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Understanding Analytically: Role of Hydrogen in Plasma Nitriding

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We present an analytical model to understand role of hydrogen in plasma nitriding. Using this model the change in density of N_2^+ and H_2^+ ions at plasma sheath-edge for various N_2 and H_2 composition in the gas mixture has been estimated. At plasma sheath boundary energetic electrons from the cathode surface, i.e. secondary electrons, cause intense ionization. Moreover, the discharge current is directly related to secondary electron emission coefficient (γ_e) and ion current. In typical nitriding N_2-H_2 discharge, the ion current due to two ions species (N_2^+ and H_2^+) depends on ionization cross-section (σ) and partial pressure of the gas. The ionization cross-section of N_2, i.e., is ~ 2.5 times larger than the ionization cross-section of H_2, for electron energy ranging between 30-300 eV. The analytical model showed that for 30%N_2-70%H_2 gas composition the ion current N_2^+ and ion current for H_2^+ ions at plasma sheath edge are nearly equal. With increasing nitrogen partial pressure N_2^+ ion concentration increases and hence the ion current. This result obtained from analytical modelis consistent with detailed spectroscopic investigation that has been carried out to understand the role of hydrogen byidentifying the species at the substrate surface and plasma sheath-edge. In this experiment, dominant species near the substrate surface were atomic nitrogen N and atomic hydrogen H, however at plasma sheath-edge dominant ionic species were N_2^+ and H_2^+ for all N_2-H_2 composition. These observations are self consistent with the mechanism that N_2^+ and H_2^+ ions at plasma sheath-edge are formed by electron impact ionization at plasma sheath-edge and accelerate via sheath, on reaching cathode, i.e. the substrate surface, N_2^+ and H_2^+ ions dissociate on impact. It directly implies that for 30%N_2-70%H_2 gas composition the concentration of atomic nitrogen [N] and atomic hydrogen [H] are equal, i.e. [N]=[H] andexplains the formation of single phase nitrided layer containing a-Fe (N) structure. However,when[N] ≥ [H]a multi-phased, multi-layered nitrided structures with $Fe_{2\text{-}3}N$ (ε) + Fe_4N (γ') is formed.

Keywords
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