Reverse discharge in bipolar HiPIMS and its dependence on magnetic field geometry

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Bipolar high-power impulse magnetron sputtering (BP-HiPIMS) represents a variant of high-power impulse magnetron sputtering (HiPIMS) discharge where the application of a positive voltage pulse (PP) follows a HiPIMS sputtering negative voltage pulse (NP). This PP plays an important role in propelling ions toward the substrate, increasing the deposition rate of films and enhancing their densification and hardness. However, during the PP, there is sometimes registered a reduction in both plasma and floating potentials, which indicates a reverse discharge (RD) occurrence (see Fig. 1). The RD arises mainly from two factors [1]: the generation of secondary electrons by Ar^+ ions impinging on the grounded metallic surfaces in the vacuum chamber and the presence of the mirror configuration of the magnetron's magnetic field in the direction to the target. Since RD is maintained mainly by the generation of Ar^+ ions that are accelerated to the substrate, the presence of RD may lead to a deterioration of deposited film quality. Here, we will focus on the effect of the magnetic field geometry on the presence of the RD during PP.

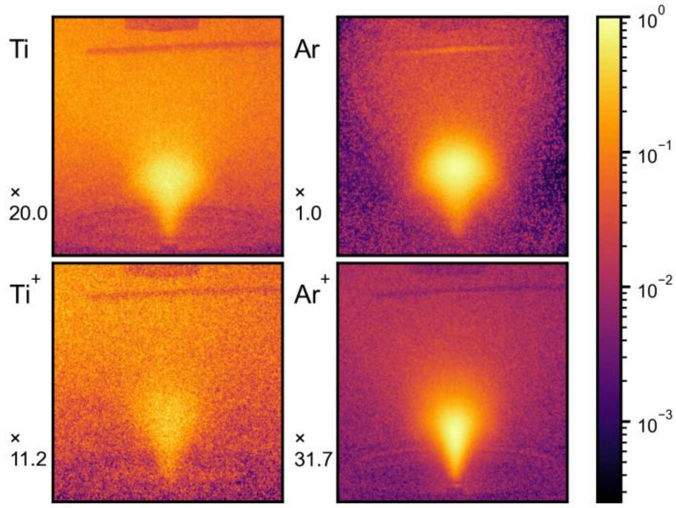

Fig. 1: Light emission from different plasma species proving the presence of RD during a long PP in BP-HiPIMS. Magnetron is positioned at the bottom and the substrate is at the top. Light is recorded by emICCD camera equipped with appropriate band-pass filters. Adapted from [1].

In the experimental setup, a BP-HiPIMS power supply was connected to a circular magnetron target made of titanium with a 100mm diameter. Adjustments to the magnetron's magnetic field, in terms of geometry and strength, were made by altering the positioning of its inner and outer permanent magnets. All experiments were carried out at a constant Ar pressure of 1Pa and an average power density in a period of 380Wcm^{-2}. The NP (a length of 100µs) was followed by the PP (a length of 500µs) after a delay of 10µs. The floating potential was monitored by wire probes located at the discharge centerline and distances of 35, 60, and 100mm from the target. An emICCD camera equipped with a band-pass filter (a central wavelength of 811nm and FWHM of 3nm) monitored light emission from Ar atoms with a time resolution of 5µs in the perpendicular direction to the discharge axis.

The findings indicate that the delay between the start of PP and the onset of RD, as evidenced by a drop in the floating potential, V_f, systematically decreases with a decrease in the outer magnetic field strength (transition from unbalanced to balanced magnetic field geometry). It is proved (see Fig. 2) that the drop in V_f relates to the RD ignition as the anode light patterns appear (the target is anode during PP). When the inner magnetic field strength is decreased (the magnetic mirror effect at the discharge centerline is weakened), the ignition of RD is postponed. For the weak inner magnetic field, the transition into RD is not registered during the whole PP. The geometry of the magnetic field also influences the shape of the anode light patterns recorded immediately after the RD ignition (see Fig. 2(b) II and V). These patterns evolve during PP into a common shape that resembles a "light bulb" (see Fig. 2(b) III and VI).

We can conclude that the geometry and strength of the magnetron's magnetic field are crucial in influencing the RD ignition during PP. By selecting an optimal magnetic field configuration, it may be possible to either prevent the RD formation or expedite its occurrence during PP in BP-HIPIMS discharges.

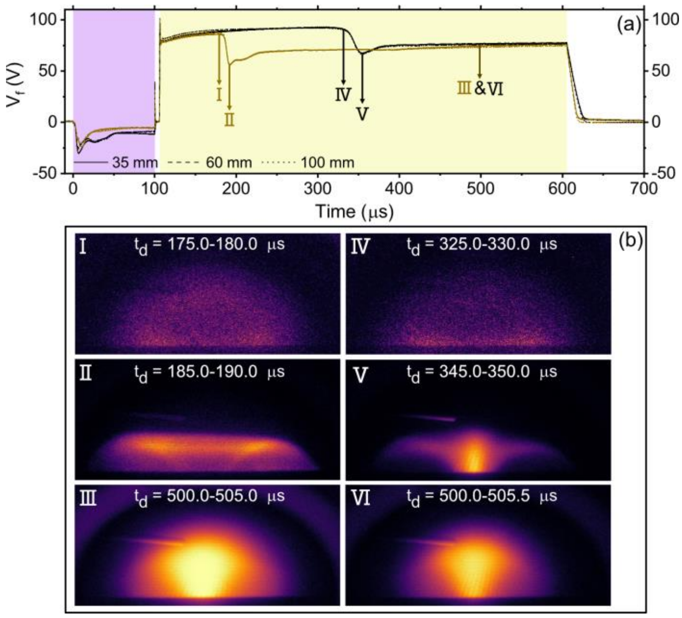

Fig. 2: (a) Time evolution of the floating potential (V_f) for unbalanced (black line) and balanced (brown line) magnetron's magnetic field configuration in BP-HiPIMS (purple and yellow sections of the graph mark NP and PP, respectively). (b) Light emission from Ar atoms recorded for both magnetic field configurations at times which corresponds to arrows in pane (a) marked by roman numerals. Adapted from [2].

[1] A.D. Pajdarová, T. Kozák, T. Tölg, J. Čapek: On double-layer and reverse discharge creation during long positive voltage pulses in a bipolar HiPIMS discharge, *Plasma Sources Sci. Technol.* 33 (2024) 055007.
[2] M. Farahani, A.D. Pajdarová, T. Kozák, J. Čapek: A reverse discharge in bipolar HiPIMS: The effect of the magnetic field configuration, *Plasma Sources Sci. Technol.*, prepared.