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Copper film deposition and anode temperature measurements in a vacuum arc with tungsten anode

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Abstract

Copper films deposited by a radial expanding plasma plume from a tungsten hot refractory anode vacuum arc were investigated. The arc was sustained between a consumed water-cooled cylindrical copper cathode (30 mm diameter) and a cylindrical anode (32 mm diameter, 30 mm height) that was heated by the arc current. The anode temperature was measured at 2, 12 and 22 mm from its front side by high temperature W/5% Re–W/26%Re thermocouple probes ($T1$, $T2$ and $T3$ respectively). Coatings were deposited on glass substrates which were exposed to the plasma flux. Distances to substrate (L) were 80–165 mm and arc currents I=150–300 A. The film thickness was measured by profilometry and macroparticle (MP) contamination was determined by the optical microscopy.

It was found that the anode temperature increased with arc current ($T1$ ~2300 K for I=150 A and 2500 K for I=250 A) and slightly decreases with gap distance. The number of MPs on portion of the substrate facing of the anode decreased as function of MP size, while total number of MPs was approximately 3 mm^{-2} min^{-1} (for I=300 A, L=110 mm, h=10 mm). The MP size distribution had a similar shape as observed with a Mo anode, but the amount of MPs was about 15% less using the W anode. The deposition rate at L=80 mm, h=10 mm and I=300 A was about 3.6 μm/min. The larger surface temperature was reached by using higher current with the W anode, due to its lower rate of vaporization in comparison to previously used Mo and graphite anodes.

Keywords: Vacuum arc; Refractory tungsten anode; Film deposition; Deposition rate; Anode temperature; Macroparticle; Radial plasma expansion

1. Introduction

The vacuum arc is used as a plasma source to produce metallic coatings [1]. In the hot anode vacuum arc (HAVA) macro-particle (MP) free plasma is produced by evaporation of the anode material [2]. Another type of arc with a hot anode which produces MP-free metallic plasma is the Hot Refractory Anode Vacuum Arc HRAVA [3]. The HRAVA initially operates as a conventional cathodic vacuum arc, supported by cathode spot plasma jets. The jets initially deposit cathode material on a non-consumable anode. At a later stage, when the anode is heated sufficiently by the arc to reach sufficiently high temperatures, the coating on the anode is re-evaporated. Eventually cathode material from the plasma ceases to condense on anode. The cathode material, including MPs which are evaporated in the interelectrode gap plasma, forms a MP-free plasma which expands radially [3]. This radially expanding plasma can be used for depositing metallic coatings [4,5,6].

The deposition characteristics and anode temperature distribution were measured previously for molybdenum (Mo) [4,5,6,7] and graphite [4,8,9] anodes. It was observed that the deposition rate increased and MP contamination decreased with arc current I. The MP decrease was explained by an increased MP evaporation efficiency during their passage through the anode plasma plume, caused by the anode temperature, plasma density and plasma temperature increasing with arc current. It was observed that the graphite anode surface temperature increased from 1900 to 2300 K when I increased from 175 to 340 A [8,9]. A surface temperature of 2300 K was measured on a Mo anode already at I=145 A [7]. Calculations shown that for I=340 A, the Mo anode surface temperature will be ~2700 K

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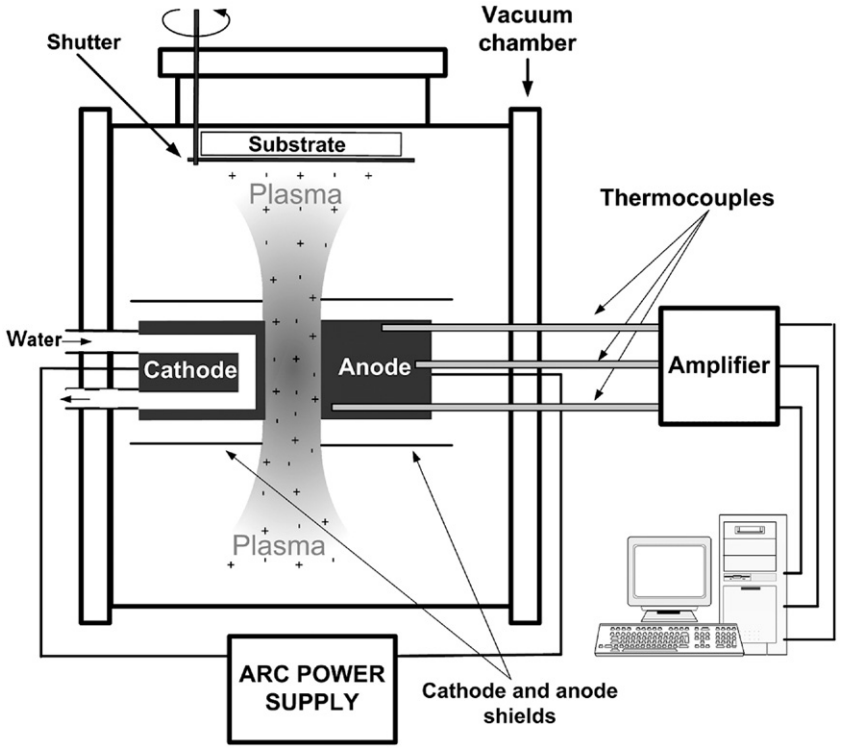

Fig. 1. Schematic drawing of the experimental HRAVA deposition system and the radial plasma expansion.

[10] which is near its melting temperature, preventing the use of Mo anodes at high temperatures (>2300 K). Therefore, it is important to use a more refractory anode material, e.g. tungsten (*W* melting point — 3653 K vs. 2883 K for Mo). Heretofore *W* anodes were not investigated in HRAVA discharges. The objectives of the present work were i) to operate a HRAVA with a *W* anode; ii) to measure the anode temperature distribution, and iii) to determine the deposition characteristics (e.g. deposition rate and MP contamination).

2. Experimental setup

2.1. System assembly

The arc was contained in a stainless steel chamber with 530 mm length and 400 mm diameter (~70 l) in which the electrodes were mounted. The chamber was pumped down to a pressure of 0.67 mPa by a diffusion pump, before arc ignition. During the arc, the pressure in the chamber increased to about 13 mPa. The arcs were operated at currents of $I=150$–300 A for periods up to 190 s.

The cathode-anode assembly is shown schematically in Fig. 1. The arc was sustained between a 30 mm diameter cylindrical, water-cooled, copper cathode and a 32 mm diam, 30 mm length tungsten anode. Two Mo cylindrical radiation shields, 60 and 70 mm diameter, surrounded the anode to reduce radiative heat losses. The cathode was surrounded by Mo shield

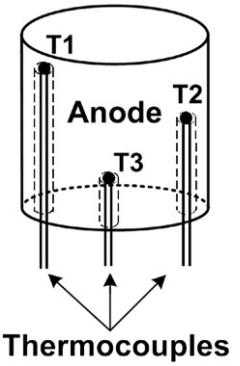

Fig. 2. Schematic diagram of the anode, showing the thermocouple locations.

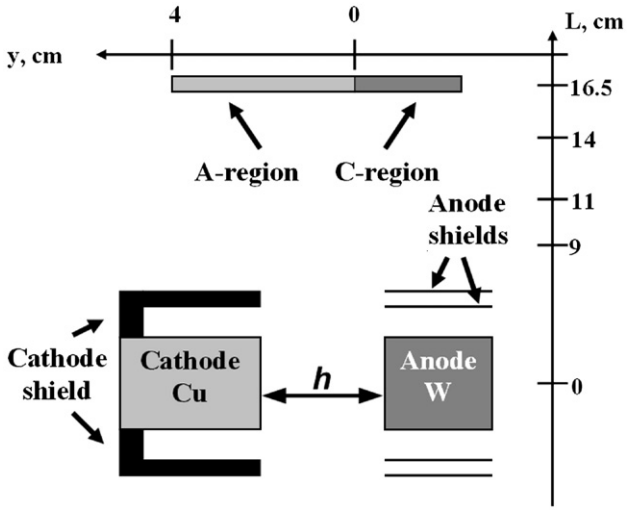

Fig. 3. Schematic diagram of the substrate placement and the definition of the A and C-regions.