Assistant Anode in a Cathodic Arc Plasma Source *

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The performance and characteristics of a cathodic arc plasma source, 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 high transparency and large area of the mesh allow a high plasma flux to penetrate the anode from the cathodic arc. The mesh helps to decrease the arc resistance and the ignition voltage of the cathodic arc in the focusing magnetic field, and to increase the life of the source, which means that the source makes the cathodic arc easily and greatly stabilized during the operation when a focusing magnetic field exists in the source.

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Cathodic arc plasma sources have been shown to give excellent results in the surface modification of materials and industrial components.\textsuperscript{[1–4]} By making two cathodic arc plasma sources in the pulsed mode work alternately in one chamber, one can easily fabricate high-quality superlattice films, which has caused great interest in the field of surface coating research.\textsuperscript{[6,7]} However, for both coating deposition and metal plasma immersion ion implantation (PIII), cathodic arc plasma sources are prone to release “macro-particles” (particles of the cathode material of a size of the order of a micrometre) 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 proposed by Akesson and co-workers.\textsuperscript{[8,9]} In a previous paper,\textsuperscript{[10]} we have reported on the effect of the magnetic filter duct on the macro-particle elimination. For transporting more plasma flux into the filter, a magnetic field is imposed between the cathode and anode in a cathodic arc plasma source to better focus the plasma in the axial direction. However, 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 and many spurs of cathodic arc fail to be triggered during the operation of the source, which is especially harmful to the deposition of superlattice films. 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.\textsuperscript{[11,12]}

In this letter, we describe the use of a mesh anode to stabilize and increase the efficiency of the cathodic arc. A simplified schematic diagram of the experimental configuration is shown in Fig. 1. The cathodic arc plasma source was composed of a negatively biased titanium cathode of 1 cm in diameter and a zero-potential anode with a hole in the centre. The anode was 16 mm from the cathode and the hole in the centre 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 high transparency and large area of the mesh allowed high plasma flux to penetrate the anode from the cathodic arc. As an integral part of the anode component, the mesh had the same voltage as the anode, and the plasma from the cathodic arc could reach the mesh easily. The cathodic arc source was operated in a pulsed mode with a triggering frequency of 33 Hz. The duration of the arc current pulse was 0.24 ms. The focusing magnetic field \(B\) was produced by an external coil wrapped around 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.

![Fig. 1. Schematic diagram of the experimental set-up with the anode mesh.](image)

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The arc current $I_a$ was characterized by the peak current of the current pulse. The voltage of the cathode before arcing is $V_c$, and the arc voltage is $V_a$. The voltage of the cathode changed rapidly from $V_c$ to $V_a$ once the cathode arc was on. Figure 2 shows the life of the cathodic arc plasma source, i.e., the times for the cathode to be able to give arcs without adjusting the source, measured at a fixed arc current $I_a$ of 100 A. The life of the source without the anode mesh is greatly limited. When the focusing magnetic field $B$ is 0.048 T, the arc cannot be triggered even if $V_c$ reaches 300 V. Long-life and stable arcing is important to cathodic arc deposition. We observed that, without the mesh, the cathodic arc could not be ignited consecutively by the trigger when the focusing magnetic field $B$ was 0.03 T and above.

![Fig. 2. Life of the source versus the focusing magnetic field $B$ with and without the mesh at a fixed arc current $I_a = 100$ A.](image)

By measuring the minimum $V_c$ for arcing, we obtained the relationship between the focusing magnetic field $B$ and the minimum arc-ignition voltage on the cathode (Fig. 3). When the focusing magnetic field $B$ was off, the minimum arc-ignition voltage with the mesh was the same as that without the mesh. As the focusing magnetic field $B$ increases, the minimum ignition voltage without the mesh increases much faster than that with the mesh. Hence, our results indicate that the mesh makes arc ignition easier at high $B$.

![Fig. 3. Minimum arc-ignition voltage $V_{min}$ between the anode and the cathode versus the focusing magnetic field $B$ with and without the mesh.](image)

Arc resistance $R$ is defined as the ratio of $V_a$ to $I_a$. It is shown that the mesh greatly changes the response of $R$ to the focusing magnetic field $B$ in this experiment (Fig. 4). Without the mesh, $R$ increases rapidly as $B$ increases, while with the mesh $R$ increases very slowly as $B$ increases. This can explain why high $B$ makes the ignition of the cathodic arc more difficult in the case without the mesh (Fig. 3). 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. 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, $R$ only changes slightly when the focusing magnetic field $B$ is varied.

A focusing magnetic field and a large anode aperture increase the plasma flux through the anode hole, but these two factors also adversely affect the ignition and stability of the cathodic arc. The situation can be improved by adding a mesh on the anode. No damage can be observed on the tungsten mesh even for a time-averaged arc current of 8 A after hours of operation. We also noticed that the Ti (the cathode) film was coated on the tungsten wire of the mesh. This helps to minimize the contamination of the mesh materials to the cathodic arc plasma.

References