Formation of Self-organized Metal-Carbon Multilayers by Ion Beam-Induced Deposition of Organometallic Precursors

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Ion beam-induced deposition (IBID) is a direct-write additive lithographic technique capable of generating nanoscale films and structures. This vacuum-based technique utilizes volatile metal-containing precursors which are decomposed into non-volatile metal containing deposits by energy transfer from ions impinging onto the substrate. A typical IBID precursor, $Me_3PtCpMe$, is commonly used to create layers for focused ion beam (FIB) milling, as well as deposition of conductive structures, e.g., modification of atomic force microscopy probes.[1] Deposition conditions in typical commercial FIB instruments often involve a high energy ion beam (5-30 keV) with deposition rates on the order of 100 nm/min, which result in homogenous PtC films. In contrast, our current work utilizes low energy (1-1.2 keV) Ar^+ and H_2^+ ion beams with low deposition rates on the order of 100 nm/hr. Under these conditions, we have found that films deposited from $Me_3PtCpMe$ exhibit spontaneous formation of well-ordered alternating layers of platinum and carbon with Pt and C layer thickness of ca. 8 nm. As a result of this layered structure, a series of rings can be seen in top-down SEM images corresponding to the number of layers present in the deposit. These PtC films exhibit continuous layers of platinum grains with diameters of up to 10 nm, in contrast to homogenous Pt IBID films of the same bulk composition, which typically contain < 5 nm Pt grains embedded in a carbonaceous matrix.[3]

We hypothesize that these self-organized Pt and C layers are formed initially by decomposition of the $Me_3PtCpMe$ precursor molecules on the surface of the film, followed by diffusion of the deposited Pt and C atoms into self-organizing layers facilitated by the energy provided by the ion beam and driven by the thermodynamic preference for Pt and C atoms to exist as segregated phases. At more typical, higher ion energies, this process is obscured by the effects of ion-mixing due to the greater ion penetration depths within the deposit. Future studies will explore the possibility that these metal/carbon multilayer deposits can also be direct deposited from other organometallic precursors containing magnetic metals such as Ni and Co that thermodynamically phase segregate from carbon.

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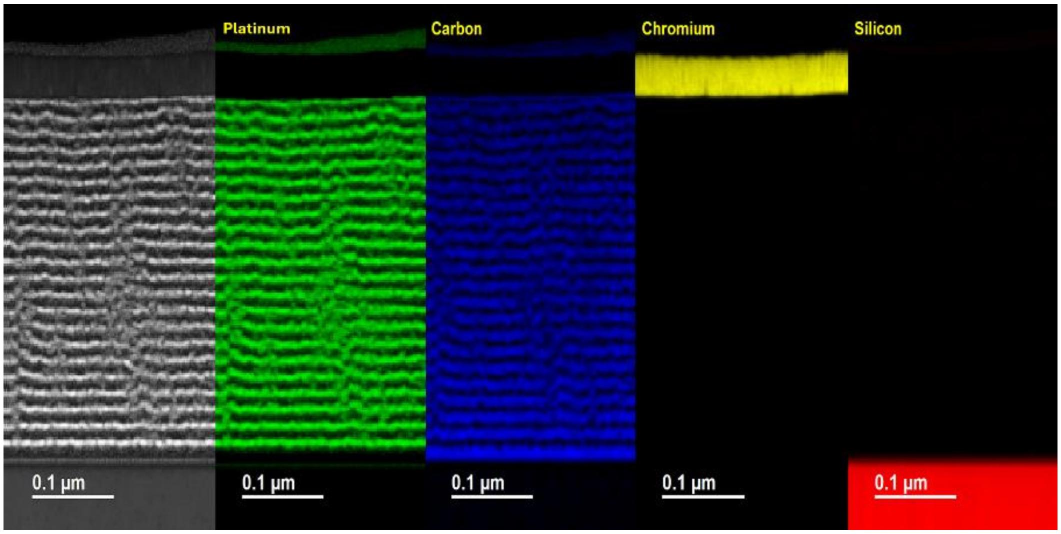

Figure 1: TEM-EELS map of 1.2 keV Ar$^+$ IBID deposit: Elemental map of a Pt/C multilayer film showing alternating layers of high purity platinum and carbon on a silicon substrate. A capping layer of chromium/platinum was used for lamella preparation.

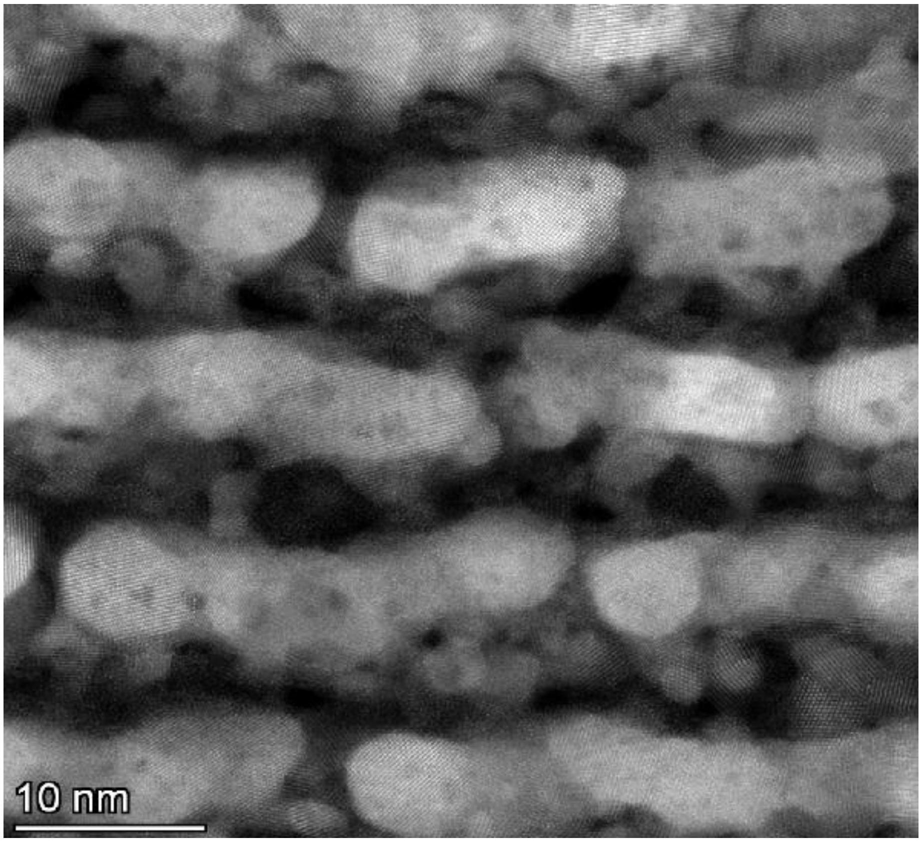

Figure 2: High annular dark field transmission electron microscopy (HAADF-TEM) micrograph of Pt grains in an Ar$^+$ IBID deposit: A high-magnification micrograph shows a maximum Pt grain size of ca. 10 nm, with most grains in the Pt layers ranging from 5 - 8 nm.