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A Low Energy Ion Beam Plasma Source with Low Electron Temperature

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Abstract

A low energy convergent ion beam plasma has been developed to study the phenomena of low temperature plasmas in the electric and magnetic fields and to apply to the plasma processing. The ion energy, electron temperature, density and space potential are controllable, which are higher than 50 eV, 0.3-1 eV, $10^{15}/m^3$-$10^{16}/m^3$ (Maximum) and 0-10 V, respectively.

1. Introduction

High-power and high-energy ion beams have been developed, for example in NBI, and utilized in the various fields for last 20-30 years. High density, high-mass and low-energy ion beams are required for the plasma deposition or etching. However, it is difficult to produce the beams overcoming the space charges, which are generated by the ion beams themselves. The ion beams themselves must charge up a target or samples. Ion beams generated by the sheath potential of plasmas are commonly utilized in the plasma processing, by reason of high efficiency. Large and uniform plasmas with high ion density (>$10^{18}/m^3$) and low electron temperature (<1 eV) in lower gas pressure discharge (<1 mTorr) are required. The beams are mostly divergent and can not be controlled directly. The low energy beam plasmas, where ions have given velocity and narrow divergence, and electron temperature is less than 1 eV, may be most effective for studying the plasma processing. The electrons work to eliminate not only the space charge but also the surface charge of the target. In this experiment, a production of the low energy ion beam plasma with low electron temperature has been studied.

2. Experimental Setup

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

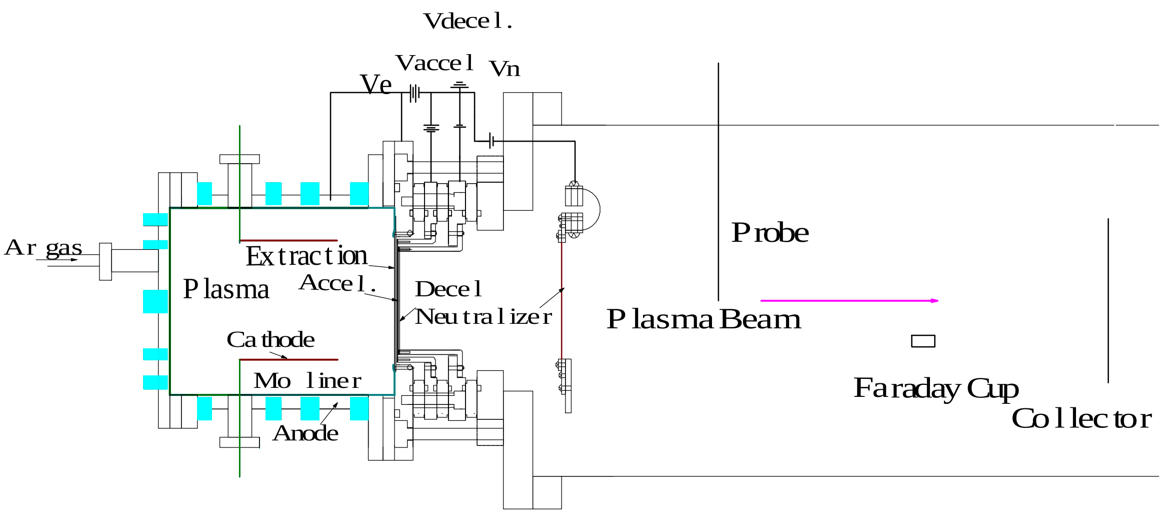

Fig. 1 *The schematic diagram of the ion beam plasma.*

is the bucket type [1]. The plasma has parameter of $n_{e\text{-source}}=10^{19}/m^3$ (at P_{dis}=2 kW), $T_{e\text{-source}}$=1.5-3 eV, p_{source} =0.1-6 mTorr.

Argon ions are extracted from the source, accelerated and decelerated by three electrodes with multi-apertures. The multi-aperture three electrodes of 80x80 mm^2 have 1000 aligned apertures. The diameters of the apertures are 1.2, 1.0, 1.0 mm and the separation is 1.5,1.0 mm, respectively. Each electrode is made of Molybdenum 1.0 mm in thickness. The density $n_{e\text{-source}}$ of the source plasma is generally in proportion to the discharge power P_{dis}, and $T_{e\text{-source}}$ increases with decreasing p_{source}. The ion energy E_{ion} (>50 eV) is changed by the extraction voltage V_E. The total available ion current through the extraction electrode is proportional to P_{dis}, which is expected to be 1 A/1 kW in extraction area of 80x80 mm^2, as the optical transparency of the electrodes is 50 % and the ion current is about 2 A/1 kW when a collector is placed at the point of the extraction electrode. However, the real beam current of the collector, which is placed at 62 cm apart from the electrodes, is a few percent of it because of the high ion space charges. Then, after the extraction, electrons, which are emitted from 25 Tungsten filaments, are added to the ion beams to eliminate the ion space charges. Consequently, the plasma beams, which are composed of low energy convergent ion beams and of low temperature electrons, are produced.

3. Experimental Results

The Ar ion density with the beam energy of 50-100 eV is as same as or even higher than the ion density in the usual NBI, though the beam current density is less than 3 mA/cm^2. In the condition, the electron source is essential to eliminate the space charges.

The effect of the charge neutralizer, which is expressed by the current of the Tungsten filaments I_n, is shown in Fig. 2a. The ion beam current at the collector I_{beam}, the total extraction current from the plasma source I_{drain}, the ion current to the accel-electrode I_{accel} , the

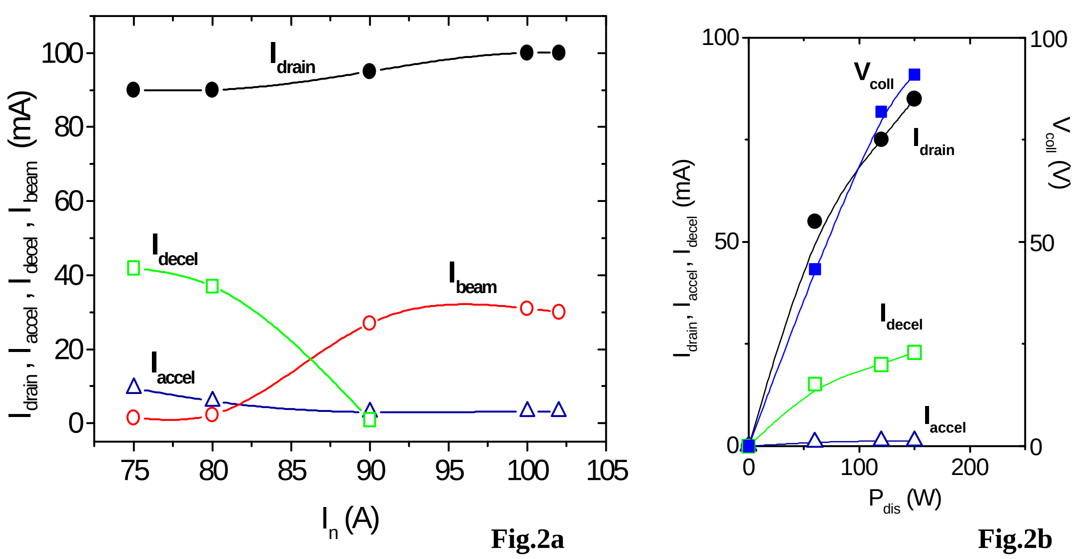

Fig.2a **Fig.2b**

Fig. 2a *The effect of the charge neutralizer.* P_{dis} *=150 W, The collector is 62 cm from the electrode. The ion energy is 100 eV.*

Fig. 2b *The voltage of the collector* V_{coll} *are plotted against* P_{dis} *when* I_n *=0 A and the collector is floating.*

ion current to the decel-electrode I_{decel} are shown against the heater current of the electron source I_n . I_{beam} describes the total ion beam current within divergence of 5 degrees. In the region of low electron emission, the ion beam current to the collector I_{beam} is nearly zero, and a half of I_{drain} flows to the accel-electrode and the decel-electrode, the remainder of that diverge due to the ion space charges and flow to the chamber wall. There, very high-energy electrons exist, which are produced by the collision with the wall, the electrodes or the collector and are accelerated due to the ion space charges. When the emission is increased, I_{accel} and I_{decel} decrease, and I_{beam} increases. There is an optimum I_n or an emission against lower T_e and higher n_e or I_{beam} . In this case, T_e = 0.8 eV , n_e =3x10^{15}/m^3, the space potential V_s = 2V at the point of 29 cm from the electrodes. V_s is controlled by changing the potential of the decel-electrode against the chamber wall.

The voltage of the collector V_{coll} are measured, when I_n =0 A and the collector is floating, which corresponds to the condition of the ion beam injected on insulating targets. V_{coll} are plotted against P_{dis} with I_{drain}, I_{accel} and, I_{decel} , as shown in Fig. 2b. The collector charges up about 90 V, which is slightly below the beam energy, in the case of P_{dis} =150 W. It means the target may suffer damage due to the potential and the neutralizer is essential.

I_{beam}, I_{drain} and I_{accel} at the optimum emission are shown against the discharge power P_{dis} in Fig.3. I_{beam} and I_{drain} increase with P_{dis}. In this case, I_{drain} means the total ion beam current within divergence of about 10 degrees. A half of ion beams extracted from the electrode arrive at the collector and the remainders flow the decel-electrode, the neutralizer and the chamber wall. The gradients of I_{beam} and I_{drain} versus P_{dis} slightly decrease with increase of P_{dis} , though $n_{e\text{-}source}$ and the total available ion current linearly increase with P_{dis}. The gradient becomes gentle from P_{dis} ~150 W. The decrease of the gradient may be caused by the insufficient neutralization.

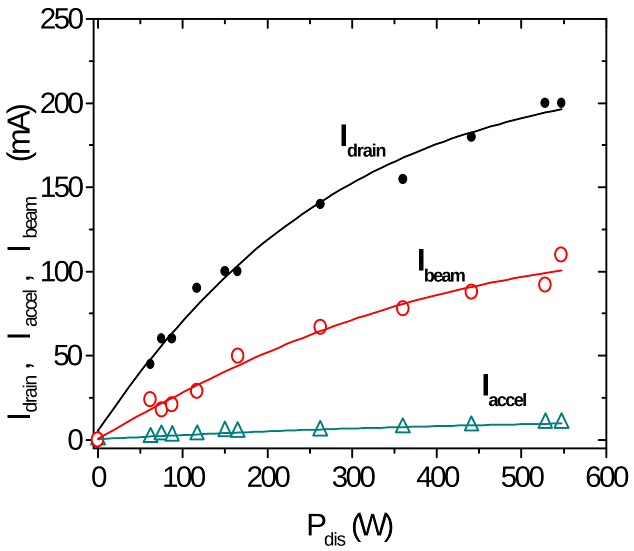

Fig. 3 *I_{beam}, I_{drain} and I_{accel} at the optimum emission are shown against the discharge power P_{dis},*

The radial profiles of n_e, j_{ion}, T_e and V_s of the ion beam plasma are shown in Fig. 4. Here, j_{ion} is the ion saturation current of the probe, which is proportional to the ion density because the ion velocity is nearly monochromatic. All parameters are uniform within 4 cm in radial direction, as the dimension of the electrodes is 8x8 cm^2. The ion density slightly exceeds the electron density at the edge of the plasma beam, because of the electron trapping in the magnetic field, V_s increases from it towards the wall.

V_s increased with the distance from the extraction electrode [1]. The ion beam plasma density decreased with the Ar neutral gas pressure, which is due to the charge exchange.

4. Discussion and Conclusion

To obtain the high-density, low-energy (100 eV) and high-mass ion beam plasma with the low electron temperature, the complete elimination of the ion space charge throughout the beam path is essential and key issue. In this experiment the electron emissive heater is used as the neutralizer. It is also important to eliminate the surface charge on the insulating target.

The electron temperature can be controlled by changing the emission and the potential of the electron source to some extent. To have low electron temperature, the electron emission must be enough. If the temperature of the heater or the emission is increased, the low electron temperature is obtained. If a lower negative potential V_n against the chamber or decel-electrode is applied to the emissive heater, the electron emission is effective. However, a high energy electron beam appears, whose energy corresponds to nearly V_n and the amount of it is a few % of the total electrons. The high-energy electron beam may be undesirable for the low temperature plasma. As the ion beam density increases with P_{dis} , the ion charge density increases for the low energy high mass ion beam, therefor elimination of ion space charge near the decel-electrode is difficult, which may interrupt to proportional increase of ion currents to P_{dis}. As the ion beam density decreases with Ar gas pressure in the chamber, due to the charge exchange, the pressure is reduced to about 10^{-4} Torr. As the 8x8 cm^2 electrodes are larger 4 times than the former electrodes (4 cm in diameter), the differential pumping is not effective. The pressure near the electrodes is lower and it causes the higher electron temperature (0.8-1.0 eV) than in the former case (T_e =0.35-0.5 eV).

The attained parameters for Argon beam plasma is that beam energy: 100 eV, the total current at the point 30 cm from the electrodes: 100 mA, the beam current density at the decel-electrode: 3 mA/cm^2 at P_{dis} =550 W. The ion energy, electron temperature, density and space potential are controllable, which are higher than 50 eV, 0.3-1 eV, $10^{15}/m^3$-$10^{16}/m^3$ (Maximum) and 0-10 V respectively. The beam density is uniform in 8x8 cm^2.

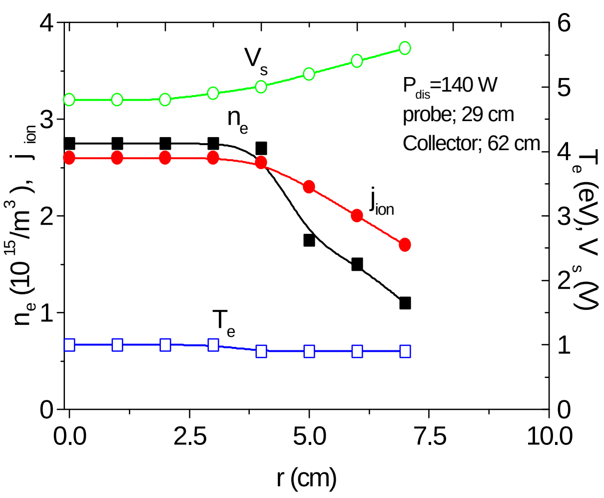

Fig. 4 *The radial profiles of n_e , j_{ion} , T_e and V_s of an ion beam plasma are shown.*

References

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