§31. Development of Spectroscopic Method for Electric Field Measurement in Biased Divertor Plasma

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The issue of biasing to plasma has become quite important recently for plasma confinement in fusion devices. To study the physics of biasing, direct measurement of the electric field distribution in front of divertor plate is highly desired. We have been developing a sensitive direct measurement of sheath electric field distribution in plasmas by using polarized laser-induced fluorescence (PLIF) spectroscopy.

A model-type experiment using the PLIF technique was made to observe the biasing effect on electric field structure in front of a negative DC biased metal disk in a He plasma flow from an ECR plasma source. The electric field strength was measured by laser-excitation of the forbidden line from the HeI 2^1S atom to the 3^1D. The laser was linearly polarized perpendicular to the magnetic field B and the electric field E. The selection rule shows that the Stark-induced transition takes place for the $\Delta m_l = \pm 1$ transition while the electric quadrupole transition which is independent of E is induced for $\Delta m_l = \pm 2$. Consequently, the anisotropic population is produced between the upper level (3^1D), emitting polarized laser-induced fluorescence depending on E.

The He plasma was produced by an NTT-type ECR plasma source under the same conditions as in ref. 1. A brass circular plate with diameter of 25 mm was inserted perpendicularly to the plasma flow axis. A DC bias voltage V_0 from −140 V to −650 V was applied with respect to the ground. The spectroscopic observation system with the excitation laser was almost the same as in ref. 1.

Figure 1 shows the spatial profiles of the electric field measured for the various bias voltages, where Z indicates the distance from the plate surface. It is noted that the E-profile at $V_0 = -140$ V is almost linear relative to Z. This means that the net positive charge density is constant in the sheath. With increasing the bias voltage the profiles obviously deviate from the linear dependence, especially at the vicinity of the substrate. Such behavior is originated from a non-uniform distribution of He-ions in the sheath. The distribution is dominated by the collisions between He-ions and atoms in the sheath because the sheath thickness is larger than the ion mean free path under the higher bias voltage. From the measured E-profile the sheath potential is obtained for each bias voltage, which is found to agree well with the applied bias voltage. The sheath thickness defined as the distance from the plate to the point where E =0 was found to be proportional to the applied bias voltage to the 3/5 power. The present experimental results are well explained by the collisional sheath model.

For application of our PLIF technique to divertor experiments in the magnetic fusion devices, it is essential to make a single laser-shot determination of E possible. For this purpose, sufficient metastable atoms should be injected to the position of interest in plasma. The required density is evaluated to be 10^{10} cm^{-3} for the determination under the present experimental conditions in which the observation volume was only 5.4 x 10^{-3} cm^3. In fusion devices, the observation volume required can be usually two orders of magnitude larger than in the present experiments. Then the required density in the divertor plasma will be reduced down to 10^8 cm^{-3}.

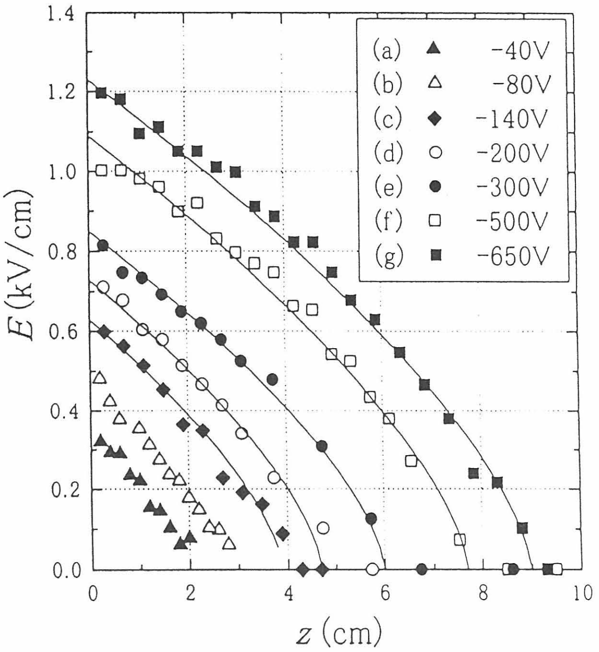

Fig. 1. Spatial distributions of measured electric field in front of the biased plate inserted into the plasma flow for various bias voltages.
The solid curves are calculated on the basis of the collisional sheath model.

References
1) M.Watanabe, K.Takiyama and T.Oda, Jpn. J. Appl. Phys. **39** (2000) L116.