Electron post-irradiation of platinum nano-structures created by electron-beam-induced deposition from $Pt(PF_3)_4$

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Electron-beam-induced deposition[1,2] (EBID) allows the rapid fabrication of three-dimensional nano-devices and metallic wiring of nano-structures within a scanning electron microscope (SEM). Deposited structures often contain undesirable contaminants such as carbon or oxygen as a result of species present in the precursor and contaminants from the vacuum chamber and the substrate. To mitigate carbon co-inclusion in deposits, a carbon-free precursor, tetrakis trifluorophosphine platinum ($Pt(PF_3)_4$) can be used, and several reports on its use are now published.[3] We previously reported results with this precursor where we observed the deposits were essentially amorphous.[4]

Since then, other reports[5,6] have shown evidence that deposits from this precursor yield deposits containing nanocrystalline platinum. We show the results of further experiments where we demonstrate that the morphology of the deposits changes with the electron fluence, and that the degree of platinum nanocrystallinity (as evidenced by TEM and SAD analysis) can be increased by post-irradiating the deposit with electrons (Figures 1 and 2). For the first time we demonstrate that beam-induced crystallinity in EBID deposits can be achieved using electron doses similar to those achieved in the course of normal deposition. As a result, the SEM operator can directly control the morphology of the created deposits according to desired specification of nanocrystallite sizes, *in-situ* without breaking vacuum.

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[1] S.J. Randolph, J.D. Fowlkes and P.D. Rack, Crit. Rev. Solid State and Mat. Sci. **31**, 55–89 (2006)
[2] N.Silvis-Cividjian and C.W. Hagen, Electron beam induced Nanometer scale deposition, in Advances in Imaging and Electron Physics, Vol. 143, Academic Press, 2006, ed. P.W. Hawkes.
[3] J. D. Barry *et al.*, J. Vac. Sci. Technol. B **24**, 3165–3168 (2006)
[4] A. Botman, M. Hesselberth and J. J. L. Mulders, J. Vac. Sci. Technol. B **26**, 2464-2467 (2008)
[5] J. Li, M. Toth, A. Botman, K. A. Dunn, C. J. Lobo, R. L. Moore and B. L. Thiel, manuscript in preparation
[6] M. Takeguchi, M. Shimojo and K. Furuya, Appl. Phys. A **93**, 439-442 (2008)

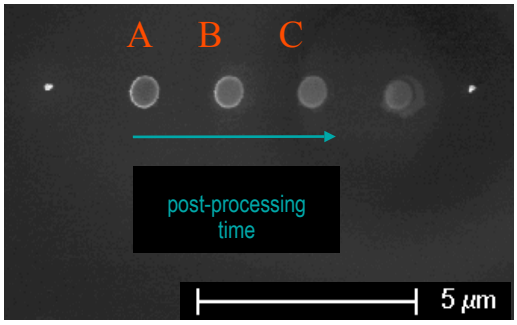

Figure 1: Four identically-made large deposits from $Pt(PF_3)_4$ performed in low-vacuum mode (0.16 Torr) onto a bulk Si substrate with a defocused stationary beam (20 kV, 790 pA, 4 minutes), between two focused pillar deposits (used as markers). Deposit A was not post-irradiated; deposit B was post-irradiated with electrons at 20 kV and 7.2 nA for 2 minutes (over the same area as the deposit) and C for 10 minutes.

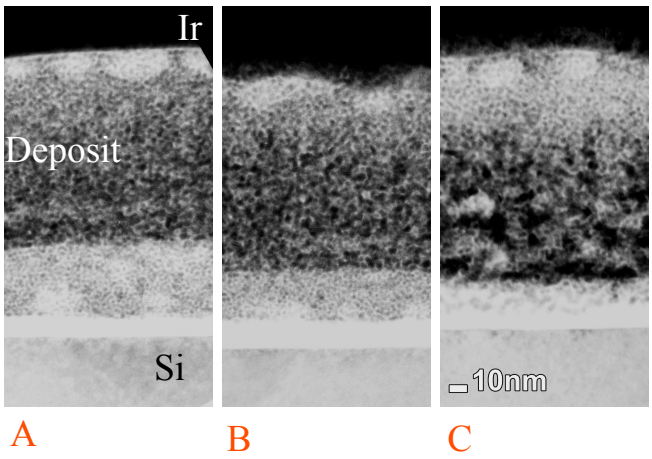

Figure 2: STEM-HAADF cross-section images of deposits A, B and C from Figure 1 (covered with Iridium as protection during the lift-out sample preparation before TEM analysis). The material contains platinum nanocrystallites (confirmed by SAD analysis), whose size and density increase as a function of electron post-irradiation. The other features present in these images will also be discussed.