Sensitivity analysis of various physics processes in industrial HiPIMS: A global plasma modelling perspective

Kristína Tomanková(*)[1,2], Kryštof Mrózek[1,2], Adam Obrusník[2], Alexander Fromm[3], Frank Burmeister[3]

[1] *Department of Plasma Physics and Technology, Masaryk University, Brno 611 37, Czech Republic*

[2] *PlasmaSolve s.r.o., Brno 602 00, Czech Republic*

[3]*Fraunhofer Institute for Mechanics of Materials IWM, Freiburg 79108, Germany*

(*) *kristinatomankova@mail.muni.cz*

High Power Impulse Magnetron Sputtering (HiPIMS) presents a revolution in the coating industry, enabling the production of superior-quality thin films with high density. As opposed to conventional magnetron sputtering, power fed into a HiPIMS process takes the form of short highly energetic pulses followed by a longer off-time allowing for cooling of the target. The HiPIMS plasma is then characterized by a high degree of ionization. [1] However, introducing peak power of amplitudes up to two orders of magnitude higher than during regular magnetron sputtering unveils a whole new range of physics phenomena that govern the process. Understanding these processes on a deep level is crucial in order to enhance the efficiency of this technology, especially on a larger scale. In this context, physics-based numerical simulations stand out as a valuable tool to provide insight into such complex plasma processes. Considering that one experiment with an industrial HiPIMS coater requires 100-800 kWh of electricity to run, plus additional material and operational costs, a well-validated predictive simulation model would enable significant energy and material savings.

This contribution presents a time-dependent volume-averaged global plasma model of reactive HiPIMS that can predict the overall behavior and macroscopic response to variations in operational parameters. This model is designed to reflect the functionality of a commercial HiPIMS coater used for deposition of Al_2O_3 and SiO_2 thin films.

Even though literature features several advanced HiPIMS models [2], works aiming for a detailed model description of HiPIMS for practical and industrial applications are still rare. The developed models typically require many non-orthogonal tuning parameters or they lack experimental validation.

In contrast to previously published global models, our approach was to develop the model from the ground up, focusing on each key physics phenomenon intrinsic to HiPIMS. Utilizing the high computational efficiency of global models, it is possible to clearly demonstrate the importance of various physics processes in a very short amount of time. We perform a sensitivity analysis on multiple effects to quantitatively outline their influence on the process. The analysis covers phenomena like sputter wind, target heating, ion return probability or target poisoning. Additionally, an estimation of the model inaccuracy is presented with respect to the plasma kinetic system and different rate coefficient expressions. In this context, our research involves a "stepping back" from already published numerical models that include dozens of source terms, and it is not clear whether all these source terms hold equal importance.

The contribution will also describe concrete steps that we are undertaking towards the development of a spatial model of an industrial HiPIMS process and preliminary simulation results, if available. The ultimate goal is to reach a „digital twin" of HiPIMS by employing a combination of different simulation methods.

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