Generation of high-energy-density plasma using Compound Parabolic Concentrator and high-contrast laser

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In the fast ignition approach, a fusion plasma is heated by energetic electrons generated through the interaction between a high-intensity laser pulse and the plasma. Using a cone-attached target has improved plasma heating efficiency [1, 2]. The cone guides the high-intensity pulse to a high-density region of the fusion plasma, surrounded by a long-scale, over-critical-density plasma. A high-contrast laser pulse has revealed that the cone structure also plays a crucial role in suppressing the spatial spread of energetic electrons, further enhancing plasma heating. Our recent study demonstrates the enhancement of plasma heating by irradiating a petawatt-class high-contrast laser onto a target attached with a compound parabolic concentrator (CPC) [3]. With its parabolic-shaped wall, the CPC is designed to focus the incident laser light at the tip by reflecting it by the inner walls, thereby concentrating the energy. To maximize the CPC's focusing effect, minimizing plasma expansion along the inner walls is essential. Our experiments employed a CPC attached to a multi-layer target irradiated by a high-intensity laser with a two-order-of-magnitude improved pulse contrast achieved using a plasma mirror. The multi-layer target consisted of sequential plastic, copper, plastic, titanium, and plastic layers. Resonance X-rays from the copper and titanium layers were measured using X-ray spectrometers and X-ray monochrome imagers [4], as well as an electron spectrometer [5] was used to assess the energy distribution of energetic electrons. The thermal electron temperature of the plasma was inferred by comparing the experimental X-ray spectrum with simulated one calculate with a collisional-radiative spectral code (PrismSPECT). Analysis of the X-ray spectrum from the titanium layer, located 7-μm-depth from the target surface, indicates that the plasma was heated to at least 500 eV. These findings suggest that the interaction between the high-contrast, high-intensity laser and the CPC significantly improves plasma heating efficiency.

References

[1] Norreys,P.A. et al., Phys.Plasmas **7**, 3721 - 3726 (2000).

[2] Kodama,R. et al., Nature **412**, 798 - 802 (2001).

[3] A.G.MacPhee. et al., Optica **7**, 129 (2020).

[4] S. Sakata et al., Nature Comm.**9** 3937 (2018).

[5] Ozaki,T. et al., Review of Scientific Instruments **85**, 11E113 (2014).

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