§9. Development of Helium Supersonic Pulsed Beam for Plasma Diagnostics

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Atomic beam sources have provided useful plasma diagnostic techniques, such as the determination of electron temperature and density in the plasma edge of nuclear fusion devices. On the other hand, we have tried to measure the electric field (*E*-field) formed in various plasmas by means of laser-induced fluorescence (LIF) spectroscopy. In this scheme, atoms in the metastable helium level 2 ^1S are excited to $n\ ^1D$ levels (n=3 or 4) due to forbidden excitation using a dye laser, and only the polarization of LIF is observed, because it is a function of the *E*-field. For plasmas without helium gas, however, the development of an intense, collimated, short pulselength, metastable helium beam source is essential. In this study, therefore, a supersonic helium atomic beam source was developed and its temporal behavior and spatial distribution were examined.

The helium high-pressure gas was injected into a vacuum chamber by a commercial electromagnetic valve with a nozzle diameter of d_N=0.8 or 1.0 mm. In order to extract the central part of the injected beam, a skimmer with a horn aperture of 1 mmϕ was also used. The fundamental beam properties, such as pulse shape, flux intensity, beam divergence and velocity, were examined using a fast acting ionization gauge (FIG). The FIG was located at a distance of L=20 or 35 cm downstream from the skimmer. Furthermore, the FIG was mounted on a movable base that can be displaced under vacuum (–25 mm) to measure the spatial distribution of the helium beam along a direction perpendicular to the beam axis.

The temporal and spatial profiles of He atomic beam intensity is shown in Fig. 1. This figure was obtained by changing the FIG position in a direction perpendicular to the beam axis. As can be seen, for nozzle-skimmer distance of x_s =35 mm [Fig. 1(b)], a temporally and spatially narrow density profile was obtained, while for x_s =5 mm there was a diffused beam, showing that the nozzle-skimmer distance had a decisive influence on the nature of the atomic beam. This marked change of the beam with the nozzle-skimmer distance may be attributed to an interaction of the helium beam with background gas [1, 2]. That is, the helium atoms which do not pass through the skimmer diffuse into the vacuum chamber. If the expansion region between the nozzle and skimmer is not sufficiently large, as is the case for x_s =5 mm [Fig. 1(a), (c)], the high-density residual gas prevents the supersonic beam component from penetrating due to scattering with the residual gas. On the other hand, the expansion volume for x_s=35 mm is large enough to restrain this effect, and thus the characteristics of the injected beam are significantly improved, as shown in Fig. 1(b), (d). In fact, a numerical simulation based on simple gas dynamics, in which the beam attenuation due to the residual gas was incorporated, successfully reproduced the experimental results [1].

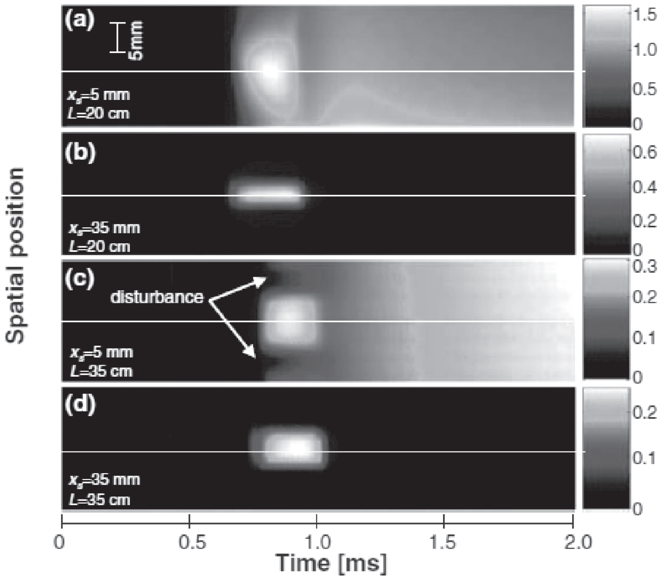

Fig. 1. Temporal and spatial profile of helium beams for conditions of d_N = 0.8 mmϕ and nozzle backing pressure of 25 atm. Measurements were made at L=20 ((a), (c)) or 35 cm ((b), (d)) from skimmer.

The peak beam density at L=20 cm from the skimmer was found to be ~1.4×10^{14} cm^{-3} for a condition of d_N= 1.0 mmϕ, x_s=35 mm and P_b=25 atm. Assuming that the spatial resolution of the FIG is 5 mmϕ (instrumental width) and the profile is described by a Gaussian shape, the full width at half maximum (FWHM) of the beam was determined to be 4.0 mmϕ by applying a deconvolution procedure, and thus a collimated, intense, pulsed helium beam with a divergence angle of ~1.1° was achieved.

The velocity of the pulsed atomic beam was also measured using a time-of-flight technique. Here, the sound speed and terminal velocity correspond to 1.0×10^3 and 1.77×10^3 m/s, respectively, for a temperature of 300 K. The time delays, observed using the FIG, at 20 and 35 cm from the skimmer give a velocity of 1.7×10^3 m/s, indicating that the beam was traveling at near terminal velocity, satisfying the supersonic condition.

In summary, a supersonic He pulsed beam source was developed for measurement of electric fields in plasmas by means of polarization LIF spectroscopy. A supersonic beam with short pulselength (~300 μs), narrow divergence (~1.1°), and high density (~1.4×10^{14} cm^{-3}) at a distance of 20 cm from the skimmer has been achieved.

References

[1] Andruczyk, D., Namba, S. *et al*.: Plasma Devices Oper. **14** (2006) 81.
[2] Namba, S., Andruczyk, D. *et al*.: Jpn. J. Appl. Phys. **45** 10B (2006) 8099.