§2. Characteristics of Hydrogen Supersonic Cluster Beam Generated by a Laval Nozzle

Murakami, A. (Grad. Univ. Advanced Studies),
Miyazawa, J., Yasui, K., Murase, T., Yamada, H.

The supersonic cluster beam (SSCB) injection method is being developed as a new fueling method for the Large Helical Devise (LHD) experiment [1, 2]. SSCB is an improved version of cluster jet injection (CJI) developed for HL-2A, where liquid nitrogen of 77 K is used for gas cooling [3], or the supersonic gas injector (SGI) developed for NSTX, where a Laval nozzle is used to generate supersonic gas jet [4]. In SSCB, high-pressure hydrogen gas cooled to less than 77 K by a GM refrigerator will be injected to vacuum through a fast solenoid valve with a Laval nozzle. Before applying SSCB to LHD, it has been tested in a test vacuum chamber.

The experimental setup is shown in Fig. 1. A fast solenoid valve is equipped with a Laval nozzle of 300 μm throat diameter. The valve is installed in the vacuum chamber and cooled by a GM refrigerator via connection with copper plate and shafts. The temperature T_0 of copper valve jacket is measured by a thermocouple. A semiconductor laser is guided in the chamber to perpendicularly intersect the gas flow. The distance between the nozzle exit and the laser chord is 17 mm. A fast CCD camera is arranged in the direction perpendicular to both the gas flow (x-direction) and the laser beam (y-direction). A typical CCD image of 8.0 MPa H_2 cluster jet at 125 K and the cross section of the Laval nozzle are shown in Fig. 2. A straight emission line that is scattered by clusters is observed along the laser beam.

The scattering signals are detected when the temperature is below ~180 K as expected from the scaling calculation using Hagena parameter [2]. Figure 3 shows scattering signal profiles along the laser light direction (y), where the temperature is varied from 119 K to 143 K. The exposure time of the CCD camera is fixed to 10 ms and the backing pressure P_0 is fixed to 5 MPa for this scan. The width of 5.8 mm in Fig. 3 denotes the exit hole diameter of the Laval nozzle. These profiles are axisymmetric. The full-width of half-maximum (FWHM) is 6.2 ± 0.2 mm. The FWHM does not depend on temperature. Two peaks observed in the profiles indicate that the cluster flow is hollow. Similar hollow profile was observed in the study on plasma produced by laser pulses irradiating a cluster target generated by a Laval nozzle [5]. The peak scattering signals increases with $\sim T_0^{-5}$. The increase of the scattering signal means physically that the average cluster diameter becomes large [6]. It is expected that the cluster which has larger diameters will be formed at temperatures below 119 K. The peak scattering signals also increases with $\sim P_0^3$. The divergence of cluster jet has been decreased after installation of the Laval nozzle from 22.5° to ~10°.

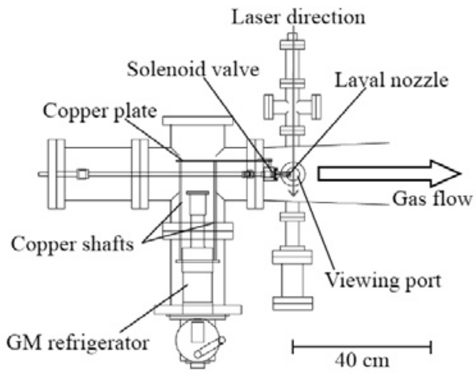

Fig. 1. Schematic of the experimental setup. A solenoid valve installed in the vacuum chamber is cooled by the GM refrigerator through copper plates.

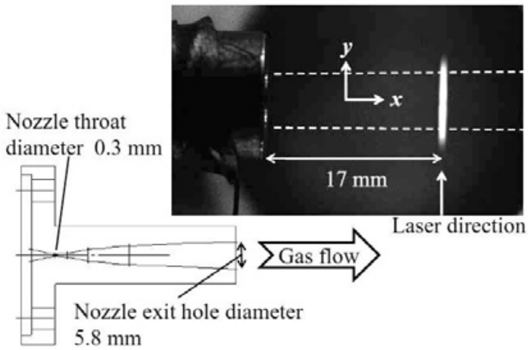

Fig. 2. Typical CCD image in the case of H_2 at 125 K and the cross section of the Laval nozzle. The backing pressure is 8.0 MPa, and the exposure time is 10 ms. The laser beam direction (y) is perpendicular to the gas flow (x). The broken lines denote extension of the exit hole with a diameter of Laval nozzle (5.8 mm).

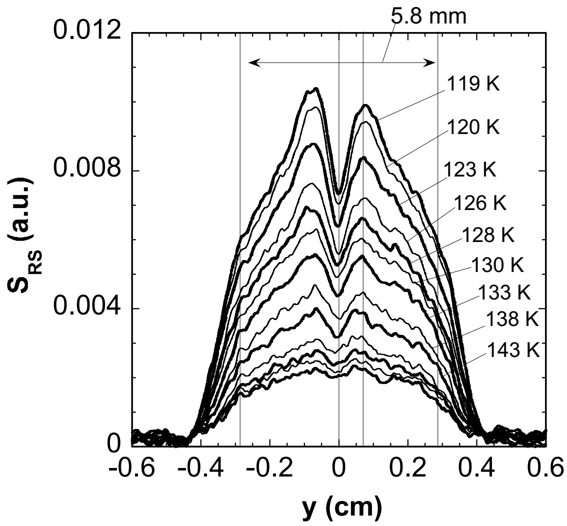

Fig. 3. Scatter signal profiles normalized by the exposure time (μs), where the temperature is varied from 119K to 143K.

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