STABLE OPERATION OF LARGE CATHODE USING AN OSCILLATING SOURCE MAGNET CURRENT IN FILTERED VACUUM ARC PROCESS

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1. INTRODUCTION

Amorphic diamond films deposited by filtered vacuum arc (FVA) method has been attracted much attention due to their superior mechanical and optical properties [1-3]. FVA process has many advantages against other CVD or PVD process: high ionization ratio up to 90%, ion energy ranging from 10 to 100eV suitable for high quality armophic diamond film deposition and the ability to exclude macro particles from the deposited film. However, several problems concerned with the graphite cathode erosion are to be solved. The vacuum arc on graphite cathode shows relatively large instability in the arc spot motion and localized cathode erosion under some operation condition. Instability of the arc spot motion limits continuous operation of the FVA source, which results in poor productivity. In addition, the localized erosion degrades the efficiency of the cathode usage. Efficient erosion of the cathode by stable arc spot is thus prerequisite for the industrial application of the amorphic diamond coatings by the FVA process.

Instability of the arc spot motion is known to be related closely to the arc spot shift to the edge of the cathode or abnormal increase in arc voltage caused by the increased resistance of the plasma when the electrical current across the magnetic field lines [4,5]. The former reason of the instability could be minimized by controlling the arc spot motion. The movement of arc spot is strongly influenced by the existing magnetic field [6-8]. The arc spot tend to move in the retrograde direction given by $-\mathbf{J}\times\mathbf{B}$ and towards the opening of the acute angle formed by the field line and the cathode surface [9,10]. In order to stabilize the arc spot motion, it would be thus essential to design the magnetic field to confine the arc spot within the top surface of the cathode.

The abnormal increase in arc voltage is the main reason for the arc instability when using mirror magnetic configuration where the polarities of the source and the extraction magnet are parallel. On the other hand, the cusp magnetic configuration where the magnetic field diverts to the anode effectively suppresses the instability caused by the increasing arc voltage. The cusp configuration is thus used by many researchers [11-13]. However, the magnetic field diverts electrons to the duct wall so that a very small central section can be available for transporting electrons through the magnetic filter [11]. The cusp configuration also makes the arc spot move around the edge of the cathode, which further degrades the efficiency of the beam transport. In contrast, the mirror configuration has an advantage of efficient ion beam transport.

In the present work, we investigated the effect of the magnetic field structure on the cathode erosion behavior. We used the mirror magnetic configuration for the high efficiency of ion beam transport. Using a permanent magnet of opposite polarity behind the cathode combined with oscillated current of the source magnet, we could obtain stable arc in the mirror magnetic configuration and increase the lifetime of the cathode. The cathode erosion was so uniform that more than 90% of the cathode volume could be used during the lifetime.

2. EXPERIMENTAL

Fig. 1. Shows the schematic of FVA system used in the present work. The FVA source was composed of graphite cathode of diameter 80mm, ring type anode of inner diameter 90mm, 60 degree bending plasma duct for magnetic filtering and 4 solenoid magnets for extraction, bending, outlet and deflection, respectively. The plasma duct was

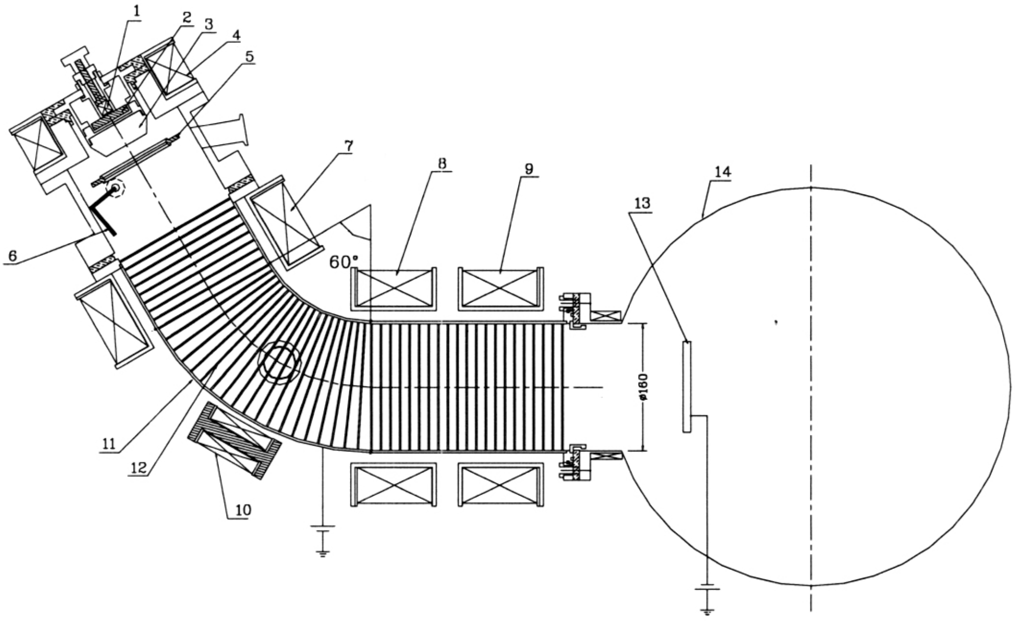


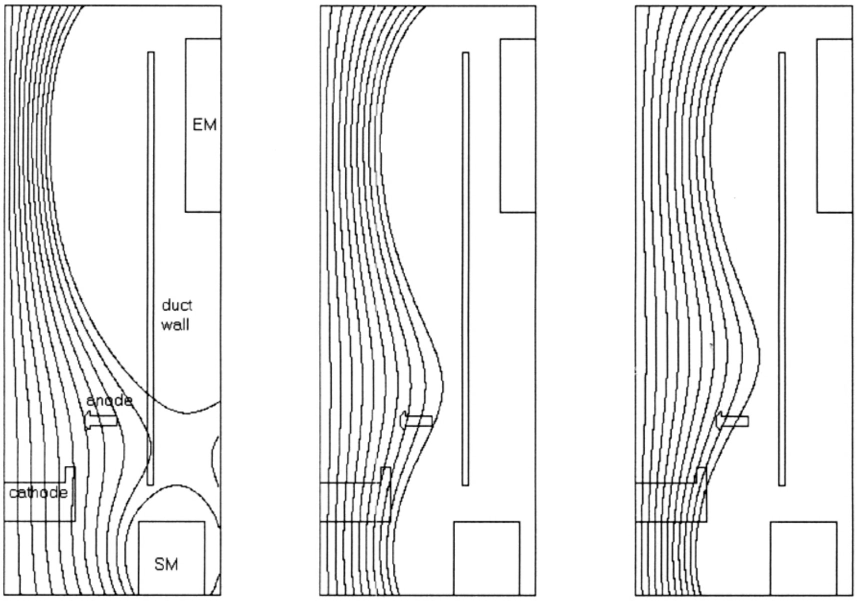
Fig. 1. Schematic of the filtered vacuum arc deposition system used in the present work :
(1) Nd-Fe-B magnet (2) cathode yoke (3) cathode (4) source magnet (5) anode (6) striker
(7) extraction magnet (8) bending magnet (9) outlet magnet (10) deflection magnet (11) plasma duct
(12) baffle (13) substrate holder (14) vacuum chamber

electrically isolated from the ground that a bias voltage can be applied. The solenoid magnets could generate the center magnetic field of 250 Gauss at the maximum current of 5A. Baffles in the duct were designed to prevent macroparticles from rebounding from the duct wall. Substrate holder of 115mm in diameter was placed at the distance of 130mm from the exit of the FVA source. In order to measure the beam current, the substrate holder was electrically isolated from the reaction chamber. When measuring the beam current, the substrate holder was biased by –100V to exclude the contribution of electrons.

Solenoid source magnet (maximum center magnetic field of 150Gauss) was installed around the cathode. We also placed a magnetic yoke (diameter 50mm, thickness 10mm) and a permanent magnet Nd-Fe-B magnet (diameter 15mm, thickness 10mm, surface magnetic strength 4000Gauss) at 5mm and 17mm from the back surface of the cathode, respectively. The magnetic field near cathode was simulated by using Poisson code for various configurations of the permanent magnet, yoke and the current of the solenoid source magnet [14]. Self magnetic field due to the arc spot was ignored in the simulation. The current of the extraction magnet was fixed at 3 A for the simulation. Erosion behaviors were investigated by observing the eroded cathode after operating the FVA source until the stable ignition of the arc by the trigger cannot be obtained (defined by lifetime). The arc source was operated in Ar environment at the pressure of 17mPa.

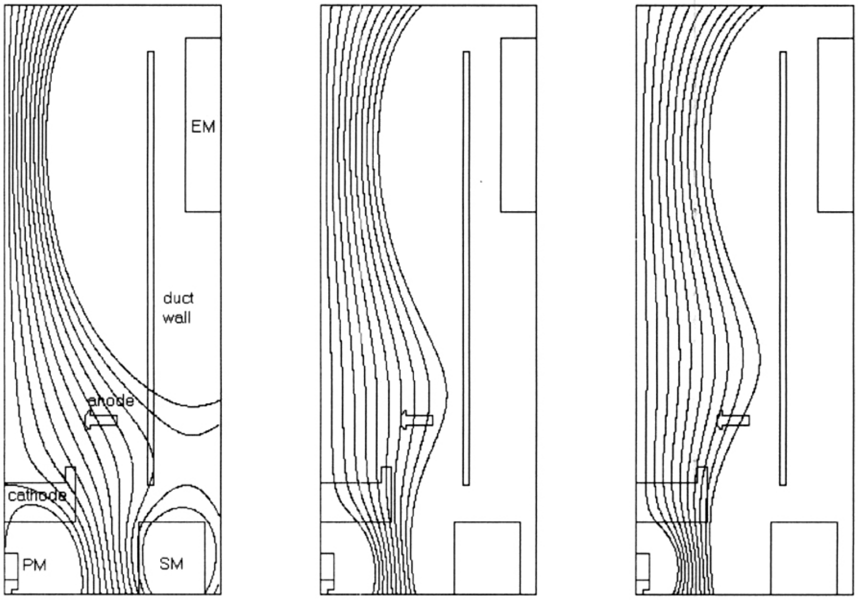
3. RESULTS AND DISCUSSION

In the mirror magnetic configuration of the present work, the arc spot became unstable with increasing the magnetic strength of the source magnet. Fig. 2 shows the magnetic field structure for various strengths of the source magnet. With increasing the current of the source magnet, i.e. increasing the magnetic strength, the opening of the acute angle formed by the magnetic field line on the cathode surface directed outward. Arc spot thus tends to move to the edge of the cathode resulting in the arc instability. We could not obtain stable arc motion in this configuration.



(a) (b) (c)

Fig. 2. Magnetic field structure near cathode without permanent magnet and yoke for various currents of the source magnet (SM) of (a) 1A, (b) 3A and (c) 5A. Current of extraction magnet (EM) was fixed at 3A.



(a) (b) (c)

Fig. 3. Magnetic field structure near cathode with permanent magnet (PM) only for various current of the source magnet (SM) of (a) 1 A, (b) 3 A and (c) 5 A. Current of extraction magnet (EM) was fixed at 3 A

This instability could be suppressed by placing a permanent magnet of opposite polarity to that of the solenoid source magnet on the backside of the cathode. It can be shown in Fig. 3 that the opening of the acute angle directed much more to the center of the cathode at the same current of the source magnet as in Fig. 2. However, the angle between the magnetic field line and the cathode surface also increased as the current of the source magnet increased.

Erosion behaviors of the cathode were in good agreement with the simulation results. Fig. 4 (a) shows the eroded cathode when the current of the source magnet was 1A. Deep erosion in the center region showed that the arc spot moved around mainly in the center of the cathode. When the current of the source magnet increased to 3A, arc spot appeared to move in wider region of the cathode as shown in Fig. 4 (b). This behavior can be understood by considering that the larger opening of the acute angle was developed with higher current of the source magnet as shown in Fig. 3 (a) and (b). Higher current of the source magnet again reduced the arc stability.

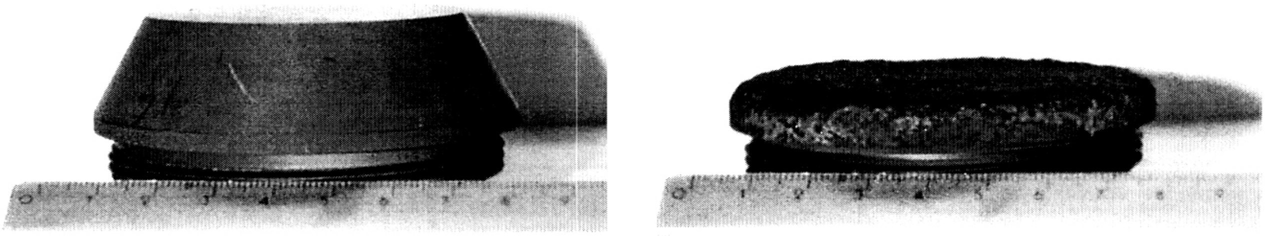
(a) (b)

Fig. 4. Morphologies of the used cathodes eroded with the permanent magnet only. The source magnet current was (a) 1 A and (b) 3 A..

This result evidently showed that the arc instability of mirror magnetic configuration could be suppressed by using a permanent magnet of opposite polarity. The effect of the permanent magnet can be controlled by placing a yoke between the magnet and the cathode. Combination of the yoke and the permanent magnet can increase the efficiency of the cathode by about 20% as can be estimated from eroded volume of the cathode for the lifetime. More efficient erosion of the cathode could be obtained by oscillating the current of the source magnet. Oscillating the magnetic strength of the source magnet can dynamically changed the magnetic field structure near the cathode. By oscillating the current of the source magnet, the acute angle between the magnetic field line and the cathode surface was periodically varied. Arc spot can thus move around in wider region of the cathode surface. Fig. 5 showed the morphology of the eroded cathode when the current of the source magnet oscillated from 0 to 1A (a) and from 0 to 1.5A (b). In contrast to deep erosion in the center region under static source magnetic field (Fig. 4 (a)), much wider erosion was observed by the current oscillation as can be seen in Fig. 5 (a). Eroded area was proportional to the maximum current of the source magnet as can be compared between Fig. 5 (a) and (b).

(a) (b)

Fig. 5. Morphologies of the used cathodes eroded with both the permanent magnet and the yoke. The source magnet current was oscillated in the range of (a) 0.0~1.0 A and (b) 0.0~1.5 A



(a) (b)

Fig. 6. Morphologies of tapered cathode (a) before and (b) after use for 2000 min with both permanent magnet and yoke. Current of the source magnet varied from 1.0 to 3.0 A at 0.1 Hz.

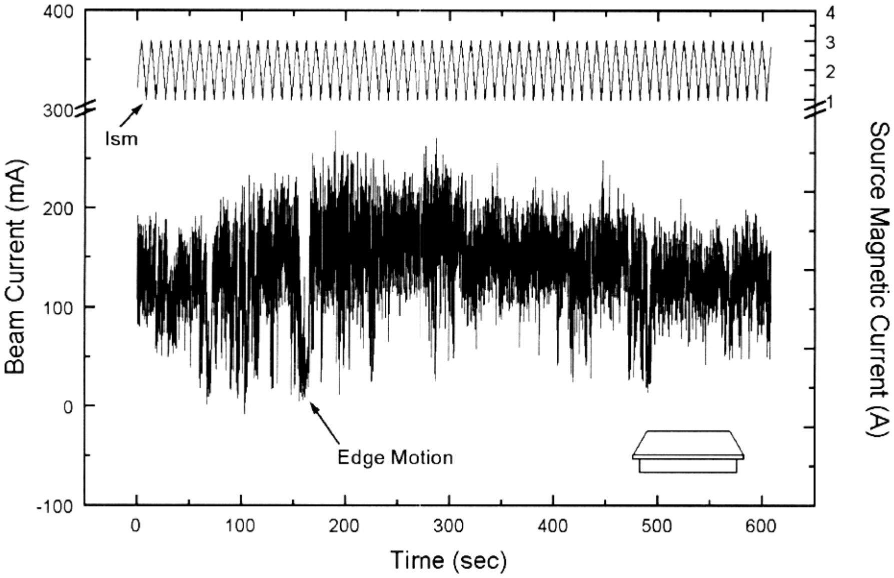


Fig. 7. Time variation of carbon beam current for tapered cathode. Current of the source magnet varied from 1.0 to 3.0A at 0.1 Hz. Inlet of graph shows the shape of the cathode

Fig. 6 (a) and (b) respectively show the tapered cathode before and after operating the arc source for 2000min at the arc current of 60A. More than 90% of the cathode volume could be used in the present operation condition that the source magnet current was oscillated from 1 to 3A. Fig. 7 shows the stable beam current could be obtained in the present condition. It should be noted that the arc spot near the edge moved to the top surface of the cathode as can be seen in the beam current change at about 160sec (arrow in Fig. 7). These results show that uniform erosion of the cathode and stable beam current could be obtained in the mirror magnetic configuration by using oscillated current of the source magnet and placing a permanent magnet of opposite polarity behind the cathode.

Amorphic diamond films were deposited on Si (100) wafer for various substrate bias voltages ranging from 0 to –250V. With increasing the bias voltage, the hardness measured by nanoindentation and the residual compressive stress measured by beam deflection method decreased from 65 to 45GPa and 6.4 to 3.2GPa, respectively. The content of graphitic component was increased with increasing the negative bias voltage as observed in EELS and Raman spectroscopy.

4. CONCLUSIONS

The most significant result of the present work is that arc instability in the mirror magnetic configuration could be suppressed by placing a permanent magnet of opposite polarity behind the cathode. This result means that the present magnetic configuration is suitable for the filtered vacuum arc system of high efficiency of the beam transport and the cathode erosion. We could further show that oscillating the source magnet current was effective to extend the area of the arc spot movement. By using oscillated current of the source magnet and tapered cathode of diameter 80mm, continuous operation for 2000min at the arc current of 60A was obtained, where more than 90% of the cathode volume could be used.

5. REFERENCES

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