Study of the efficiency of magnetic island macroparticle filters for different vacuum arc configurations

2012 J. Phys.: Conf. Ser. 370 012016

(http://iopscience.iop.org/1742-6596/370/1/012016)

Study of the efficiency of magnetic island macroparticle filters for different vacuum arc configurations

A Arias Duran[1,3], M Fazio[2], A Kleiman[2,3], L Giuliani[2,4], A Marquez[2,4] and D Grondona[2,4]

[1]LP&MC, Dept. de Física, FCEyN-UBA, and IFIBA-CONICET, Cdad. Universitaria, Pab. I, C1428EGA Cdad. Autónoma de Buenos Aires, Argentina
[2]INFIP, UBA-CONICET, Cdad. Universitaria, Pab. I, C1428EGA Cdad. Autónoma de Buenos Aires, Argentina.
[3]Fellow of CONICET
[4]Member of CONICET

E-mail: grondona@df.uba.ar

Abstract. In the present work, we studied the efficiency of a magnetic island filter for two vacuum arc designs, pulsed and continuous. The magnetic island filter consisted in a straight duct with an external solenoid and a magnet enclosed in a housing (magnetic island) located inside the duct on its axis, and both magnetic fields are in opposite direction. The housing of the magnetic island obstructs the line of sight between the cathode and the substrate. In this arrangement, the charged plasma components move along the curved magnetic field lines, around the magnetic island, but the macroparticles move in straight paths and deposit on the wall of the magnetic island housing. The performance of the filter was characterized for different external and internal field strengths. The plasma transport efficiency was analyzed by measuring the ion saturation current with Langmuir probes and the deposited mass rate. The ion transmission efficiency around the system axis achieved values around 25%. Observation of the coating surface morphology with optical microscopy determined that the macroparticles were effectively removed.

1. Introduction

Coatings produced by vacuum arc deposition have macroparticles incorporated; therefore they have not the quality required for some applications. Magnetic filtering techniques are used to remove the macroparticles from the plasma jet emitted in cathodic arc discharges. In this kind of filters a magnetic field with intensity higher than that required for electron magnetization is applied. The magnetized electrons are forced to spiral along the magnetic field lines. The ions are not magnetized but follow the electrons in order to maintain a quasineutral state of the plasma jet. However, the macroparticles trajectories are not considerably affected by the magnetic field, so they travel in straight trajectories and impact the filter walls.

A great variety of magnetic filters with different geometries has been implemented [1,2]. The simplest magnetic filter is the straight filter. This filter consists in a duct with a coil wrapped which generates an axial magnetic field. In this kind of filter, although the ratio of the plasma to macroparticles in the coating increases due to the ion confinement, the filter is not very efficient in macroparticle reduction because the substrate is in the line of sight of the cathode.

The ‘‘magnetic island filter’’ is a straight filter in which a central shield is inserted. The shield is a magnetic structure that helps guiding the plasma around it. This filter does not have a line of sight between cathode and substrate [1,3]. The island is an electromagnetic coil or a permanent magnet located inside the duct, on its axis. The magnetic fields generated by the straight filter and the island are in opposite direction on its axis. In this arrangement, the charged plasma components move along the curved magnetic field lines, around the magnetic island to the treated surface, but the macroparticles move in straight paths and deposits on the case of the magnetic island (figure 1). This kind of filter is well suited for small substrates and shows a great efficiency removing macroparticles [4,5].

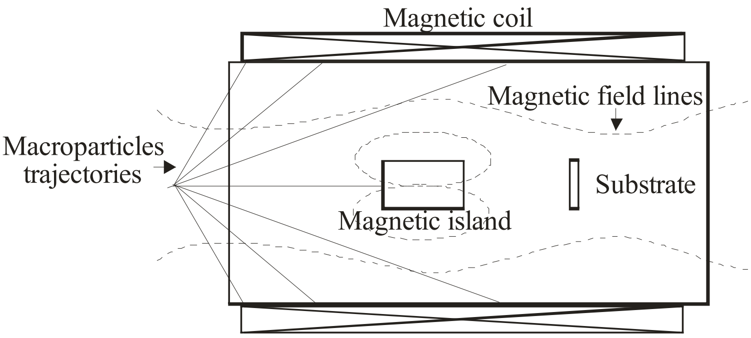


Figure 1. Schematic diagram of a magnetic island filter.

In this work, the performance of magnetic island filters for two vacuum arc designs, pulsed and continuous, were studied. The plasma transport efficiency and macroparticle reduction in Titanium coatings were compare with those obtained with a straight filter for different magnetic field configurations.

2. Experimental set-up

The experimental study of the magnetic filter was carried out in a dc vacuum arc and in a pulsed vacuum arc discharge. In figure 2 schematic drawings of both vacuum arcs are shown.

In the pulsed device (figure 2(a)), the arc was produced by discharging an electrolytic capacitor bank with C = 0.075 F, connected to a series inductor-resistor (L = 2 mH, R = 0.33 Ω), which critically damped the discharge. The arc duration is about 35 ms, with a peak current of (450 ± 20) A and an interelectrode voltage of (45 ± 5) V. The charging voltage was 280 V and the arc was ignited with a mechanically controlled tungsten rod. The chamber pressure was maintained at a base pressure $< 10^{-2}$ Pa during the whole arc discharge with an oil diffusion pump. A grounded Ti cathode (5 cm in length and 1 cm in diameter) was located 1 cm in front of an annular anode with an aperture of 5 cm and a thickness of 2 cm. The entrance of the straight magnetic filter was placed at the end of the anode, separated by a 1 cm insulating ring, at 4 cm from the cathode frontal surface. The magnetic field is generated by an external coil wrapped around a stainless steel tube (22 cm long, 5 cm inner diameter). The coil (3 layers of 30 turns each) was fed with dc current from an independent power source. The magnetic field strength was measured with a calibrated Hall probe with a precision of 10%, and was characterized with the value measured at the duct center (B_{ext}). The range of B_{ext} values investigated was 3 – 43 mT. The magnetic island filter consisted of cylindrical permanent magnets enclosed in an aluminum jacket (1 cm diameter and 2 cm long). The amount of permanent magnets inside the jacket was modified. Two different magnetic island field strengths (B_{isl}) were employed, one of 10 mT and the other of 60 mT. These values were measured at the duct axis on the jacket frontal surface. The magnetic island was placed at the duct axis at 11 cm from the cathode frontal surface.

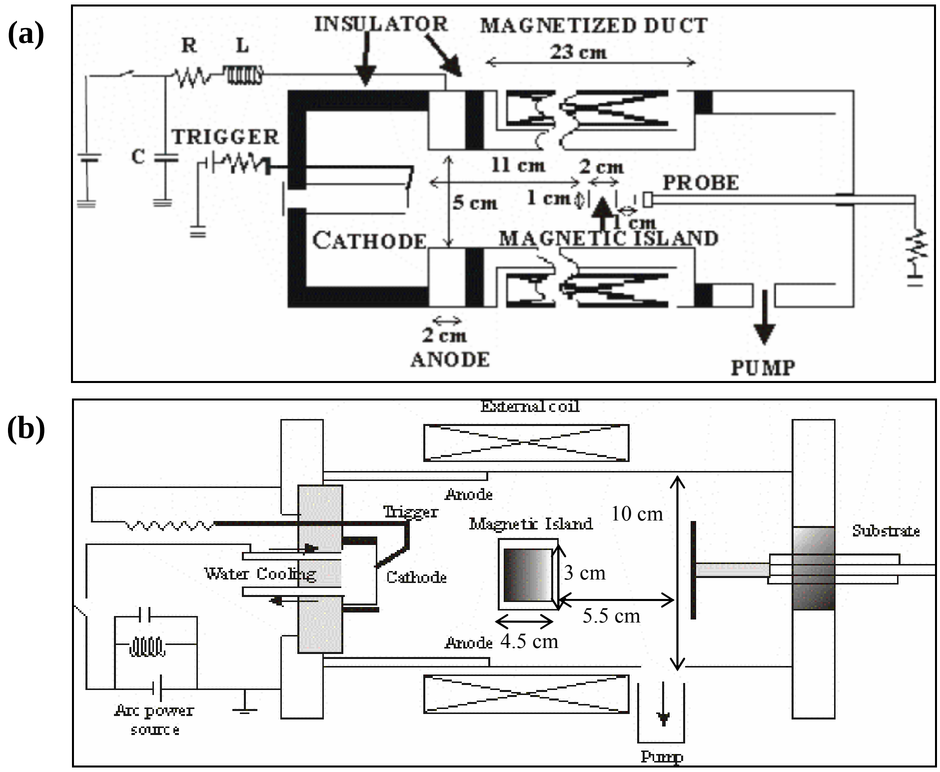


Figure 2. Schematic diagrams of the magnetic island in the vacuum arcs: (a) pulsed discharge and (b) dc discharge.

In the dc cathodic arc (figure 2(b)) the discharge circuit consisted in a current supply (18 kW, 150 A) in parallel with a capacitor bank (165 mF) connected to the electrodes through a series inductor (2.8 mH) in order to provide arc stability. The arc was run with a 125 A current. A Ti cathode of 5 cm in diameter and an annular copper anode of 8 cm inner diameter were employed. Both electrodes were refrigerated during the arc discharge by a water cooling system by means of a centrifuge pump with a nominal discharge of 50 l/min. The substrate chamber was electrically insulated and connected with the main discharge chamber through a straight duct (25 cm long, 10 cm inner diameter), which operates as the straight magnetic filter. One vacuum system, composed of a mechanical and two diffusion pumps, pumps the chamber to a base pressure of less than 10^{-2} Pa. The field of the straight magnetic filter was generated by an external coil of 20 cm in length with 30 turns of 18 cm in diameter). The range of B_{ext} values investigated was 0 – 8 mT. The jacket of the magnetic island filter was a cylinder of 3cm diameter and 4.5 cm long with cylindrical permanent magnets inside. Two different magnetic island field strengths were employed, one of 11 mT and the other of 36 mT. The magnetic island was placed at the duct axis at 20 cm from the cathode frontal surface.

Plots of the field lines on a longitudinal plane (from the axis to the external coil radius) for two field configurations applied to the dc and pulsed arcs are shown in figure 3. Figure 3(a) and (b) correspond to the pulsed vacuum arc system with B_{ext} = 43 mT and B_{isl} = 60 mT and 10 mT, respectively. Figure 3(c) and (d) correspond to the dc vacuum arc with the same value of B_{ext} = 7mT and with B_{isl} = 36 mT and B_{isl} = 11 mT, respectively.. Values of the field component parallel to the axis registered with the Hall probe are also indicated in figure 3.

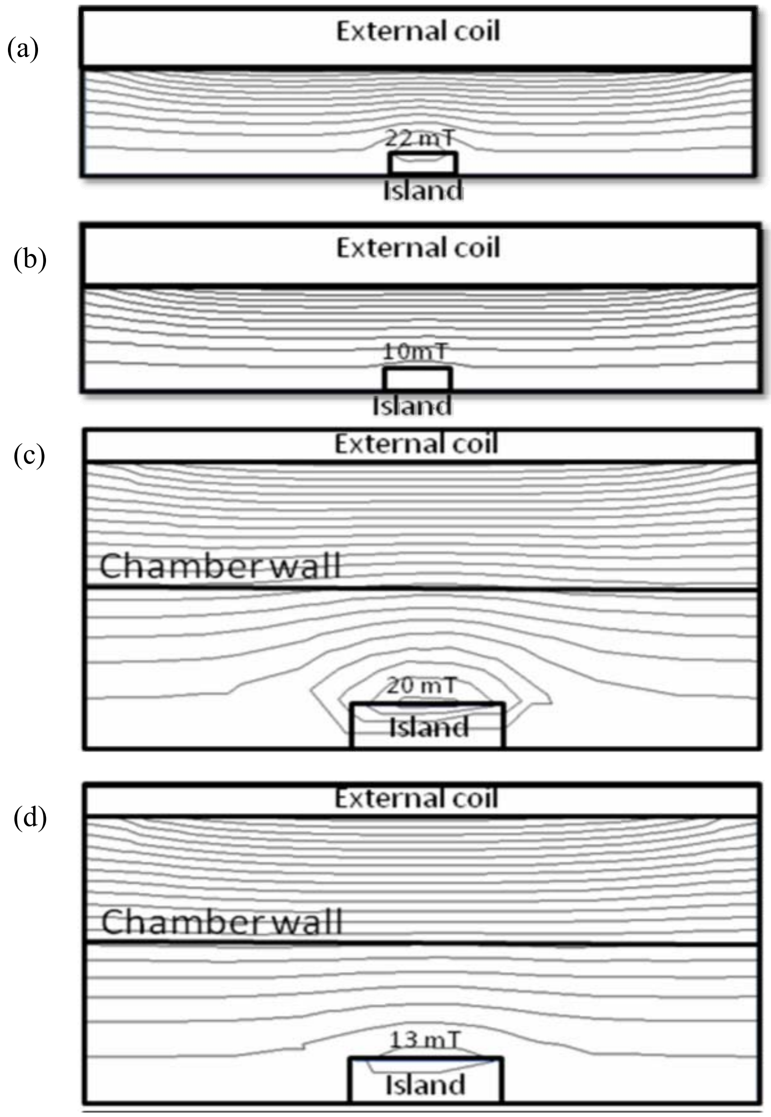


Figure 3. Magnetic field configuration for the island filter: (a) pulsed arc, B_{ext} = 43 mT and with B_{isl} = 60 mT; (b) pulsed arc, B_{ext} = 43 mT and with B_{isl} = 10 mT; (c) dc arc, B_{ext} = 7mT and with B_{isl} = 36 mT; and (d) dc arc, B_{ext} = 7mT and with B_{isl} = 11 mT.

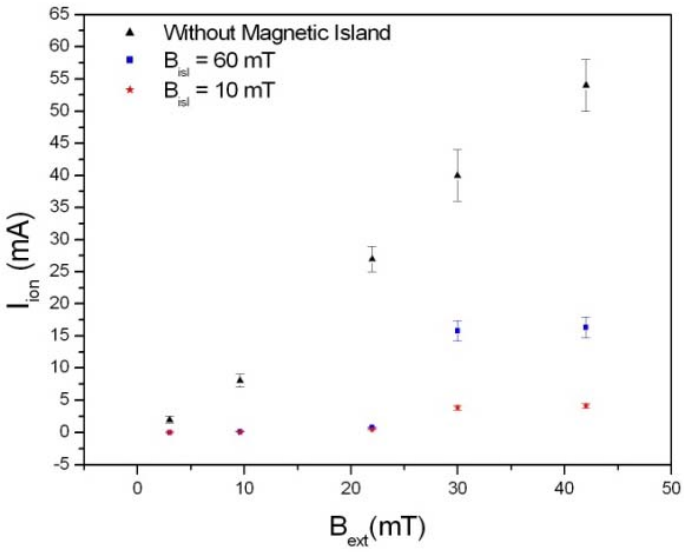
In order to evaluate the efficiency of the plasma passage through the island, the ion flux was measured with a probe in the pulsed vacuum arc and the growth rate was determined in the dc arc for different field configurations. In the pulsed arc, a circular plane copper probe (0.6 cm diameter) was placed at 14 cm from the cathode frontal surface at the tube axis and at 1 cm behind the magnetic island jacket. For the measurement of the ion saturation current, taking into account the relatively high plasma potential [6], the probe was simply biased to ground through a resistance of 300Ω to ensure that the probe voltage was well below the floating potential during the discharge. The electrical signals were registered using a four-channel digitizing oscilloscope (100MSs^{-1} sampling rate, 60MHz analogical bandwidth). In the dc arc, steel circular samples of 3 cm diameter placed 5.5 cm behind the magnetic island have been exposed to the discharge for 180 s. The growth rate was assessed by weighting the samples before and after the deposition process using an Ohaus scale, model AS200 and assuming that the film had bulk Ti density (ρ_{Ti} = 4.5 g/cm^3).

The surface morphology of coatings deposited on silicon substrates was observed using an optical microscope (Olympus BX60M). In the pulsed arc the silicon substrates were exposed to 5 discharges, while in the dc arc they were exposed in the same conditions as the steel samples.

3. Results

In figure 4 the ion saturation current (I_{ion}) measured in the pulsed arc (figure 4(a)) and the growth rate (r) measured in the dc arc (figure 4(b)) as function of B_{ext} without and with the presence of the magnetic island inside the chambers are presented.

(a)



(b)

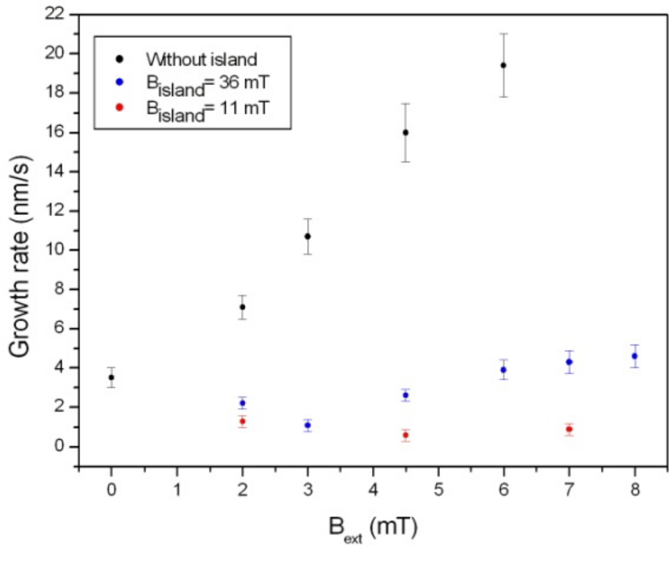


Figure 4. Ion flux as function of the magnetic field strength: (a) ion current measured in the pulsed arc and (b) growth rate (r) measured in the dc arc.

In figure 4(a), it can be observed that without the island I_{ion} increased as B_{ext} increased, varying from 2 mA for the lowest B_{ext} to 55 mA for B_{ext} = 43 mT. With the island, when B_{ext} was lower than 25 mT the registered ion flux was not significant independently on the B_{isl} value, while for higher B_{ext}

I_{ion} augmented, I_{ion} for B_{isl} = 60 mT being a factor 4 higher than I_{ion} for B_{isl} = 10 mT. The measurements of *r* as function of the magnetic filed in the dc arc (figure 4(b)) showed a similar behavior to I_{ion}. Without the island *r* augmented from 3.5 nm/s up to 19 nm/s corresponding to B_{ext} = 6 mT. For higher values of B_{ext} *r* could not be determined because the ion flux was so concentrated on the axis that a burned spot appeared on the surface after the deposition process. With the island, for the case B_{isl} = 11 mT *r* varied slightly with B_{ext} taking a value of approximately 1 nm/s, while for the case B_{isl} = 36 mT *r* increased with B_{ext} achieving a value of 4.5 nm/s.

In figure 5 optical micrographs (with 500x magnification) of Ti coatings show the surface morphology typically observed without and with the magnetic island filter in both vacuum arcs. The pictures presented in figure 5 correspond to samples deposited in the following conditions: (a) with the pulsed arc without the island, with B_{ext} = 43 mT; (b) with the dc arc without the island, with B_{ext} = 6 mT; (c) with the pulsed arc with the island with B_{ext} = 43 mT and B_{isl} = 60 mT; and (d) with the dc arc with the island with B_{ext} = 7 mT and B_{isl} = 36 mT. An estimation of the coating thickness of the pulse vacuum arc was obtained from the charge deposited, which was calculated from the probe ion current integration. The coating thicknesses obtained with B_{ext} = 43 mT and without the island was ~ 4 nm (figure 5(a)), and with B_{isl} = 60 mT a thicknesses of ~ 1 nm (figure 5(c)). The coating thickness with the dc arc was obtained from the deposited mass. The values obtained with B_{ext} = 6 mT was ~ 3.2 μm (figure 5(b)); and with B_{ext} = 6 mT and B_{isl}=36 mT was ~ 0.7 μm (figure 5(d)).

Without the island many macroparticles of different sizes could be distinguished onto the substrate for all B_{ext} values, in the case of the dc arc the number of macroparticles was higher and macroparticles with larger diameters were observed. Using the magnetic island filter it can be seen that practically no macroparticles were visible for both arcs.

(a) (b) (c) (d)

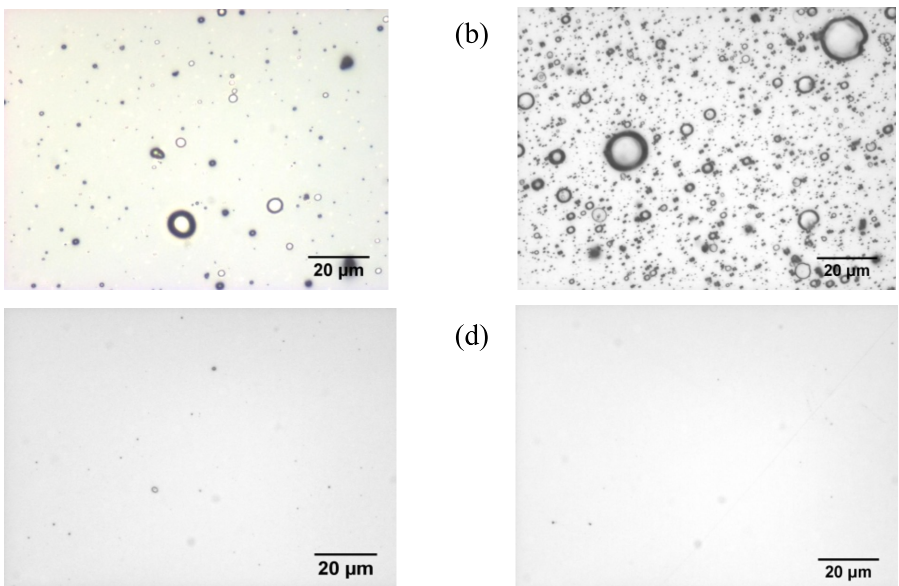


Figure 5. Optical micrographs of Ti coating surfaces: (a) pulsed arc without the island, with B_{ext} = 43 mT; (b) dc arc without the island, with B_{ext} = 6 mT; (c) pulsed arc with the island with B_{ext} = 43 mT and B_{isl} = 60 mT; (d) dc arc with the island with B_{ext} = 7 mT and B_{isl} = 36 mT.

4. Conclusions

In the present work, we studied the efficiency of the magnetic island filter for two vacuum arc systems, one pulsed and the other continuous. The geometrical dimensions of the filter for both systems were chosen according to the cathode and the straight filter diameters with similar proportions. The performance of the filter was characterized for different external and internal field strengths. The ion transmission efficiency was characterized by comparing the ion flux for the maximum B_{ext} with and without the island on the axis. The maximum axial ion flux that passed around the magnetic island was found for the maximum B_{isl} and achieved values around 25% for both systems. The fact that the higher ion transmission was found for the field configurations with higher strengths could be associated to decrease of the magnetic diffusion diminishing the ion losses to the chamber wall. The amount of macroparticles present on the film obtained with the magnetic island filter was compare with those present on the film obtained with the simple straight filter for different magnetic field configurations. Observation of the coating surface morphology with optical microscopy determined that the macroparticles were effectively removed.

Acknowledgments
This work was supported by grants from Universidad de Buenos Aires and CONICET.

References
[1] Karpov D A 1997 S*urf. Coat. Technol.* **96** 22-33
[2] Anders A 2008 *Cathodic Arcs* (New York: Springer)
[3] Aksenov I I, Belous V A, Padalka V G and Khoroshikh V M 1982 Swedish Patent Nº 82188-8
[4] Kleiman A, Márquez A and Boxman R 2008 *Plasma Sources Science and Technology* **17** 015008
[5] Bolt H, Koch F, Rodet J L, Karpov D and Menzel S 1999 *Surf. Coat. Technol.* **116–119** 956-62
[6] Giuliani L, Grondona D, Kelly H and Minotti F O 2007 *J.Phys. D: Appl. Phys.* **40** 401-8