Direct local deposition of high-purity Pt and Pd nanostructures by a novel combination of EBID and ALD

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Nanomanufacturing of future devices will require novel approaches that rely on bottom-up processing directly at nanoscale dimensions instead of conventional lift-off lithography. Electron beam induced deposition (EBID) is a direct-write deposition technique that is currently considered for various nanoprototyping applications due to its ability to pattern with sub-10 nm resolution. The technique suffers however from incomplete precursor decomposition and hence a high impurity content. Platinum EBID from $MeCpPtMe_3$ typically yields a purity of only ~16 at.%, while for palladium EBID from $Pd(hfac)_2$ values not higher than 6 at.% have been reported. Several methods to improve the material quality have been studied,[1] but the deposition of nearly 100% pure metallic nanostructures remains a challenge.

Recently, we introduced a novel approach for direct-write deposition of high-quality Pt nanostructures based on a combination of EBID with the atomic layer deposition (ALD) technique.[2] The combinatorial EBID-ALD approach, illustrated in Figure 1, basically combines the patterning capability of EBID with the high material quality and excellent thickness control of ALD.

Pt structures were fabricated with a material purity of virtually ~100 at% as confirmed by energy dispersive X-ray spectroscopy (EDX). An EBID seed layer of a few nm was found to be sufficiently thick to induce ALD growth (Figure 2). For large area structures the overall throughput of the combinatorial technique is higher compared to EBID, since the patterning through the deposition of a thin seed layer can be combined with parallel thickening by ALD.

In this contribution we present, in addition to the results for Pt, recent results for Pd combinatorial EBID-ALD. Selective Pd deposition (purity for ALD > 90 at.%) on the low-purity EBID seed layer material has also been achieved recently. Pd is the ideal material for contacting carbon-based materials such as carbon nanotubes and graphene, since its work function matches the work function of carbon structures well.

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[1] A. Botman, J.J.L. Mulders and C.W. Hagen, Nanotechnology **20**, 327001 (2009).

[2] A.J.M. Mackus, J.J.L. Mulders, M.C.M. van de Sanden, and W.M.M. Kessels, J. Appl. Phys. **107**, 116102 (2010).

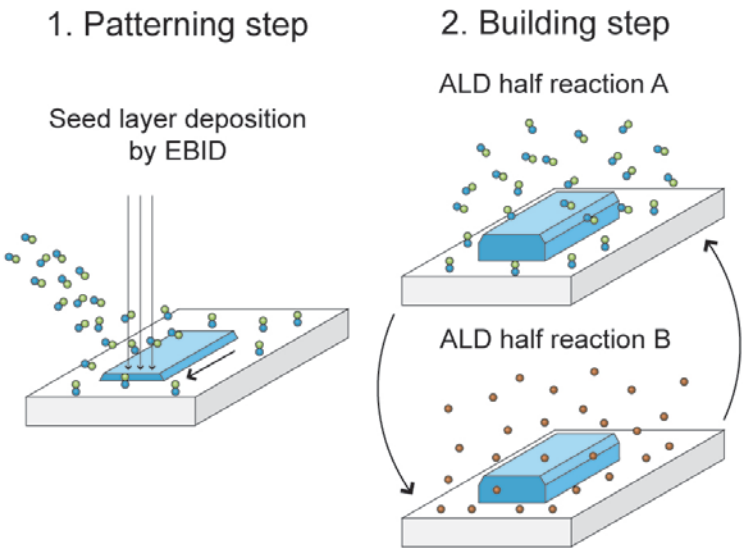

Figure 1: Schematic representation of the combinatorial EBID-ALD approach. The lateral dimensions of the structure are defined in the patterning step by deposition of a low-purity seed layer using EBID. During the ALD building step, the surface is alternately exposed to two gaseous reactants which react with the surface in self-limiting half-reactions. The structure is built layer-by-layer in the second step, which enables an accurate control of the film thickness and typically a good material quality. Key within the approach is that the ALD growth occurs selectively on the EBID seed layer material.

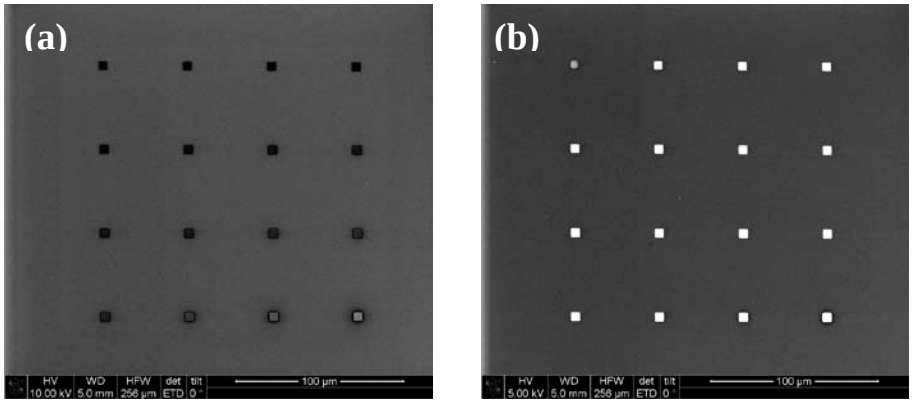

Figure 2: SEM images of (a) an array of seed layers of various thicknesses ranging from 0.3 nm to 25 nm by Pt EBID from $MeCpPtMe_3$ precursor, and (b) an equivalent array after 500 cycles Pt ALD ($MeCpPtMe_3$ precursor + O_2 reactant). From the difference in contrast it can be concluded that selective Pt ALD occurred on the EBID seed layers, which was confirmed with EDX micro-analysis.