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High Power Impulse Magnetron Sputtering: An overview on the benefits of ultra-short pulse operating mode

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This work highlights the benefits of operating the HiPIMS discharge in ultra-short pulse (< 10μs) mode, with the help of a comparative analysis on the results corresponding to the topological, structural and mechanical characterization of Cu thin films deposited by dcMS and HiPIMS. Operating the HiPIMS discharge with ultra-short pulses of 3μs, in the presence of an additional magnetic field, makes it possible to grow high-quality thin films, with low RMS surface roughness, high hardness to Young's modulus ratio, and low coefficient of friction. The additional magnetic field changes the plasma sheath's properties, improves the ion transport towards the substrate, leading to high metal ionized flux fraction and high deposition rates.

High Power Impulse Magnetron Sputtering (HiPIMS), an attractive physical vapour deposition technology, has revolutionized the abilities of magnetron sputtering, enabling new perspectives in thin films engineering, especially due to its dense plasma and high ionization degree of sputtered material.

The main aim of the present study was to make a step towards HiPIMS industrialization, trying to overcome its deposition rate drawback, which may have serious economic consequences for industrial process, to optimize its process and to enhance and tailor the properties of thin films deposited by HiPIMS / reactive-HiPIMS from a large variety of sputtering targets ($Fe_{73.5}Cu_1Nb_3Si_{15.5}B_7$, Ti, Ni, Cu, Zn, Ta, W etc.).

To fulfill the goal, we investigated the processes occurring at the target and substrate surface, as well as the target-to-substrate particle transport processes. Cathode voltage and current waveforms, fast imaging, tunable diode-laser induced fluorescence, tunable diode-laser absorption spectroscopy, time-resolved optical emission spectroscopy, time-averaged ion current of an electrical probe, energy-resolved mass spectrometry and deposition rate investigations were performed for this purpose.

The results of all our studies have led to the same conclusion: operating the HiPIMS discharge with ultra-short pulses (< 10 μs) offers several remarkable benefits: (*i*) enhancement of deposition rate (we found that in HiPIMS assisted by an external magnetic field created with a toroidal-shaped permanent magnet placed in front of a strong balanced magnetron, for some materials, the deposition rate is even higher compared with the case of conventional *dc* magnetron sputtering) [1]; (*ii*) possibility to control the ionization degree which allows to tune the properties of the films (density, adhesion, hardness, friction and roughness) [2]; (*iii*) stoichiometry preservation in the case of films sputtered from multi-elements targets. There are a few other benefits, worth mentioning, for the reactive HiPIMS discharge as: (*i*) hysteresis reduction; (*ii*) overcoming the problems related to the transition between metal and compound mode; *(iii)* avoidance of electric arc development; (*iv*) possibility to tune the composition and structure of elemental or compound (oxides, nitrides and oxinitrides) thin films [3].

To exemplify some of these benefits, the table below presents values of deposition rate (S), fraction of ionized metal species flux (Θ), RMS surface roughness (R), average grain size (D), hardness (H), and Young's modulus (E) corresponding to 800 nm nanocrystalline Cu thin films deposited by direct current magnetron sputtering (dcMS) and HiPIMS operated with ultra-short pulses of 3 μs in the presence / absence of an additional magnetic field (*m.f.*).

	S (Å/s)	Θ (%)	R (nm)	D (nm)	H (GPa)	E (GPa)
dcMS	5.8	3	12.1	11.3	2.6	119.6
HiPIMS	3.8	50	5.8	24.7	2.9	129.5
m.f.-HiPIMS	7.7	80	1.5	35.6	3.7	148.2

References

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