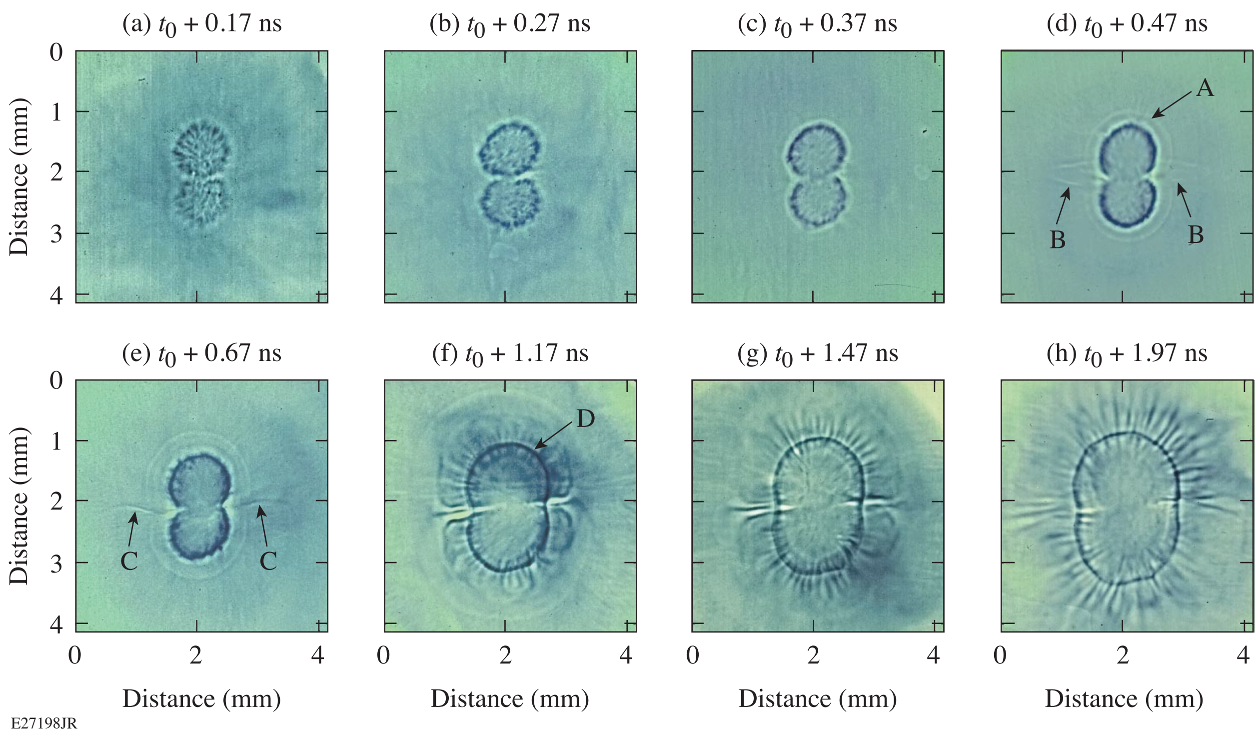

Figure 2
Proton radiographs of two-beam interactions with 50-μm-thick plastic foils taken at eight different times. Diagnostic signatures of the plasma–vacuum boundary (A), outflowing plasma (B and C), and magnetic fields (D) close to the laser focal regions are highlighted.

of the largest-magnitude magnetic fields that are generated at the edge of each laser spot, unhindered by stagnating plasma flows. It is important to note that no previous studies have identified this possibility or attempted to drive reconnection at such close laser-spot separation.

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