Anneal effects on electron beam induced deposits of platinum from $Pt(PF_3)_4$

Matthew H. Ervin, Daniel Chang, Barbara Nichols, and Alma Wickenden
U.S. Army Research Laboratory, 2800 Powder Mill Road
Adelphi, MD 20783, USA

John Barry and John Melngailis
Institute for Research in Electronics and Applied Physics
University of Maryland, College Park, MD 20742, USA

We are investigating electron beam induced deposition (EBID) as a damage-free and resist-less means of incorporating non-conventional materials such as polymer fibers, nanowires and carbon nanotubes (CNTs) into integrated circuits. A novel inorganic platinum precursor – $Pt(PF_3)_4$ – is used in this work, as it has been previously demonstrated to deposit Pt with conductivity close to bulk Pt when deposited using high dose rates.[1] Pt depostitions were carried out in an FEI 620 dual beam system (FIB/SEM) using a 10kV electron beam and a gas delivery needle while keeping the chamber pressure at about $2.0 * 10^{-5}$ mBar.

While previous work has shown that the Pt resistivity was lower when it was deposited using higher beam currents, [1] device resistances were also observed to decrease when EBID contacted devices were annealed at relatively low temperatures. This should not be surprising as beneficial effects of elevated temperatures (during deposition) have also been found for ion beam-formed copper contacts.[2] This suggests that annealing may improve the quality of EBID-formed contacts perhaps by driving off reaction-byproducts/contaminants. Here deposits were annealed on a hot plate at 100^o C and 200^o C, under a constant flow of nitrogen gas, for 30 minutes per anneal step. Figure 1 shows the shrinkage of a thick deposit as a function of anneal temperature. Figure 2 shows that a 0.5 micron thick deposit shrinks by 16% when annealed at $100\,^o$ C. EDX was used to measure the chemical composition of the deposits before and after annealing. While there was no significant F peak in the spectra, there was a noticeable P contribution which unfortunately was unresolved from the Pt M-line peak. Therefore, the spectra were normalized to the Pt L-line peak so that a change in the combined P K-line/Pt M-line peak represented a change in the P concentration. The P concentration decreased with annealing, qualitatively confirming that the deposit purity improved. Experiments are under way to determine if, and by how much, annealing improves the Pt conductivity.

$Pt(PF_3)_4$ EBID contacts were use to contact a carbon nanotube (CNT) which had been nanomanipulated (with a Zyvex S100 in a Hitachi S4500 SEM) onto gold contacts on SiO_2/n++ Si in order to fabricate a back-gated field effect transistor (FET). This CNT FET, shown in Figure 3, passed current demonstrating successful integration of the CNT into the circuit. Annealing this device resulted in a reduction of the device resistance, from a non-Ohmic ~400 kOhm as-deposited, to an Ohmic 90 kOhm, after the 200^o C anneal. This shows the beneficial effects of a low temperature anneal by lowering the contact resistance and possibly increasing the Pt conductivity.

[1] J. Barry, et al., J. Vac. Sci. Technol. B **24**, 3165 (2006).
[2] A. D. Della Ratta, et al., J. Vac. Sci. Technol. B **11**, 2195 (1993).

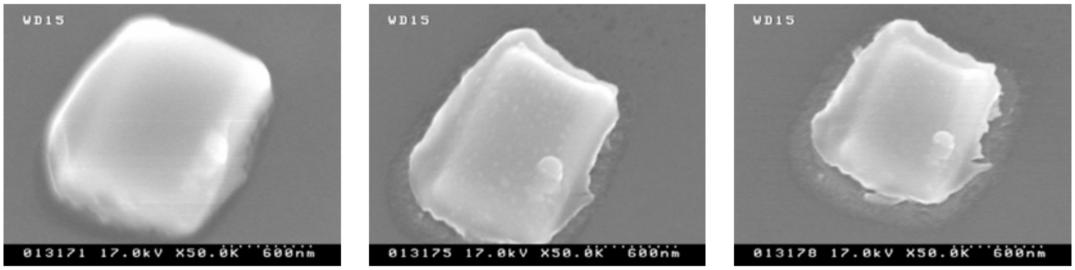

Figure 1: SEM images of a thick deposit: A) as-deposited, B) after 100C anneal, and C) after 200C anneal.

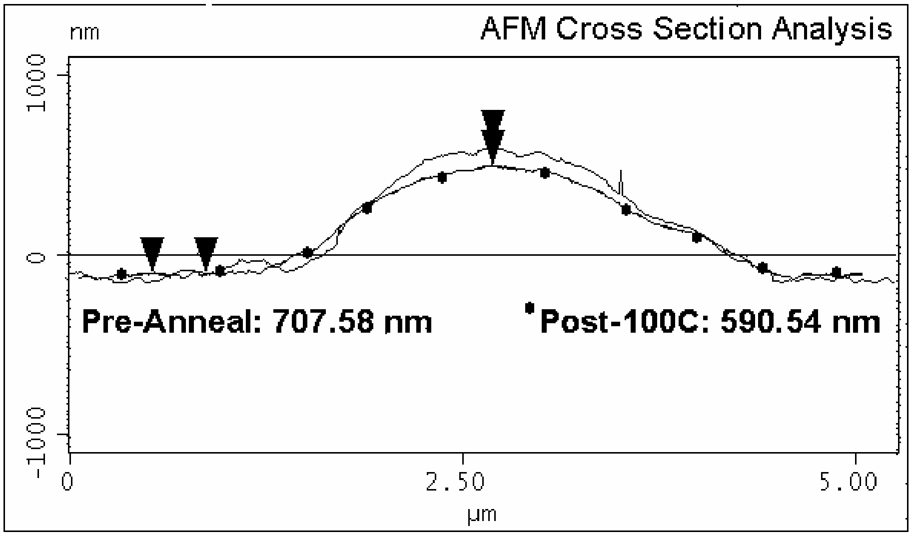

Figure 2: AFM Cross-sectional analysis of Pt deposit before and after annealing.

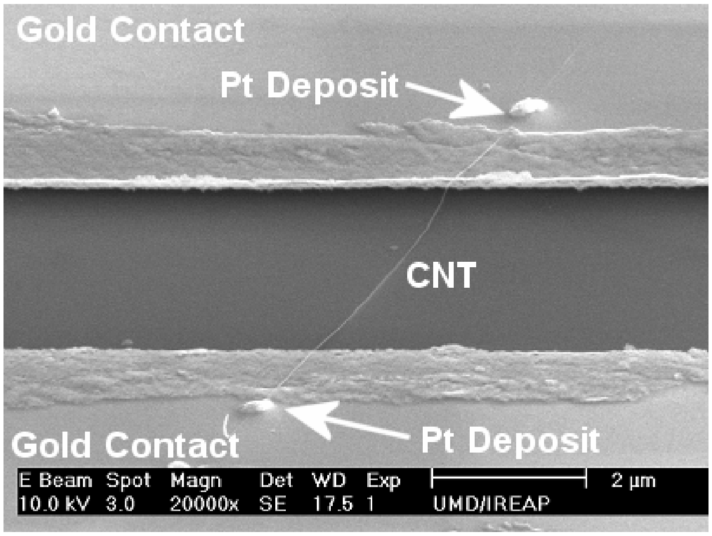

Figure 3: SEM image of CNT FET made with EBID contacts to a CNT nanomanipulated (with a Zyvex S100 in a Hitachi S4500 SEM) onto gold contacts on SiO_2/n++ Si.