Surface & Coatings Technology 203 (2008) 501–504

Contents lists available at ScienceDirect

Surface & Coatings Technology

journal homepage: www.elsevier.com/locate/surfcoat

Chromium and titanium film deposition using a hot refractory anode vacuum arc plasma source

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ARTICLE INFO

Available online 27 June 2008

Keywords:
Vacuum arc
Refractory anode
Deposition rate
Chromium film
Titanium film
Macroparticle

ABSTRACT

The radially expanding plasma jet generated in a Hot Refractory Anode Vacuum Arc (HRAVA) was used to deposit thin chromium and titanium films on glass substrates. The arc was sustained between a water-cooled cylindrical cathode and a non-consumed cylindrical tungsten anode separated by a 10 mm gap, for time periods up to 120 s, operating with a current (I) of 200–300 A. The chromium cathode was 30 mm diameter and 20 mm height, and was used with 32 mm diameter, 30 mm height anode. The titanium cathode was 60 mm diameter, 25 mm height and was used with a 60 mm diameter, 15 mm height anode.

Thin films were deposited on glass substrates exposed to the anodic plasma. A mechanical shutter controlled the deposition onset and exposure duration time. The distance from the arc axis to the substrate (L) was varied between 80 and 145 mm. The film thickness was measured by a profilometer, and macro-particles (MP) presence on the coating surface was examined by optical microscopy. It was found that the deposition rate of Cr films increased with arc current and reached ~1.4 µm/min at I=300 A, L=80 mm. The total MP flux was less than 1 $mm^{-2}min^{-1}$ for I=300 A, L=110 mm. The deposition rate of Ti films reached 1.8 µm/min at I=300 A, L=100 mm.

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1. Introduction

Vacuum arc plasma has numerous important technological applications such as metallic coatings and ion beams generation [1,2]. The main problem is obtaining macroparticle (MP) free plasma. In the hot anode vacuum arc (HAVA), plasma is generated by evaporating anode material [3], but there may be a practical problem in containing a significant volume of molten anode material. A discharge mode with a refractory anode and an expendable cathode, named the hot refractory anode vacuum arc (HRAVA), has been studied recently and overcomes this problem. The HRAVA starts as a conventional cathodic vacuum arc and the plasma jets produced by cathode spots initially deposit cathode material on a non-consumable refractory anode. The coating on the anode is re-evaporated when the anode is sufficiently heated by the energy of the cathodic jets. 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 [4]. This expanding plasma was used for depositing metallic coatings [5].

HRAVA deposition characteristics were measured previously only for a Cu cathode [6–9]. The HRAVA deposition characteristics (deposition rate, MP distribution etc.) were compared with a conventional cathodic arc, and it was found that the HRAVA was overwhelmingly advantageous in terms of deposited area, deposition rate, mass deposition rate, cathode material utilization efficiency, and MP contamination [10]. It was observed that the deposition rate increased and MP contamination decreased with arc current I. The MP decrease was explained by increased MP evaporation during their passage through the anode plasma plume, because the anode temperature, plasma density and plasma temperature increase with arc current [7,9]. However, operation of graphite and Mo anodes at higher currents, and hence higher temperatures, was problematical: contamination of coatings and anode damage were sometimes noted [8]. These problems did not occur, however, when using a W anode. Therefore lower MP contamination and higher deposition rates could be obtained with a W anode, operating at higher currents, than with graphite and Mo anodes [9]. The anode temperature distribution (including the steady state distribution) in a tungsten anode was investigated in detail in Ref. [9].

The Cu cathode erosion in cathodic arcs is larger than that from Cr or Ti cathodes [1]. The latter, more refractory, cathode materials have important applications for hard coatings, but have not heretofore been investigated studied in HRAVA arcs. The objectives of this investigation were to deposit Cr and Ti thin films using a HRAVA, and to determine their deposition rate and MP contamination.

2. Experimental setup

2.1. Vacuum chambers and electrodes

Cr and Ti HRAVAs were studied in separate stainless steel chambers: (a) 400 mm length, 160 mm diameter and (b) 530 mm length and

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doi:10.1016/j.surfcoat.2008.06.168

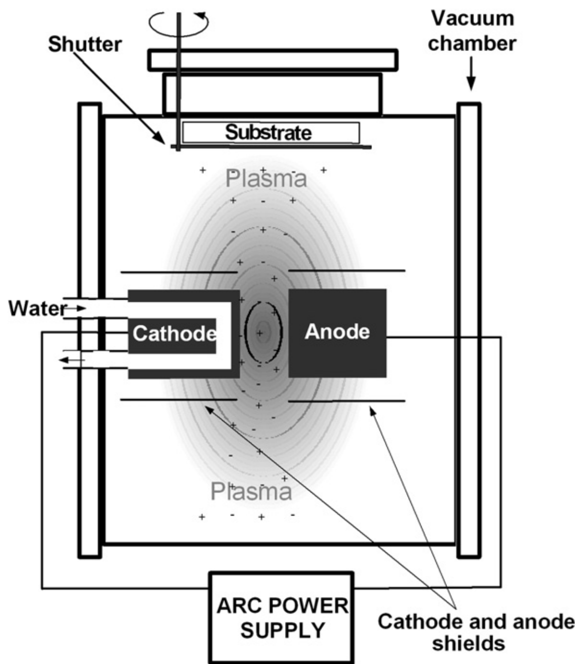

Fig. 1. Schematic diagram of the HRAVA deposition systems and radially expanded plasma.

400 mm diameter, respectively. The cathode–anode assembly was mounted in the chambers as shown schematically in Fig. 1. The chambers were diffusion pumped down to pressures of (a) 2.6 mPa and (b) 0.67 mPa before arc ignition. During the arc, the pressure in the chamber increased to about (a) 26 mPa or (b) 13 mPa. The arcs were operated at currents of I=200–300 A for periods up to 120 s. The arc was excited by a welding power source (Miller XMT-400 CC/CV). The anode was grounded and the chamber was floating.

The cathodes were water cooled. Both the cathode and the anode were surrounded by Mo shields. The anode shield reduced radiative heat loss from the side of the anode. The electrode and shield dimensions, as well as the chamber differed according to the cathode material, as detailed in Table 1.

The cathode shield prevented the MPs emitted from the cathode spots from reaching the “A region” of the substrate. The cathode shield position determined the location of the boundary, designated as y=0 (Fig. 2), between regions on the substrate with low and high MP contamination, designated as the anodic (A) and cathodic (C) regions, respectively. The C-region of substrate faced the cathode and can contain MPs emitted from the spots. The A-region of the substrate faced the anode and collected plasma flux containing few MPs [5,7]. The interelectrode gap was h=10 mm in all experiments.

2.2. Substrates

The substrates were 75×26 mm^2 glass microscope slides. The slides were mounted on a water-cooled holder, located at distances of L=80–145 mm from the electrode axis. A Mo shutter was placed in front of the substrate (Fig. 1) and used to control the exposure time of the substrate to the plasma.

Table 1
Chamber choice and dimensions of electrodes and shields

Chamber	a (Cr-cathode)	b (Ti-cathode)
Cathode diameter (mm)	30	60
Cathode height (mm)	20	25
Cathode shield diameter (mm)	50	70
Anode diameter (mm)	32	60
Anode height (mm)	30	15
Anode shield diameters (mm)	60, 70	None

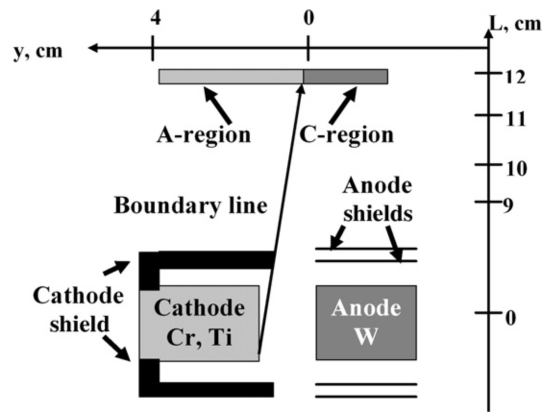

Fig. 2. Schematic diagram of the substrate placement along axis y and the definition of the A and C-regions. The boundary line indicates the placement of A- and C-regions at different distance from the electrode axis.

2.3. Coating characterization

MP flux was determined using an optical microscope equipped with a digital camera. MPs with diameters>3 μm were counted at y=~5 mm in the A-region on substrates exposed to the plasma for a 30 s deposition time starting 1 min after arc ignition.

The film thickness (H) was measured by profilometry at the C–A boundary on the substrate (Fig. 2). Film thickness growth (ΔH) was determined between times 0–15 s, 15–30 s, 30–45 s, 45–60 s, 60–75 s, 75–90 s, 90–105 s, and 105–120 s from arc ignition and for I=200, 250 and 300 A. Film thickness growth as a function of distance from the electrode axis for the Ti and Cr cathodes were measured for I=200 A and L=80, 100, 115, 130 and 145 mm.

3. Experimental results

3.1. Deposition rate

The temporal evolution of the deposition rate $V_{dep}=\Delta H/\Delta t$ at y=0 (Fig. 2) is presented in Fig. 3 for Cr with L=80 mm, and in Fig. 4 for Ti with L=100 mm, with I=200, 250, and 300 A as a parameter. It can be seen that the deposition rate for Cr with I=300 A was ~0.4 μm/min at ~15 s after arc ignition, and reached a steady-state level of ~1.4 μm/

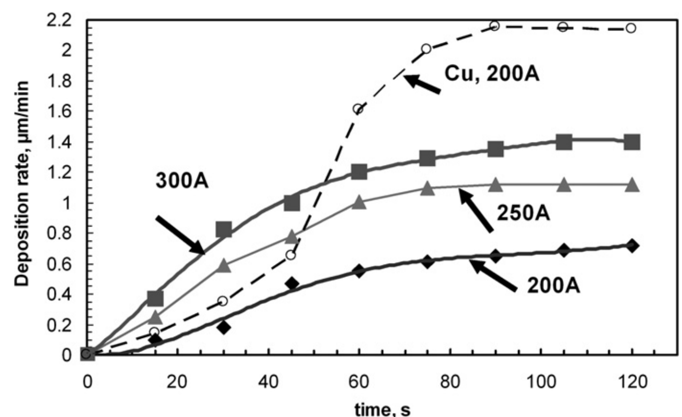

Fig. 3. Temporal evolution of the deposition rate at y=0, L=80 mm for Cr (I=200, 250 and 300 A). The dashed curve is for Cu (I=200 A) from Ref. [9] that presented to comparison.

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