Direct Write Nanofabrication for Quantum Computing in Silicon and Color Centers in Diamond

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We present on-going work using direct write nanofabrication to create deterministic single donor devices for quantum computing research, as well as, individual color centers in diamond. This work is carried out using the SNL nanoImplanter (nI). This is a 100 kV focused ion beam system setup for both mass resolution using an ExB filter and single ion implantation using fast blanking and chopping. We combine this with a lithography pattern generator for nanofabrication. We have demonstrated ion source operation including P and Sb for donor implantation in Silicon, Si for SiV creation in diamond and Li for light ion beam microscopy.

The creation of single donor based quantum computing goes back to Kane[1]. We have implemented a fabrication pathway that combines focused ion implantation with *in-situ* counted ion detection. We have integrated avalanche photodiodes with quantum transport nanostructures and demonstrated low temperature transport in counted samples[2]. We have detected Sb ions down to 20 keV generating at most ~1200 e-h pairs/ion with a SNR of 2. This FIB approach allows for a positioning accuracy of <35 nm, defined by the beam spot size. Figure 1 shows (a) the combined ion detector and nanostructure, (b) quantized ion detection and (c) transport data showing a charge offset from a counted donor at low temperature.

Color centers in diamond have been used for a range of applications from metrology to single photon sources for secure quantum communication[3]. Here we have demonstrated the ability to deterministically implant ions into photonic nanostructures with high spatial resolution. Separately, we have demonstrated the ability to detect single ion implants using an *in-situ* diamond detector with a SNR approaching 4 for detection of single 200 keV Si ions. Figure 2 shows (a) an SEM image of a diamond nanobeam array, (b) photoluminescence for the ion implanted sample and (c) a histogram of single ion detection in diamond.

Direct write nanofabrication has been demonstrated for single atom devices in silicon and diamond using a top-down ion implantation approach.

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[1] B. E. Kane, Nature **393**, 133-137 (1998)
[2] M. Singh *et al.,* submitted to APL
[3] I. Aharonovich *et al.,* Rep. Prog. Phys. **74**, 076501 (2011)

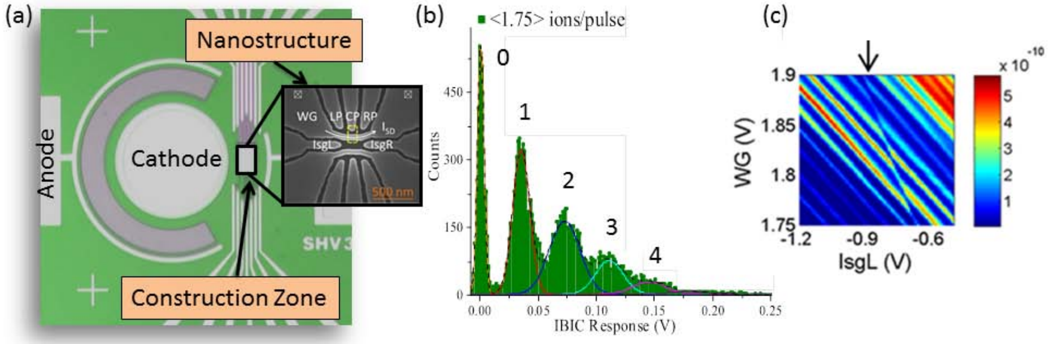

Figure 1: (a) Optical image of the integrated *in*-situ single ion detector and SEM of the nanostructure for low temperature transport. (b) Histogram of the detector response showing quantized single ion detection for 200 keV Si ions with an average of 1.75 ions per pulse. (c) Low temperature transport data taken on a counted implant sample, the charge offset shown is likely due to an electron tunneling between the electrostatically formed SET and the donor.

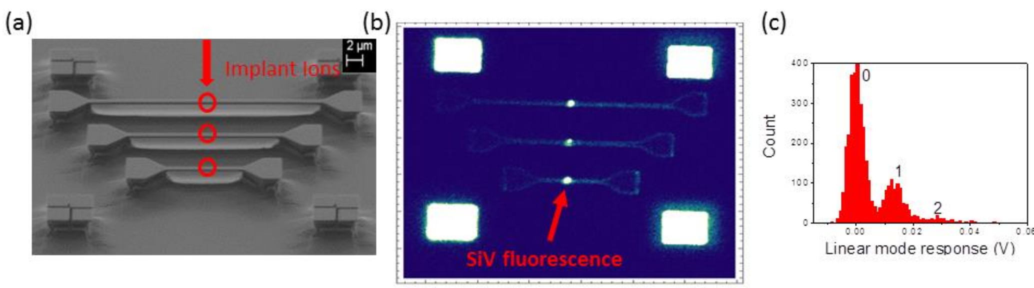

Figure 2: (a) SEM image of the diamond nanobeams (fabricated at Harvard) showing the implant locations. (b) Photoluminescence of the nanobeams after ion implantation showing the spatial location of the implanted ions relative to the nanobeams (c) Histogram of an *in-situ* diamond detector response showing quantized single ion detection for 200 keV Si ions with an average of 1 ion per pulse, demonstrating low energy single ion detection in diamond.