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Damage of a Hot Filament Discharge Cathode Operated with High Frequency Alternating Current
高周波電流による熱陰極放電フィラメントの損耗

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To extend the time between maintenance services of a hot cathode arc discharge ion source, a tungsten filament cathode has been operated with an AC heating. Operation with an AC heating can mitigate the concentration of filament erosion on the negative terminal of the cathode operated by a DC heating current, and the erosion rate for an AC heating was reduced to 70 % of that for a DC heating. Both the discharge current and the ion saturation current in plasma exhibited fluctuations. The discharge current fluctuated with the amplitude of 21 % of the average, and the fluctuation amplitude of the ion saturation current was about 7 % of the average.

1. Introduction

In the field of semiconductor manufacturing, the ion source plasma operated with hot cathodes has an advantage of power efficiency and stability over other producing ions and their beams. However, hot cathodes have finite lifetimes due to evaporation and sputtering of cathode materials immersed in plasma. To extend the lifetime of a cathode, mechanisms causing the accelerated erosion of cathodes were investigated by several authors. [1]

The negative potential end of the filament is heated up more than the positive potential end, and the erosion of hot cathode concentrates at the negative potential end in the case of DC heating of the cathode [2]. This localized erosion makes the cathode lifetime shorter. An induction of alternating heating current can separate one spot of largest erosion for DC heating current into two spots at both ends of the filament to elongate the filament lifetime. However the fluctuation of plasma arises due to the change in position of the point which emits the thermal electron from the hot cathode. The stability of plasma and the lifetime of a cathode operated by alternating heating current have been investigated by changing the AC frequency.

2. Experimental setup

An ion source whish has been developed for a medium current ion implanter for semiconductor manufacturing process [3] has been tested. The schematic diagram of the ion source chamber is shown in Fig.1. A cylindrical vacuum chamber attached to the source is 200 mm inner diameter, and 400 mm length. The molybdenum arc chamber produces and confines plasma in a volume of 90 mm height, 36 mm width, and 29 mm depth.

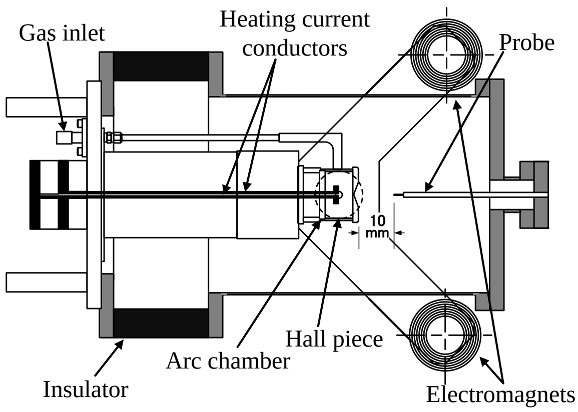

Fig.1. Schematic diagram of ion source chamber.

To reduce inductance for supplying power at higher AC frequency, a low inductance bus bar line with the cross-section area of each conductor as large as 8 x 2 mm^2 has been employed. The length of each conductor is 265 mm and the spacing between them is 1 mm. The test tungsten filament was 0.4 mm diameter. The total length of the tungsten was 60 mm, but only the top 30 mm has been exposed to the plasma. The radius of curvature at the end has been set to 1.5 mm. Discharge gas is introduced into the arc chamber through a hole opened on the sidewall of arc chamber. An external magnetic field in the direction parallel to the filament is produced by a pair of electromagnets set on both sides of the vacuum chamber. Magnetic field intensity at the center of the ion source can be independently controlled to minimize the warpage of produced magnetic field lines of force.

3. Result

3.1 Oscillation of discharge current

To investigate fluctuation of plasma caused by operation of hot cathode with AC heating power, we observed the discharge current with a high speed data recorder (KEYENCE GR-7000) coupled to a current probe (IWATSU SS-250) by keeping the filament heating power constant at 100 W. A typical waveform of discharge current of Ar plasma excited by 15 Hz AC is shown in Fig.2. The frequency of discharge current is twice the frequency of filament heating current and the fluctuation amplitude is as large as 21 % for the average value of the discharge current.

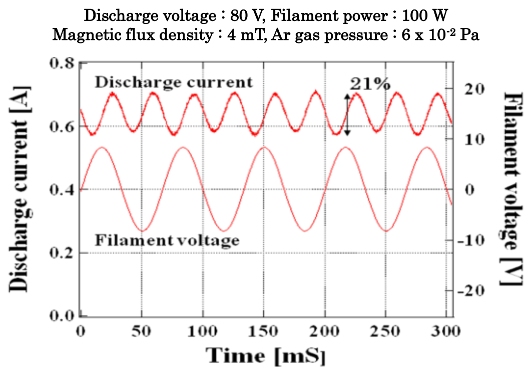

Fig.2. Waveforms of discharge current and filament voltage.

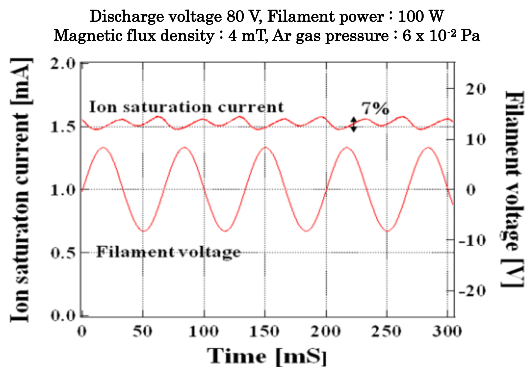

Fig.3. Oscilloscope waveforms of the ion saturation current and filament voltage.

3.2 Ion saturation current

Fluctuation in ion saturation current of plasma was measured with a Langmuir probe. The tungsten probe is 0.3 mm diameter, 2.0 mm length and placed at the position 30 mm from the center of the arc chamber, which is about 10 mm away from the ion extraction hole. Figure 3 shows a typical waveform of the ion saturation current operated with 15 Hz AC current. The ion saturation current oscillated with the amplitude 7 % of average.

3.3 Distribution of erosion on a filament

Figure 4 shows the distribution of erosion along a filament after driving with an AC and DC power supply for 1.5 hours, the source was operated with 1 A discharge current. For 0.4 mm diameter tungsten filament of 60 mm length, about 14 A heating current was necessary to produce 1 A discharge current. By operating the filament with DC power supply, the erosion point has concentrated at the negative side of the filament. The AC operation seems to reduce and homogenize erosion of the filament.

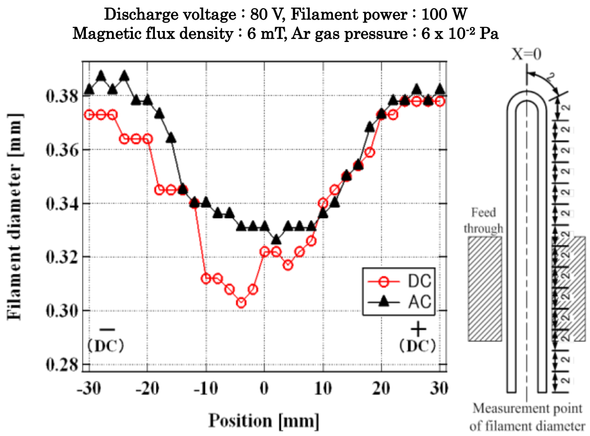

Fig.4. Erosion distributions of filaments.

4. Summary

A hot filament cathode was operated with AC heating current. Both the discharge current and the ion saturation current have shown fluctuations when AC current has heated the cathode. The AC operation has shown the filament erosion can be homogenized compared to the case of DC operation, with which the filament has exhibited enhanced erosion at the side of the filament connected to the negative terminal of the heater power supply.

References

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[2] K. W. Ehlers and K. N. Leung: *Rev. Sci. Instrum*. **50** 3, (1979), 356.

[3] N. Miyamoto, *et al.* : *Rev. Sci. Instrum*. **73** 2, (2002), 818.