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Automating Experiments Using Charged Particle Beam Nanofabrication Tools

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Motivation

Automated deterministic placement of single defect emitters in a wide range of materials, including 2D materials

Currently broad beam implantation is used, which lacks
- Positioning precision
- Active center yield
- Spot size and number of ions in a single spot
- Implant verification
- Requires an anneal

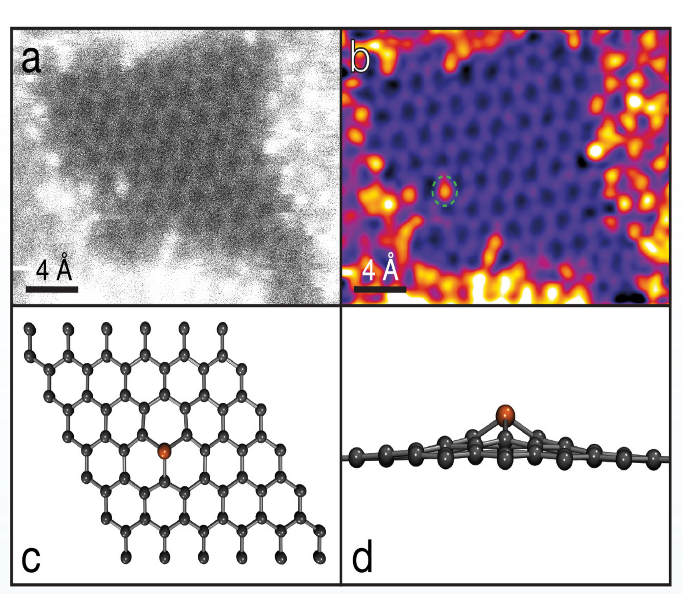
Approach

We propose to use automated low energy retarding implantation and utilize the following

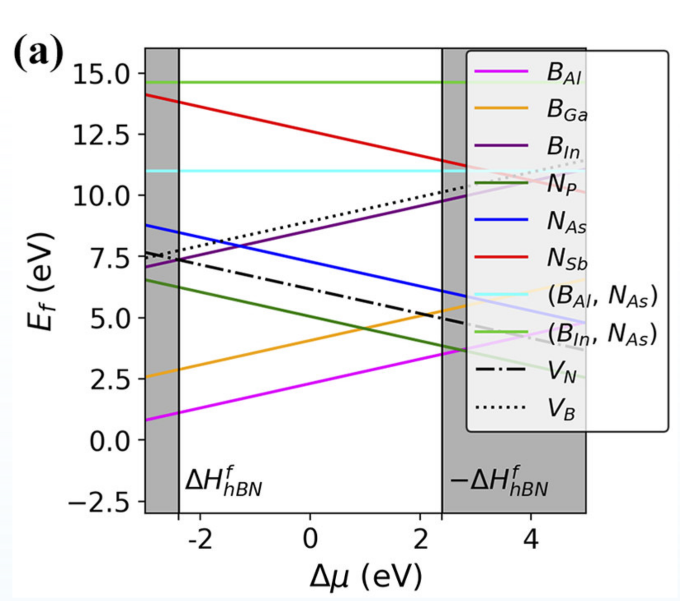
Implantation into (2D) materials with ultra-low ion energy
- Example: 30 eV for P in Graphene

Develop low-energy focused ion beam (FIB) implanters
- Ex: Photonics requires sub-wavelength positioning accuracy

FIBs are in keV energy range with 10-100 nm-spot sizes
- Use biased sample holder to make <100 eV on-target



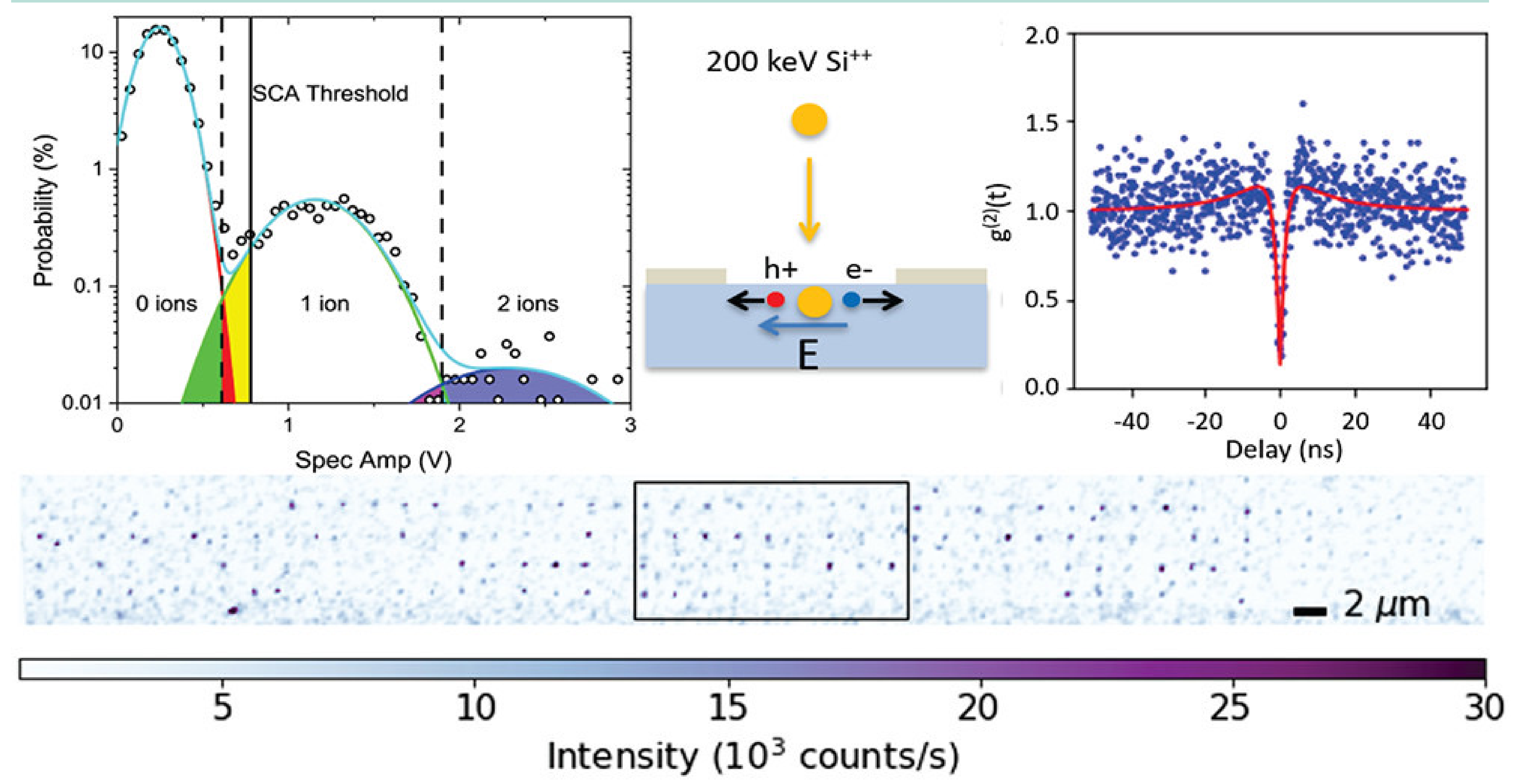
T. Susi, 2D Mater. 4 (2017)



M. R. Fiorentin et al., Nanomat. and Nanotech., 10 (2020)

Our approach involves the Raith Velion, Zeiss Orion Plus, and A&D NanoImpalnter FIBs to
- Implant single low energy ions (5 – 200 keV)
- Control positioning and implant spot size
- Validate implants with in-situ characterization methods
- Feedback errors to operator

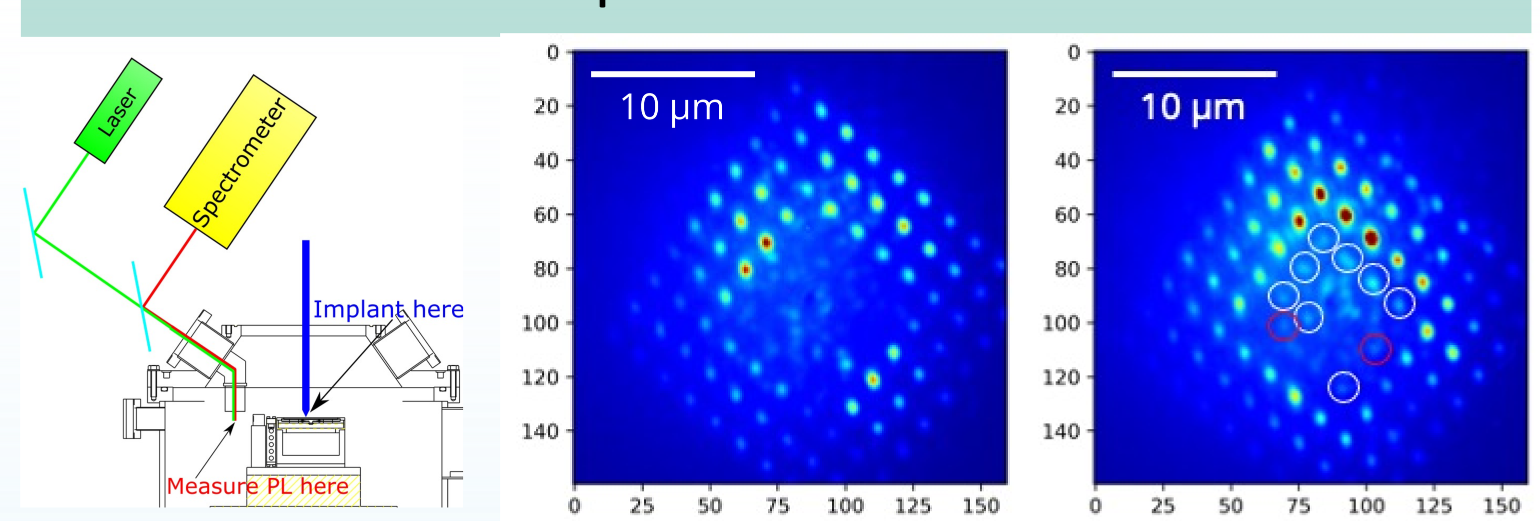
Single SiV in Diamond Manufacturing



Titze M., Nano Lett. 2022, 22, 8, 3212–3218

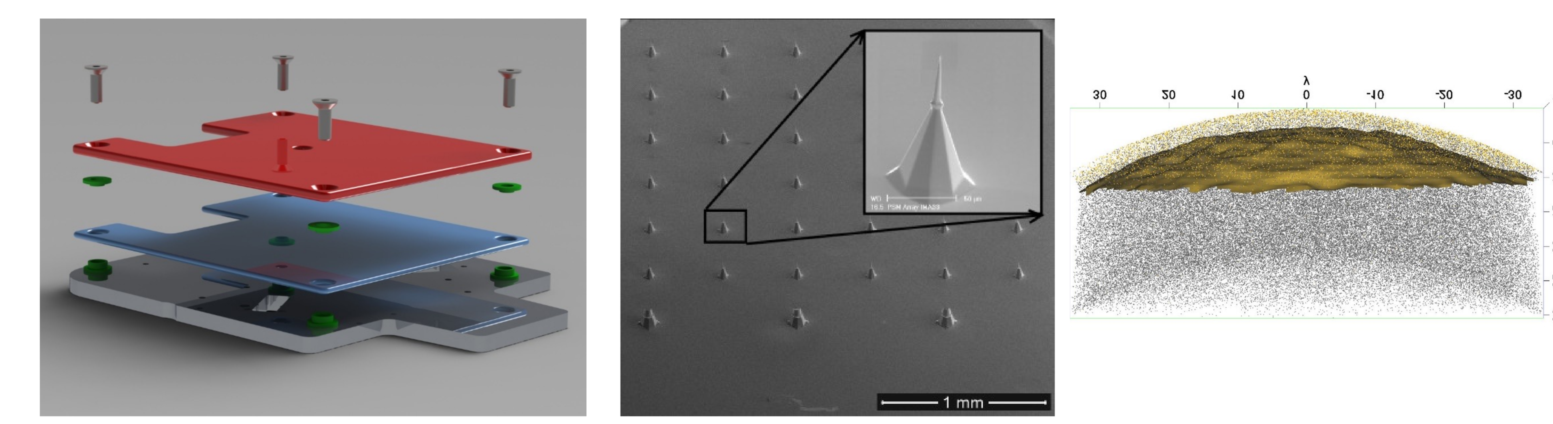
In-situ counted ion implantation for arrays of single silicon vacancy (SiV) defects
- In-situ detection measures implanted ions with a 2-fold improvement of the implant error to form a single SiV compared to timed implantation
- 7-fold improvement compared to timed implantation, with 2.98% SiV yield
- Hanbury–Brown–Twiss interferometry confirms 82% single photon emitters

Implant Validation



SiV in SiC ot require high-temperature annealing to activate
- Measure background PL
- Implant
- Measure PL
- (Re)Implant locations that do not have PL

Low Energy Implants

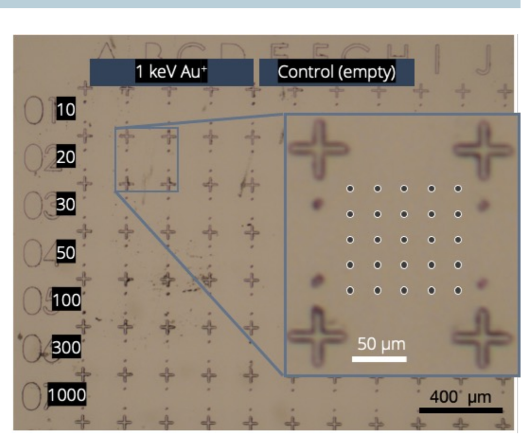


Using a biased sample holder design, 20 Angstrom deep 1 keV Au deposition, confirmed by Atom Probe Tomography

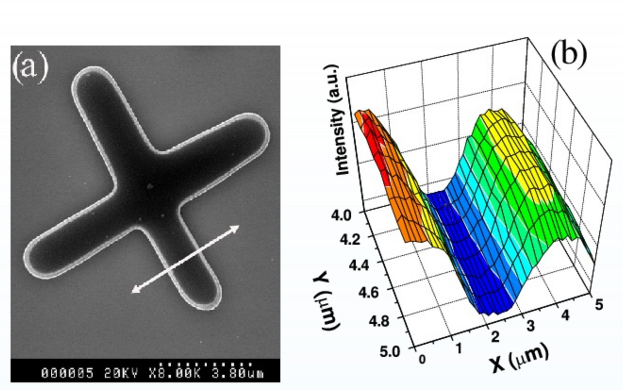
Ongoing efforts
- Lower energies
- Smaller spot sizes

Experiment Automation

Designing samples for ease of navigation
- Alpha numeric sectors
- Global positioning marks
- Local alignment
- Realignment in-situ



Automating position correction after the marker scan
- Rigid transformation with user input
- Automatic write-field alignment using marker intensity profiles



Automating column control
- Execute ion implant/mill at predefined points
- In-situ 2nd channel of information data capture (SEM, PL, etc.)
- ML Feature recognition (Canny edge, Hough)
- Implant/Mill validation
- Decision making feedback to repeat or move

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