§8. Development of a Supersonic Beam Source for Rapid Plasma Cooling

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Since population inversions between excited states in ionized helium ions due to gas contact cooling was found in TPD plasmas [1], the population mechanism in non-equilibrium plasma and required conditions for lasing have been studied experimentally and theoretically [2][3]. Gain coefficient related to lasing transition, however, was not high enough to realize an oscillation of the VUV laser.

In order to increase the population densities of the relevant upper levels by using this method, the plasma should be cooled more rapidly due to elastic and inelastic collisions with the neutral atoms. Therefore, the high-density gas with the narrow spatial distribution has to be injected into the TPD plasmas. In this study, particularly, we have focused on the plasma cooling by using the supersonic beams consisting of atoms and atomic clusters. Since the cluster density is the same order of magnitude as that of solid states, it is expected that the plasma electrons quickly lose the kinetic energy in collision with clusters and rapidly recombine with ions through a three-body collisional recombination.

The developed cluster source consists of source chamber with a pulse valve and a skimmer, and target chamber with a detector. By using high-pressure jets, clusters can be formed in the flowing gas expanding into vacuum. When the gas is sufficiently cooled, the Van der Waals forces create the solid atomic-cluster in the gas jets. Laval nozzle with the throat of 0.2 or 0.5 mmϕ was used in order to create high density and large size cluster efficiently. Moreover, a seeding technique, that is, the mixture gas diluted with helium, was adopted for increase clustering efficiency [4]. The spatial density distributions of gas jets (argon, helium and mixture of helium 30%-argon 70%) were measured with a fast ionization gauge (FIG), which was located at 15 cm from the skimmer.

Fig. 1 shows the temporal and spatial distribution of supersonic beam at backing pressure 25 atm with Ar-He mixture, nozzle-skimmer distance 37 mm. The data were measured by changing the position of FIG in the perpendicular direction to the beam axis. Valve opening time was set to be 0.2ms. In this figure, the abscissa axis is time delay, and vertical axis is the spatial position. Both temporally and spatially narrowed distribution (<0.5 ms, <8 mm at FWHM) was obtained. Maximum beam density was found to be $\sim 1\times10^{14}$cm^{-3}. According to Hagena empirical law [5], the average number of atoms within cluster by using this nozzle is $\sim 10^4$ atoms.

On the other hand, in the case of nozzle-simmer distance 5 mm, broadened distributions were obtained, and seemed to be the diffusive beam expanding from skimmer. Increasing the distance, the beam shapes gradually became narrower, temporally and spatially. This phenomenon was explained by the attenuation of the supersonic beam in collision with the background gases. That is, in the case of shorter distance, large amount of expanding gas from the nozzle were scattered with the skimmer, resulting in increasing the background gases responsible for the beam attenuation in source chamber. Therefore, the optimized distance should be selected to obtain high-density beams.

By using the cluster source developed in the present study, we will attempt to increase the inverted population density between the excited states (n=2-3 transition) of ionized helium ions (lasing wavelength; 164nm).

References

[1] Sato, K, et al., Phys. Rev. Lett. **39**, 1074 (1977).
[2] Otsuka, M., et al., J. Quant. Spectrosc. Radiat. Transf. **21**, 41 (1979).
[3] Furukane, U., et al.,J. Phys. D **22**, 390 (1989).
[4] Hayes, J.M., Chem. Rev. **87**, 745 (1987).
[5] Hagena, O.F. et al. J. Chem. Phys. **56**, 1793 (1972).

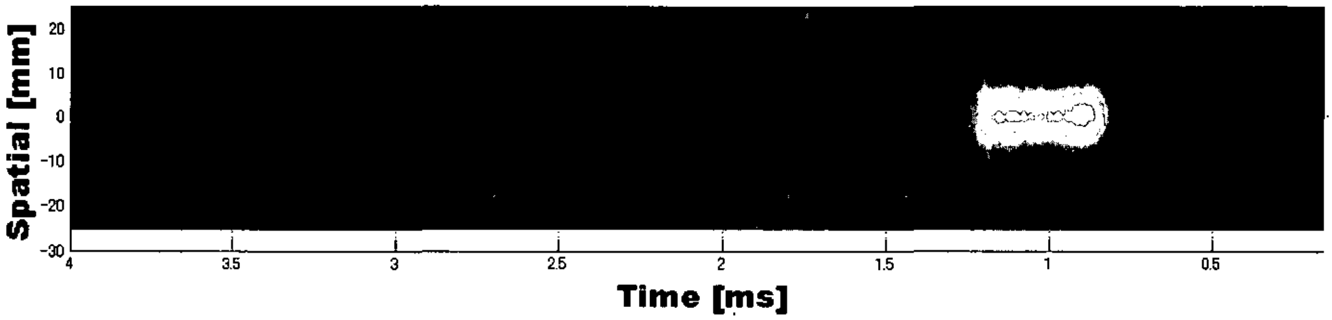

Figure 1. Temporal and spatial distribution of the produced supersonic beam.