PRODUCTION OF A LOW ENERGY ION BEAM PLASMA WITH LOW ELECTRON TEMPERATURE

H. Kiyama and S. Kiyama

Electrotechnical Laboratory, 1-1-4 Umezono, Tsukuba-shi, 305-8568, Japan

Abstract

In this experiment, a low energy ion beam plasma, whose parameters are controllable, has been developed to study the phenomena of low temperature plasmas in the electric and magnetic fields. The basic idea of this beam type source is that the electrons and the ions are separately controlled to produce the necessary energy, temperature and density. The ions are extracted by 3 electrodes from a plasma source. After the extraction, electrons are added to the ion beam to eliminate the ion space charges. Consequently, the beam plasma is produced. At an optimum value of the emission of the electron source, the ion density is maximum, which is about one order higher than without the electron source, and the divergences in energy and in space of the ion beam are minimum, furthermore the electron temperature is minimum, about 0.3 eV.

1. Introduction

Ion beams generated by the sheath potential are effective and useful for the usual processing plasmas, but are mostly divergent and difficult to be controlled. High ion density plasmas of low electron temperature in lower gas pressure are required for the purposes. The plasmas which have these characteristics are difficult to be produced in steady discharges. Alternatively, the low energy beam plasmas, whose ions have given velocity and narrow divergence, and electron temperature is less than 1 eV, may be most effective for studying the processing plasmas. The electrons may work also to eliminate the charge up of samples. In this experiment, a production of a low energy ion beam plasma with low electron temperature has been studied.

2. Experimental Setup

The beam plasma apparatus consists of plasma source, ion extraction electrodes and electron source. The schematic diagram of it is illustrated in Fig. 1.

The plasma source is the bucket type. The dimensions of the plasma source are 16 cm x 16 cm and 19 cm in length and the ion extraction area is 8 cm x 8 cm. The source plasma is produced with Ar gas which pressure p_{source} is 1-6 mTorr and has the parameter's of n_e<10^{19}/m^3 (at P_d=2 kW), T_e=1.5-3 eV. The density n_e of the source plasma is generally in proportion to the discharge power P_d, and T_e increases with decreasing p_{source}. The total available ion current through the extraction electrode is proportional to the discharge power, and is about 1 A /1 kW, if the transparency of the electrodes is 50 %.

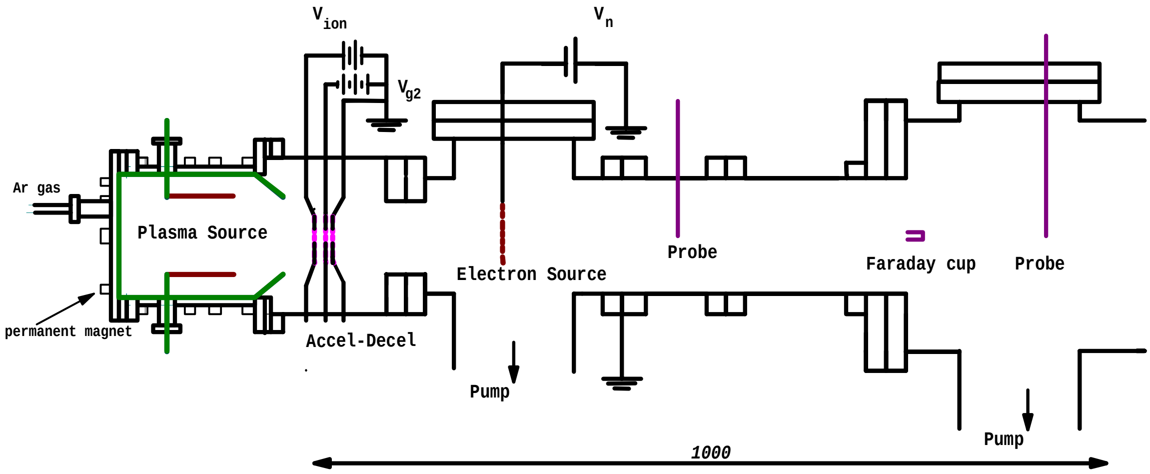

Fig. 1. The schematic diagram of the ion beam plasma system.

Ions are extracted by 3 electrodes from the plasma source. The extraction electrode for ion beam is set up at 5 cm far from the end of the plasma source. The extraction system consists of multi-aperture three electrodes with 400 aligned apertures in a circle of 4 cm in diameter [1]. The diameters of the apertures are 1.2 mm, 1.0 mm and 1.0 mm, respectively and the separation of electrodes are 1.0 mm. The accel and decel voltage is relatively large (~2 kV). The ion energy V_{ion} is changed by the extraction voltage.

As the Ar ion energy is low (50-100 eV) and the density is high, Ar beam may diverge and may not transmit in a long distance, due to the ion space charges. To eliminate the space charge, an electron source is set up. The electron source consists of 25 wires made of tungsten. Consequently, the plasma beam, which is composed of low energy ion beam and low temperature electrons, is produced. The auxiliary magnetic coil was required, because the ion source is apart from the electron source in this case.

3. Experimental Results

The ion density (I_{ion} :ion saturation current of a probe), n_e and T_e of the plasma beams are shown against the heater current of the electron source I_n in Fig. 2a. The ion energy is 100 eV. The parameters are measured at 36 cm far from the extraction electrode. When I_n is small, the electrons may originate in the secondary emission. I_{ion} , n_e and T_e increase with I_n because the ion space charges are eliminated. There is an optimum value for I_n, at which T_e is minimum and n_e is maximum. Consequently, the high density and low temperature plasmas can be obtained at this point. When I_n is increased beyond the optimum point, T_e increases and n_e decreases.

When the voltage of the neutralizer to the chamber wall is changed, T_e changes, as shown in Fig. 2b. These facts show that, the electron temperature can be controlled by changing the electron emission and the neutralizer voltage to the space potential.

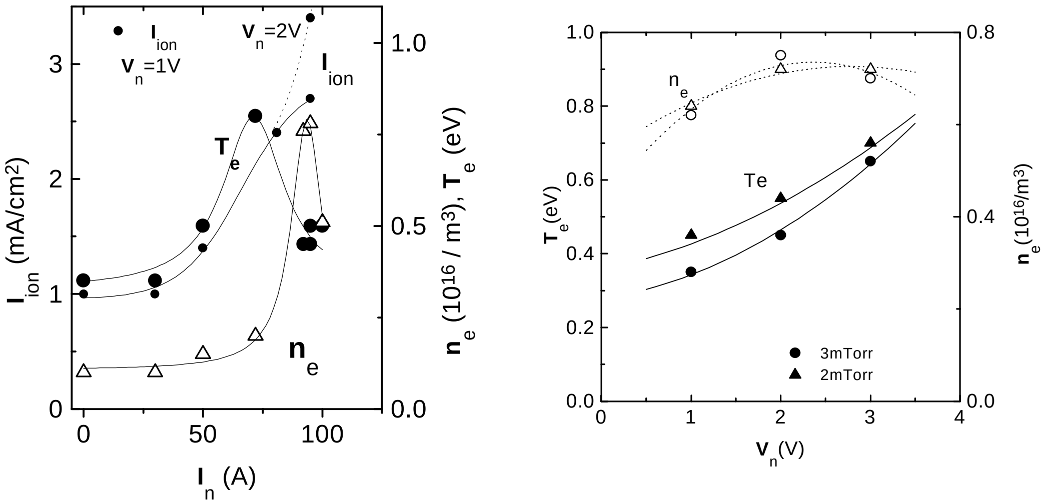

Fig. 2. a) I_{ion}, T_e, n_e vs. the heater current of the neutralizer and b) T_e, n_e vs. the potential of it.

The total ion beam current $I_{total\ ion}$ and n_e at the lowest electron temperature (0.35-0.45 eV), that is, at optimum I_n, are presented against P_{d} in Fig. 3, comparing with n_e of the plasma without the neutralizer. $I_{total\ ion}$ and n_e increase with the discharge power of the source plasma. n_e of the beam plasma with neutralizer is about 10 times higher than without it. The low energy high density ion beam requires the neutralizer which cancels the space charge critically.

The energy spectrum of the beams and the divergence are measured by a Faraday cup and single probes. The energy spectrum of the ion beams with and without neutralizer are shown in Fig. 4. The faraday cup is at 65 cm apart from the extraction electrode, where the gas pressure p_{chamber} is about 1×10^{-4} Torr. The energy spectrum of the ion beam with neutralizer is very sharp. The half width of the 100 eV beam with and without neutralizer are 2.5 % and 5%, respectively. The beam plasma includes slow ions because of charge exchange with neutral Ar. The ratio of the ion current of the beam of 1-95 eV to 100 eV for the beam with and without neutralizer were 0.2 and 0.35, respectively. Here, real beam

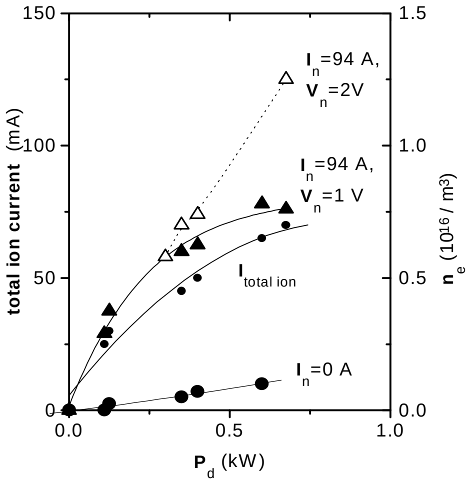

Fig. 3. $I_{total\ ion}$ and n_e versus P_{d} .

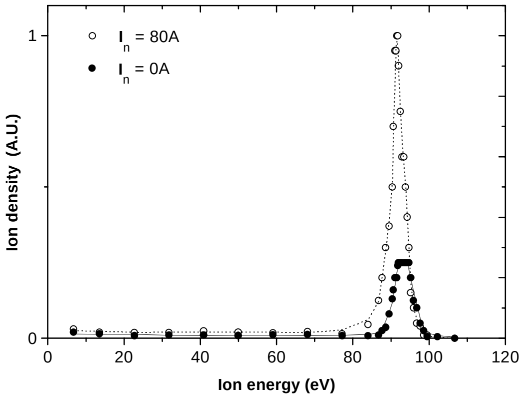

Fig. 4. The energy spectrum of the ion beam.

energy against the space potential is not 100 eV, especially for the beam without neutralizer, because the potential of the faraday cup is against the potential of the chamber.

The radial profiles of the parameters of ion beam plasmas are shown in Fig. 5. The space potential of the beam plasma and T_e without neutralizer are higher than with it. The profile of I_{ion} and n_e are broad. V_s increased with the distance from the extraction electrodes. Then, the beam without neutralizer is divergent. V_s and T_e of the ion beam plasma with neutralizer are low. The ion beam is convergent and the divergence is about 5 °. The ion beam plasma decreases with the Ar neutral gas pressure, which may be due to the charge exchange.

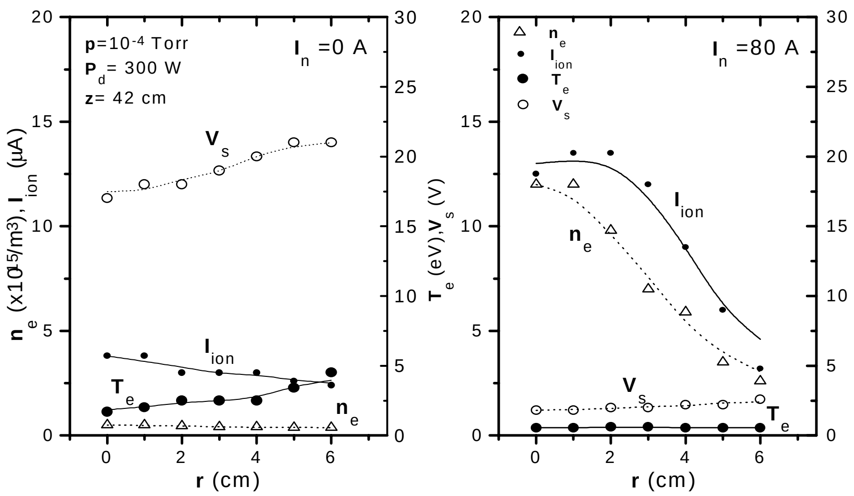

Fig. 5. I_{ion}, n_e, T_e and V_s profiles of the beam plasmas with and without neutralizer.

5. Conclusion

(1) Argon plasma beam, which is composed with low energy ion beam (50-100 eV) and low temperature electrons (0.35-0.5 eV), is produced.

(2) For the production of the low energy ion beam, the electron source is necessary to eliminate the ion space charge. With it, ion beam density increases 5-10 times, the beam is convergent in energy and in space, and can transmit in a long distance.

(3) The ion density can be controlled by the discharge power of source plasma. The electron temperature can be controlled by changing the emission and the potential of the electron source.

(4) The half width of the energy spectrum of the beam is 2.5 % and the divergence of the ion beam in space is about 5 °.

(5) The maximum electron density is $10^{16}/m^3$ and the ion current is 70 mA for the present aperture area of which diameter is 4 cm.

(6) As the ion beam plasma decreases with Ar gas pressure in the chamber, due to the charge exchange, the pressure must be reduced (less than 10^{-4} Torr in distance of 100 cm).

Reference

[1] H. Kiyama: Electrical Engineering in Japan **95**(4), (1975) 261.