Self-Organization of Ripples on Titanium Sputtered with Focused Ion Beam

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We report the formation and self-organization of nano- and micro-scale structures during sputtering of titanium crystal surface at room temperature with a rastered 1 nA, 30 keV Ga+ Focused Ion Beam (FIB). We use in-situ real-time secondary ion and secondary electron imaging to follow the evolution of surface features from a low dose of $7.5 \times 10^{16}$ ions/cm$^2$ to a high dose of $4.8 \times 10^{18}$ ions/cm$^2$ and characterize the final surface morphology using AFM. In contrast to usual expectation that surface topology produced at normal ion beam incidence consists of hillocks or depressions, we observe periodic ripples with regular spacing. We provide evidence to demonstrate that the ripples form spontaneously rather than by “direct writing” of the FIB. Ripples on surface of a single crystal are oriented in the same direction, but the ripple orientation changes with the crystallographic orientation of the sputtered titanium crystal surface. We explain the observation using a model in which the ripple structure is the result of the balance between the erosion rate and the anisotropic diffusion of adatoms and vacancies on surface activated by the ion beam sputtering. When the ion beam is tilted by a small angle up to 30 degree, the ripple orientation is still determined by the crystallographic direction. However, when the FIB incident angle is increased to 45 or 60 degree, curved ripples occur at high ion doses. No existing models can explain the morphological evolution from the well developed straight ripples to the curved ones. We therefore attempt to present a new model, which attributes the formation of curved ripples to competition between the formation of ripples due to adatom surface diffusion and the formation of incident-angle dependent Bradley-Harper type ripples.