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Synchronized metal-ion irradiation as a way to control growth of transition-metal nitride alloy films during hybrid HIPIMS/DCMS co-sputtering[1]

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High-power pulsed magnetron sputtering (HIPIMS) is particularly attractive for growth of transition metal (TM) nitride alloys for two reasons: (i) the high ionization degree of the sputtered metal flux, and (ii) the time separation of metal- and gas-ion fluxes incident at the substrate. The former implies that ion fluxes originating from elemental targets operated in HIPIMS are distinctly different from those that are obtained during dc magnetron sputtering (DCMS), which helps to separate the effects of HIPIMS and DCMS metal-ion fluxes on film properties. The latter feature allows one to minimize compressive stress due to gas-ion irradiation, by synchronizing the pulsed substrate bias with the metal-rich-plasma portion of the HIPIMS pulse. Here, we use pseudobinary TM nitride model systems TiAlN, TiSiN, TiTaN, and TiAlTaN to carry out experiments in a hybrid configuration with one target powered by HIPIMS, the other operated in DCMS mode. This allows us to probe the roles of intense and metal-ion fluxes (n = 1, 2) from HIPIMS-powered targets on film growth kinetics, microstructure, and physical properties over a wide range of M_1M_2N alloy compositions. TiAlN and TiSiN mechanical properties are shown to be determined by the average metal-ion momentum transfer per deposited atom. Irradiation with lighter metal-ions (M_1 = Al^+ or Si^+ during M_1-HIPIMS/Ti-DCMS) yields fully-dense single-phase cubic $Ti_{1-x}(M_1)_xN$ films. In contrast, with higher-mass film constituent ions such as Ti^+, easily exceeds the threshold for precipitation of second phase w-AlN or Si_3N_4. Based on the above results, a new PVD approach is proposed which relies on the hybrid concept to grow dense, hard, and stress-free thin films with no external heating. The primary targets, Ti and/or Al, operate in DCMS mode providing a continuous flux of sputter-ejected metal atoms to sustain a high deposition rate, while a high-mass target metal, Ta, is driven by HIPIMS to serve as a pulsed source of energetic heavy-metal ions to densify the dilute TiTaN and/or TiAlTaN alloys. No external heating is used and the substrate temperature does not exceed 120 C. This development allows for widening the application range of hard TM nitride coatings to new classes of technologically-relevant temperature-sensitive substrates, such as components made by plastics, glasses, aluminum alloys, and tempered steels.

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