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Electron Temperature Control in a Hot Cathode Arc Discharge Plasma

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1. Introduction

Control of electron temperature T_e has lots of interest in advanced plasma applications as well as basic plasma researches. So far, some methods for the temperature control were applied such as pulse modulation, bias grid, RF heating and so on. In this study, we have attempted that the temperature control by means of varying a quantity of thermal electron emission and a distance of the discharge gap, because the thermal electron emission and the gap distance are essential to sustain arc discharge plasmas.

2. Experimental Setup

2.1 *Compact Hot Cathode Arc Plasma Generator*

Experiments were performed by using the Compact Hot Cathode Arc Plasma Generator, which had been constructed in our laboratory as shown in Fig. 1. The device has a glass vacuum vessel with 0.8 m in length and 0.14 m in diameter, and is equipped with two solenoidal magnetic coils, which produce a flux density of 10 mT in steady state. Argon gas was poured from discharge region then Argon plasmas were produced in steady state by sophisticated dc discharge system, which is designed to improve the ionization efficiency using a divergent magnetic configuration and a heated LaB_6 spiral coil cathode. The electron density n_e can be controlled by changing the discharge current I_d. Typical plasma parameters are the electron density $n_e < 5 \times 10^{17}$ m^{-3} and

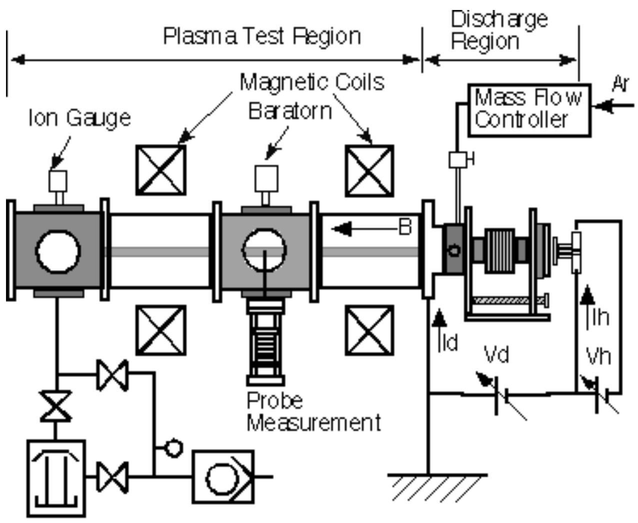


Fig. 1. Schematic diagram of the Compact Arc Plasma Generator. The power supply for the cathode heating is floated from the ground.

the electron temperature T_e < 10 eV. The plasma diameter is about 0.01 m. A generated plasma flowed into the plasma test region through a orifice at the center of the anode, which diameter is 4 mm. Neutral pressure measured in the plasma test region P_n was less than 0.27 Pa in this study. The anode orifice divides the plasma source and the plasma test regions. The main vacuum pump is a diffusion pump (90 liters/sec).

The electron temperature in the plasma test region was measured by a single Langmuir probe. The location of the probe was 0.4 m away from the anode orifice, where is between two magnetic coils.

2.2 *Discharge Region*

The details of the discharge part are shown in Fig. 2. This region consists of mainly four parts, a hot cathode, a water-cooling capper anode, a floated electrode and a bellows. A LaB_6 cathode (DENKA Beta Plus, Type C-2) was used for a hot cathode. The cathode has double spiral coil structure in order to avoid the influence of magnetic field. The diameter of the cathode is 10 mm and the length is 25 mm. The cathode temperature is increased by ohmic heating followed with direct current I_h. A quantity of thermal electron emission depends on the temperature of the cathode. The emission current density j can be described as a function of the cathode temperature T by the Richardson-Dushman equation as following;

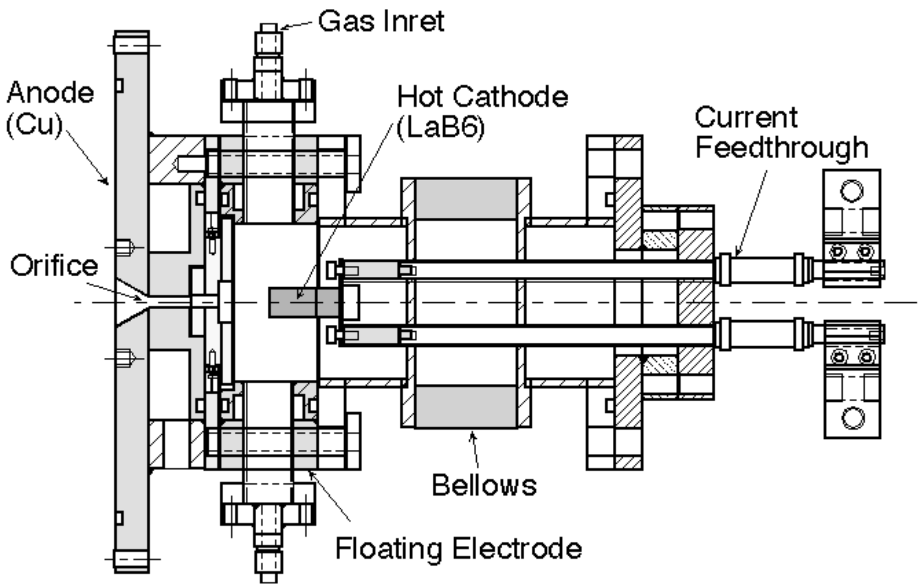


Fig. 2. Details of discharge region of the Compact Arc Plasma Generator. The hot cathode is surrounded by a floating electrode with a glass port and a bellows.

$$j = AT^2 \exp\left(-\frac{e\phi_w}{kT}\right), \qquad (1)$$

where A is Richardson constant, ϕ_w is the work function of the cathode material, k is the Boltzmann constant. Figure 3 shows the plots of the eq (1) for several cathode materials. The thermal electron emission has strong dependence on the cathode temperature in our experimental conditions. Due to the discharge voltage V_d was limited to 200 V by the DC power supply, I_h > 26 was needed to make a breakdown for Argon.

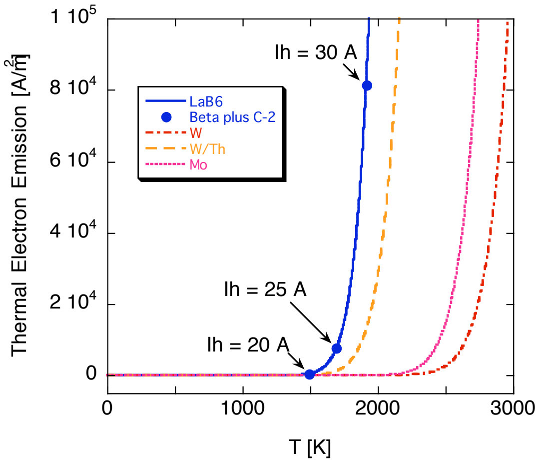


Fig. 3. Dependence of thermal electron emission on the cathode temperature for the materials LaB_6, W, W/Th and Mo.

A bellows connected between the Anode and the cathode in order to vary the discharge gap (see in Fig. 2). To avoid thermal damage caused by electron and ion heat flux, the bellows is electrically floated. Both flanges of the bellows are fixed at a linear guide rail in order to allow moving in the axis direction. The variable distance is from 15 mm to 45 mm as the discharge gap.

3. Experimental Results and Discussion

Figure 4 shows the dependence of V_d and T_e measured at the center of the plasma column on the cathode heating current I_h. V_d is increased by decreasing of I_h in the range of 15 and 28 A. The V_d is almost constant between I_h = 5 and 15 A. In the case of I_h = 0.3A, the cathode temperature was sustained by plasma itself. With respect to T_e, we observed high-energy tail within all I_h region of the experiments. The bulk T_e shows almost constant value (~ 2 eV), however, the T_e of high-energy tail components is gradually increased by rising of I_h. During I_h variation, the different heating mode of the cathode is observed as shown in Fig. 5. In the case of high I_h (Fig. 5 (c)), the tip of cathode is dark. This means the temperature of the part is low because of the low resistivity due to the large cross section of the heating current path. However, the cathode has high-capability of thermal electron emission because the area of high temperature (bright) region is enough large, therefore, V_d becomes small. On the other hand, at I_h = 0.3 (Fig. 5 (a)), the tip of cathode becomes the brightest part of the cathode. It seems that self-heating caused by the concentration of ion influx is occurred at this position. In this case, the electron emission area is smaller than the other cases. Therefore, V_d is needed to rise in order to keep the discharge current.

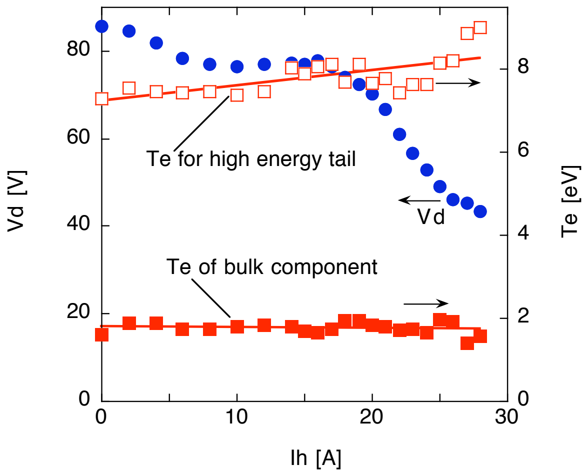
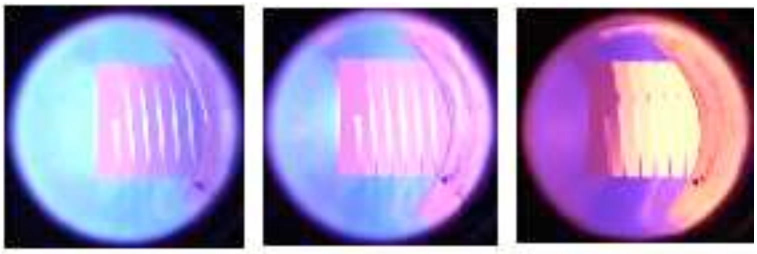


Fig. 4. Dependence of the discharge voltage V_d and electron temperature T_e on the cathode heating current I_h during Ar discharge (I_d = 5 A, Gas flow = 1.5 sccm, P_n = 1.9 mTorr). Closed circles, open squares and open circles show V_d, T_e of high energy tail component and T_e of bulk component, respectively.



(a) Ih = 0.3 A (b) Ih = 12 A (c) Ih = 26 A

Fig. 5. Photographs of the hot LaB_6 cathode for different cathode heating current during same conditions as Fig. 4. The anode is located on the left side of each photo.

3. Summary

Experiments were performed by using the Compact Hot Cathode Arc Plasma Generator with a LaB_6 hot cathode and a variable gap driving system. Decreasing the heating current of the cathode, probe measurements showed decrease of T_e of high-energy tail component for Argon plasmas. Simultaneously, a change of cathode heating mode was observed. These results indicate a possibility of the control of T_e (or energy distribution function) by using these methods.