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THE INFLUENCE OF ELECTRON OSCILLATION ON PLASMA TRANSPORT THROUGH A MAGNETIC DUCT

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A magnetic duct is inserted between the cathodic arc plasma source and the chamber to eliminate the macroparticles. In this paper, the plasma output of the magnetic duct is determined as a function of the magnetic field and the bias voltage under the Bilek biasing mode and entire duct biasing mode. The computer simulation and the experimental result indicate that the $\vec{E} \times \vec{B}$ drift results in an extra diffusion flux under the Bilek biasing mode. The test verifying the electron oscillation was conducted in the magnetic duct biased in the Bilek mode. The electron behaviour under Bilek biasing mode is different from that under entire duct biasing mode. The Bilek biasing mode has a lower plasma output than the entire duct biasing mode.

Keywords: cathodic arc plasma, plasma transport, magnetic duct, computer simulation
PACC: 5275, 5230, 5280, 2925

I. INTRODUCTION

Cathodic arc plasma is of increasing importance in thin-film deposition of metals, oxides, nitrides, semiconductors and amorphous carbon,[1−5] metal ion implantation employing line-of-sight implantation with a three-electrode system[6], as well as metal plasma immersion ion implantation.[7−9] The desirable features of a cathodic arc plasma source are the high flux and large fraction of ions in the metal plasma. However, cathodic arc plasma sources suffer from macro-particle contamination, and the reduction or elimination of macro-particles has been studied.[10,11] The most common method to remove macro-particles is to employ a curved magnetic duct. One drawback of the magnetic duct is the reduction of the plasma flux due to the recombination at the duct wall. Several methods have been proposed to optimize the ion flux transport efficiency through the curved magnetic duct.[12] A technique of inserting a positively biased plate near the outer wall of the magnetic duct to reflect positive ions and reduce electron loss to the duct was proposed by Bilek.[13] In this configuration, a small bias on the plate suffices.

In our previous work [14], we compared the Bilek biasing mode and the entire duct biasing mode with respect to the plasma output of the magnetic duct. It was found that the plasma output (characterized by the ion current on the collecting plate I_P) is higher when the entire duct rather than the Bilek plate alone is biased. The computer simulation predicted that some electrons which have certain moving velocity and direction will oscillate in the magnetic duct under the Bilek biasing mode.[15] In the work described here, the mechanism of the electron oscillation is further analysed. Experiments have been conducted to verify this prediction. The influence of this oscillation on the plasma transport has also been investigated.

II. EXPERIMENTAL DETAILS

The basic experimental apparatus has been described previously.[14] An isolated aluminium electrode (the "Bilek bias plate") is placed on the outer quadrant of the inner surface of the duct wall and is biased to enhance the plasma transport through the duct. The plate is insulated from the duct wall by a sheet of plastic. The magnetic duct is biased in two ways: (a) biasing the Bilek plate only, and (b) biasing the entire duct. In the second mode, the duct and the Bilek plate are connected in parallel, so that the plate

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becomes a part of the duct wall. The duct and the Bilek plate are biased via a capacitor bank of 22mF.A 160 mm×220 mm large area plane collector plate, negatively biased to −70V, was positioned in the vacuum chamber about 20cm from the duct exit to monitor the ion flux I_P transported through the duct. This bias voltage was chosen by varying the bias voltage over a range to confirm that it was within the ion saturation current regime.[9] A simplified schematic of the experimental configuration is shown in Fig.1. To limit the number of variables, the titanium cathodic arc current was fixed at 100A. The cathodic arc current and ion currents I_P were characterized by their peak values.

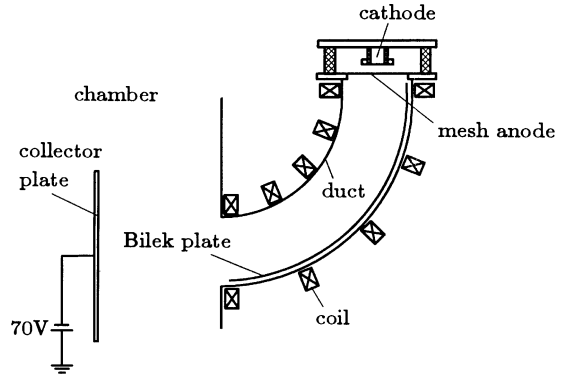


Fig.1. Schematic diagram of the experimental apparatus, showing the cathodic arc plasma source, magnetic duct with the Bilek plate, and collector plate.

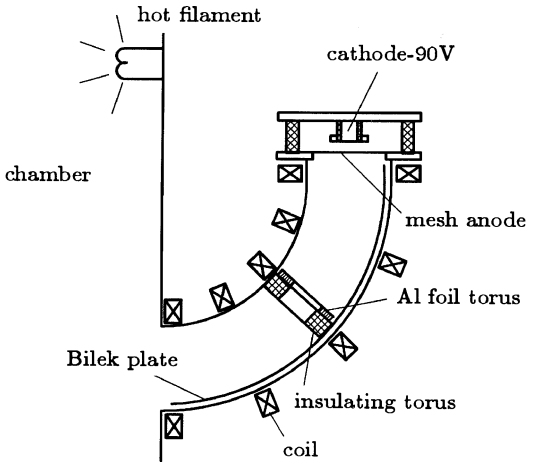


Fig.2. Schematic drawing of the electron oscillation experiment.

The electron oscillation experiment was conducted with an insulating torus positioned inside the duct (Fig.2). The hole of the insulating torus is about 4cm in diameter. A hot filament generated electrons. The duct is out of the line-of-sight of the filament, so the electrons generated from the filament cannot fly into the duct directly. An aluminium foil torus was stuck to the side of the insulating torus facing the cathode. The aluminium foil torus collects the electrons flying from the right to the left but not the electrons flying from the left to the right. The cathode was charged to −90V but did not produce a cathodic arc.

III. RESULTS AND DISCUSSION

The ion transverse diffusion leads to the loss of the transported plasma. The ion transverse diffusion flux to the wall is caused mainly by collisions between the particles in the duct.[12] The flux associated with cross-field diffusion is given by Fick's law: $\Gamma = -D\nabla n$, where ∇n is the gradient of the plasma density, $D = kT_e/16B$,[16] k is Boltzmann's constant, T_e is the electron temperature, and B is the magnetic field strength in the duct. The plasma output $I_P \propto 1/\Gamma$, so $I_P \propto B$. Here the relation of I_P versus B in this experiment deviates from $I_P \propto B$ (Fig.3). So there are other causes for the plasma diffusion besides the collisions. The uneven magnetic field in the duct, with a denser magnetic field in the inner side of the duct torus, could cause the drift motion of the electrons and the ions in the plasma. This could decrease the plasma output of the duct. The entirely biased duct has a higher plasma output than the Bilek biased duct, so there is an extra diffusion mechanism in the Bilek biased duct. The electron velocity is typically 10^6m/s and ion velocity 10^4m/s in the cathodic arc plasma.[17] The electron density is usually several times that of the ion density.[18] In a very short time, the ion can be considered as motionless compared with the electrons. A computer code was developed to simulate the particle motion in the magnetic duct and, according to the simulation, it is believed that some electrons would oscillate in the biased magnetic duct.[15] The magnetized electrons move along the magnetic field. When the electrons leave the duct, the electric field at the duct outlet will pull back the electrons and make them move along the opposite direction. When the electrons move close to the cathode, the electric field of the negatively powered cathode pushes back the electrons and makes them move towards the duct outlet again. Thus the electrons oscillate in the duct. The initial position, velocity and direction of the flying electrons must satisfy a certain requirement to make the electrons oscillate. The oscillating requirement is hard to be met in the entirely biased duct and few electrons oscillate. The oscillating requirement is more

easily met under the Bilek biasing mode and considerable electrons will oscillate in the duct. The oscillating electrons will produce a pronounced effect on the plasma motion under the Bilek biasing mode. While the electrons oscillate, the $\boldsymbol{E} \times \boldsymbol{B}$ force will drift the electrons towards duct wall. Thus the electrons will fly in a zigzag way and finally strike the wall, and the whole plasma may drift towards the wall.

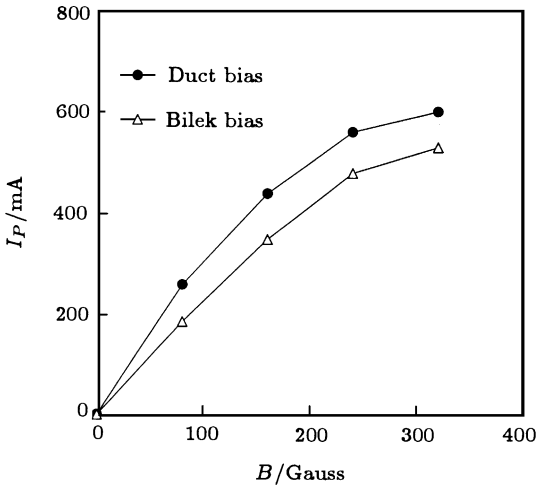


Fig.3. I_P versus B with the entire duct or the Bilek plate bias voltage=+20V. B is the magnetic field strength in the duct.

The result of the electron oscillation test is shown in Fig.4. This result indicates that the electric and magnetic fields trap the electrons in the chamber generated from the hot filament, make the electrons fly into the duct and oscillate in the duct. The collected electron current on the aluminium foil torus I_f increases with the biasing voltage and decreases with the magnetic field. The electron drift rate is $v_d = E/B$. The larger the v_d, the more the electrons which deviate from their original trace and strike on the aluminium foil. The computer simulation indicates that the electric field is less than 150 V/m in most parts of the duct space when the bias voltage of the Belik plate is less than 20V. Most of the electrons entering the duct are trapped by the magnetic field lines above the duct exit, because the filament is above the duct exit and the electrons emitted from the filament cannot move across the magnetic field lines. These electrons are liable to escape from the duct after one cycle of oscillation. The average velocity of the electrons emitted from the filament is $v_e = 5.53 \times 10^3\ T^{0.5}$ m/s, where T is the temperature of the filament. Supposing that the electrons trapped by duct magnetic field enter the duct without collision, the average time for these electrons to finish one cycle of oscillation is $2L/v_e$, L being the length of the duct. During this time, the electrons will drift a distance of $d = v_d 2L/v_e$ towards the duct wall. Within this experiment limit, the larger d means that the electrons have more opportunity to strike on the aluminium foil torus (Fig.2). Figure 5 shows that the drifting distance of the electrons d increases as the electrical field increases and decreases as the magnetic field increases.

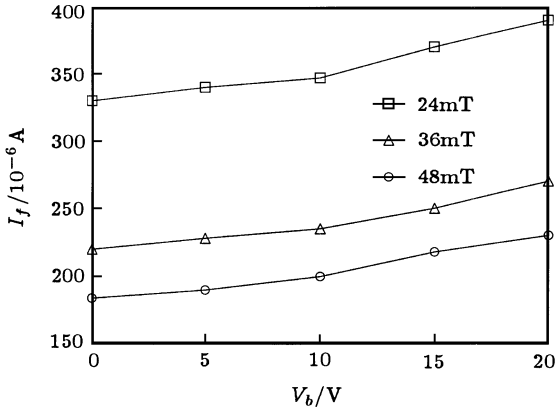


Fig.4. The collected current on the aluminium foil torus I_f versus bias voltage V_b with the magnetic field B as a parameter under the Bilek biasing mode.

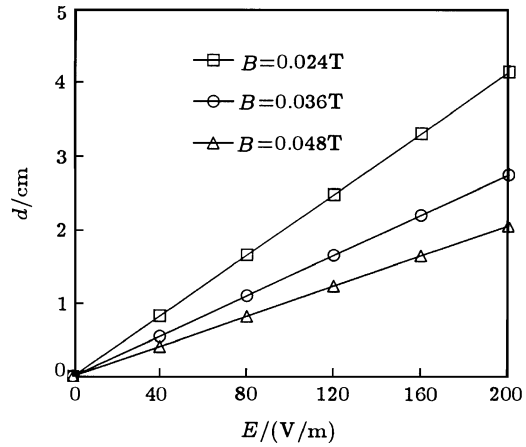


Fig.5. The drifting distance d of the electrons during one cycle of oscillation as a function of the electrical field E for various magnetic field strengths in the duct biased in the Bilek mode. The temperature of the filament is 2000K. The length of the duct is 0.5m.

IV. CONCLUSION

One of the purposes of inserting a biased plate covering the outer part of the duct wall instead of biasing the entire duct is to reduce the electrons lost to the duct wall, because the electrons take an important part in guiding the ions to go through the duct. But the experimental results have shown that

the entire duct biasing mode has a higher plasma output than the Bilek biasing mode. This work indicates that besides some factors which affect the diffusion in the plasma, such as collisions and the effective area of the duct wall where the biasing voltage is applied and the ions can be pushed back into the plasma, the electron drift caused by the $\boldsymbol{E} \times \boldsymbol{B}$ force contributes to the plasma transverse-diffusion in the duct under the Bilek biasing mode. Some electrons could oscillate in the duct, and this enhances the electron drift-motion. So the plasma suffers more loss to the duct wall in the Bilek biasing mode. The stronger the electron drifting, the more the plasma loss. The drift extent of the electrons increases as the electrical field increases and decreases as the magnetic field increases.

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