Pillar Growth Rate Dependences in Ion-Beam-Induced Deposition

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Ion-Beam-Induced Deposition (IBID) is a process in which precursor molecules absorbed on a substrate surface are decomposed by an ion induced reaction, resulting in a localized material deposition. Due to its high flexibility for the shape and location of the deposits, IBID is a powerful tool for prototyping 3D nanostructures, such as pillars. It has advantage over a closely related technique of Electron-Beam-Induced Deposition (EBID) on growth rate. However, higher growth rate is still in demand. IBID (EBID)-pillar growth rate can be controlled by changing parameters as ion beam energy and current,[1] and the precursor pressure.[2] In this work, we particularly concentrate on the effect of the precursor substrate residence time on IBID-pillar growth, by changing the substrate temperature, and ion beam dwell time and refreshment time.

Pillars were grown on a Si substrate with a 1 pA 30 keV Ga^+ FIB at normal incidence using a $(CH_3)_3Pt(C_PCH_3)$ precursor. We found that the vertical growth rate increases significantly with decreasing substrate temperature T in a small range (30-15 ^oC), while the lateral resolution increases slightly (Fig. 1). With decreasing dwell time τ_d or increasing refreshment time τ_r, the vertical growth rate increases (Fig. 2a-b). Refreshment time dependence is more pronounced with a short dwell time than with a long one (Fig. 2b-c). With an optimal combination of these parameters, the vertical growth can be enhanced nearly tenfold as compared to under the usual growth condition shown in Fig. 1; while the lateral resolution is almost unaffected (Fig. 3). In conclusion, this work suggests that to enhance the pillar growth rate, increasing the precursor residence time on the substrate is preferable to increasing the precursor pressure in the whole chamber,[2] in particular with concerns for cost and safety. It also indicates that under most IBID conditions, the pillar growth rate is limited by the supply of the precursor, not ions. Thus, this work would improve our understanding on the complex ion-precursor interaction involved in IBID.

[1] K. T. Kohlmann-von Platen et al.: J. Vac. Sci. Technol. B **10** 2690 (1992).
[2] Y. R. Choi et al.: Scanning **28** 311 (2006).

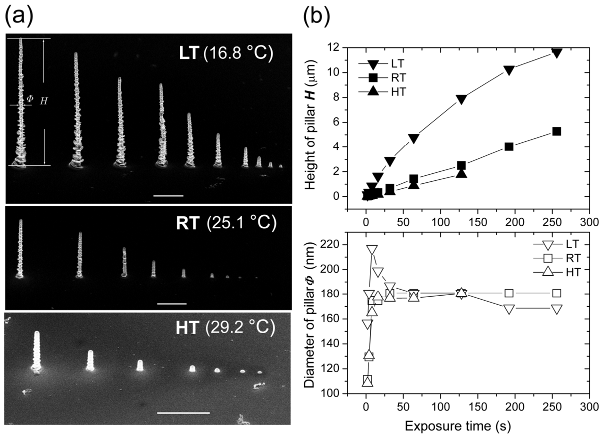

Figure 1: Effect of substrate temperature T effect on IBID-pillar growth. (a) Tilted 52^{o} SEM images of three pillar groups grown at spot mode with different exposure times, and at different substrate temperatures (scale bar: 2 μm); (b) Diameter Φ and height H of pillars. The measurement of the pillar diameter did not include the side-wall extensions.

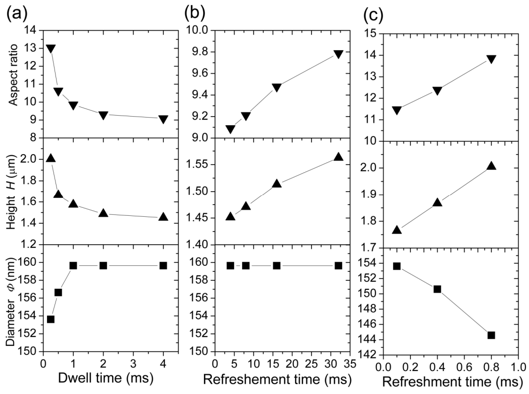

Figure 2: Effects of ion beam dwell time τ_d and refreshment time τ_r on IBID-pillar growth. DiameterΦ, height H, and aspect ratio of pillars grown with (a) different τ_d and a long τ_r (4.0 ms); different τ_r and (b) a long τ_d (4.0 ms) or (c) a short τ_d (0.1 ms). In (a-c), all pillars were grown at room temperature, and the total exposure time for each pillar was 60 s.

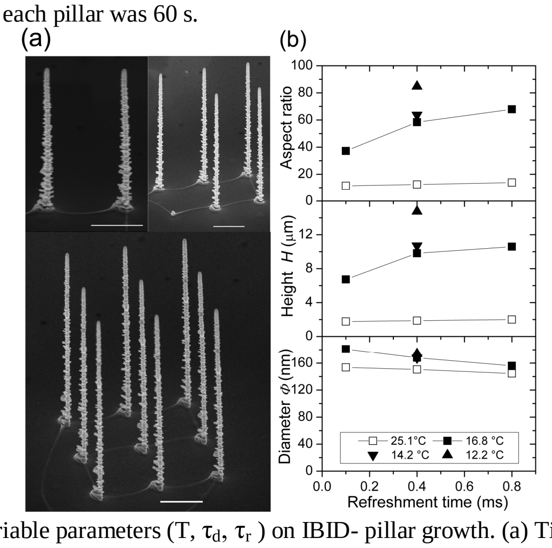

Figure 3: Effects of variable parameters (T, τ_d, τ_r) on IBID- pillar growth. (a) Tilted 52^{o} SEM images of pillars grown at 16.8 ^{o}C (scale bar: 2 μm); (b) diameterΦ, height H, and aspect ratio of pillars. In (a-b) all pillars were grown with a short dwell time τ_d (0.1 ms), and the total exposure time for each pillar was 60 s.