The Roles of Secondary Electrons and Sputtered Atoms in Ion-Beam-Induced Deposition

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The direct writing technology of ion-beam-induced deposition (IBID) is a powerful tool for prototyping 3D nanostructures due to its high flexibility for the shape and location of the deposits. To gain full control over the dimension and purity of the deposits, a detailed understanding of the mechanisms of IBID is required. The decomposition of precursor molecules in IBID has been postulated to be caused by: primary ion impact, sputtered atom impact, secondary electron impact, and thermal spikes.[1] Several studies have examined issues related to the sputtered atom impact[2] or secondary electron impact[3]. However, it is still an open debate which one plays a more important role. In this paper, we concentrate particularly on the separate contributions of sputtered atoms and secondary electrons in IBID by comparing the *in-situ* measured yields of deposition, sputtering and secondary electron emission as functions of Ga^+ focused ion beam incident angle θ (0°-45°) and energy E (5-30 keV) (Fig. 1). $(CH_3)_3Pt(C_PCH_3)$ was used as precursor.

We found that deposition yield *Yd* has the same angular dependence as secondary electron yield *Yse* $[1/\cos(\theta)^{1.35}]$, but weaker than that of sputtering yield *Ys* $[1/\cos(\theta)^{2.0}]$ (Fig. 2a). It clearly suggests deposition has a stronger correlation to secondary electrons, than to sputtered atoms. As shown in Fig. 2b, *Yse* and *Ys* change faster with energy than *Yd* does. However, no clear correlations between energy dependences of *Yd, Yse* and *Ys* have been found. It is known that the energy spectrum of secondary electrons shifts to a lower value with decreasing ion beam energy,[4] and the dissociation cross section for precursor molecules depends on electron energy.[5] Therefore, for different ion beam energies, only the comparison of the yields is not enough to build a clear correlation between deposition and secondary electron emission, probably *the energy* of secondary electrons also has to be taken into account. Further work on the energy spectrum of secondary electrons and the energy dependent electron-impact-cross section would allow us to build a more detailed model.

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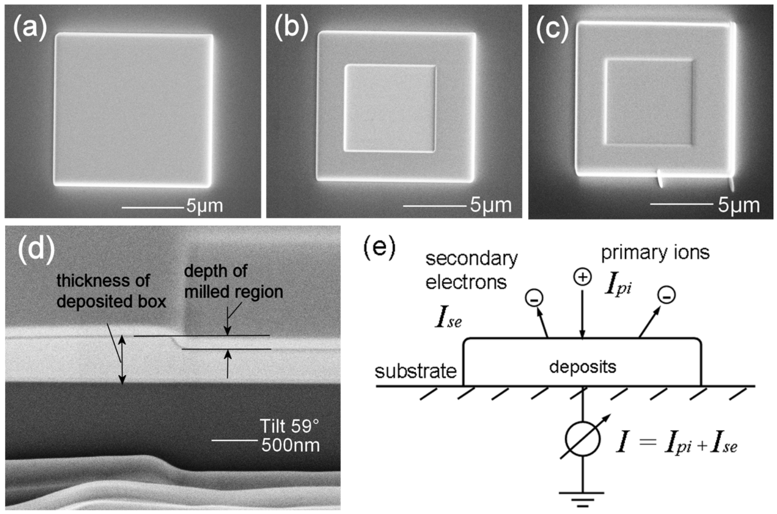

Figure 1: Processes of *in-situ* measurement of (a-d): deposition and sputtering yield, and (e): secondary electron yield. SEM images of (a) a IBID Pt box grown on Si substrate; (b) central part of the box, milled with same FIB settings but without precursor exposure; (c) a EBID marker layer plus an IBID protection layer; d) deposition thickness and sputtering depth were determined by cross sectioning; (e) sketch of sample current measurement. I_{pi} and I_{se} are the currents of primary ions and secondary electrons, respectively.

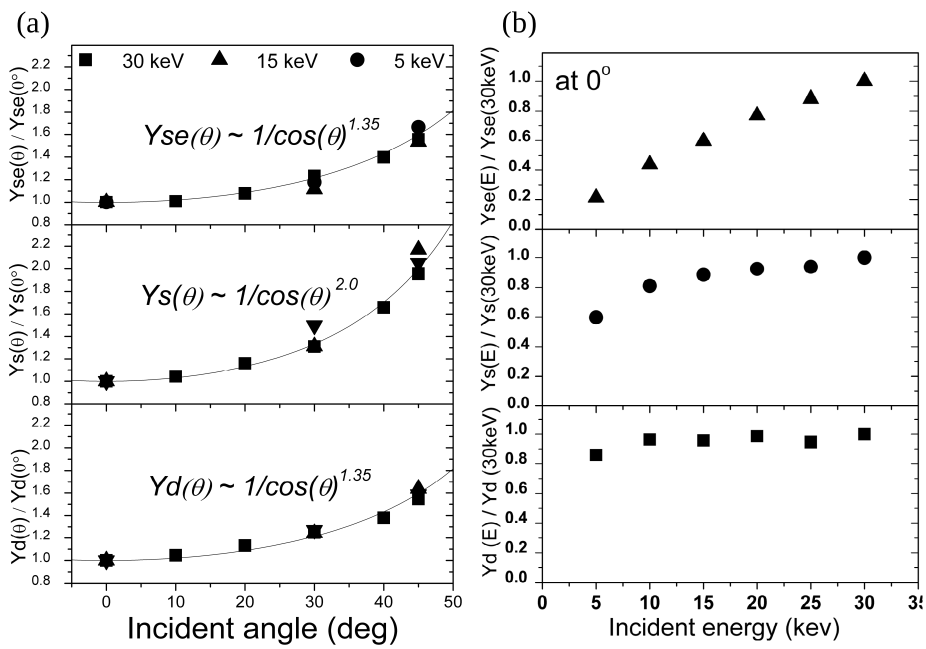

Figure 2: Angular and energy dependences of *in-situ* measured deposition yield *Yd*, sputtering yield *Ys* and secondary electron yield *Yse*. (a) Angular dependence of *Yd, Ys* and *Yse* measured with different beam energies. All *Yd, Ys* and *Yse* have been normalized to 0^o. (b) Energy dependences of *Yd, Ys* and *Yse* measured at 0^o. In all cases, the ion beam current density was 0.5 pA/μm^2.