SPATIAL-RESOLVED OPTICAL EMISSION SPECTROSCOPY OF THE SPOKE IN NON-REACTIVE HIPIMS

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Spokes, also known as ionisation zones, have been observed at specific conditions in many types of magnetron sputtering discharges. This contribution shows the spatial-resolved optical emission spectroscopy of the spoke in non-reactive high power impulse magnetron sputtering discharge. Using the signals from a cylindrical probe and the fast photodiode the passing spoke was captured and its position was determined. The spatial-resolved emission of titanium atoms was investigated within the spoke for different working pressures.

1. Introduction

Over the last few years, it has been discovered that the plasma in a magnetron sputtering (MS) discharges is not always homogeneously distributed above the racetrack. Under certain conditions, the plasma is self-organised into rotating spokes [1], also known as ionisation zones [2]. They have already been observed in direct current magnetron sputtering (dcMS) [3, 4], high power impulse magnetron sputtering (HiPIMS) [1, 2, 5, 6] and radio frequency magnetron sputtering (rfMS) [7] discharges.

The spoke properties are highly dependent on the experimental conditions such as magnetic field strength, target material or the chamber geometry [8-12]. Based on the spoke shape, several groups can be distinguished: non-recognizable spokes, stochastic spokes, diffusive spokes, triangular spokes, and round spokes [13]. It has been found that the transition from the well recognizable spokes to homogeneously distributed plasma in non-reactive HiPIMS is only observed for the target materials with the second ionisation potential higher than the first ionisation potential of argon (15.76 eV), and a self-sputter yield larger than 1 [14].

The spokes usually rotate in the E × B direction in the HiPIMS discharges [1, 5, 6] with velocities of about 10 $km \cdot s^{-1}$, i.e., 10% of the electron drift velocity [1, 2, 5, 6, 15]. The spoke mode number is strongly dependent on the discharge current, working gas pressure, and magnetic field strength [9, 13, 16, 17]. Both, an increase [5, 13, 17, 18] as well as a decrease [9, 11, 13, 15, 16] in the spoke mode number were observed depending on the particular experimental setup.

For an in-depth insight of the spoke phenomena in HiPIMS, it is necessary to obtain extensive data of the plasma parameters inside the spoke, preferably by non-invasive diagnostic methods. This contribution shows the spatial-resolved optical emission spectroscopy (OES) of the spoke in HiPIMS discharge. The excitation temperature of Ti atoms was determined using Boltzmann plots.

2. Experimental setup

The experimental setup can be seen in figure 1. The pulses in the non-reactive HiPIMS discharge were 100 µs long with a repetition rate of 5 Hz. The 3-inch titanium target and argon as a working gas were utilised. The experiment was run at pressures: 0.4 Pa, 1.0 Pa and 1.6 Pa to investigate both triangular and round spokes [13].

Using the signals from the cylindrical probe and the fast photodiode the passing spoke was captured and its position was determined. Both signals were synchronised with the acquisition of the optical emission spectrum by the ICCD detector with the gate time of 100 ns. The emission spectra were acquired in a single-shot regime, i.e., for each spectrum exists one set of waveforms acquired at the same time from a single HiPIMS pulse.

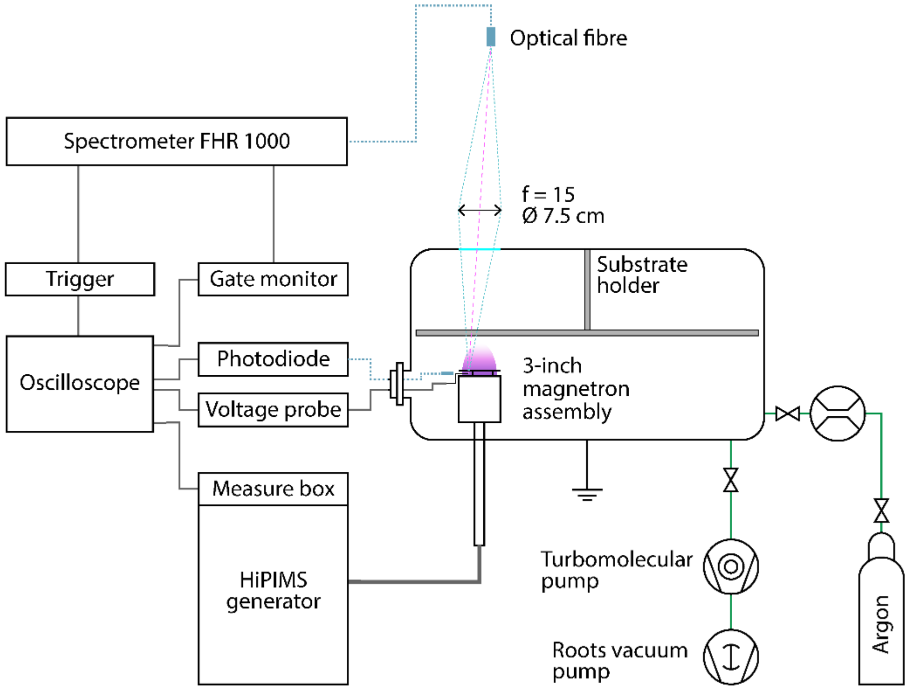

Fig. 1. Simplified scheme of the experimental setup.

3. Results

In figure 2, the intensities of the selected Ti I atom line (499.91 nm) are plotted for investigated working pressures and floating potential within the spoke. Taking into account various spoke lengths, the scale of the x-axis was normalized. Thus, 0 marks the head and 1 marks the tail of the spoke. The spoke was uniformly divided into 16 bins. Each point of the intensity evolutions in the graph in figure 2 is calculated as the mean of the integrated intensities of all spectra assigned to the appropriate bin by the time where the spectrum was captured. Characteristic evolution of titanium atom's spectral line intensities shows rather monotonous behaviour within the spoke for each measured working pressure. The floating potential of the spoke shown by the grey line in figure 2 remains stable in given discharge parameters.

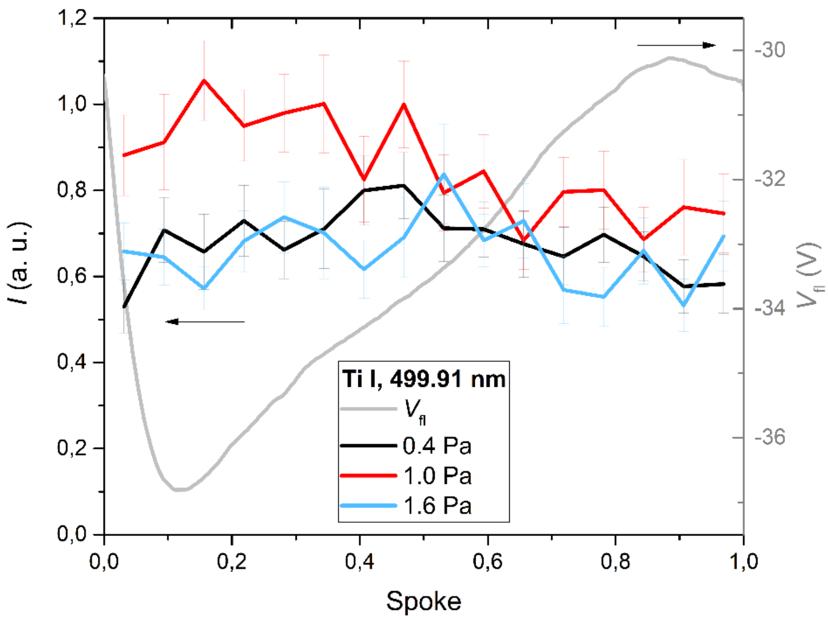

Fig. 2. The spatial-resolved evolution of Ti atom spectral line intensities within the spoke for pressures: 0.4 Pa, 1.0 Pa and 1.6 Pa in a reference to the floating potential within the spoke.

The excitation temperature of the Ti atoms was determined by the Boltzmann plot method. The typical one is shown in figure 3. The evolution of the excitation temperature within the spoke is shown in figure 4 for each investigated pressure. The excitation temperature is constant within the spoke in a margin of standard error for all used pressures. Despite the standard error of about 20%, the excitation temperature of the titanium atoms is approximately 8 000 K within the spoke for all measured pressures.

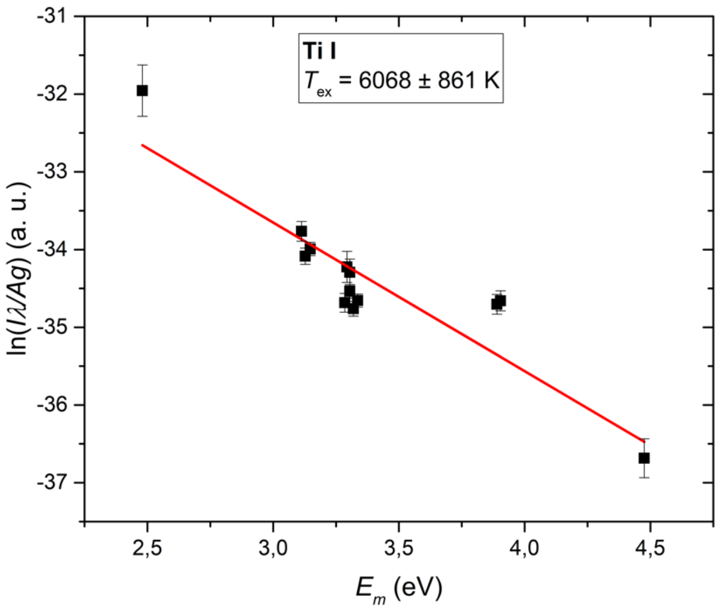

Fig. 3. Typical Boltzmann plot used for calculation of excitation temperature for the working pressure of 1.0 Pa.

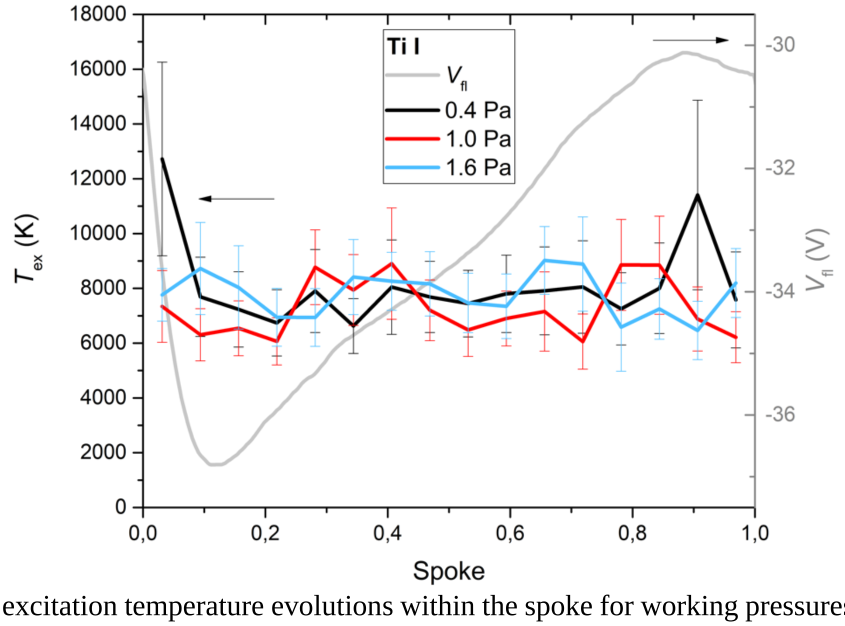

Fig. 4. The Ti I excitation temperature evolutions within the spoke for working pressures: 0.4 Pa, 1.0 Pa and 1.6 Pa in reference to the floating potential within the spoke.

4. Conclusion

The evolution of the titanium atom spectral line intensities and the floating potential within the spoke has been measured for working pressures: 0.4 Pa, 1.0 Pa and 1.6 Pa. The excitation temperature of the titanium atoms was determined by the Boltzmann plot method. The excitation temperature of the Ti atoms is approximately 8 000 K and remain constant within the spoke in a margin of standard error for all investigated pressures.

5. Acknowledgments

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