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On three different ways to quantify the degree of ionization in sputtering magnetrons

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High power impulse magnetron sputtering (HiPIMS) is an ionized physical vapor deposition (IPVD) technique that has received significant interest lately [1]. However, proper definitions of the various concepts of ionization are lacking while quantification and control of the fraction of ionization of the sputtered species are crucial in magnetron sputtering, and in particular in HiPIMS deposition. Here we distinguish between three approaches to describe the degree (or fraction) of ionization: the ionized flux fraction F_{flux}, the ionized density fraction F_{density}, and the fraction α of the sputtered metal atoms that become ionized in the discharge (sometimes referred to as probability of ionization). By studying a reference HiPIMS discharge with a Ti target, we show how to extract absolute values of these three parameters and how they vary with peak discharge current. Using a simple model, we also identify the physical mechanisms that determine F_{flux}, F_{density}, and α as well as how these three concepts of ionization are related. This analysis finally explains why a high ionization probability does not necessarily lead to an equally high ionized flux fraction or ionized density fraction.

[1] J. T. Gudmundsson, N. Brenning, D. Lundin and U. Helmersson, High power impulse magnetron sputtering discharge, Journal of Vacuum Science and Technology A, 30(3) (2012) 030801

[2] A. Butler, N. Brenning, M. A. Raadu, J. T. Gudmundsson, T. Minea and D. Lundin, On three different ways to quantify the degree of ionization in sputtering magnetrons, Plasma Sources Science and Technology, 27(10) (2018) 105005

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