Magnetic field topology for altering ion density in bipolar sputtering

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Abstract: In this work, a drastic change in the spatial ion distribution in bipolar magnetron sputtering discharge is reported upon changing the magnetic field topology. A significant increase in ion number density at certain time delays is also registered when topology is changed toward the unbalanced type. A transitory torch-shaped ionization zone consequently disappears, along with the low-energy part of the ion energy distribution, due to no additional ionization in this case.

Keywords: bipolar HiPIMS, magnetic field topology, plasma diagnostics, mass spectrometry, LIF imaging

Enhanced plasma ionization is the key feature of high-power sputtering, as a result of high electron density in the cathode vicinity and transport in the crossed electric (**E**) and magnetic (**B**) fields [1,2]. Even though unipolar High Power Impulse Magnetron Sputtering (HiPIMS) has demonstrated great advantages for high quality film deposition [3], this technique is not universal, revealing insufficient level of ion bombardment in certain cases. While the most convenient and effective method to control the energy of the plasma ion species in magnetron sputtering is the use of negative substrate bias voltage, this approach becomes much more complicated when considering electrically insulating substrates especially in industrial environments.

This issue called for a new approach in a context of industrial innovation and challenges. The *bipolar* HiPIMS regime (abbreviated as BPH), by adding a tuneable positive pulse to the classical HIPIMS plasma pulse, has enabled several advances, and quickly gained in popularity due to the ability to control the energy of the incoming ion flux during film growth, without intentional substrate biasing [4,5]. Consequently, we recently studied in our group the BPH regime that allows to achieve a similar control without having to bias the substrate [6].

Particularly relevant for thin film deposition, the degree of balance (or unbalance) of the magnetron source should also play an important role for guiding the ion flux toward the substrate in BPH discharges. One may suggest different ion distribution and propagation, depending on magnetic field topology above cathode, or, in other words, to which extent, the field is “opened.” These questions, however, remain weakly explored. Addressing this point, this work reports ion density enhancement by varying the magnetic field topology in a BPH-based system (see Figure 1).

The time- and space-ion number density distribution above the cathode (see Figure 2) and the ion energy distribution functions (IEDFs, see Figure 3) were measured using quadrupole mass spectrometry [7] and laser-induced fluorescence [8-9] techniques, respectively.

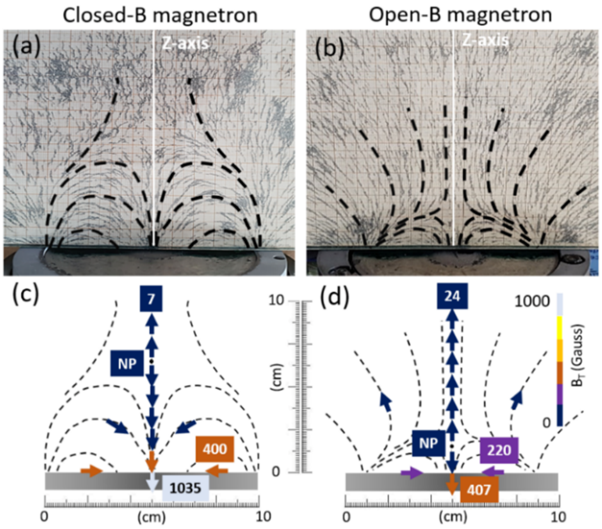

Fig. 1: Experimental B-field mapping in the closed (a) and open (b) magnetron cases. The corresponding schematic field topologies are shown in (c) and (d).

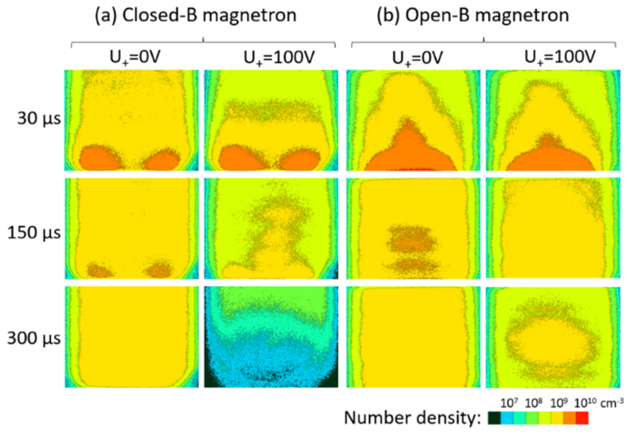

Fig. 2: Time-resolved Ti^+ ground state density distributions measured at 5 mTorr above the cathode for (a) closed-B and (b) open-B topologies using a positive voltage of 0 and 100 V, with a negative current peak of 26 A. The delay time starting with the negative pulse is shown on the left. All sub-images are normalized to one value and calibrated. Logarithmic color space is used. Region of interest corresponds to 70x102 mm.

Mass spectrometry data show that a fraction of (intermediate energy) Ti ions disappears when the B-field topology is changed. This corroborates with our LIF data showing the extinction of a torch-like shape spatial distribution (disappearing sooner at higher positive voltage).

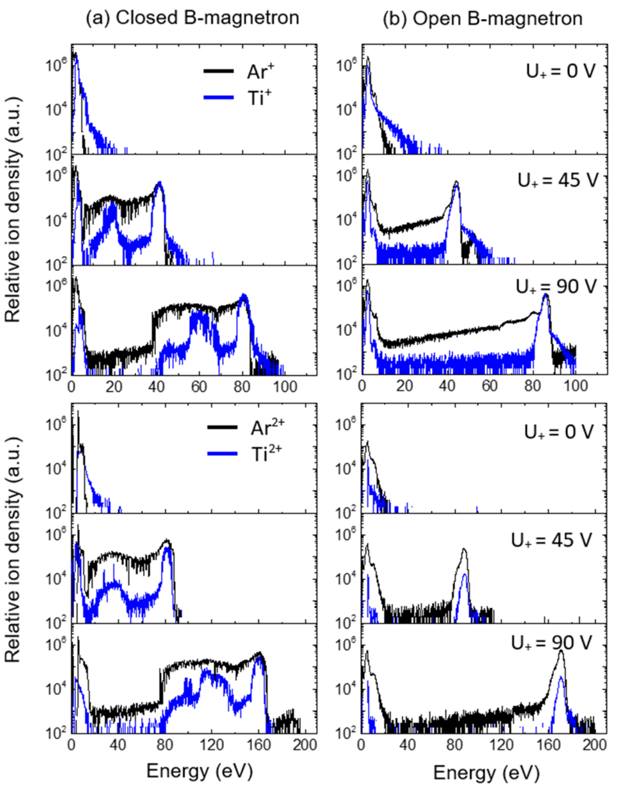

Fig. 3: Time-averaged IEDFs of Ar^+, Ti^+, Ar^{2+} and Ti^{2+} in the unipolar (U_+=0 V) and bipolar (U_+=45 and 90 V) discharges in (a) closed-B and (b) open-B topologies using a negative current peak of 26 A. The changes induced by U_+ result in altering of the corresponding mean energy for both magnetron sources. Mind the double energy scale for Ar^{2+} and Ti^{2+}.

It is also shown that the Ar ion density has been found lower in the open-B topology, which may be particularly relevant for high quality film synthesis.

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