Neutron generation from Deuterium Clusters by using an Intense Femtosecond Laser

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1. Introduction

Some experiments demonstrated the possibility of laser-driven fusion employing deuterium clusters by collisions of high-energy ions produced from laser heating [1,2]. Deuterium clusters have a spherical shape and consist of a few thousand deuterium atoms bound together by weak attractive Van der Waals forces. Clusters of deuterium molecules are irradiated by a superintense ultrashort laser pulse, and electrons are quickly removed from the clusters by optical field ionization, which then leads to isotropic Coulomb explosion due to the repulsion of the remaining positive ions. The fast deuterons ejected from the exploding clusters suffer the collisions with the deuterons ejected from the other clusters in the plasma, which results in nuclear fusion.

In this paper, we investigated the relationship of the maximum ion emission energy to the variation in the ASE time width on a scale of several nanoseconds. The measurement and the analysis of the ion distribution along the plasma channel with different backing pressures and its effect on the neutron generation were also included.

2. Experiment and Results

Figure 1 shows the scheme of the experimental setup for the nuclear fusion reaction in gases of deuterium clusters. The laser we used was a 10-Hz, Ti:sapphire, chirped pulse amplification laser delivering 280 mJ of laser energy per pulse with 30-fs pulse widths and a wavelength of 800 nm. This laser beam was focused into the cluster plume at 2.5 mm under the exit of a deuterium gas jet by using a *f* /12 planoconvex lens. If we assume the laser beam diameter inside the cluster plume to be 100 μm to consider the defocusing effect of the plasma channel, the laser intensity is ~10^{17}W/cm^2. A laser energy meter was placed at a right angle to the beam splitter on the laser propagation axis after the gas jet. The laser absorption was measured by comparing laser energies detected with and without the presence of clusters. The measured absorption efficiency of laser energy was around 90%.

In order to characterize the energy distribution of the deuterium ions produced, we employed a Faraday cup that was placed 93.5 cm from the laser focal point and aligned 90° from the laser propagation axis. An initial 50-ns-wide current spike was detected from the photoelectron current due to high-energy gamma rays.

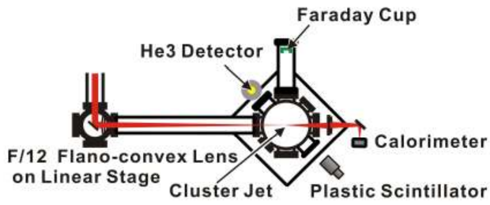

Fig. 1. Arrangement for laser-induced fusion reactions in cluster gases.

The temporal characteristics of ASE in the femtosecond laser system used in this experiment were simply analyzed by using fast photodiodes. We could find double prepulses preceding the main pulse by ~10 ns. On the background pedestals of the main pulse and prepulses, ASE signals with levels of 10^{-8} – 10^{-6} compared to main pulse were widely spread over several nanoseconds around the main pulse.

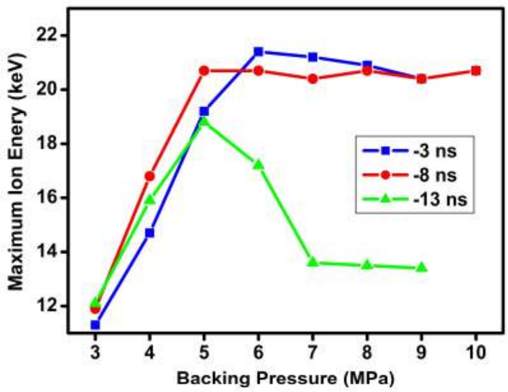

Fig. 2. Dependence of the maximum ion energy on the backing pressure for various opening times of the pulse picker (-13 ns, -8 ns, and -3 ns compared to the main laser pulse).

To investigate the dependence of the maximum ion energy on the existence of a prepulse and on the ASE width, we measured the deuteron energies by using a time-of-flight (TOF) method. Figure 2 shows that at low backing pressure, the existence of a prepulse seems to have a positive effect on the production of high-energy ions, but the total ion current is lower for the case of a prepulse. Up to 5 MPa of backing pressure, the maximum ion energy increases as the backing pressure increases. For pressures over 6 MPa, the existence of the prepulse causes a vivid decrease of the maximum ion energy compared to the tendency seen without the prepulse. At a certain size distribution of clusters, the prepulse causes big-sized clusters to become very-low-energy charged cluster fragments, and these cluster fragments seems to produce low energy ions by interacting with the main pulse. The saturation of the maximum ion energy for the cases without a prepulse is reported by others [3]. The reason for the leveling off of the maximum proton energy above 5 MPa is that the laser intensity is insufficient to expel all electrons from the larger clusters produced at these pressures.

The ion energy at the peak ion signal in the case of 3-ns ASE was measured and is plotted in Fig. 3. The maximum ion energy was hard to measure because the level of the Faraday cup signal was very low compared to the noise level, so instead of the maximum ion energy, we chose the ion energy value at the peak ion current signal. At a 3-MPa backing pressure, the highest energy ions come from a region behind the center of the plume. At low backing pressure, the laser easily penetrates the clusters and transfers energy along the whole length of plume. As the backing pressure is increased, ion signals were impossible to identify behind the center of plume, and the peak ion signals came from front outskirts of the plume. The plasma channel does not grow deep inside the plume and even gets shorter as the backing pressure is increased. To the compare the results for 5 MPa and 7 MPa, the ion energy increased for 7 MPa. At the range of ion energies in this experiment, the fusion reaction depends more on the ion energy than on the ion current, so we may expect a higher neutron yield for 7 MPa, but at 8 MPa, high energy ions come only from the surface of the gas plume, and even the energy is lower than the value at 7 MPa. We can conclude that the laser intensity was not enough to ionize clusters at 8 MPa efficiently.

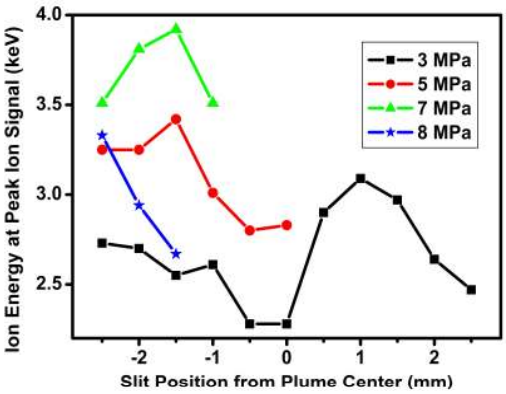

Fig. 3. Spatial distribution of the ion energy along the plasma channel at different backing pressures.

To check the production of DD fusion neutrons effectively in these experiments, we employed a He^3 neutron detector attached on the side wall of the reaction chamber. A calibrated neutron-sensitive plastic scintillator was installed outside the reaction chamber to determine the neutron yield. The scintillator was 5 inches in diameter. The photomultiplier tube signal was calibrated as 0.79 ns·volt per neutron with a detection efficiency of 0.3%.

The fusion yield was measured at different gas jet backing pressures. About 3×10^3 neutrons in the 4π direction were detected at a backing pressure of 7 MPa. Figure 4 shows that the yield increases with higher backing pressure up to 7 MPa, which implies that the neutron yield increases for larger clusters. As the size of the cluster increases, the Colulomb force within ionized clusters increases, which in turn results in the production of higher energy deuterons. Because the DD fusion reaction cross-section depends highly on the deuteron energy, large clusters are needed to get high neutron yields. In the range of gas backing pressures over 8 MPa, the neutron production was decreased.

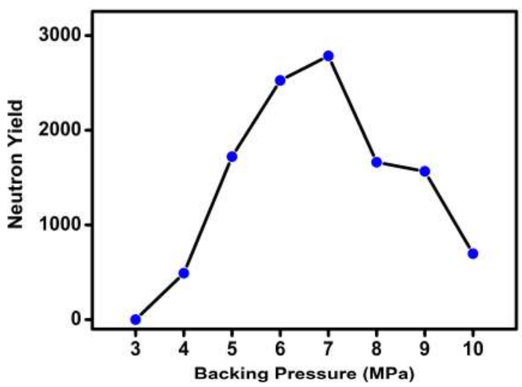

Fig. 4. Dependence of neutron yield on the D_2 backing pressure.

3. Conclusion

The prepulse and the ASE effects on the ion emission were investigated by controlling the ASE time width. The intensity of prepulses was high enough to produce a preplasma so that laser absorption for the main pulse was obstructed to reduce the maximum ion energy. To get a high neutron yield, we had to remove prepulses properly, but the ASE effect was negligible for changing time widths of the pulse. By laser-induced Coulomb explosion of clusters, 3×10^3 neutrons for 4π were generated. The neutron yield showed a very sensitive response to the size of the clusters.

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