M U N I

COMMENTARY TO HABILITATION THESIS[1]

Diagnostics of High Power Impulse Magnetron Sputtering Discharge

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The presented thesis is divided into two chapters. The first chapter deals with plasma self-organization in high power impulse magnetron sputtering (HiPIMS), and the second chapter is dedicated to determining the absolute number density of sputtered species in the magnetron discharge.

In 2011, it was observed in HiPIMS discharges that in some cases, the plasma is not homogeneously distributed above the target, but it is concentrated in regions of enhanced ionization, called spokes. The spokes were observed only for a certain combination of experimental parameters, such as discharge current, operating pressure, and target material.

This work aims to show my contribution to the investigation of the spoke phenomena in HiPIMS discharge using optical emission spectroscopy, high-speed camera, and strip probes. Our extensive study of spoke images for various pressures, discharge currents, and magnetic fields led to the development of a methodology that allowed us to categorize spoke based on its appearance. The results from strip probes showed us how dynamic phenomenon spokes are and that a statistical approach is needed to study them.

The second part of the thesis is dedicated to investigating the number density of the sputtered titanium species in magnetron sputtering, which is one of the essential plasma diagnostics tasks. The time- and space-resolved dynamics of the sputtered species in the ground state is significant for understanding the plasma chemistry and kinetics and could be used to cross-validate the plasma models.

The objective of the work was to determine the density of titanium atoms and titanium ions in different places from the target surface in direct current magnetron sputtering and in HiPIMS. In the HiPIMS case, time-resolved measurements were also required. In this part of the thesis, I presented a simple, non-invasive optical method called the effective branching fraction method for studying the magnetron sputtering process. This method enabled us to determine the density of titanium atoms and titanium ions. Furthermore, we applied laser induced fluorescence and atomic absorption to estimate sputtered species density. These investigations brought essential information that contributed to understanding the HiPIMS discharge.

I have chosen eight research articles related to the spokes and dynamics of sputtered particles in HiPIMS discharge as a part of my thesis. My contribution to these articles is summarised in the following tables, with particular attention to the experimental work, supervision of students, manuscript preparation, and research direction.

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[1] The commentary must correspond to standard expectations in the field and must include a brief characteristic of the investigated matter, objectives of the work, employed methodologies, obtained results and, in case of co-authored works, a passage characterising the applicant's contribution in terms of both quality and content.

[1][2] KLEIN, Peter; HNILICA, Jaroslav; HUBIČKA, Zdeněk; ČADA, Martin; ŠLAPANSKÁ, Marta; ZEMÁNEK, Miroslav; VAŠINA, Petr. Cathode voltage and discharge current oscillations in HiPIMS. *Plasma Sources Sci. Technol.* 2017, 26, 055015.

Experimental work (%)	Supervision (%)	Manuscript (%)	Research direction (%)
30	50	35	15

[2] HNILICA, Jaroslav; KLEIN, Peter; ŠLAPANSKÁ, Marta; FEKETE, Matej; VAŠINA, Petr. Effect of magnetic field on spoke behaviour in HiPIMS plasma. *J. Phys. D: Appl. Phys.* 2018, 51, 095204.

Experimental work (%)	Supervision (%)	Manuscript (%)	Research direction (%)
25	100	50	90

[3] KLEIN, Peter; LOCKWOOD ESTRIN, Francis; HNILICA, Jaroslav; VAŠINA, Petr; BRADLEY, James W. Simultaneous electrical and optical study of spoke rotation, merging and splitting in HiPIMS plasma. *Plasma Sources Sci. Technol.* 2017, 50, 015209.

Experimental work (%)	Supervision (%)	Manuscript (%)	Research direction (%)
30	50	25	10

[4] KLEIN, Peter; HNILICA, Jaroslav; ZEMÁNEK, Miroslav; BRADLEY, James W; VAŠINA, Petr. The statistics of spoke configurations in high-power impulse magnetron sputtering discharges. *J. Phys. D: Appl. Phys.* 2019, 52, 125201.

Experimental work (%)	Supervision (%)	Manuscript (%)	Research direction (%)
35	50	30	20

[5] VAŠINA, Petr; FEKETE, Matej; HNILICA, Jaroslav; KLEIN, Peter; DOSOUDILOVÁ, Lenka; DVOŘÁK, Pavel; NAVRÁTIL, Zdeněk. Determination of titanium atom and ion densities in sputter deposition plasmas by optical emission spectroscopy. *Plasma Sources Sci. Technol.* 2015, 24, 065022.

Experimental work (%)	Supervision (%)	Manuscript (%)	Research direction (%)
10	25	20	-

[6] FEKETE, Matej; HNILICA, Jaroslav; VITELARU, Catalin; MINEA, Tiberiu; VAŠINA, Petr. Ti atom and Ti ion number density evolution in standard and multi-pulse HiPIMS. *J. Phys. D: Appl. Phys.* 2017, 45, 055201.

Experimental work (%)	Supervision (%)	Manuscript (%)	Research direction (%)
35	50	30	25

[2] Bibliographic record of a published scientific result, which is part of the habilitation thesis.

[7] HNILICA, Jaroslav; KLEIN, Peter; VAŠINA, Petr; SNYDERS, Rony; BRITUN, Nikolay. Revisiting particle dynamics in HiPIMS discharges. I. General effects. *J. Appl. Phys.* 2020, 128, 043303.

Experimental work (%)	Supervision (%)	Manuscript (%)	Research direction (%)
50	-	40	90

[8] HNILICA, Jaroslav; KLEIN, Peter; VAŠINA, Petr; SNYDERS, Rony; BRITUN, Nikolay. Revisiting particle dynamics in HiPIMS discharges. II. Plasma pulse effects. *J. Appl. Phys.* 2020, 128, 043304.

Experimental work (%)	Supervision (%)	Manuscript (%)	Research direction (%)
50	-	40	90