Linking Intrinsic Plasma Characteristics to the Microstructure and Properties of Thin Films

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From its inception, the benefits of sputter deposition have stemmed from the presence of plasma in the vicinity of the growing film. Bombardment with charged particles and energetic photons affect the substrate initial condition and all stages of film growth: nucleation, coalescence, texture evolution, and recrystallization. Measuring and controlling the fluxes and energies of the charged particles incident at the substrate is essential to achieving low-temperature growth of high-quality thin films. Under typical direct current magnetron sputtering (DCMS) conditions, the dominant ion species incident at the growth surface while sputtering with N_2/Ar gas mixtures optimized to obtain stoichiometric nitride films is Ar^+, while the ratio of the gas-ion flux to deposited metal flux J_i/J_{Me} is ≤ 1. Densification is achieved by increasing the ion energy E_i commonly above 100 eV. However, at higher ion energies, a steep price is extracted in the form of residual ion-induced compressive stress resulting from both recoil implantation of surface atoms and trapping of rare-gas ions in the lattice. An alternative approach is offered by strongly magnetically-unbalanced magnetron sputter deposition systems, which allow ion-to-neutral flux ratios J_i/J_{Me} incident at the growing film to be varied over extremely wide ranges (up to > 20) at very low ion energies ($E_i \sim$ 10-20 eV) (below the lattice displacement threshold). Using high-flux, low-energy ion irradiation during deposition opens new kinetic pathways to independently control the texture (from completely 111 to completely 200) and microstructure (from underdense to fully dense) in transition metal (TM) nitride films grown on amorphous substrates as well as to achieve low-temperature epitaxy of refractory materials and metastable alloys.

The invention of high power impulse magnetron sputtering (HiPIMS) opened the way to exploit metal-ion irradiation, which is particularly attractive for low-temperature growth of refractory ceramic thin films. HiPIMS discharges can ionize up to 90% of the sputtered metal flux; equally important is the time separation between metal- and gas-ion fluxes incident at the substrate. In recent years, it has been demonstrated that the use of synchronized bias to select the metal-rich portion of the ion flux provides a new dimension for ion-assisted growth in which momentum can be tuned by selection of the metal ion in the hybrid/cosputtering configuration and stresses can be eliminated/reduced since the metal ion is a component of the film. Thus, the control of intrinsic plasma conditions continues to drive research and caters to tooling-component, and microelectronics industry, as will be exemplified in the presentation.