Integration of Ion Implantation with Scanning Probe Alignment

A. Persaud, I. W. Rangelow*, and T. Schenkel[1]
E. O. Lawrence Berkeley National Laboratory, 1 Cyclotron Rd, 5-121, Berkeley, CA 94114
*Institute of Microstructure Technologies and Analytics, University of Kassel, Germany

We describe a scanning probe instrument which integrates ion beams with imaging and alignment functions of a piezo resistive scanning probe in high vacuum. Energetic ions (1 to a few hundred keV) are transported through holes in scanning probe tips [1]. Holes and imaging tips are formed by Focused Ion Beam (FIB) drilling and ion beam assisted thin film deposition. Transport of single ions can be monitored through detection of secondary electrons from highly charged dopant ions (e. g., Bi^{45+}) enabling single atom device formation.

Fig. 1 shows SEM images of a scanning probe tip formed by ion beam assisted Pt deposition in a dual beam FIB. Ion beam collimating apertures are drilled through the silicon cantilever with a thickness of 5 μm. Aspect ratio limitations preclude the direct drilling of holes with diameters well below 1 μm, and smaller hole diameters are achieved through local thin film deposition [2]. The hole in Fig. 1 was reduced from 2 μm to a residual opening of about 300 nm. Fig. 2 shows an *in situ* scanning probe image of an alignment dot pattern taken with the tip from Fig. 1. Transport of energetic ions through the aperture in the scanning probe tip allows formation of arbitrary implant patterns. In the example shown in Fig. 2 (right), a 30 nm thick PMMA resist layer on silicon was exposed to 7 keV Ar^{2+} ions with an equivalent dose of 10^{14} ions/cm^2 to form the LBL logo.

An exciting goal of this approach is the placement of single dopant ions into precise locations for integration of single atom devices, such as donor spin based quantum computers [3, 4]. In Fig. 3, we show a section of a micron size dot area exposed to a low dose (10^{11}/cm^2) of high charge state dopant ions. The Bi^{45+} ions (200 keV) were extracted from a low emittance highly charged ions source [5]. The potential energy of B^{45+}, i. e., the sum of the binding energies required to remove the electrons, amounts to 36 keV. This energy is deposited within ~10 fs when an ion impinges on a target. The highly localized energy deposition results in efficient resist exposure, and is associated with strongly enhanced secondary electron emission, which allows monitoring of single ion impacts [4]. The *ex situ* scanning probe image with line scan in Fig. 3 shows a single ion impact site in PMMA (after standard development).

In our presentation, we will discuss resolution requirements for ion placement in prototype quantum computer structures [3] with respect to resolution limiting factors in ion implantation with scanning probe alignment.

References:

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Acknowledgments: We thank J. A. Liddle, and the staff of the National Center for Electron Microscopy for their support. This work was supported by NSA and ARDA under ARO contract number MOD707501, and by the U. S. DOE under contract No. DE-AC03-76SF00098.

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[1] Email: T_Schenkel@LBL.gov, phone: 510-486-6674

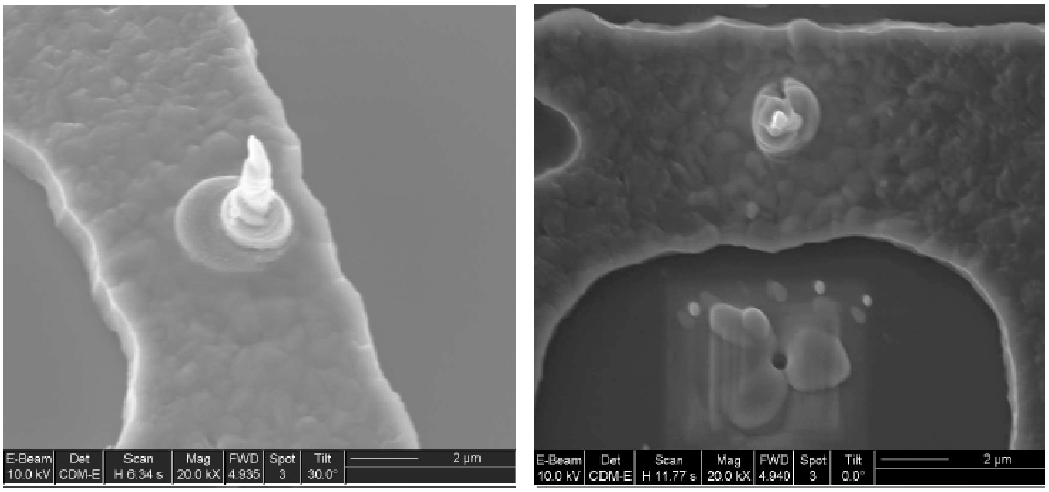

Figure 1: Scanning probe imaging tip (left), and ion beam collimating aperture (right) both formed by ion beam assisted Pt deposition in a FIB on a piezoresistive scanning probe sensor.

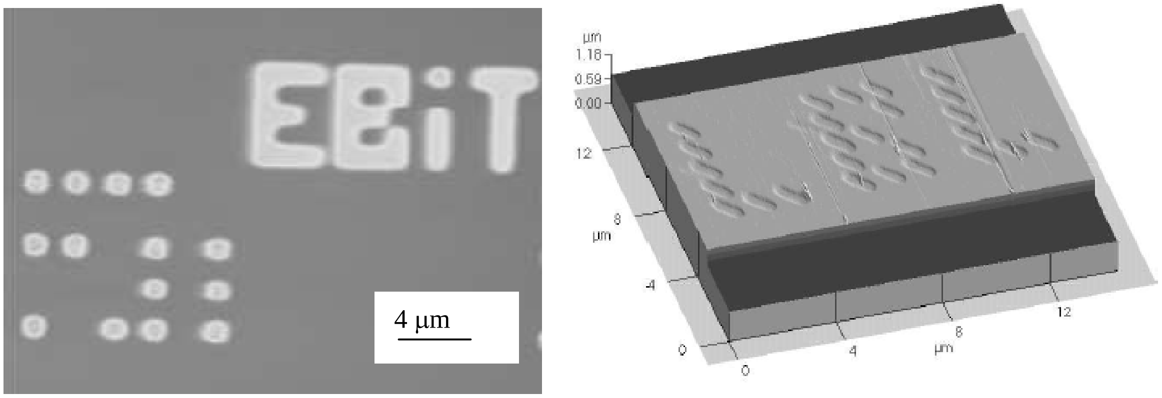

Figure 2 : *In situ* scanning probe image of alignment markers (1 µm diamter) obtained with the tip from Figure 1 in high vacuum (10^{-7} torr) (left). Right : Pattern formed in PMMA by ion implantation with scanning probe alignment. Ions used here were 7 keV Ar^{2+}.

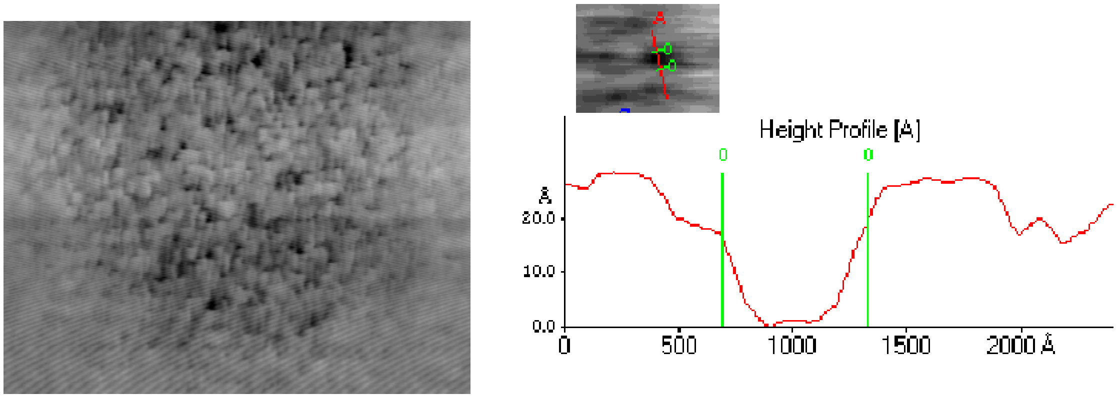

Figure 3: *Ex situ* scanning probe image of a 4 µm wide area were PMMA was exposed with Bi^{45+} ions (200 keV) (left). Right: *Ex situ* scanning probe image and line out of a single ion impact site after resist development.