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Expanding the Energy Range from eV to MeV and Fabrication of Sources Enabling Novel Focused Ion Beam Nanofabrication and Modification

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Multi-species focused ion beam (FIB) has the capability of running a variety of ion species allowing tailoring of the ion to the application enabling new applications of FIB such as localized doping and the creation of single defect centers [1]. Additionally, through variation of the ion energy from eV to MeV, specific depths within the sample can be targeted enabling targeting of deeply buried layers inaccessible by traditional FIB systems[2]. The combination of these capabilities opens up new areas of study including quantum information science and 2D materials.

QIS is a quickly growing field with the ultimate promise of revolutionizing information security, transmission speed and breakthroughs in sensing. Scaling of quantum systems still poses a challenge with solid-state being an ideal system due to their inherent scalability when compared with other systems such as trapped atoms. Defect centers in semiconductors have been found to exhibit good quantum properties, such as coherence time and single photon emission rate. To enable engineering of defects, non-native impurity-type defects are ideal since unintentional native defects can reduce the coherence time of the intentionally introduced defects. FIB is a powerful tool for the creation of impurity-type defects in a variety of semiconductors. By combination of FIB with in-situ photoluminescence, the confidence on the number of optically active defects can be improved. However, tailoring the defect to the specific material host requires availability of a variety of ion species.

We have fabricated novel ion sources for Nitrogen, Magnesium and Lithium ions enabling localized creation of new defect emitters. The N source is based on an AuSn eutectic alloy thin film implanted with 200 keV N ions up to $5x10^{17}$ ions/cm^2. We use elastic-recoil detection to confirm the N concentration in the foil post-implantation, shown in Figure 1a[3]. The process of making the tip is shown as the inset in Figure 1a. The tip is then installed in a 100 keV ExB FIB and N emission is confirmed by the mass spectrum, shown in Figure 1b. The mass spectrum is taken by sending the DC beam into a Faraday cup for detection of the Au and Sn peaks. For measuring the N peak, a pulsed ion beam induced charge (IBIC) measurement is used with a diamond detector. We find emission of N^+ and N^{++} and use the IBIC measurement to estimate the N^{++} beam current of 20000 ions/s. The Mg and Li sources are more conventional liquid metal alloy ion sources based on AuSi eutectics with the ternary element added as an impurity. Figure 2a shows a result of Li ion implantation into SiC creating an array of V_{Si} color centers. The color centers are observed in-situ using photoluminescence enabling creation of a fully deterministic array of single and two-photon emitters, as confirmed by second-order autocorrelation.

Two-dimensional (2D) materials have attracted significant research interest due to their potential for ultra-thin devices. Additionally, revolutions in heterogeneous integration may be achieved by leveraging the differences in bandgap for different 2D materials. One issue in integration of 2D materials for QIS is the deterministic creation of color centers. By using low energy ions, deterministic stopping within atomic monolayers can be achieved, allowing impurity-type doping of 2D materials for ion energy in the 10 – 100 eV range. We developed a new low energy stage for our FIB systems that uses decelerated to enable impurity doping into 2D materials over a range of energies down to eV. These ions are produced by our FIB system and decelerated, as shown in Figure 2b. The inset to Figure 2b shows a to-scale drawing of the low-energy sample holder with the two grounded plates shown in red and gray while the high-voltage plate is shown in blue. The sample is located under a small hole (0.5” diameter) in the top plate [4].

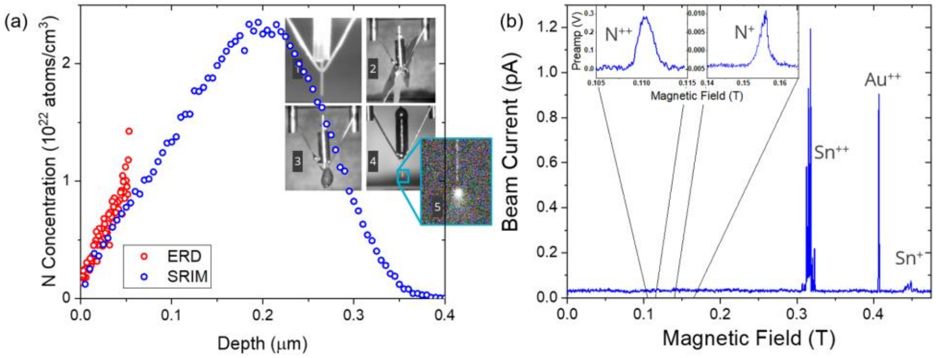

Figure 1. (a) ERD measurement of the N concentration in the implanted foil. Inset: Fabrication of a AuSnN source from implanted AuSn foil. The tip is heated to remove surface contaminants followed by filling of the tip with pieces broken off the implanted foil. The pieces are melted and the fill process is repeated until the reservoir is filled. Lastly, emission is confirmed. (b) Mass spectrum from the AuSnN source showing emission of Au and Sn by directing the beam to a Faraday cup. To observe the low current emission of N ions, a pulsed IBIC measurement is used.

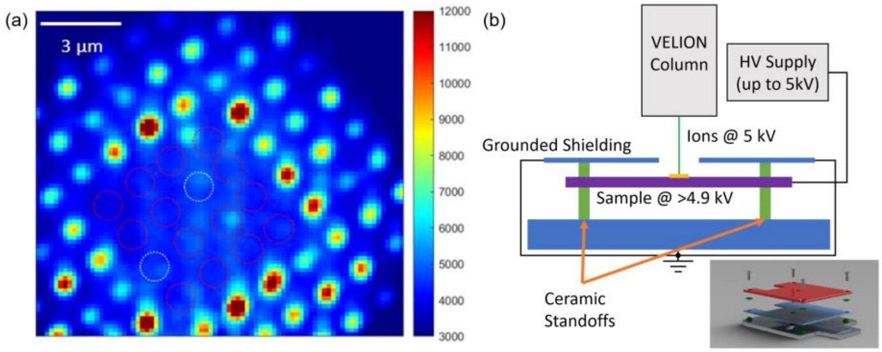

Figure 2. (a) Room-temperature photoluminescence image from an array of V_{Si} observed in our in-situ photoluminescence setup utilizing a 785 nm pump laser and detection in the 880 +/- 40 nm band. The outer three rows are implanted with 500 ions/spot while each inside location, denoted by the red and white circles, has been implanted with 3 ions/spot. The white circles denote locations where an emitter is observed which will be excluded from successive implantations. (b) Low-energy implantation scheme showing the sample held at a bias to decrease the ion landing energy. Inset: Sample holder design with the high voltage plate being held isolated between the top and bottom grounded plates

References:

[1] M. Titze et al., arXiv:2112.02049
[2] A. Lozovoi et al., Nat. Electron., 4, 717 (2021)
[3] B. L. Doyle, P. S. Peercy, Appl. Phys. Lett. 34, 811 (1979)

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