§21. Magnetic Confinement of Cryogenic Plasma Produced in Superfluid Liquid Helium

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Mobility of positive or negative ions in superfluid liquid helium (LHe) is more than 10^4 times greater than those in normal fluid helium. Mixture of such ions in LHe may be similar to a collisionless plasma in rarefied gases, and we proposed previously the possible existence of cryogenic plasma state. The purpose of the present research is to investigate experimentally the confinement of the cryogenic plasma by mirror or cusp magnetic field configuration.

In recent years, we tried to generate a cryogenic plasma in LHe between a pair of needle tungsten electrodes with tip curvature radius 50 micrometer and separation 1.5 mm by applied pulsed voltage of 20 kV, duration 1 microsec and current 50 A. We observed the time-resolved optical light emission from 380 nm to 720 nm through spectrometer and a multi-channel array. The results demonstrated that neutral He atomic lines such as 587.6 nm were extremely broadened because of Stark effects caused by the presence of thick ambient plasma in cryogenic environment. The plasma density just after the pulsed discharges attained to be as large as 5×10^{18} cm^{-3}. The maximum electron temperature was measured to be 35,000 K from line to continuum intensity ratio around various spectral lines. The Coulomb coupling coefficients were around 0.1 that is 5 times larger than the values in conventional gaseous discharges in room temperature. The plasma in peripheral region surrounded by superfluid LHe was estimated to be extremely low-temperature cryogenic plasma after the pulsed discharges.

In addition to the neutral He atomic lines, two strong series of spectral lines without any broadening were observed near 430 nm and 395 nm. The former was identified to be emission from rotational-vibrational transitions in diatomic He molecules, whereas the latter was not reported in previous literatures and the origin of the emission is not understood at the moment.

Last year, we observed the spatial resolution of this localized cryogenic plasma through the Stark broadening of spectral line 587.6 nm. The position of focusing lens is moved precisely by 3 dimensional adjustable optical benches, and focal spot on the slit of the spectrometer is changed for each shot of pulsed discharges. An example of the results is shown in the Fig. 1. The time evolution of plasma density is obtained for various positions off-diagonal distance in the plasma from axis of electrodes. The plasma density distribution is estimated to be a rotating ellipsoidal shape with half widths of long and short radii, respectively, 0.8 mm and 0.2 mm.

The decay time of the cryogenic plasma without magnetic field is presently very short. To lengthen the decay time, the presence of magnetic field in LHe is necessary. The situation was previously analyzed by Shikin.1) At initial stage, gaseous plasma of 10 atm described above in a large bubble between electrodes is formed. On the other hand, in later afterglow stage, the bubble disappears because of rapid cooling effect of ambient superfluid LHe. In such period, pure cryogenic plasma in LHe is formed. Multi-electrons are located in a small bubble with radius on the order of 1 nm in superfluid LHe, and positive ions are confined in neutral He atoms forming an ice ball (cluster). In order to confine this cryogenic plasma, we are designing and fabricating a split-type superconducting coil with magnetic field strength of 2 T.

It is emphasized that the cryogenic plasma in the present study involves various unknown phenomena to be explored in future such as cluster formation, superfluid plasma state and technology applications of ion superfluidity to electronic devices.

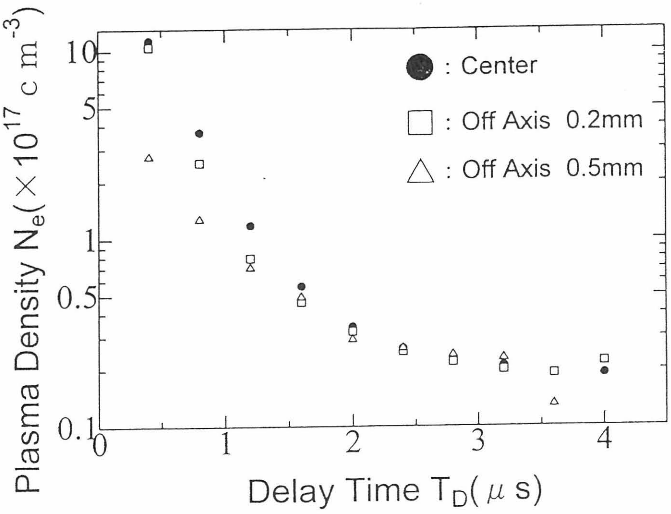

Fig. 1 Decay of plasma density at various position from axis of needle electrodes.

Reference

1) Shikin, V. B., Sov. Phys. Usp., Vol. 20, (1977) 226.