First Observation of Pellet Ablation Clouds Using Two-Directional Simultaneous Photography in GAMMA 10/PDX

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The study of pellet ablation mechanisms is an important subject for plasma fueling in fusion plasmas. In GAMMA 10/PDX, sub-millimeter hydrogen pellet injection experiments are conducted in the higher electron density plasma for detached plasma experiments. We observed the pellet ablation cloud by two-directional simultaneous photography during the GAMMA 10/PDX pellet injection experiments. The three-dimensional pellet ablation cloud and its trajectory were clearly obtained for the first time.

Keywords: pellet ablation cloud, two-directional simultaneous photography, high-speed camera, GAMMA 10/PDX

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Pellet injection is one of the most useful techniques for particle fueling in fusion plasma devices [1–7]. To understand ablation cloud formation around a pellet on interaction with the background plasma, temporal and spatially resolved imaging observation is useful. In many fusion plasma devices, radiation intensity profiles of ablation clouds were observed using a high-speed camera system and Hα line emission measuring array systems. However, there have been few observations of the pellet ablation cloud by the two-directional simultaneous photography using two-to-one optical fiber and a high-speed camera system. In Ref. [3], three-dimensional observations for pellet ablation traveling in plasma were shown with using the stereo observation technique. However, using the stereogram method, it is impossible to obtain the information about the back of the pellet. Simultaneous measurement in both vertical and horizontal directions can obtain not only the back-side information but also the three-dimensional profile of pellet ablation clouds.

GAMMA 10/PDX is a tandem mirror device with the main confining region of central cell, two axisymmetric minimum-B anchor cells, and two plug and barrier cells [8, 9]. In the west end region, the divertor simulation experimental module (D-module) was installed for divertor simulation experiments using the end-loss plasma from the core plasma. The x and y axes are defined perpendicular to the magnetic field in the vertical and horizontal directions, respectively, and the z axis is parallel to the magnetic field. The mid-plane is z = 0 m. Typical electron densities and temperatures are about $2 \times 10^{18}\,\mathrm{m}^{-3}$ and 25 eV in the central cell and $1 \times 10^{17}\,\mathrm{m}^{-3}$ and 25 eV in the end cell without additional gas injection into D-module. We could successfully simulate the detached plasma formation with the injection of an additional neutral gas in D-module. The plasma density of the core plasma was low compared to the SOL plasma of normal fusion devises. To study the mechanisms of the detached plasma formation in the higher plasma density region, we perform the pellet injection into the central cell plasma to increase the core plasma density. The pellet ablation study is also important for understanding the pellet fueling mechanisms. In addition, it is useful for studying pellet ablation mechanisms to observe the pellet ablation cloud and the pellet trajectory in the plasma directly. In this paper, we describe the two-directional simultaneous photography system and the first result of the pellet ablation measurement in the tandem mirror GAMMA 10/PDX.

Figure 1 shows the schematic of the two-directional simultaneous photography (TDSP) system [10] and a sub-millimeter hydrogen pellet injection system [6, 7] installed in the central cell. The TDSP system consists of wide-angle lenses, dual branch optical fiber bundles, TV lens, and a high-speed camera (MEMRECAM GX-1, NAC Inc.). The x- (vertical) and y-direction (horizontal) images are observed through the horizontal side port at z = 0 m and on the upper side port at z = −0.10 m, respectively. The frame rate of the high-speed camera, imaging size, and bit depth are 10,000 fps, 320×240 px, and 8 bit, respectively. The vertical and horizontal direction images

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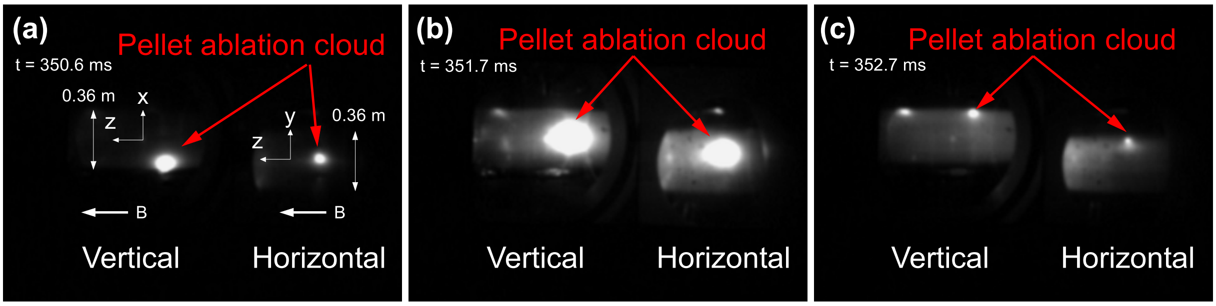

Fig. 2 Pellet ablation clouds observed using the TDSP system. (a), (b), and (c) show t = 350.6 ms, 351.7 ms, and 352.7 ms, respectively. The left and right side images show the vertical and horizontal images, respectively.

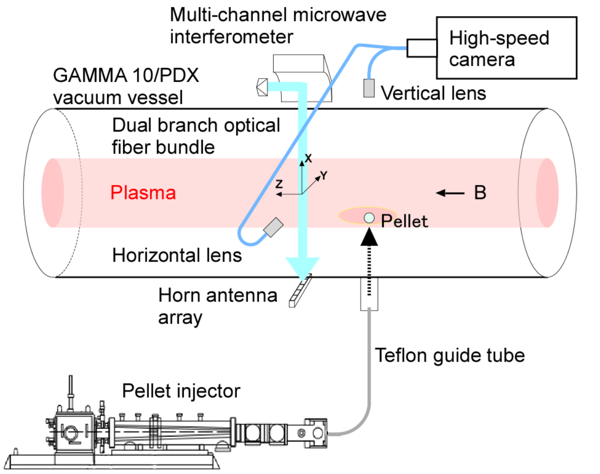

Fig. 1 Schematic of the TDSP system, sub-millimeter hydrogen pellet injection system, and multi-channel microwave interferometer system in the central cell.

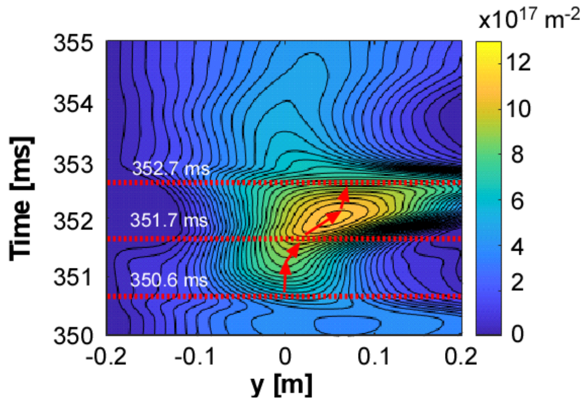

Fig. 3 Temporal behavior of the radial profile of line density observed by the multi-channel microwave interferometer system. The times of ablation cloud images shown in Fig. 2 are indicated. Peak line density temporal position is also presented in arrows.

are obtained in the same frame of the camera system. The pixel resolution is 6.5×10^{-3} m/pix. The pellets are injected from the lower side port at z = −0.10 m through the Teflon guide tube from the pellet injector, which is a pipe-gun type pneumatic pellet injector to produce the sub-millimeter pellet. The diameter and length of the pellet are controlled by the barrel size and by adjusting the feed gas flow rate. We used the pellet of approximately 0.66 mm in diameter and 1.9 mm in length in this experiment. The injected fueling pellet speed is approximately 200 m/s.

The pellet ablation clouds were observed by the TDSP system for the first time (Fig. 2). The vertical and horizontal wide-angle images were obtained in the same frames. Figure 2 (a) shows the images of both the vertical (left) and horizontal (right) directions just after the pellet incident in the plasma at t = 350.6 ms. The shape of the pellet ablation clouds is elliptical in both the vertical and horizontal directions. As seen in images Fig. 2 (b), the pellet ablation cloud is located at the plasma center in the vertical (left) direction and is slightly moved from the plasma center at y ∼ 0 m to the position at y ∼ 0.05 m in the horizontal (right) direction at t = 351.7 ms. In addition, the outline shape of the pellet ablation cloud is a teardrop shape, which extends to the direction along the magnetic field. Since it has almost the same shape in both the vertical and horizontal directions, it is considered to be a teardrop shape in three dimensions. This suggests that there is some non-uniformity in the plasma particle flow into the pellet ablation cloud. In Fig. 2 (c), the pellet ablation cloud in the vertical direction (left) moves to the upper part of the plasma, and that in the horizontal direction (right) also moves significantly from the center to the plasma edge at t = 352.7 ms. Using the algebraic reconstruction technique method [11] for each x–y plane at every z position, we can study the tomography image of the pellet ablation cloud and its motion. Details of the tomography technique will be presented elsewhere. The pellet crossed diagonally in the plasma and the pellet ablation cloud had a teardrop shape in the plasma center regions. This observation would not have been possible if only one-directional photography measurement was used. This is also confirmed by the behavior of the electron line density radial profiles obtained using multi-channel microwave interferometer system [12] in Fig. 3. The electron line density increases from t = 350.6 ms and the FWHM of the increased electron line density radial profile remains almost constant, about 0.18 m, before t = 351.7 ms. The electron line density peak moves to the outer region after t = 351.7 ms, which is the same motion as observed for the pellet ablation cloud in the horizontal direction. The line density profile is strongly correlated by the pellet ablation cloud motion.

We performed observations of the pellet ablation cloud and its trajectory in plasma using the TDSP system in the GAMMA 10/PDX pellet injection experiment for the first time. This system can observe both the pellet ablation cloud and pellet trajectory in three dimensions. Moreover, it shows the pellet ablation cloud formation by background plasma particle flow and the correlation between the pellet ablation cloud motion for particle fueling and the electron density radial profile. We continue to develop the analyzing method for the TDSP system.

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