NANOWELDING AND NANOTOOL FABRICATION USING ELECTRON-BEAM-INDUCED DEPOSITION

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Electron-Beam-Induced-Deposition (EBID) is a versatile, single-step fabrication technique that promises to find many interesting applications in nanotechnology [1]. We demonstrate that EBID can be used for welding of 3D nanoscale objects from beneath to the substrate and for fabrication of a large variety of nanotools. These tools can be used for manipulation of nanoobjects using an Atomic Force Microscope (AFM) and for different biological applications. EBID occurs when a sample is exposed to the electron beam in an electron microscope (EM). The electron beam decomposes hydrocarbon molecules that are always present in small quantities in the vacuum chamber of the EM and forms a layer of carbonaceous deposit on the sample surface. This deposit is mechanically very strong and can be grown in different shapes. Fig. 1 shows modifications to AFM probes that were grown by the EBID method. They include a high-aspect-ratio needle of 20 nm in diameter for imaging of biological objects (a), hooks and tweezers of different shapes (b and d) for manipulation with biological molecules and a nanoscalpel (c). The nanoscalpel was used to cut a narrow (20 nm) gap in a thin gold film (Fig. 2). This formed nanoelectrodes for measurements of electron conductance through a nanoparticle that was manipulated into the gap. The tools shown in Fig 1 were grown by slow scanning of the electron beam out from the AFM tip surface into vacuum. The shape of the deposited free standing structures was controlled by varying deposition parameters and scan direction using a lithography package.

It is known that EBID is mainly caused by the secondary electrons backscattered by atoms of both the sample and substrate [2]. We discovered that, because the secondary electrons are spread beyond the exposed area, this deposit can be grown in areas of geometric shadow. Fig 3 shows a pseudo-3D image obtained with an AFM of the area around and beneath a 300 nm Fe-Ni-Co nanoparticle that was first exposed to an electron beam in an EM and then removed using an AFM tip. The larger circle corresponds to the diameter of the nanoparticle. A 5 nm layer of deposit can be seen in the area of the geometrical shadow. This layer forms a very strong weld. The strength of EBID welding is investigated by welding 100 nm polycrystalline Fe-Ni-Co nanoparticles to a SiO_2 substrate and attempting to remove them by AFM manipulation. This generally resulted in breaking the particle or AFM probe unless the probe was first strengthened by deposition of a layer of EBID. We suggested using a short time exposure to the electron beam for welding complex 3D objects from beneath to the substrate [3].

We have obtained a number of complex 3D shapes by rotating the sample and thus changing the deposition angle. In particular, we found that when a blade-shape structure like that shown in Fig. 4 is rotated at 90º and then exposed to the electron beam, the deposit starts to grow simultaneously on both sides of the blade. To get insight into the mechanism of EBID we performed Dynamic Monte Carlo simulations.

References:

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[2] N. Silvis-Cividjian, C.W. Hagen, L.H.A. Leunissen, P. Kruit, Microelectronic Engineering **61–62** (2002) 693–699.
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Figures:

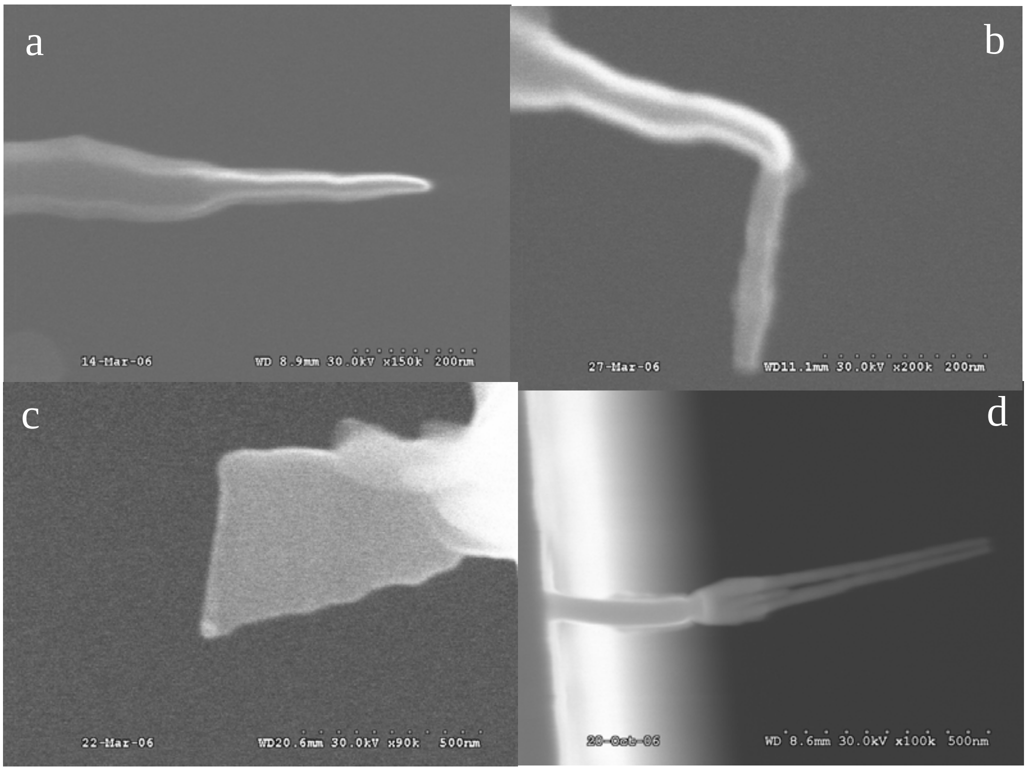

Figure 1. EBID tools deposited on AFM probes. (a) High aspect ratio probe (b) Scalpel for side incisions. (c) nanoscalpel viewed side on. (d) nanotweezers.

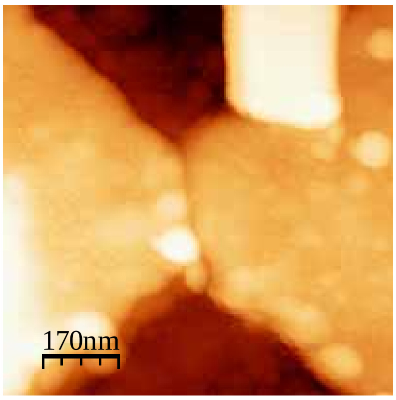

Figure 2. 20nm electrode gap formed by scratching gold with an EBID acalpel.

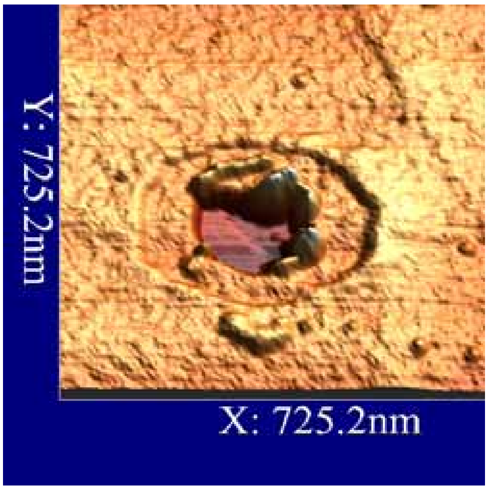

Figure 3. 3D representation of an AFM image showing deposit formed in the area of geometric shadow beneath a 300nm particle, the particle has been removed.

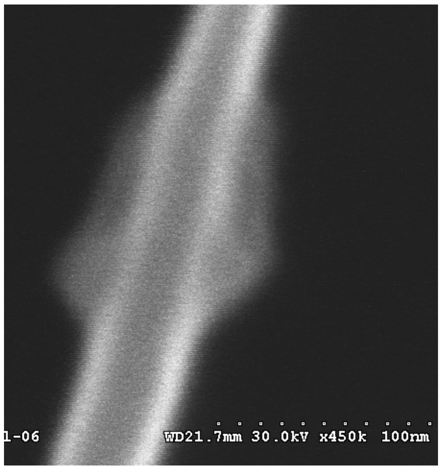

Figure 4. Growth through a deposited blade.