Initiation of anode material evaporation in a transferred arc device

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Abstract: The anode region of a high intensity argon arc has been studied experimentally. In the experiments, the copper vapor from the anode was detected using a spectrometer, the arc-anode configuration was recorded using a CCD camera, and the anode heat transfer was measured calorimetrically. The results show that the transition to a constricted attachment from the multiple-attachment will coincide with the anode material evaporation.

Keywords: arc-anode attachment, anode phenomena, spectroscopic diagnostics

1. Introduction

Control of the anode heat transfer is of utmost importance in a number of applications of plasma arcs, ranging from plasma for coatings and other materials processing uses to welding and cutting, because the attachment mode determines the anode lifetime and plasma generator performance. Anode heat transfer has been widely investigated for situations where the anode has been a passive recipient of electrons from the plasma [1-6]. The anode boundary layer properties in high intensity arcs have been measured with Langmuir probe system [3] and spectroscopic diagnostics [4]. Further investigations with laser Thomson scattering system have illuminated the processes that lead to the transition between the arc-anode attachment modes [5, 6]. However, the transition to a destructive mode of anode attachment with melting and/or evaporation of the anode material has been studied much less. The difficulty with such investigations is that the heat transfer is not only influenced by the arc current and current density, but the fluid dynamics and magneto-fluid dynamic effects play an important role, with instabilities leading to abrupt attachment changes and accompanying changes in heat transfer.

In this study, results of experiments are reported where the heat flux to the anode is increased in a controlled manner until anode evaporation occurred and the presence of metal vapor led to a transition to another attachment mode.

2. Experimental

2.1 Experimental setup

The arc generation system is shown in Fig. 1. A dc arc is generated between a rod-shaped tungsten cathode and a flat copper anode, which are water-cooled. The arc is constricted by an assembly of water-cooled copper disks. The argon plasma working gas is provided through a gas distributor, which has a straight flow arrangement. A 10

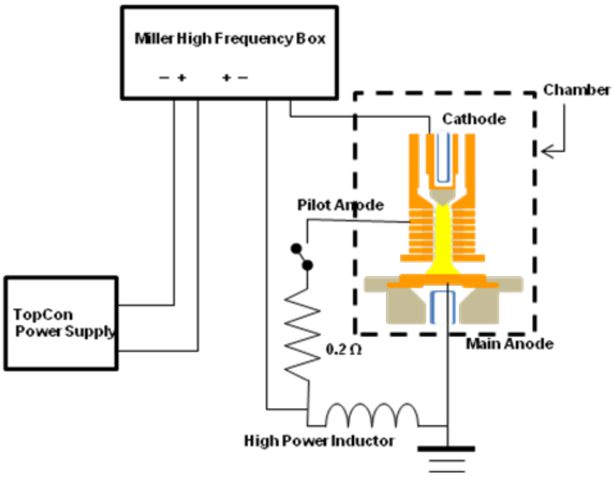

Fig. 1 Electrical schematic of the experimental setup.

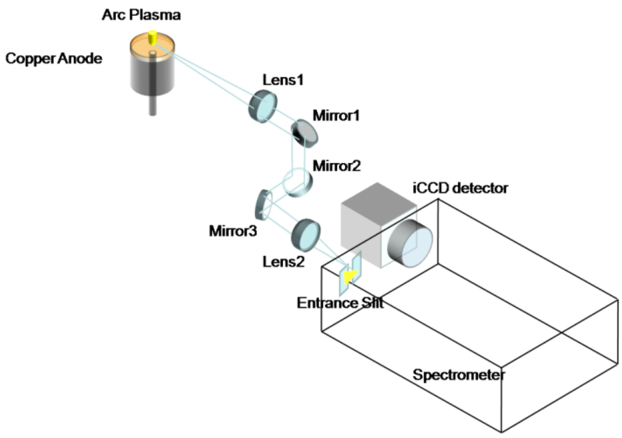

Fig. 2 The schematic of the spectroscopic system.

mm-gap between the constrictor and the anode allows observation and performing diagnostics in the anode region. The whole system is housed in a controlled atmosphere chamber which is evacuated before each experiment and filled with pure argon. More details are mentioned in [6]. The principal parameters that are varied are arc current: 80, 100 and 120 A, plasma gas flow rate of the working gas parallel to the arc axis: 2, 3, 5, 7, 10 and 15 slpm, and flow rate of the cooling water: 3.2 – 11.2 slpm.

2.2 Analysis

The emission from the copper vapor was observed by time resolved spectroscopy to detect the instant when anode material evaporation occurred. Spectroscopic data were obtained using a one meter focal length spectrometer (Acton Research, AM510) with an intensified CCD detector (Princeton Instruments) which has a display of 298x1158 pixels. An optical system is used to focus the light from the arc onto the entrance slit of the spectrometer. The optical components, which consist of two lenses, three mirrors and an iris diaphragm, are shown in Fig. 2. The combination of optics is used to magnify and rotate the arc image before it enters the spectrometer. A CCD camera at the exit plane of the spectrometer is used to record the data. The combination of the spectrometer and the CCD detector has a spectral resolution of 0.01 nm per CCD pixel and a radial spatial resolution of 0.02 mm per CCD pixel. The size of the CCD array allows observation of a radial spatial region of 4.5 mm and a spectral range of 11.5 nm. Spectroscopic data was obtained every 5 s during arc operation.

Images of the arc configurations were taken using another CCD camera (Panasonic, Lumix) with an exposure time of 0.5 ms. Images were taken every 5 s during arc operation.

The heat transfer measurements were made by measuring the temperature increases of the cooling water by K-type thermocouples, which are placed at the cooling water inlet and outlet of the anode. With known cooling water flow rates, the heat transfer to the anode is simply given by

$$P = \left(T_{out} - T_{in}\right) \times Q \times C_{water} \qquad (1)$$

where the T_{out} and T_{in} are the cooling water temperatures at the outlet and inlet, respectively. Q is the cooling water mass flow rate and C_{water} is the water specific heat.

3. Experimental results

Fig. 3 shows images of the arc appearance modes for different arc currents and working gas flow rates. The attachment mode is diffuse mode at higher working gas flow rate. With decreasing working gas flow, the attachment mode transitions to a multiple-attachment mode from diffuse mode. With further decreasing working gas, the attachment mode finally changed to a constricted mode. These results show that the anode attachment mode transits to the constricted mode from the multiple-attachment mode with a reduced cathode jet, as has been observed earlier [3, 6]. Fig. 4 shows the relationship between the working gas flow rate and the total heat transfer to the anode from the arc. The total heat transfer becomes lower with decreasing working gas flow rate. This result indicates that the convection heat transfer from the arc to the anode becomes lower with decreasing working gas flow rate due to the formation of the anode jet.

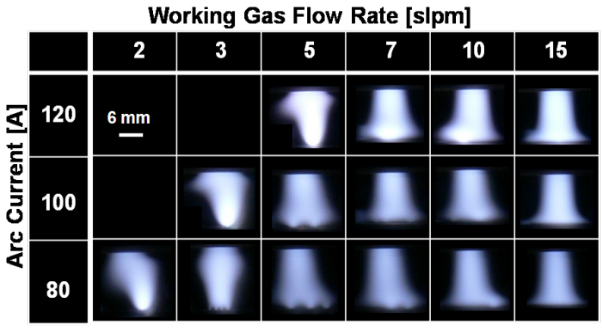

Fig. 3 CCD camera images of arc appearance modes for different arc current and the working gas flow rate.

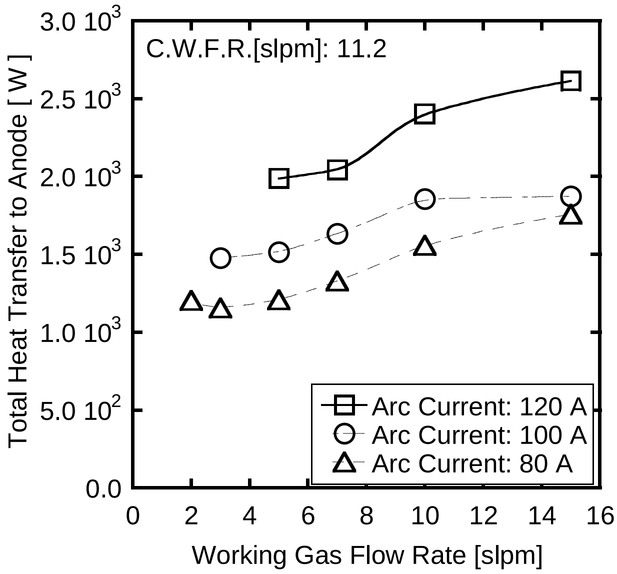

Fig. 4 The relationship between the working gas flow rate and the total heat transfer for different arc current.

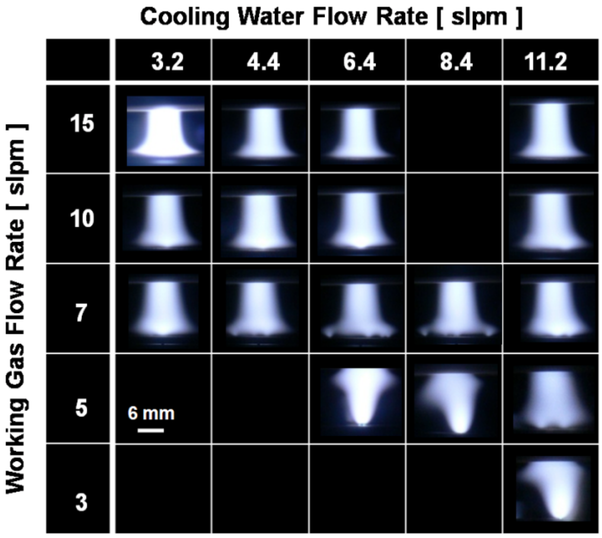

Fig. 5 CCD camera images of the arc appearance modes for different working gas flow rate and cooling water flow rate with constant arc current: 100 A.

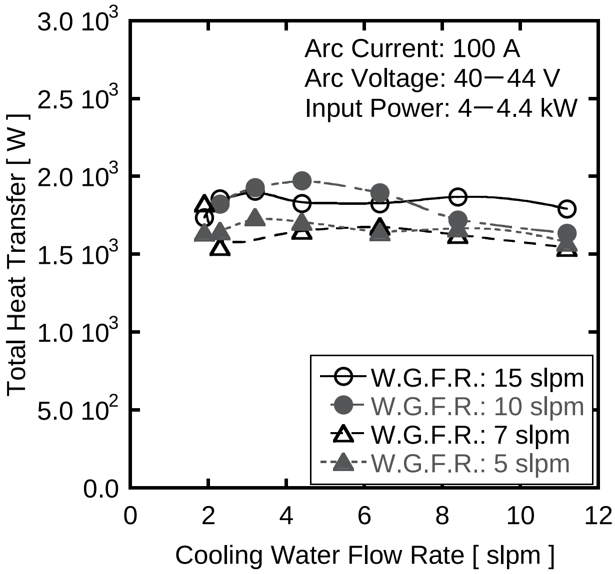

Fig. 6 The relationship between the cooling water flow rate and the total heat transfer for different working gas flow rate.

Fig. 5 shows arc images for different flow rates of working gas and cooling water with 100 A of arc current. With decreasing flow rate of the cooling water, the attachment mode transitions to the constricted mode from multiple-attachment mode, when the flow rate of the working gas is 5 slpm. Fig. 6 shows the relationship between the flow rate of cooling water and the total heat transfer to the anode from the arc. The total heat transfer is almost constant with changing the flow rate of cooling water in this range.

Fig. 7 shows the emission intensity from copper vapor as a function of time, with 5 slpm of working gas flow rate, 8.4 slpm of cooling water flow rate, and 100 A of arc current. The attachment mode is a multiple-attachment mode before 35 s as indicated by the shaded area. After 35 s, the attachment mode changed to the constricted mode. The attachment mode transitioned to the constricted mode from the multiple-attachment mode after emission from copper vapor appeared, even though the operating conditions did not change. Fig. 8 shows the comparison between the arc-anode attachment mode (a) before evaporation and (b) after evaporation with 100 A of arc current, as a function of working gas and cooling water flow rate. The grey area, the shaded area, and the white area indicate the presence of a diffuse mode, a multiple-attachment mode and a constricted mode, respectively. While the arc was in the multiple-attachment mode with 3 to 10 slpm of working gas flow rate, anode material evaporation could start, resulting from two factors; (i) an enhanced heat flux with decreasing flow

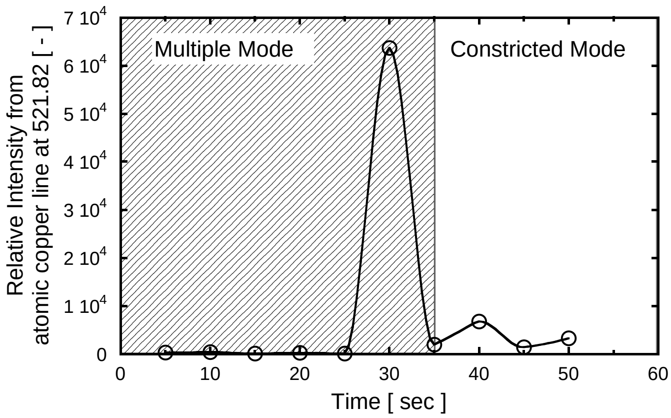

Fig. 7 The emission intensity at 521.82 nm from copper vapor as a function of time, at 100 A of arc current, 5 slpm of working gas flow rate and 8.6 slpm of cooling water flow rate. Different modes are characterized as follows. Shaded area: multiple mode. White area: constricted mode.

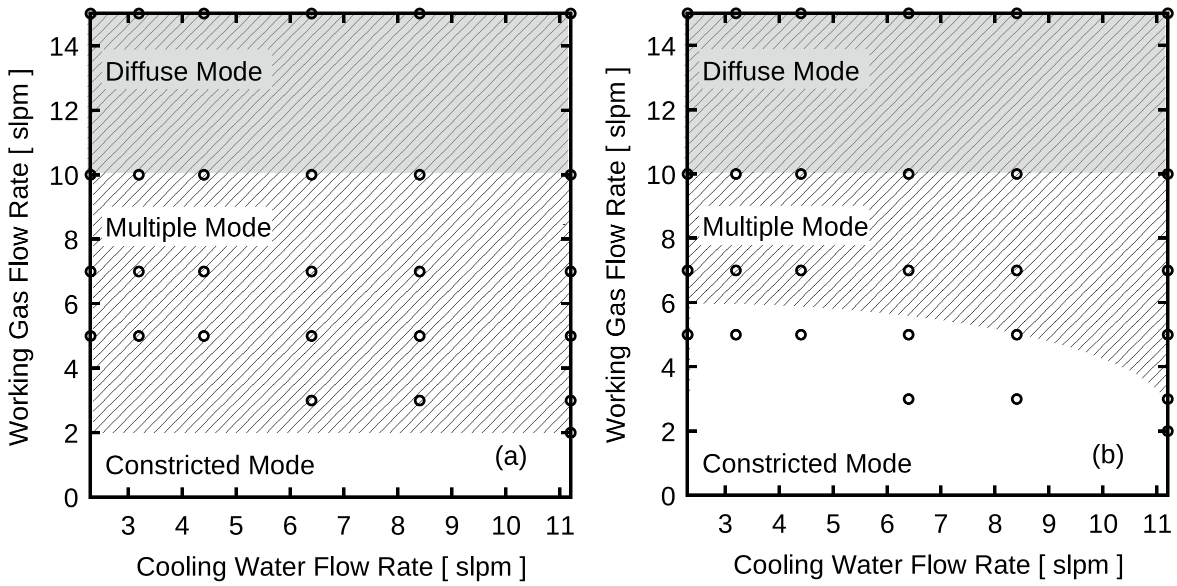

Fig. 8 The comparison between the arc-anode attachment mode (a) before evaporation and (b) after evaporation, as a function of flow rate of working gas and cooling water flow rate with 100 A of arc current.

from the cathode, (ii) a reduced cooling rate at local spot of the anode surface with decreasing cooling water flow. After evaporation started, the multiple-attachment mode transitioned to the constricted mode at constant operating conditions. This result indicates that one of the driving forces, which lead to the transition to a constricted attachment mode from the multiple-attachment mode, would be the anode material vapor addition in the arc, resulting in the enhanced local electrical conductivity. Further experimental investigation with higher time-resolution spectroscopy is needed to provide a better understanding of the processes that lead to the transition between the different attachment modes. It appears however, that even with lower total heat transfers to the anode, high local heat fluxes can occur due to an electron heating run-away as predicted by the instability analysis by Yang and Heberlein [6].

4. Conclusion

The effect of anode evaporation in high intensity arcs has been studied experimentally. Anode heat transfer from the arc was measured calorimetrically, the copper vapor was detected using spectroscopy, and arc-anode attachment configurations were recorded using a CCD camera. The results indicate that it is easy to transition to the constricted attachment from a multiple-attachment when local overheating of the anode surface occurs. This transition would be attributed to the anode material vapor addition in the arc, resulting in higher electrical conductivity.

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