Target Injection and Engagement for Neutron Generation at 1 Hz

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Target injection is a key technology to realizing inertial fusion energy. Here we present the first demonstration of target injection and neutron generation. We injected more than 600 spherical deuterated polystyrene (C_8D_8) bead targets during 10 minutes at 1 Hz. After the targets fell for a distance of 18 cm, we applied the synchronized laser-diode-pumped ultra-intense laser HAMA and successfully generated neutrons repeatedly. The result is a step toward fusion power and also suggests possible industrial neutron sources.

Keywords: target injection, deuterated polystyrene, laser-diode-pumped laser, DD fusion, neutron source

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High-repetition injection of fusion targets is a key to power plants and is also essential for high-repetition experiments, such as those we are performing [1, 2]. Therefore, much research has been conducted on target suppliers [3,4], injectors [5], and tracking systems [6,7]. Here we present the first demonstration of target injection, engagement, and the resulting neutron generation.

Figure 1 shows the target injector, which is installed in the center of the vacuum chamber. The target used here is a solid spherical deuterated polystyrene (C_8D_8 or CD) bead having a diameter of 1.1 ± 0.1 mm and a sphericity of 99%. A target loader stores more than 10,000 CD targets at a time. The targets stored inside the target loader free-fall by gravity onto a 110-mm-diameter disk that rotates at 6 rpm. Each target on the disk is automatically conveyed to the exit hole and falls on a parabolic trajectory to the laser focal point of the HAMA laser [2] 18 cm below the exit hole at 1 Hz. The hole is shaped as an ellipse with major and minor axes of 4.0 and 2.0 mm, respectively, and a depth of 8.0 mm.

We also developed a laser controller to adjust the laser shooting time. To estimate the arrival time at the focal point, we set two photodiodes at 60 mm and 100 mm above the focal spot. The laser controller detects the transit time from the two photodiodes and estimates the arrival time at the focal point. At the predicted arrival time, it sends a shooting-request signal to the HAMA laser. As soon as

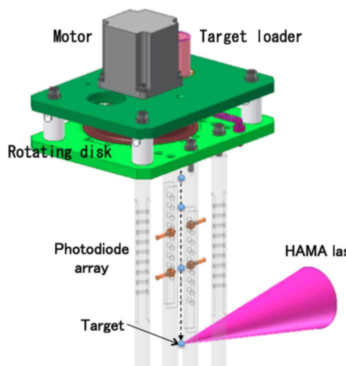

Fig. 1 Target injection system. Target loader stores more than 10,000 targets. Rotating disk has holes to catch and feed targets to the exit hole above a laser focal point. Each target falls through two photodiodes that predict the arrival time at the laser focus point.

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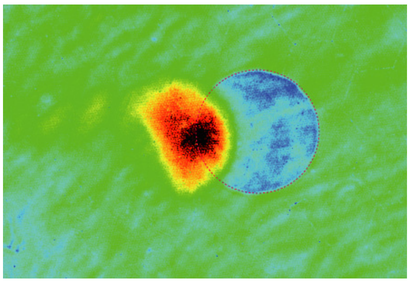

Fig. 2 Snapshot of target engagement. The falling target is engaged by the HAMA laser. Intensified CCD camera (Princeton Instruments PI-MAX3) with an IF filter (394 nm) is opened for 20 ns.

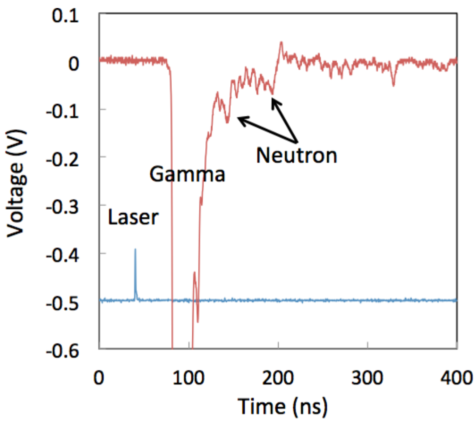

Fig. 3 Neutron generation. The neutron detector is a 6-in.-diameter plastic scintillator (NE102) coupled to a 2-in.-diameter photomultiplier (H7195). The axis is perpendicular to the main beam. Neutrons at 2.45 MeV arrive 60 ns after the gamma signal, and scattered neutrons signals arriving around 100 ns later are observed (Tektronix DPO7104).

the HAMA laser receives the signal, it engages the injected target with an appropriate delay time. The synchronization was within 50 µs, which is sufficient for target engagement.

A 2ω probe, 300 fs in pulse length [8, 9] captures a snapshot of an injected target irradiated by the HAMA laser, as shown in Fig. 2. The laser energy on the target is 1 J, and the pulse duration and are wavelength are 300 fs and 800 nm, respectively. Figure 2 shows that the laser is focused on the surface, blowing the plasma off.

The laser intensity at the focal point is 2×10^{18} W/cm^2, which is high enough to generate neutrons. As a result of the engagement, we produced 2.45-MeV DD neutrons. Figure 3 shows the neutron time-of-flight signals detected by plastic scintillators coupled to photomultipliers. The neutron energy was calculated by the time-of-flight method. The maximum neutron yield was $2.5 \times 10^4/4\pi$ sr.

At a 1 Hz rate, we injected more than 600 targets during 10 min. On average, approximately 43% of the targets were irradiated by the HAMA laser, and neutrons were observed 3%, as plotted in Fig. 4. Because the radius of the target is 0.55 mm, the laser hits only targets falling inside a 0.55-mm-radius circle. Currently, the observed target placement accuracy is such that only 68% of the targets are within 0.55 mm of the focal point in the laser perpendicular direction, leading to an average hit rate of less than 50%, in agreement with the experiment. The placement accuracy in the Y direction (laser axial direction) was 1.4 mm at 1 σ, which is 14 times the Rayleigh length, reducing the neutron-generation average to less than 5%. The target loader is fully open to the irradiation chamber, which is evacuated to a pressure of 2.6×10^{-3} Pa. To generate neutrons continuously requires a mechanical function to increase the placement accuracy.

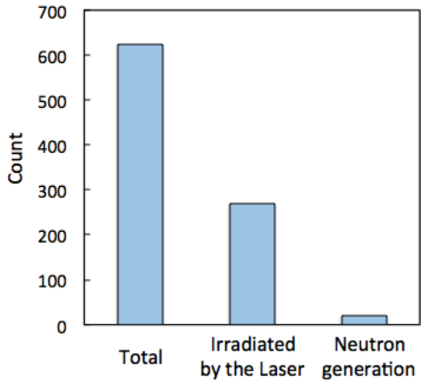

Fig. 4 Achieved target engagement. We injected 624 targets at 1 Hz, of which 270 were hit by the laser. Neutrons were generated from 20 irradiated targets.

We first demonstrated target injection, engagement and neutron generation at 1 Hz. We injected more than 600 spherical CD bead targets during 10 min at 1 Hz. To achieve target engagement, we developed a laser controller to synchronize the laser-diode- (LD-) pumped ultra-intense laser HAMA and successfully generated neutrons.

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