Investigation of RF and DC plasma electron sources for material processing applications

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***Abstract*—This work presents the design, development and experimental results obtained from an RF plasma cathode Electron Beam (EB) gun for material processing applications. EB currents of up to 38 mA at –60 kV were extracted and correlated to Optical Emission Spectroscopy (OES) measurements. OES measurements and Argon II ratios were used to compare hollow and flat electrode designs as well as to examine changes in other key plasma parameters (i.e. plasma pressure and excitation power). The spectroscopic measurements and Argon II ratios indicated a higher ionization rate for the hollow electrode geometries and plasma parameters that generated larger EB currents (i.e. higher excitation power and lower pressure). The RF plasma cathode gun was compared to a DC plasma cathode gun. The DC plasma cathode produced larger currents than the RF plasma chamber. This result agreed with the OES measurements, which showed a higher ionisation in the DC plasma.**

Keywords—electron source; plasma cathode; hollow cathode, electron beam gun; optical emission spectroscopy; RF plasma.

I. INTRODUCTION

Electron Beam (EB) processes such as welding or additive layer manufacturing in metal can benefit from the advantages of plasma cathode guns. Long cathode life, uniform EB quality from the beginning to the end of the process, and operation in a coarse vacuum environment without causing contamination of the cathode are some of the advantages of plasma cathode guns. In addition, the plasma cathode investigated in this work is RF excited, which allows fast switching of the beam. This is a great advantage in applications such as additive manufacturing with powder bed, in which the beam could be switched on and off so that melting is only carried out when the beam is at the desired position. The RF plasma cathode gun was described previously in [1] and it has been investigated and optimised in the presented work. The results present current measurements of the extracted EB as well as optical emission spectroscopy (OES) measurements from the plasma [2]. Different plasma cathode geometries have been designed, manufactured and investigated. This paper also compares the RF plasma cathode results to those from a DC plasma electron source.

II. DESIGN OF THE RF ELECTRON SOURCE

The plasma cathode EB gun comprises two main parts: the plasma gun body where the plasma is generated by an RF excited signal, and the acceleration region which is used to extract a beam into the vacuum chamber. Fig. 1 shows the plasma gun body and two of the plasma chamber designs: flat electrode geometry (left) and hollow electrode geometry (right). In both plasma chamber designs an RF signal is applied between the plasma chamber electrodes (right and left ends of the quartz tube) to generate a plasma. Once the plasma is generated in the quartz tube an EB is extracted to the vacuum chamber through the plasma chamber aperture by applying an accelerating field between the gun body and the anode. The anode and vacuum chamber are not shown in Fig. 1.

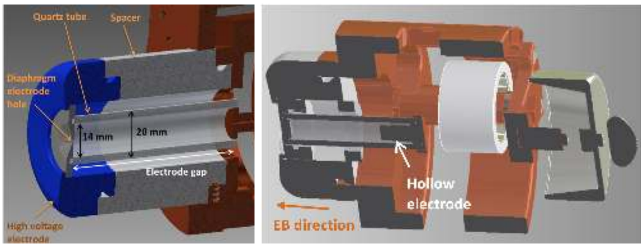

Fig. 1. Flat electrode plasma chamber (left) and hollow electrode plasma chamber (right). Reproduced by permission of TWI Ltd.

III. ELECTRON EMISSION AND OES RESULTS

The plasma cathodes investigated used argon as the ionised gas at pressures from 2×10^{-2} to 4.5×10^{-1} mbar. The RF power applied to the plasma chamber ranged from a few watts to 100 W (delivered power). The diaphragm aperture diameter varied from 0.7 to 2 mm. Electron beams of up to 38 mA at –60 kV were extracted. An optical spectrometer was used to look at the light emitted from the plasmas generated with the different designs, pressures and powers. Argon I and Argon II lines were identified in the spectra of each of the plasma chamber designs. The ratio of spectra obtained with different parameters were used to compare the changes in the relative intensities of the ionised argon from one design to the other. This section presents the results of optical emission from the plasma cathode and comparison to the EB current extracted.

A. Flat vs Hollow Plasma Chamber Electrodes

Fig. 2 shows the EB current measurements taken from a hollow electrode cathode and a flat electrode design each with a 0.7 mm aperture diameter hole at –30 kV. The dashed lines correspond to the flat electrode design and the solid lines correspond to the hollow cathode design. In all cases the hollow cathode design produced a larger EB current. The spectra ratios showed that the relative intensities of the Argon II lines were larger in the hollow cathode design compared to the flat electrode design.

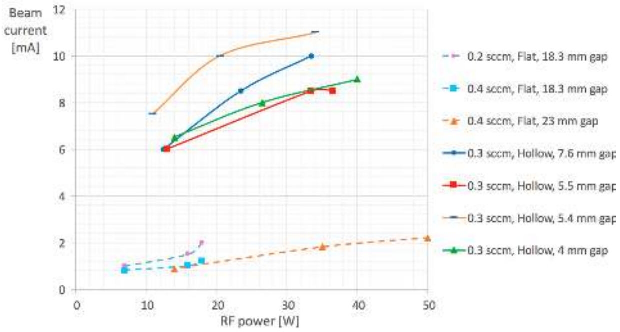

Fig. 2. EB current measurements from flat and hollow cathodes. Reproduced by permission of TWI Ltd.

B. *DC vs RF plasma cathodes*

The measurements from the RF plasma hollow cathode were compared to measurements from a DC plasma cathode gun. Fig. 3 shows the EB current extracted from the DC plasma cathode as a function of the discharge current applied to generate the plasma. The EB was extracted through a 1.7 mm diameter hole. The EB currents extracted are larger than in the RF plasma cathode gun design in all cases.

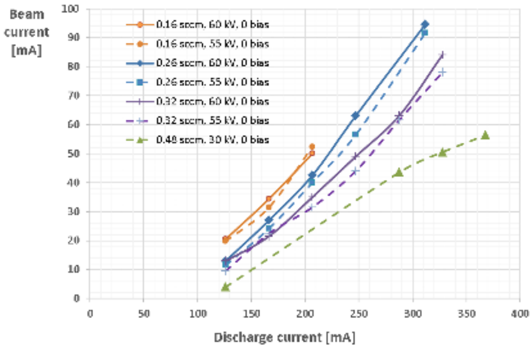

Fig. 3. EB current measurements from flat and hollow cathodes. Reproduced by permission of TWI Ltd.

In both the DC and RF plasma cathode guns the EB current extracted increased with the energy applied to the plasma. Fig. 4 shows the ratio of the Argon II lines in the DC plasma at 311.6 mA/126.2 mA. The ratios indicate a higher ionisation for a larger excitation power. This agrees with the EB current measurements which showed that a larger EB current is extracted from a higher excitation power. It can also be observed from Fig. 3 that a lower pressure generates a larger EB current. The ratio of the Argon II lines in Fig. 5 compares the DC spectra at 0.16 sccm and 0.26 sccm. Higher ionisation is shown for the lower pressures which is in agreement with the EB current measurement results. This is also the case for the EB current measurements from the RF plasma cathode gun.

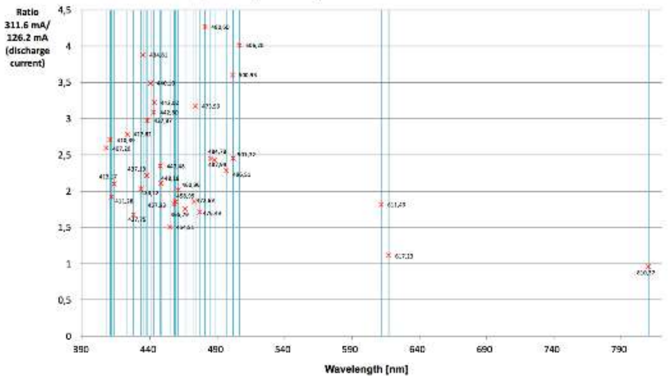

Fig. 4. Ratio of the DC plasma Argon II lines at 311.6 mA/126.2 mA. Reproduced by permission of TWI Ltd.

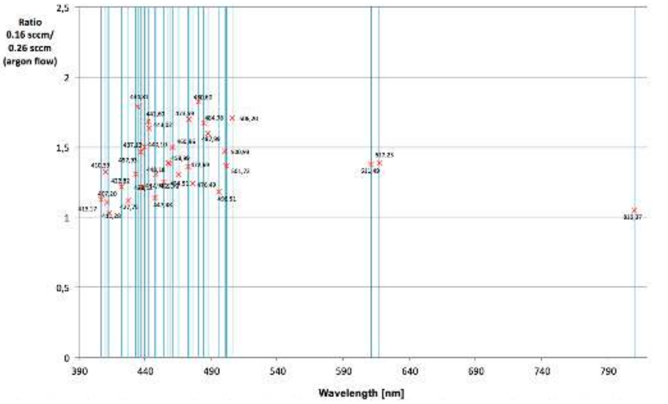

Fig. 5. Ratio of the DC plasma Argon II lines at 0.16 sccm/0.26 sccm gas flow rate, both at 311.6 mA discharge current. Reproduced by permission of TWI Ltd.

IV. CONCLUSION

Different plasma chamber geometries have been designed and manufactured. The EB current extracted from the plasma cathode increased with increasing excitation power, aperture diameter, accelerating voltage, and lower plasma pressure. The EB current results agreed with OES measurements and Argon II ratios, which showed a higher ionisation for the geometries and plasma parameters that generated larger EB currents. The plasma cathode gun was integrated into a metal 3D printer and the electron beams from the experimental setup were successfully reproduced. The plasma cathode EB gun generated sufficient power for material processing applications such as additive layer manufacturing, welding or cutting. In order to carry out a direct comparison of the DC and RF plasma gun systems, a DC plasma gun is currently being developed.

REFERENCES

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