

Vacuum Arc Movement on Various Graphite Cathode Ions Sources for Diamond-Like Films Production

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ABSTRACT

In this work, vacuum arc spot movement on various graphite cathode materials is investigated. The dependence of the arc spot velocity on physical, mechanical and electrical properties of the cathode materials is measured in the presence of a variable magnetic field. Results show that the cathode spot velocity is larger on cathodes having large grain size, low electrical resistivity and higher apparent density. They also show a decrease in the spot velocity value for cathodes having larger pore sizes and total porosity.

1. INTRODUCTION

In the past decade, there has been increasing interest in the deposition of a special form of carbon films which are hard, electrically insulating, and optically transparent. These films have been called 'diamond-like' and have been obtained by low energy ion-beam deposition [1], rf plasma decomposition of a hydrocarbon gas [2], ion beam sputtering [3], and ion plating techniques [4-5]. The arc ion plating technique studied in this work uses an electric arc between two graphite electrodes at low pressure. Ions, microparticles and neutral vapors are emitted from the cathode spot and deposited on the substrate. While the energetic ions are required to form a hard deposit, the microparticles are not acceptable and form a major disadvantage in this technique. Filtering techniques have been used to prevent the microparticles from reaching the substrate [6-7]. This is made however at the expense of reduced beam intensity and uniformity. This paper is aimed towards a possible control of the microdroplets emitted by the cathode spot. Microdroplet emission studies by Kandah and Meunier [8] showed that a control of the local power flux to a given graphite cathode site can result in important decrease of the number, the size and the width of the size distributions of the emitted droplets. This experimental study goes further in analyzing the movement of cathode spots on various graphite materials in order to decrease the residence time and local power input on given graphite surface emitting sites.

2. EXPERIMENT

The experimental setup used is shown in Figure 1. A spherical vacuum chamber 23 cm in diameter is pumped down to 10^{-4} Torr using a mechanical and an oil diffusion

pump. The graphite cathodes were made of strips (50 mm x 10 mm x 3 mm), and mounted parallel to the anode with an electrode gap of 5 mm.

A CO₂-TEA laser pulse was used to trigger the arc. After each ignition a very clear line trace is left by the arc movement which represents the arc spot path length. The mean arc spot velocity is evaluated simply by dividing this arc trace length by the arc duration time. An external magnetic field was applied parallel to the cathode surface in order to move the arc spot on the cathode in the usual retrograde direction typical of vacuum arc behavior subjected to transverse magnetic fields. This ensured a relatively straight arc trace showing the typical tree-like erosion pattern. During arcing, the arc current and the pressure are kept constant at 80 A and 10⁻⁴ Torr, respectively, otherwise will be mentioned.

The cathodes used were manufactured in two different ways to obtain different microstructures (i.e., monocrystalline and polycrystalline graphite). Monocrystalline graphite is formed in high temperature vacuum furnaces by CVD from a hydrocarbon gas. Polycrystalline graphite is formed by grinding a calcined coke into a very fine powder, mixing it with a binder, compressing it into a block, and firing it at a very high temperature to remove any volatile materials. The properties of each graphite cathode used in this work are listed in Table 1. Commercial names of the different graphite structures are used in this table and throughout this paper. Values are given according to the manufacturers.

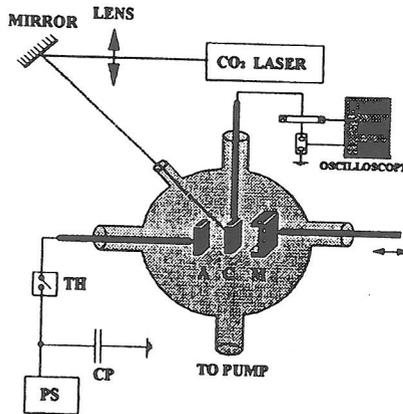


Figure 1 : Experimental set-up, C=cathode, A=anode, M=magnets, PS=power supply, Th = thyristor, CP=capacitor and triggering / shut-off circuit.

3. RESULTS

3.1 CATHODE SPOT VELOCITY AS A FUNCTION OF MAGNETIC FIELD INTENSITY

Mean cathode spot velocities were measured for all cathodes as a function of the transverse magnetic field intensity. Figure 2 shows a large spread in the arc spot velocities for the different graphite cathodes microstructures being used. The applied magnetic field varied between 0.0375 T and 0.06 T. For comparison, arc spot velocities of 20 m/s are observed on titanium cathodes using magnetic field values of 0.02 T [9]. The same magnetic field intensity of 0.02 T applied to a graphite cathode leads to a

typical mean spot velocity of only 1 cm/s. Such low overall velocity indicates strong anchoring of the cathode spot on localized hot emission regions and a weak influence of the magnetic field on spot motion. In order for graphite to yield similar velocities as those obtained on metallic electrodes, an increase of the magnetic field intensity by at least a factor of four is needed. One can see from Figure 2 that the monocrystalline graphite (PYROID) yields much stronger velocity values compared to polycrystalline graphites. Polycrystalline graphites tend to follow the order of the materials given in Table 1 for decreasing values of spot velocity.

Figure (2) : Mean cathode spot velocity as a function of magnetic field intensity for eleven different graphite cathodes at constant arc current (80 A) and pressure (10^{-4} Torr).

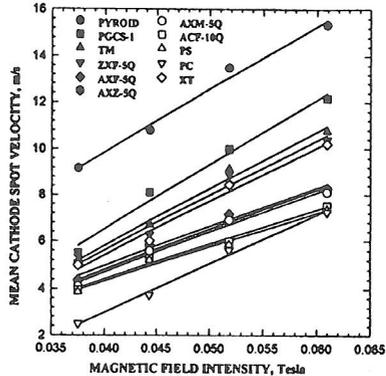


TABLE 1 : PROPERTIES OF GRAPHITE CATHODES USED IN THIS WORK

CATHODE	GRAIN SIZE (μm)	PORE SIZE (μm)	DENSITY (g/cm^3)	EI. RESISTIVITY ($\mu. \text{ohm.cm}$)
PGCS-1	15	3	1.79	1500
TM	10	1.5	1.82	1250
ZXF-5Q	1	0.2	1.8	1650
XT	20	n/a	1.71	1250
AXF-5Q	5	0.8	1.8	1400
AXZ-5Q	5	0.7	1.64	1900
AXM-5Q	5	0.8	1.74	1500
ACF-10Q	5	0.8	1.8	2500
PS	5	1.2	1.33	2900
PC	5	n/a	1.10	11500
PYROID	monocrystal	0	2.2	250

3.2 ELECTRIC RESISTIVITY

Page [10] showed that different graphite materials have very different electrical resistivity-temperature curves, and that the minimum resistivity may occur at different temperature for different cathodes. The effect of the room temperature electrical resistivity of the different graphite cathodes on the arc spot velocity is studied for cathodes having constant density, grain and pore sizes. The results showed that the

decrease in the electrical resistivity of the graphite cathodes leads to an increase in the cathode spot velocity.

3.3 PORE SIZE

The effect of pore size on arc movement is investigated using three polycrystalline graphite cathodes (AXZ-5Q, AXM-5Q and PS) showing the same grain size (5 μm) and one monocrystalline graphite (PYROID) with no grain size structure or porosity. Figure 3 shows a decrease in the arc spot velocity with the increase in the pore size at constant grain size. The white symbols refer to AXM-5Q and show higher spot velocities than AXZ-5Q which has lower pore size. This is due to the increase in the density and the decrease in the electrical resistivity.

Figure (3) : Mean cathode spot velocity as a function of pore size for three different polycrystalline graphite cathodes having the same particle size and one monocrystalline cathode.

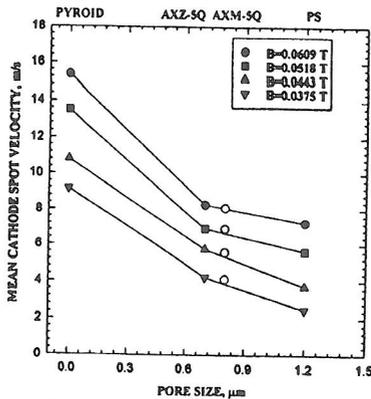
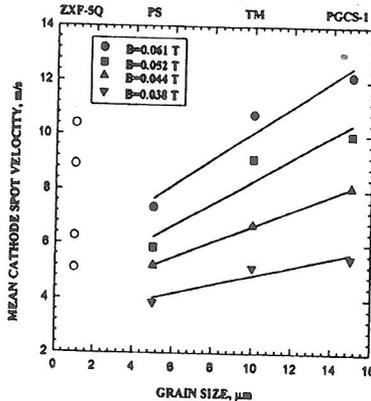


Figure (4) : Mean cathode spot velocity as a function of grain size for four different graphite cathodes having different particle and pore size values.



3.4 GRAIN SIZE

The dependence of the graphite material grain size on the cathode spot velocity in the presence of an external magnetic field is investigated for four different graphite cathodes (PGCS-1, TM, PS and ZXF-5Q), each having different grain and pore sizes. Figure 4 shows increasing arc spot mobility with an increase in the grain size. Materials in this Figure also have a correspondingly small increase in the pore size. They however can be separated in two distinct groups, one with very small pores (white symbols with 0.2 μm pores) and the other with large pores (black symbols with pores diameters

between 1.2 and 3 μm). This seems to indicate that the effect of the grain size is more important than porosity of the material. A compromise between grain size and porosity is required for optimum cathode spot velocity, each having opposite effects.

3.5 DENSITY

The effect of the cathode apparent density on the arc spot velocity is investigated for different graphite cathodes having constant grain and pore sizes. An increase in the apparent density, hence a decrease in the total porosity at constant grain and pore size, leads to an increase in the spot velocity.

3.6 : ARC CURRENT

The effect of the arc current on the cathode spot movement is studied for two different graphite cathodes (polycrystalline PGCS-1 and monocrystalline PYROID). The increase in the arc current from 60 A to 140 A led to an increase in the cathode spot velocity from 12.5 m/s to 27.4 m/s on the PYROID graphite and from 9.8 m/s to 20 m/s on the PGCS-1 graphite.

4. DISCUSSION

Structural considerations are especially important in graphite. For example, avoiding solid state defects such as dislocations, vacancies, interstitial atoms, misalignments and disorientation of atom layers is very important. These may decrease the flaws occurring in manufactured products. In the absence of any constraining magnetic field or other confinement, an arc discharge will tend to migrate at random over any surface that is at cathode potential. The migration will remain random as long as the arc is on a continuous homogeneous surface. If the graphite vacuum arc encounters a discontinuity, such as a crack or an inclusion, it tends to become trapped and rapidly erodes a deep crater at this position. This indicates the usefulness of decreasing the pore size and increasing the grain size of the material, resulting in having less flaws on the surface and increasing the retrograde spot velocity.

The nature of the thermal dependence of electrical resistivity of manufactured graphites varies widely. In general, at low and moderate temperatures, increasing temperature decreases the resistivity, the opposite being generally true at higher temperatures. The arc spot may be expected to follow preferentially zones of lowest resistivity. Hence cathodes having their minimum electrical resistivity at low temperatures are expected to show higher cathode spot velocities. Because of its thermionic nature and negative temperature coefficient of electrical resistivity, graphite is a difficult material to induce cathode spot movement on its surface and it has a tendency to produce more microparticles than other metallic electrodes [4].

The density of polycrystalline graphites seldom exceeds 80% of the theoretical value of 2.26 g/cm^3 due to the voids or pores. Single crystal and pyrolytic graphites, because of their highly ordered structures, have densities closely approaching the theoretical density. Keeping the other factors constant, the increase in the apparent density reflect in the improved mechanical strength, surface homogeneity and thermal conductivity in addition to the decrease in the electrical resistivity.

As the arc current delivered to the cathode is increased, a point is reached where a single arc will split into two arcs. The number of cathode spots is dependent on the arc current and the cathode material [11]. Graphite cathodes have different surface characteristics, this study shows that each graphite cathode has its own arc current/spot limit. For example, 3 spots were observed for PYROID at 160 A and only one spot at 110 A, while for ZXF-5Q graphite only one spot was observed at 200 A. This indicates that every graphite cathode material should be treated as a different type of electrode.

CONCLUSION

As a conclusion of this study, the use of graphite cathodes in a continuous arc ion-plating deposition system is more difficult than with other metallic electrodes, because each graphite cathode has different physical, mechanical and electrical properties. Since the arc spot movement in vacuum systems is highly dependent on the cathode surface characteristics, the choice of the type of graphite cathode used is very important and necessary.

Cathodes having lower pore size, total porosity and electrical resistivity show higher cathode spot velocities. Also the increase in the grain size and density of the graphite material helps in increasing the cathode spot velocity. An increase in the arc current increases the cathode spot velocity but may also have the consequences of increasing the number of emitted microparticles through a larger heat load in the cathode spot region [8]. This study also shows that different graphite cathodes have different arc current per spot limit.

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