Improved single ion implantation with scanning probe alignment

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Single dopant atoms can affect transport in scaled transistors and encoding of quantum information in spins of single dopant atoms or color centers enables exploration of quantum computer architectures [1, 2]. Single ion implantation with scanning probe alignment is a technique for placement of single dopant atoms with high spatial resolution [2-4]. Broad beams of low energy dopant ions (e. g. group V elements for silicon, or nitrogen for NV-centers in diamond [4]) with typical intensities of ~1 nA/mm^2 and energies of a few keV to ~100 keV are collimated by small holes in the cantilever of a scanning force microscope (Fig.1). The effective ion beam spot size is set by the aperture diameter and can range from 100 nm to as small as 5 nm. Single ion detection for formation of deterministic implant structures has been demonstrated with μm-scale transistors and 60 keV Sb^{12+} ions [3]. For these relatively large spin readout devices, the current changes from single ion implants in the transistor channel at room temperature were relatively small, dI/I~10^{-4}. In devices scaled to (sub)-100 nm dimensions, as required for single spin control and readout [5], channel current changes from single ion impacts are much increased. Fig. 2 shows an example of single ion hit detection in an etched silicon nanowire formed in SOI (300 x 130 nm^2) at room temperature. Current changes in tests with Xe^{6+} ions (48 keV) showed dI/I~10 to 20%. The current changes are induced by mobility degrading damage in the device oxide with a possible contribution of lattice damage.

In earlier work [2, 4], the scanning force microscope was operated in contact mode for imaging of device features and non-invasive alignment of the ion beam to regions of interest. In contact mode, rapid tip wear and relatively slow imaging speed impeded reproducible device implantation. In order to facilitate more rapid imaging with higher resolution and minimal tip wear, we have implemented a non-contact scanning force microscopy approach [6]. Here, cantilevers are actuated using the bi-morph effect with an AC bias at a frequency of ~70 kHz. Images are formed through sensing of the phase shift of the actuated cantilever through Piezoresistors in a Wheatstone bridge circuit. Figure 1 shows an example of a non-contact scanning probe image of a 100 nm scale silicon nanowire device. In our presentation we will discuss status and prospects of single ion implantation of (sub)-100 nm scale devices with scanning probe alignment in non-contact mode.

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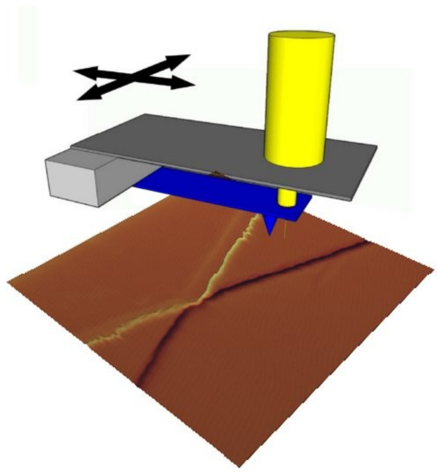

Fig. 1: Schematic of ion implantation with scanning probe alignment and an *in situ* scanning probe image (non contact mode, 9x9 μm^2) of a Fin resistor in vacuum ($5x10^{-5}$ Torr). The scan time for this area was 15 min (512x512 pixel) [1]

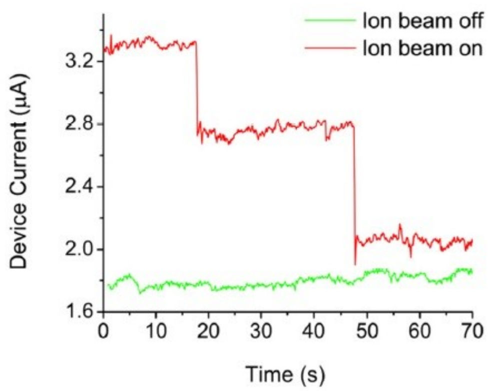

Fig. 2: Steps in nano-wire current in response to single ion hits (48 keV, Xe^{6+}) [1]