§1. Stereoscopic Measurement of Three-Dimensional Positions of Encapsulated Impurity Ablation by TESPEL Injection

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The presence of a kind of barrier of impurity transport in LHD plasmas in high-density operation was reported.[1] For identifying the position of the barrier in more detail, control of the ablation position of the encapsulated impurities by a tracer-encapsulated solid pellet (TESPEL) injector can become an useful experimental technique in near future.[2]

In order to change the ablation positions, the following two experiments were carried out in the last experimental campaign in the LHD:

1. Changing the propellant gas pressure for the pellet injection to vary the pellet injection speed.
2. Changing the plasma density to raise the electron/ion temperature for enhancing pellet ablation processes, and high-energy fast ions by NBI can also enhance the pellet ablation process in low density plasmas.

The three-dimensional ablation positions of the encapsulated impurities were observed with a stereoscopic fast framing camera installed in an outer port (3-O) with an image intensifier. Figure 1 is a stereoscopic image of the ablation cloud of the impurity (tungsten), which is the last frame of captured images of the ablation cloud. From the stereoscopic images, the three-dimensional positions of the ablation cloud can be obtained by a pin-hole camera model using information of the three-dimensional positions of benchmarks marked in the vacuum vessel in the field of view of the camera.

Figure 2 is a top view of a peripheral plasma showing the dependence of the encapsulated impurity ablation positions on the propellant gas pressure for n_e~ $2\times10^{19}m^{-3}$ as indicated as small colored dots. The ablation positions tend to move to the plasma center as the propellant gas pressure is increased. It shows that the ablation positions can be changed in the minor radius in the range of about 10cm by controlling the gas pressure from 4.5atm to 35atm. In all propellant gas pressure cases, impurity (tungsten) accumulation in the core plasma was observed at about 0.5s after the injection with observable drop of the central electron temperature and the plasma stored energy. It was spontaneously recovered at about 1.0s after the injection. Large colored circles in the figure give the dependence of the ablation positions on the plasma density for a propellant pressure of 35atm. The ablation positions move into the core plasma according to increase in the plasma density. It shows that the ablation positions can be varied in the range of about 10cm by changing the plasma density.

A poloidal cross section of the LHD plasma at the toroidal angle on which the TESPEL injector is installed is illustrated in Figure 3. The impurity ablation positions for the above two experiments are plotted. It indicates that the ablation positions are distributed in the range from ρ~0.6 to ρ~0.85, here ρ means the normalized minor radius in LHD plasmas. The analysis of the impurity deposition positions proves that the impurity accumulation occurs even when the impurity (tungsten) ablation position locates at relatively outer region (ρ~0.85) in the main plasma. It suggests that for controlling the impurity accumulation into the main plasma, the impurity deposition position have to be excluded to an outer area (ρ>0.85) at least.

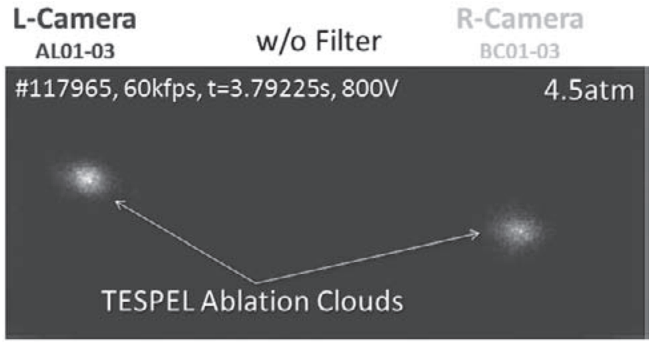

Fig. 1. A stereoscopic image of the impurity (tungsten) ablation cloud by TESPEL injection.

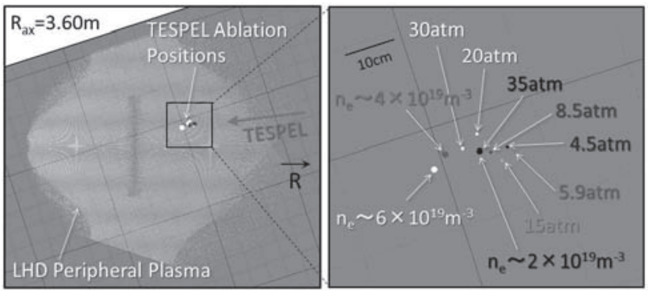

Fig. 2. A top view of a LHD peripheral plasma with indication of the ablation positions of the encapsulated impurity when the propellant gas pressure and the plasma density were changed.

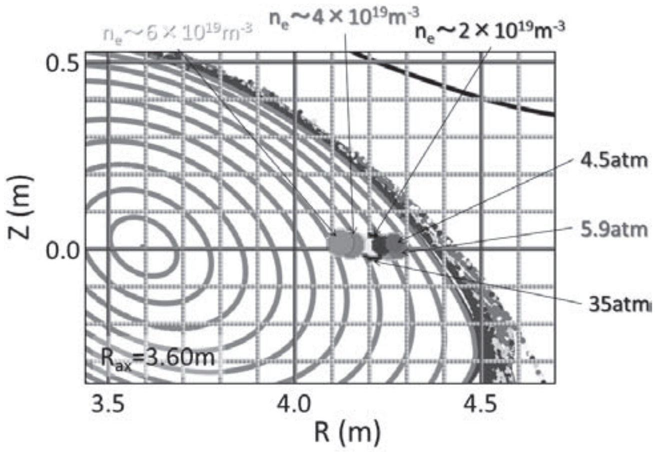

Fig. 3. A poloidal cross section of the LHD plasma with the indication of the impurity ablation positions.

1) Sudo, S. et al.: Plasma Phys. Control. Fusion **55** (2013) 095014.
2) Sudo, S. et al.: Rev. Sci. Instrum. **83** (2012) 023503.