Volume 9, Number 4
1009-1963/2000/09(04)/0279-05
CHINESE PHYSICS
April, 2000
© 2000 Chin. Phys. Soc.

# THE EFFECT OF MESH ANODE ON CATHODIC ARC IN FOCUSING MAGNETIC FIELD*

Zhang Tao(张 涛)[†a)b)], Hou Jun-da(侯君达)[b)], Tang Bao-yin(汤宝寅)[a)],
T. K. Kwok[a)], Zeng Zhao-ming(曾照明)[a)], I. G. Brown[c)], and Paul K. Chu[a)]

[a)] *Department of Physics and Materials Science, City University of Hong Kong,* 83 *Tat Chee Avenue, Kowloon, Hong Kong*

[b)] *Institute of low energy Nuclear Physics, Beijing Normal University* 100875, *China*

[c)] *Lawrence Berkeley National Laboratory, University of California, Berkeley, CA* 94720

(Received 24 June 1999)

The performance and characteristics of a cathodic arc deposition apparatus consisting of a titanium cathode, an anode with and without a tungsten mesh, and a coil producing a focusing magnetic field between the anode and cathode are investigated. The arc voltage $V_a$ is measured with a fixed arc current. The relationship between $V_a$ and the magnetic field $B$ with and without a mesh is obtained. In addition, the relationship between the arc current $I_a$ and $V_c$, the voltage to which the artificial transmission line was charged, is measured with and without the mesh to determine the minimum ignition voltage for the arc. The arc resistance increases with the focusing magnetic strength $B$ and decreases when using the mesh. Our results indicate that the high transparency and large area of the mesh allows a high plasma flux to penetrate the anode from the cathodic arc. The mesh also stabilizes the cathodic arc and gives better performance when used in concert with a focusing magnetic field.

**PACC:** 5275; 5230; 5280; 2925

## I. INTRODUCTION

Cathodic arc plasma sources have been shown to give excellent results in surface modification of materials and industrial components[1−4] However, for both coating deposition and metal plasma immersion ion implantation (PIII), cathodic arc sources are prone to release "macro-particles" (particulates of the cathode material of size on the order of a $\mu$m) that are detrimental to the treated materials. Hence, a filtering system is sometimes employed to eliminate these macro-particles from reaching the treated materials. Currently, the most common configuration providing an acceptable plasma transportation efficiency is the curved magnetic filter duct developed by Aksenov and coworkers.[5−6]

In order to increase the output plasma flux, a magnetic field is imposed between the cathode and anode in a cathodic arc to better focus the plasma in the axial direction. For a long-pulse or DC current arc source, the focusing magnetic field tends to make the arc unstable. Two interrelated factors are believed to be the cause: (1) the movement of the cathode spots to the side of the cathode, and (2) an increase in the plasma resistance due to the flow of electrical current across the magnetic field lines.[7−8] An arc stabilizing magnetic field can prevent the cathode spot from wandering off the working surface of the cathode. In the pulsed mode, confinement of the arc spot to the working surface of the cathode is less of a problem, as the duration of the cathodic arc is short enough that there is insufficient time for the cathodic arc spot to move away from the front surface of the cathode. Hence, an arc stabilizing magnetic field is less important in this case, but a focusing magnetic field can still be beneficial. However, owing to the second factor aforementioned, the magnetic field exacerbates the arc instability and decreases the arc current, especially when a hollow or annular anode is used (a hollow anode can increase the plasma flux). In this unstable condition, a higher arc voltage is needed to keep the arc on. The higher arc voltage is caused by the larger plasma voltage drop due to an increase in the electrical resistance of the plasma for conduction across the magnetic field lines. In this paper, we describe the use of a mesh anode to stabilize and increase the efficiency of the cathodic arc. The characteristics of the mesh anode are also discussed.

*Project supported by Hong Kong RGC Earmarked (Grants 9040332 and 9040344), Beijing Science and Technology New Star Plan of contract No. 952870400

†Corresponding author: Zhang Tao, Institute of Low Energy Nuclear Physics, Beijing Normal University, 100875, Fax:010 62231765, Email: zh_t@263.net

## Ⅱ. EXPERIMENTAL DETAILS

The arc source was composed of a negatively biased titanium electrode of 1 cm in diameter and a zero-potential anode with a hole in the center. The anode was 16 mm from the cathode and the hole in the center was 56 mm in diameter. A tungsten mesh (8 mm mesh size, made from 0.2 mm diameter tungsten wire) was mounted on the anode hole and the distance from the mesh to the cathode was 15.8 mm. The optical transparency of the mesh was about 95%.

The cathodic arc source was operated in a pulsed mode. The duration of the arc current pulse was 0.24 ms and the trigger voltage was 3 kV. The focusing magnetic field $B$ was produced by an external coil positioned just in front of the anode. The magnetic field strength was measured at the axis of the system and very close to the cathode surface. The vacuum chamber pressure was typically about $5 \times 10^{-3}$ Pa.

The cathode arc was powered by a charged artificial transmission line. The arc current was characterized by the peak current $I_a$, measured 30 $\mu$s after the beginning of the arc pulse. The arc voltage $V_a$ was measured at a fixed arc current $I_a$ of 100 A. The relationship between $V_a$ and the focusing magnetic field $B$ with and without the tungsten mesh was determined. The relationship between the arc current $I_a$ and $V_c$, the voltage to which the artificial transmission line was charged, was measured with and without the mesh to obtain the minimum ignition voltage for the arc. During ignition, the voltage of the cathode changed rapidly from $V_c$ to $V_a$.

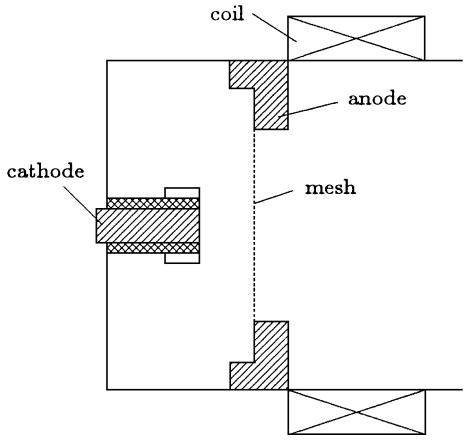



**Fig.1.** Schematic of the experimental apparatus with the anode mesh.

A simplified schematic of the experimental configuration is shown in Fig.1.

## Ⅲ. RESULTS AND DISCUSSION

The arc voltage $V_a$ value with or without the mesh was 22 V when $B$=0 (Fig.2). $V_a$ increased with $B$ in both cases with and without the mesh. With the mesh, $V_a$ increased with $B$ slowly and reached a steady value until $B$ exceeded $4 \times 10^{-2}$ T. On the other hand, for the case without the mesh, $V_a$ increased quickly as the focusing magnetic field $B$ went up. The mesh acted to slow down the increase in $V_a$ with higher $B$. The arc current $I_a$ increased with $V_c$ but decreased with the focusing magnetic field $B$ in both cases with and without the anode mesh (Fig.3). The curves for $B = 1.6 \times 10^{-2}$ T and $B = 3.2 \times 10^{-2}$ T showed a similar trend and were thus not plotted in Fig.3. The $I_a$ value with the mesh was higher than that without the mesh at the same $V_c$ and focusing magnetic field $B$.

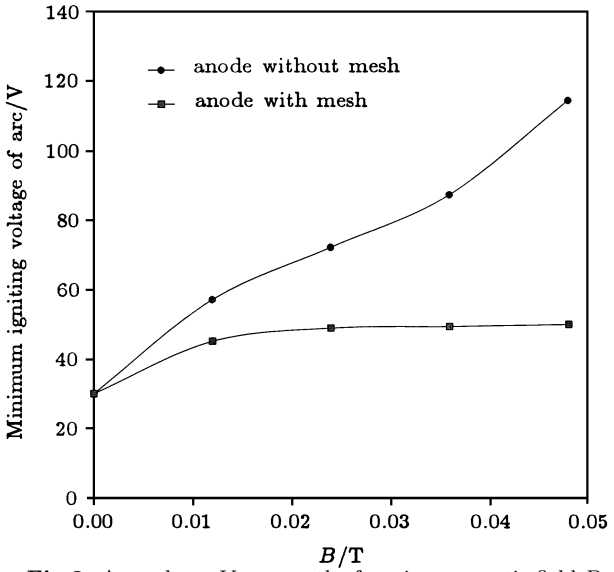



**Fig.2.** Arc voltage $V_a$ versus the focusing magnetic field $B$ for the cases with and without the mesh at an arc current $I_a$ of 100 A.

The relationship between $B$ and the minimum ignition voltage of the arc is illustrated in Fig.4. When the focusing magnetic field $B$ was off, the minimum ignition voltage with the mesh was the same as that without the mesh. When the focusing magnetic field $B$ was increased, the minimum ignition voltage without the mesh increased much faster than that with the mesh. Hence, our results indicate that the mesh makes arc ignition easier at high $B$.

The received current on the anode $I_{anode}$ decreases with the focus magnetic field $B$ (Fig.5). The $I_{anode}$ with the mesh is slightly higher than that without the mesh. The part by which the curve with mesh oversteps the curve without mesh in Fig.5 is contributed by the current received by the mesh. It is well believed that the mesh has small blockage on the plasma flux whether there is a focus magnetic field or not.

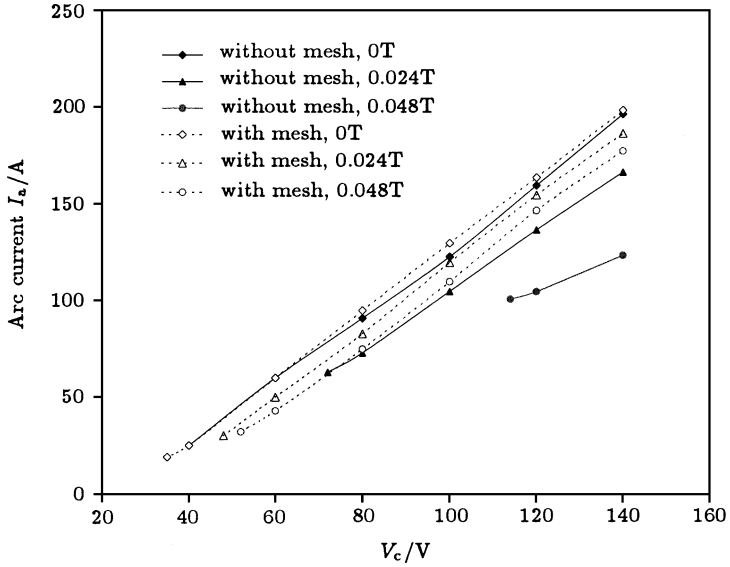



**Fig.3.** $V_c$, the voltage to which the artificial transmission line was charged, versus arc current $I_a$ at different focusing magnetic fields.

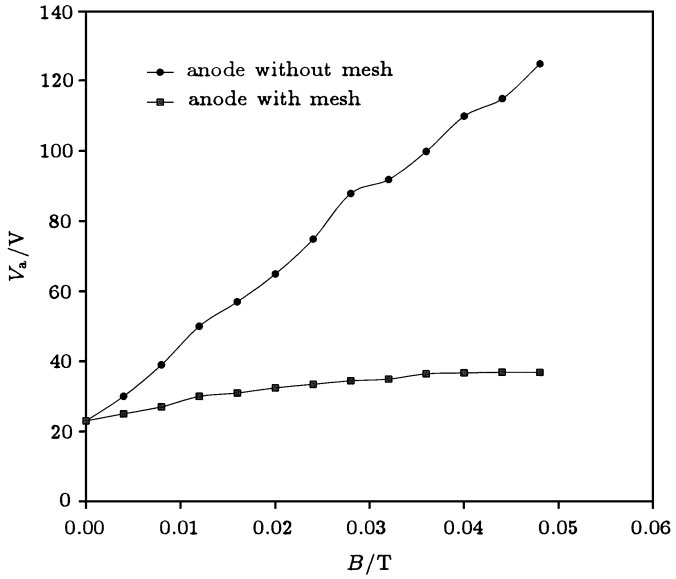



**Fig.4.** Minimum arc-ignition voltage between the anode and the cathode versus the focusing magnetic field $B$ for cases with and without the mesh.

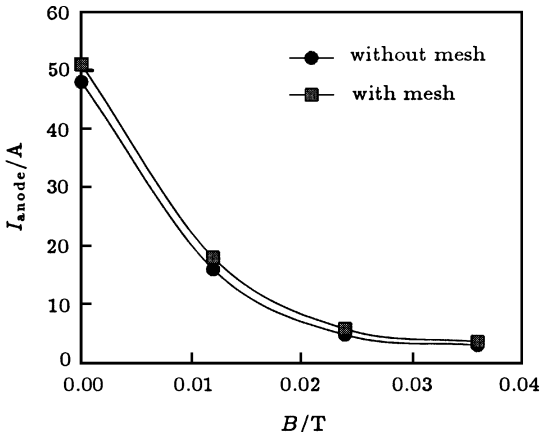



**Fig.5.** The received current on the anode $I_{anode}$ versus the focus magnetic field $B$ for cases with and without the mesh.

Without the focusing magnetic field, the plasma will extend in all directions from the cathode (Fig.6a). The plasma can touch the rim of the anode as easily as the mesh. Therefore, the mesh does not play a significant role in altering the minimum igniting arc voltage and $V_a$ when $B$=0. When the focusing magnetic field is on, the plasma from the cathode arc is confined (Fig.6b). $V_a$ without the mesh includes a component that overcomes the resistance of the plasma to penetrate across the magnetic field lines. Thus, the combination of an axial focusing magnetic field and a big anode hole increases the minimum ignition voltage, and when the arc current is constant, $V_a$ increases. We have also observed that the cathodic arc with-

out the mesh becomes very unstable when $B$ is larger than 0.03 T. A focusing magnetic field and large anode aperture increase the plasma flux through the anode hole, but these two factors also affect the ignition and stability of the cathodic arc adversely. The situation can be improved by adding a mesh on the anode. As shown in Fig.6c, the mesh is a part of the anode and the confined plasma flux from the cathodic arc can easily reach the mesh. The mesh thus reduces substantially the deleterious effects on the ignition and stability of the cathodic arc caused by the magnetic field and large anode hole size. It can also be observed that the cathodic arc discharge was quite steady for the entire range of $B$ used in this experiment.

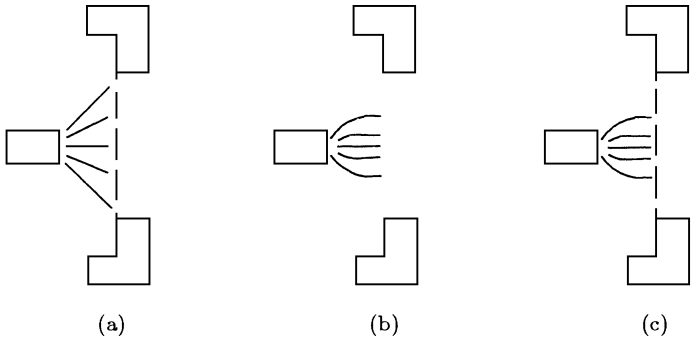



**Fig.6.** Dispersion of the plasma flux in the anode-cathode gap: (a) without magnetic field but with mesh, (b) with magnetic field but without mesh, and (c) with magnetic field and with mesh.

$V_a$ consists of the voltage drop at the electrodes (mainly cathodic drop) and that across the bulk of the interelectrode plasma. The focusing magnetic field $B$ raises the part of $V_a$ related to the plasma voltage drop due to an increase in the electrical resistance of the plasma for conduction across the magnetic field lines. The increase in the plasma resistivity with the introduction of a transverse magnetic field $B$ can be described by[8]:

$$\rho(B) - \rho(0) \approx k\rho(0)(\varpi\tau)^2 \propto B^2, \qquad (1)$$

where $\rho(B)$ is the electrical resistivity perpendicular to the magnetic field lines, $\rho(0)$=$\rho(B$=$0)$, $\omega = eB/\mathrm{m}$ is the electron cyclotron frequency, $e$ and m are the electron charge and mass, respectively, $\tau$ is the mean free time between collision, and $k$ is a constant that depends on the mean ion charge $Z$. $V_a$ increases with the focusing magnetic field $B$ as

$$\Delta V \approx cB^2, \qquad (2)$$

where $\Delta V = V_a(B) - V_a(0)$ and $c$ is a constant. In this work, the relationship between $V_a$ and $B$ without the mesh displayed in Fig.2 deviates slightly from that predicted by Eq.2. The focusing magnetic field here becomes concentrated between the cathode and the anode in the axial direction. In the interelectrode space, both the value and the direction of the focusing magnetic field vary from point to point. We have characterized the magnetic field with a one-point measurement near the cathode for simplicity. However, the magnetic field measured in this way is not exactly suitable for Eq.2, even though the trend of $B$ vs $V_a$ is correctly disclosed.

The axial magnetic field increases the plasma resistance for conduction across the magnetic field lines, or equivalently, increases the distance between the cathode and anode[9], and so the voltage drop across the plasma is increased. When the mesh is added onto the anode hole, the anode to cathode distance for the axial plasma confinement is almost unchanged when the focusing magnetic field increases. Hence, with the mesh, $V_a$ only changes slightly when the focusing magnetic field $B$ is varied (Fig.2).

Several kinds of metal mesh are used in our experiments. It is found that a brass mesh is ruined due to overheating when the time average arc current is over 2 A and a stainless mesh suffers damage at a time average arc current over 5 A after a one hour experiment. The damage manifests in the form of a hole 0.5 to 2 cm in diameter in the center of the mesh. On the other hand, when a tungsten mesh is used, no damage can be observed even for a time average arc current of 8A after one hour of operation. We have also noticed that the center of the tungsten mesh is clean but the area close to the rim is clogged up with the cathode materials. This decreases the optical transparency of the mesh. However, by selecting the mesh size in the center and the rim areas properly, this seriousness of the problem can be minimized.

## IV. CONCLUSIONS

A focusing magnetic field together with a large anode aperture is an effective way to increase the plasma flux of a cathodic arc source. Unfortunately, it makes the ignition of the cathodic arc more difficult, and the magnetic field can result in a lower arc current if the artificial transmission line power is unchanged. Moreover, the cathodic arc tends to be unstable in a strong magnetic field. Placing a metal mesh onto the anode hole stabilizes the cathodic arc and reduces the minimum igniting arc voltage, thereby enabling the use of a larger magnetic field and anode diameter. As an integral part of the anode component, the mesh has the same voltage as the anode, and the plasma from the cathodic arc can reach the mesh easily. The mesh minimizes the electrical resistance of the plasma. We also found that a tungsten mesh has the best durability, perhaps due to its high melting point.

## REFERENCES


[1] A. Anders, *Surf. Coat. Technol.*, **93**(1997), 158–167.

[2] S. Anders, A. Anders and I. G. Brown, *J. Appl. Phys.*, **74**(1993), 4239–4241.

[3] J. Koskinen, A. Anttila and H. P. Hirvonen, **47**(1991), 180–187.

[4] I. I. Aksenov and V. E. Strelnitskij, *Surf. Coatings Technol.*, **47**(1991), 98–105.

[5] I. I. Aksenov, S. I. Vakula, V. G. Padalka, V. E. Strel'nitskii and V. M. Khoroshikh, *Sov. Phys. Tech. Phys.*, **25**(1980), 1164–1166.

[6] I. I. Aksenov, V. A. Belous, V. G. Padalka, V. M. Khoroshikh, *Sov. J. Plasma Phys.*, **4**(1978), 425–428.

[7] V. N. Zhitomirsky, R. L. Boxman and S. Goldsmith, *Surface Coat. Technol.*, **68/69**(1994), 146–151.

[8] V. N. Zhitomirsky, R. L. Boxman and S. Goldmith, *J. Vac. Sci. Technol. A*, **13**(1995), 2233–2240.

[9] V. N. Zhitomirsky, B. Alterkop, U.kinrot, R. L. Boxman and S. Goldmith, XVII Int. Sym. on discharges and electrical insulation in vacuum, Berkeley, 876–880, 1996.