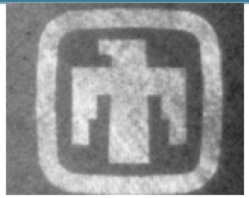
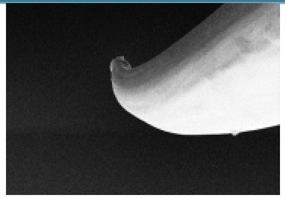
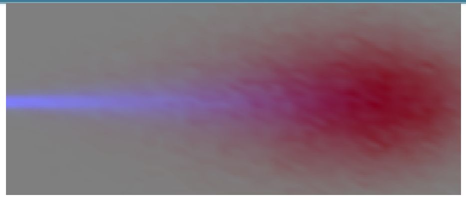
SAND2021-15215C

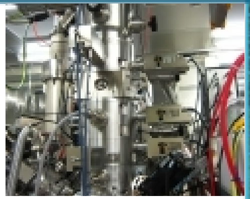
Sandia National Laboratories

Novel Focused Ion Beam Applications using the Raith VELION









FIB Capabilities available for user projects

Michael Titze, Alex Belianinov, Anthony Flores, Edward S. Bielejec

12/07/2021

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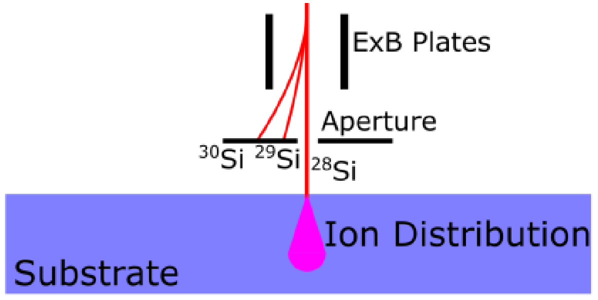
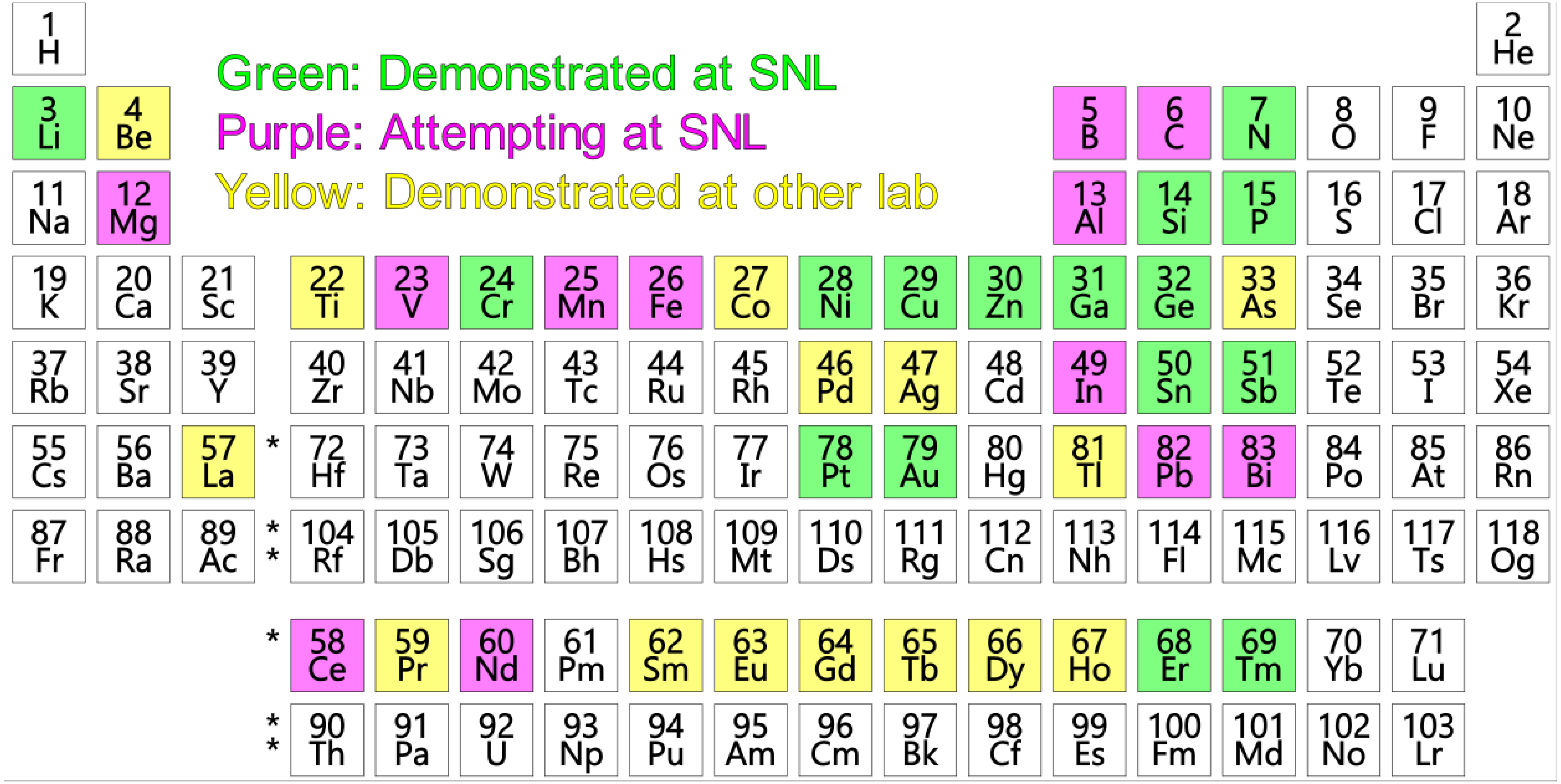
Ion Implantation for Defect Creation



Different materials require different ion species

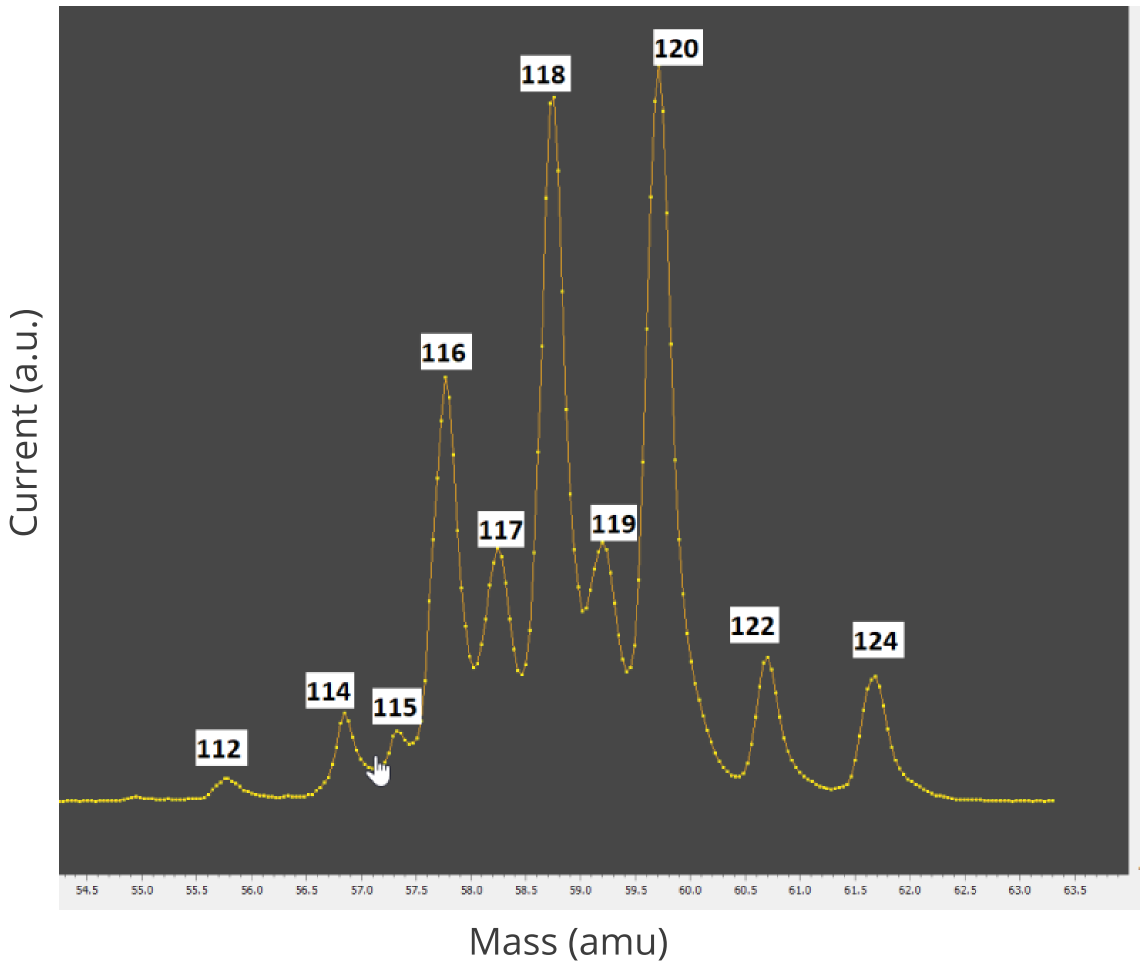
- Diamond: Si, Ge, Sn, Pb, N, Ga, Ni, …?
- SiC: N, Cr, Er
- ZnO: In
- ZnS: Cu



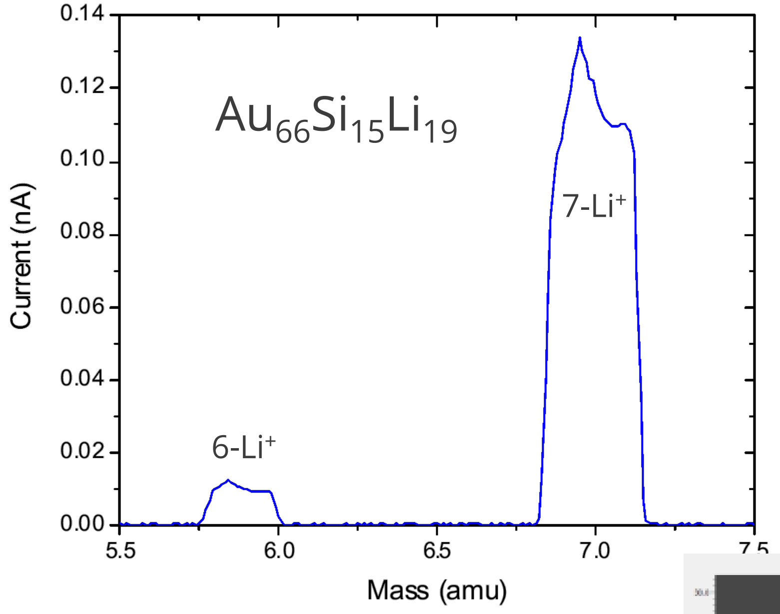
Example 1: Many Ion Species

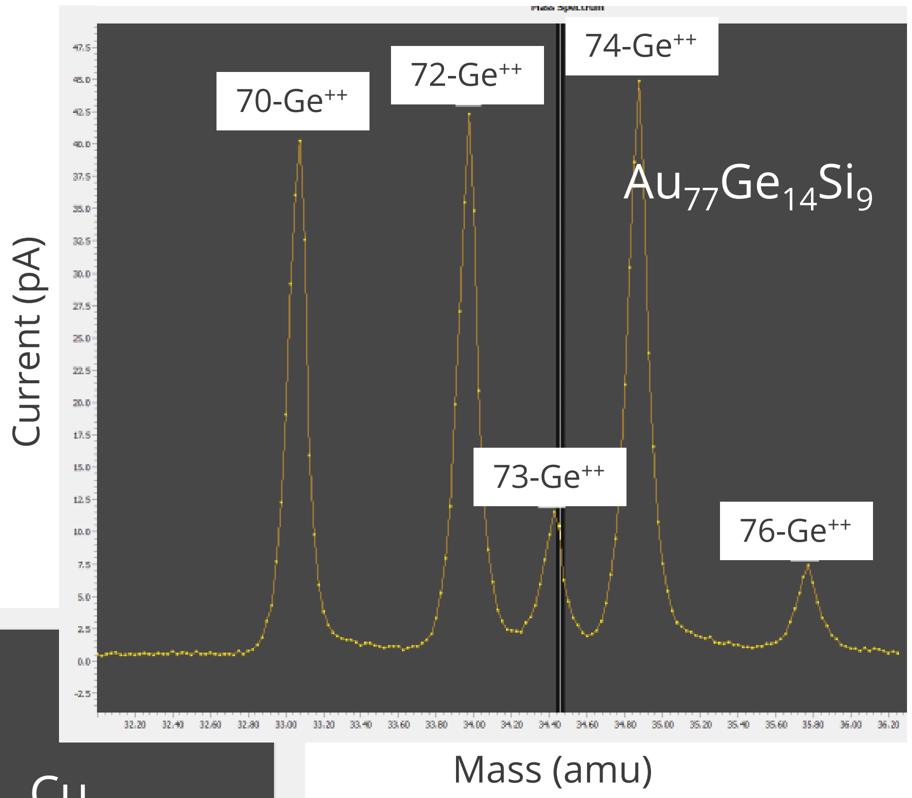
Si, Ge, Sn implantation for creating group-IV defects in diamond

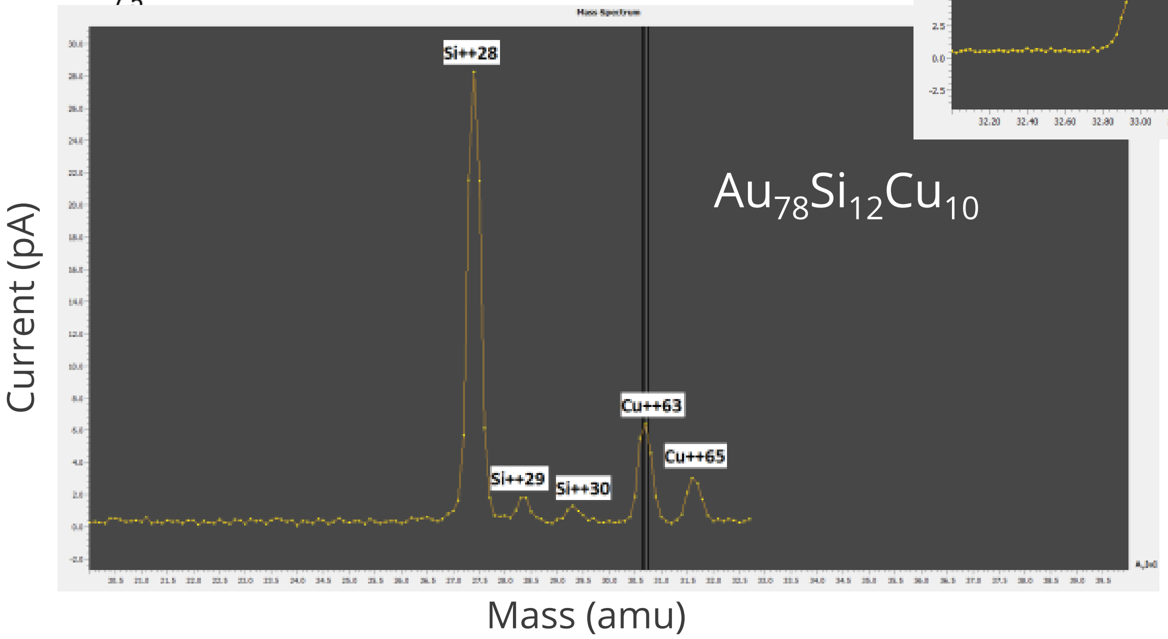
- High mass-resolution mode
  - Resolve all Sn^{++}-isotopes, $\frac{\mathbf{m}}{\mathbf{\Delta m}} > \mathbf{60}$! ! !
  - Spot size < 50 nm @ 56 keV / 28 kV
- High dose implants, enabled by **>300 pA** current



Mass Spectra of Different LMAIS







Not shown here:

1. $Au_{78}Si_{12}Er_{10}$
2. $Au_{68}Ge_{22}Cr_{10}$
3. $Au_{65}Si_{24}Zn_{11}$

7 different sources on the VELION

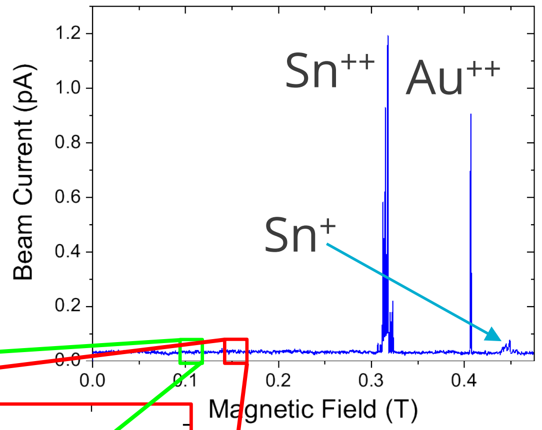
Nitrogen and Carbon as LMAIS FIB Source

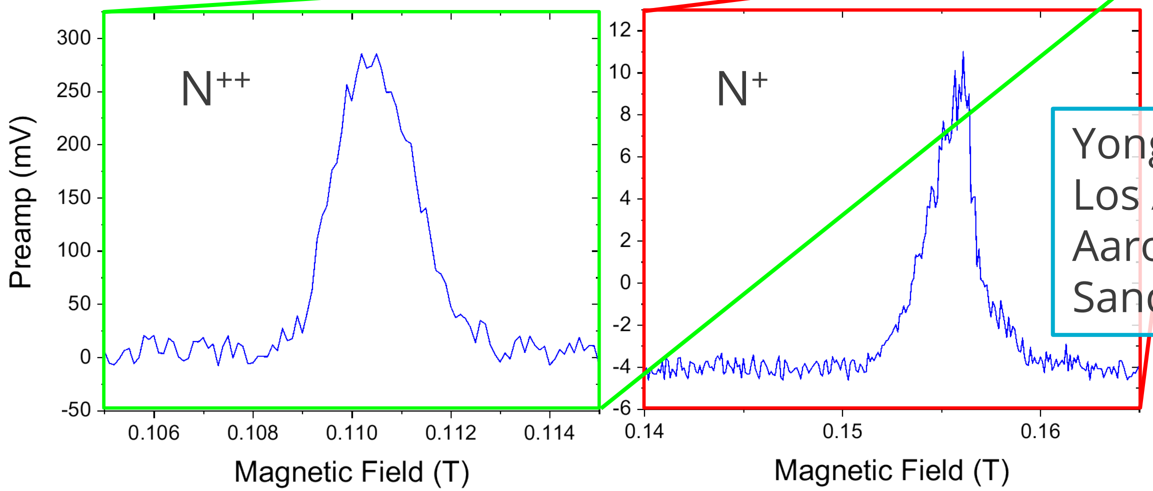
- N is relevant for diamond nitrogen-vacancy (NV) centers
- C for creating vacancies in diamond without adding in impurity atoms

→ How to create a low melting point N or C containing material?

Ion Implantation

1. Start with a $Au_{80}Sn_{20}$ eutectic
2. Implant N up to the solubility limit
3. Create a LMAIS tip of the implanted material





Yongqiang Wang, Los Alamos
Aaron Katzenmeyer, Sandia

Graphite powder

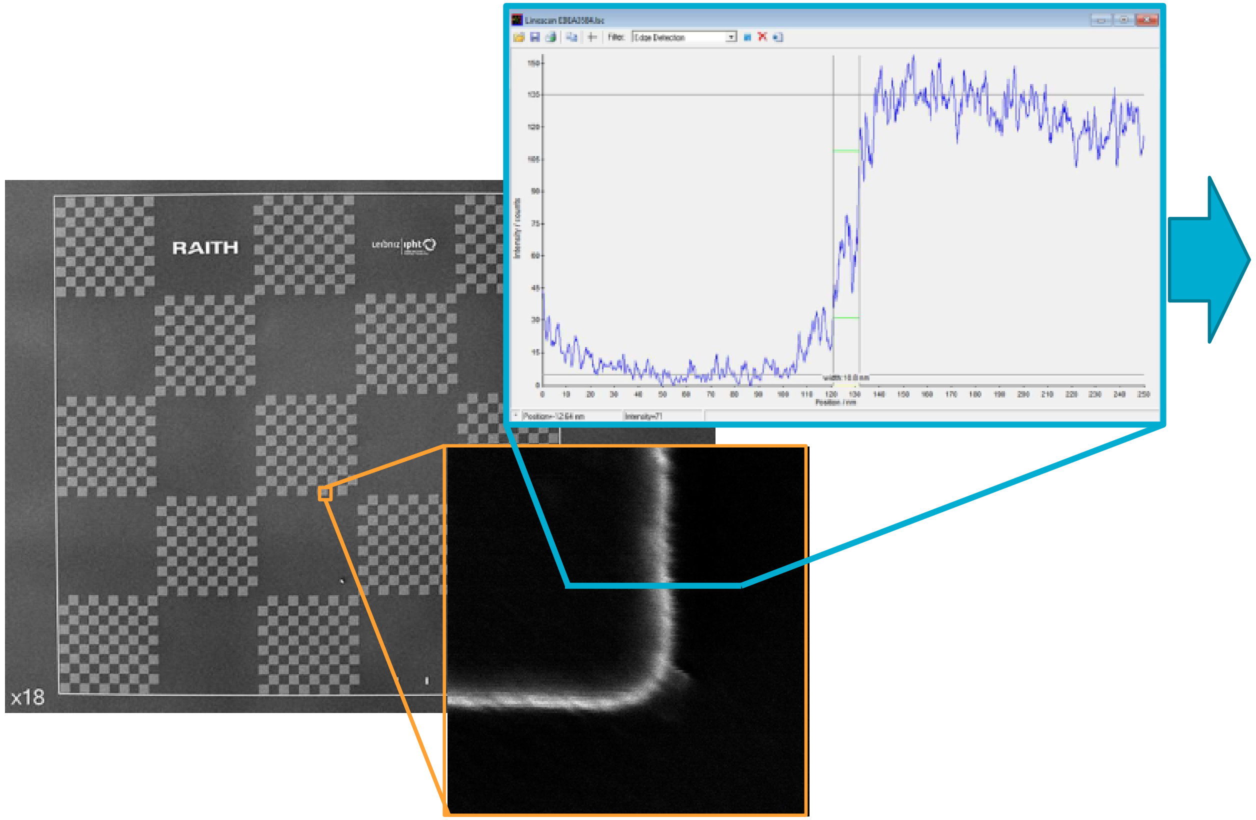
New alloys

1. AuSi eutectics can act as a host for other material
2. Start with AuSi near eutectic composition
3. Melt C inside AuSi to form AuSiC

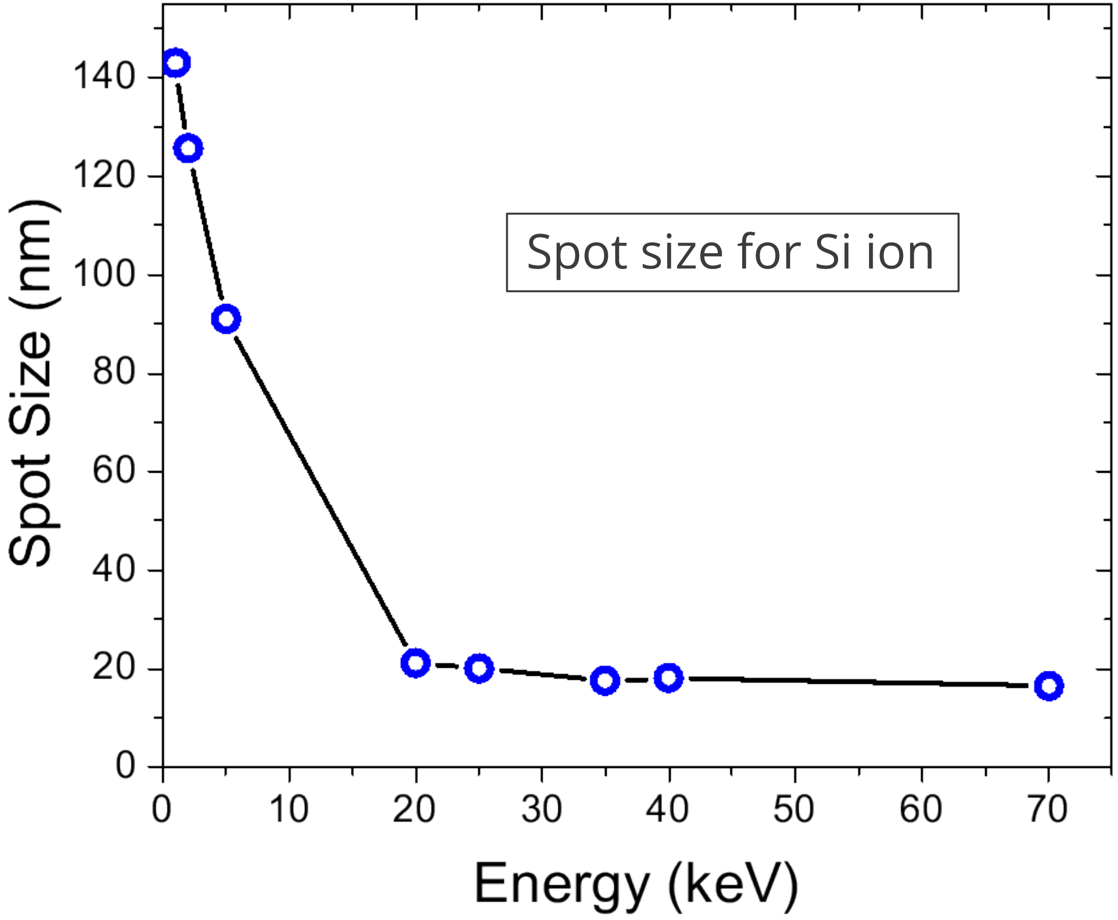
Charles Albert, ACI Alloys

Example 2: Low Energy Implantation

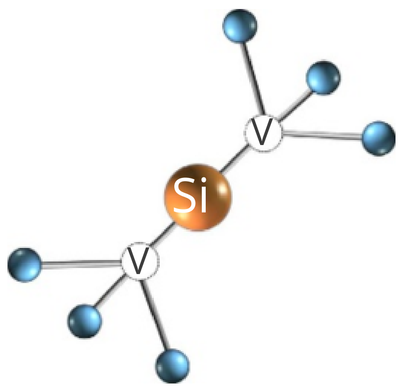
- To date, processed 17 samples



< 20 nm spot size down to 20 keV



Deterministic Ion Implantation

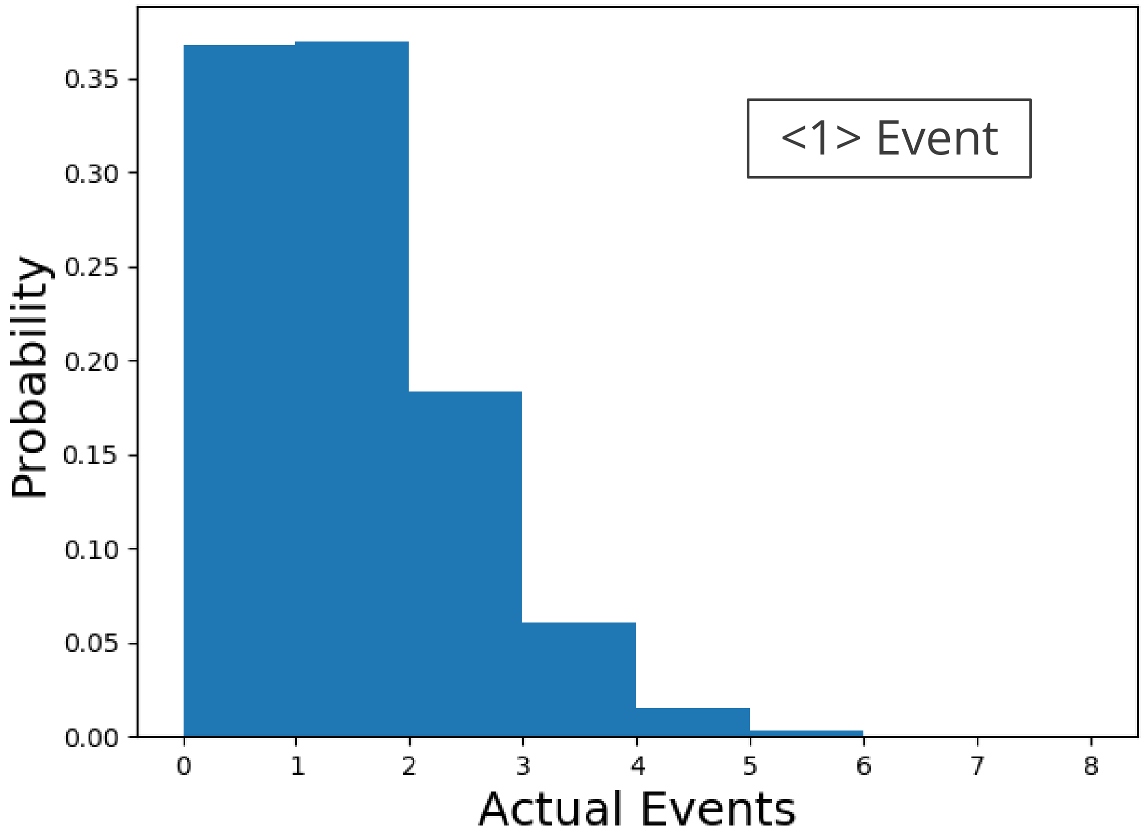


Y. Zhou et al., Nat. Comm. 8, 14451 (2017)

- Solid-state defects enable scalable quantum applications
- Color-centers are possible candidate
  - Single photon emitters require low number of ions

Typical Ion Implantation Experiment:

- Measure Beam Current, then do timed implantation
  - No real-time feedback of beam current
  - Limited by Poisson statistics



Example 3: Ion Counting

- Solid-state defects enable scalable quantum applications
- Color-centers are possible candidate
  - Single photon emitters require low number of ions

Typical Ion Implantation Experiment:

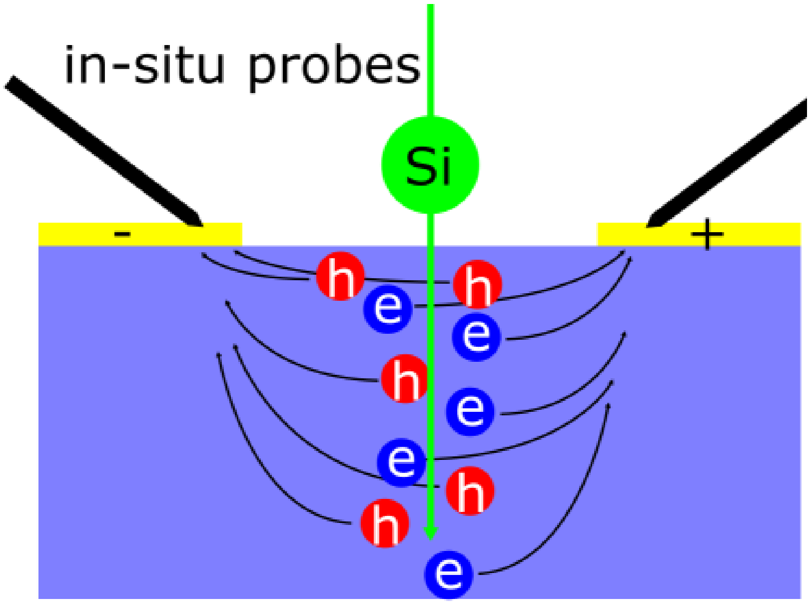
- Measure Beam Current, then do timed implantation
  - No real-time feedback of beam current
  - Limited by Poisson statistics

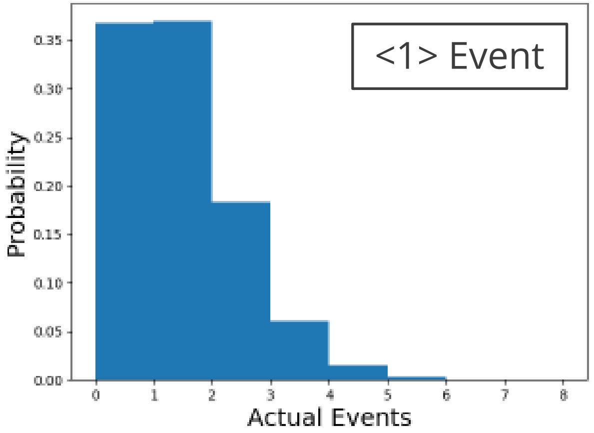
1. Few-ion implants dominated by Poisson statistics

→ In-situ counting of ions can beat Poisson statistics

$$\text{Yield} = \frac{\#\text{Measured SiV}}{\#\text{Implanted Si}}$$

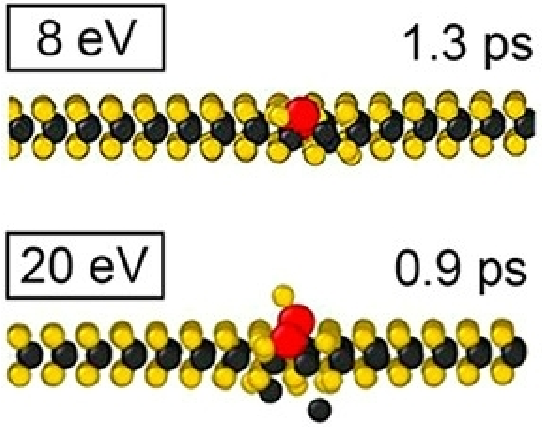
December 7, 2:00 PM - EQ01.09.03
"*In Situ* Ion Counting for Deterministic Placement of Single Photon Emitters"



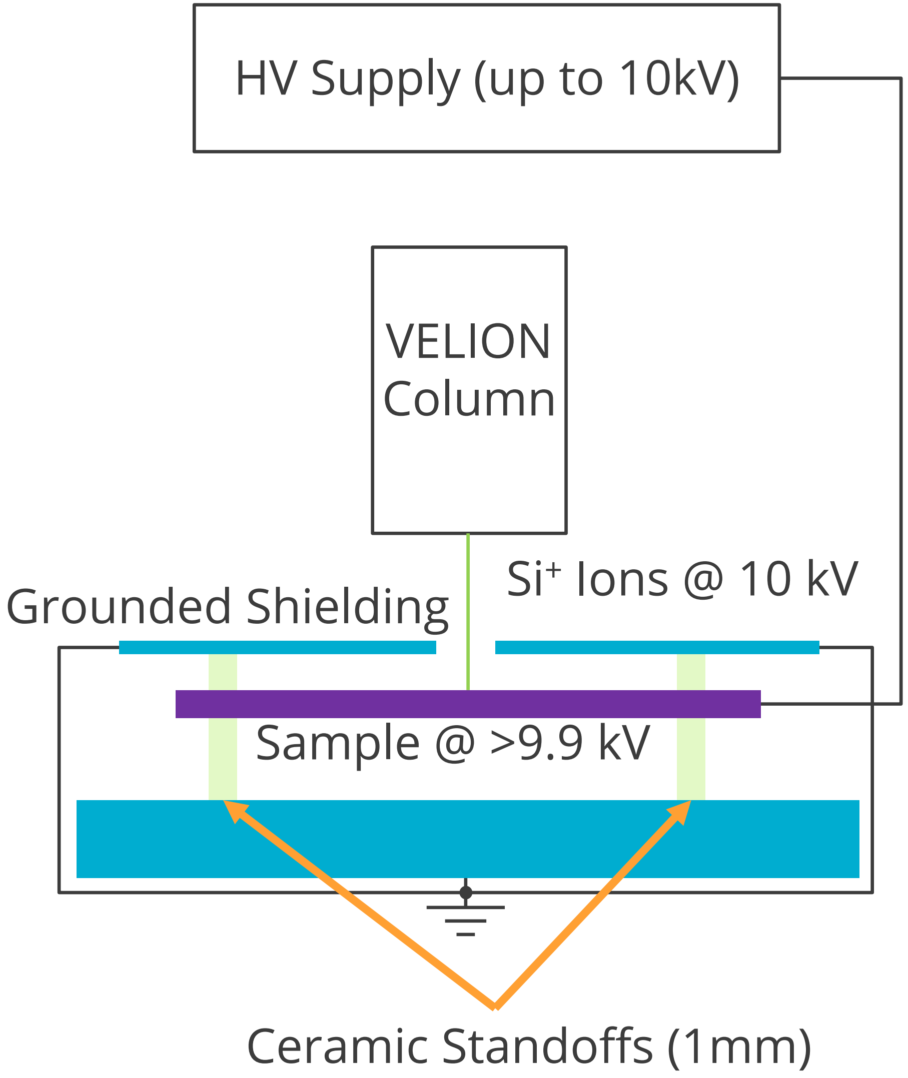


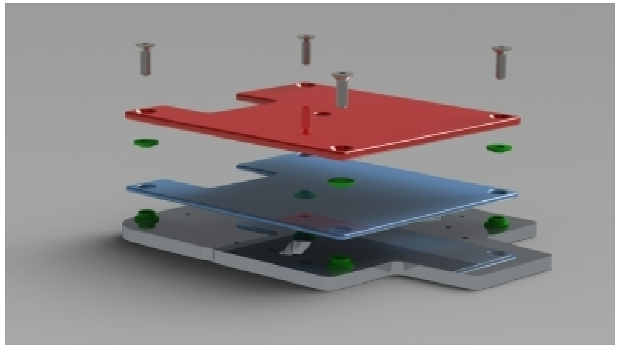
Example 4: Ultra-Low Energy Implantation

- Deterministic targeting of monolayers requires < 100 eV ion landing energy
- Low acceleration ~10 kV + biased sample to adjust landing energy



Lin et al., ACS Nano,14, 4, 3896–3906 (2020)





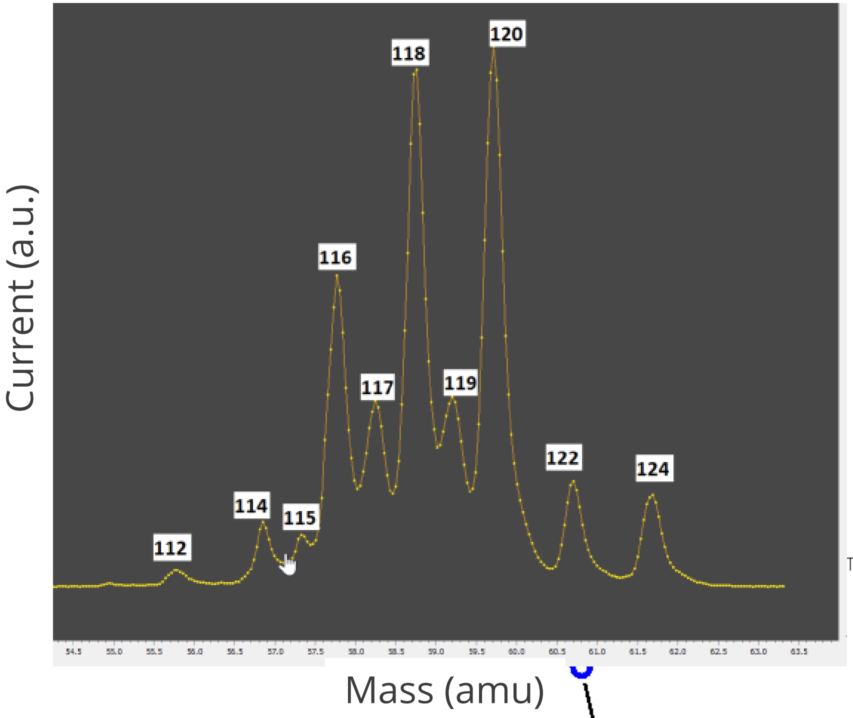
Conclusion

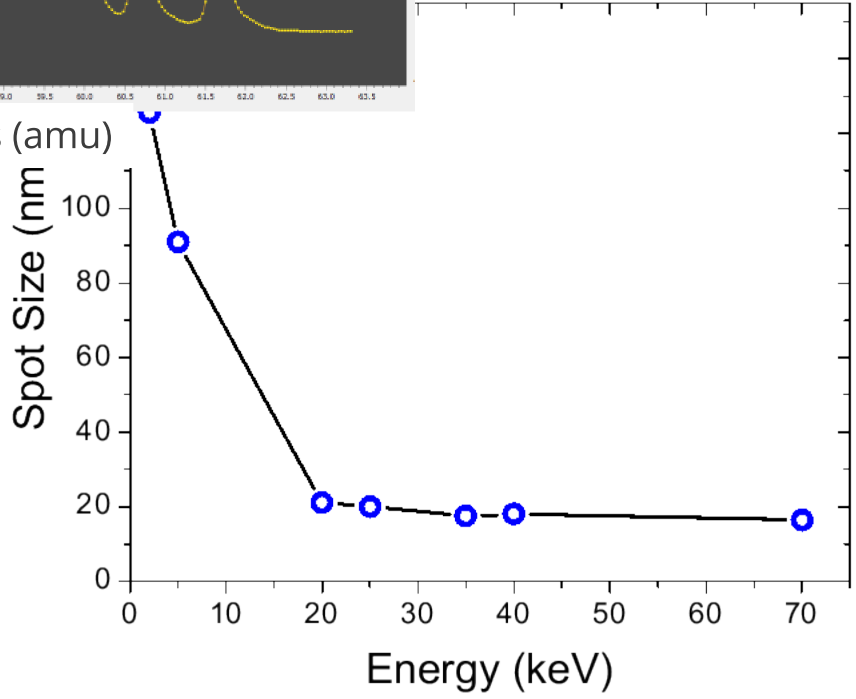
7 different LMAIS to date

17 samples implanted to date

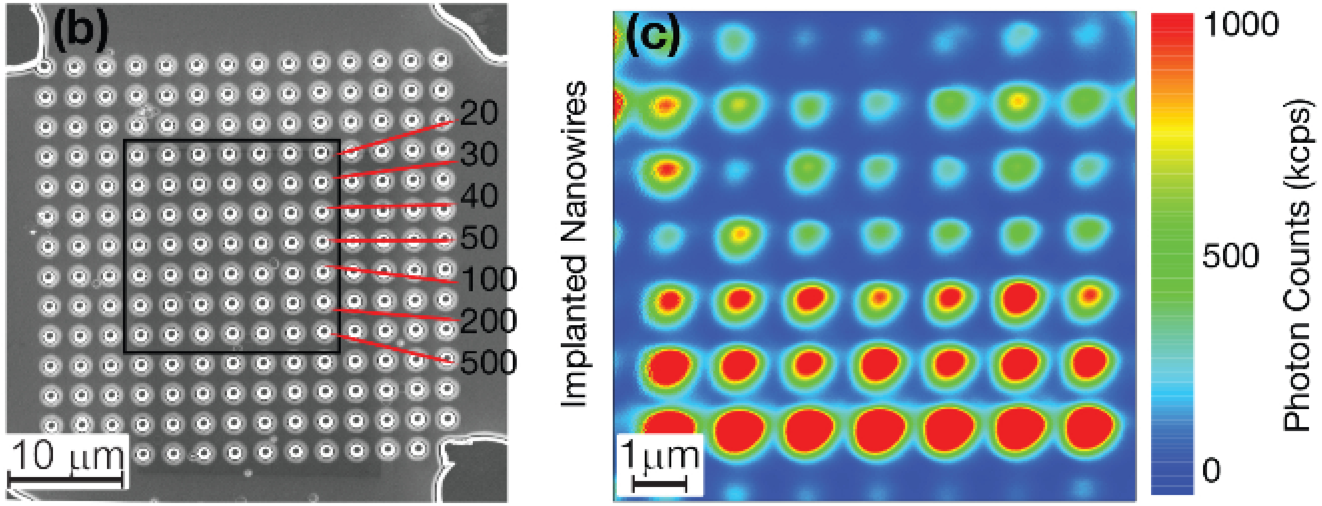
Energy range from 1 keV to 70 keV

“Everyday” spot size < 30 nm for > 20 keV

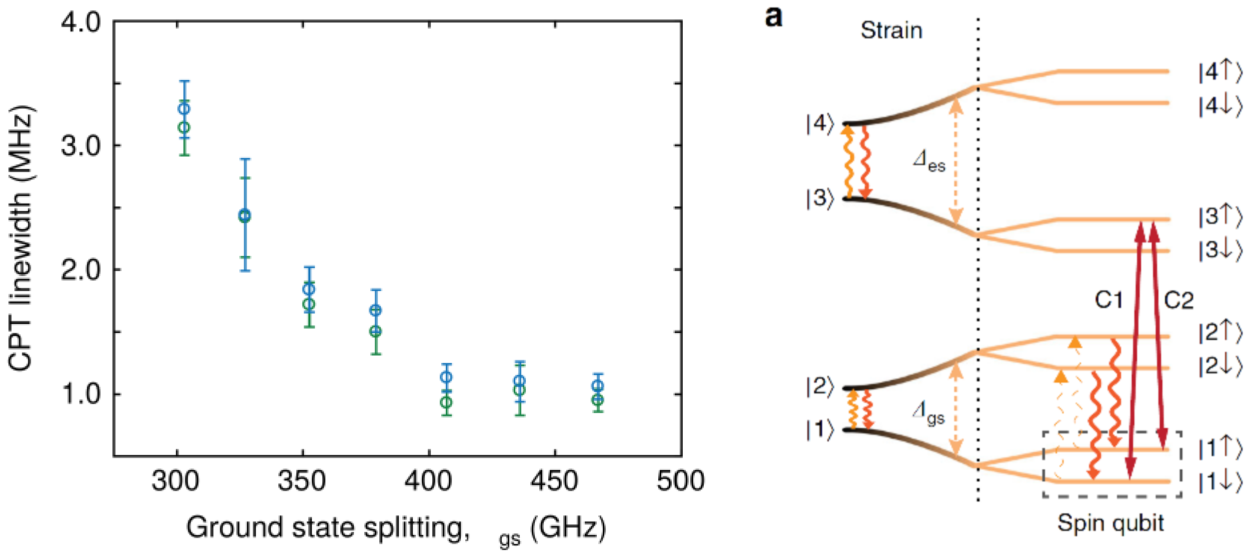




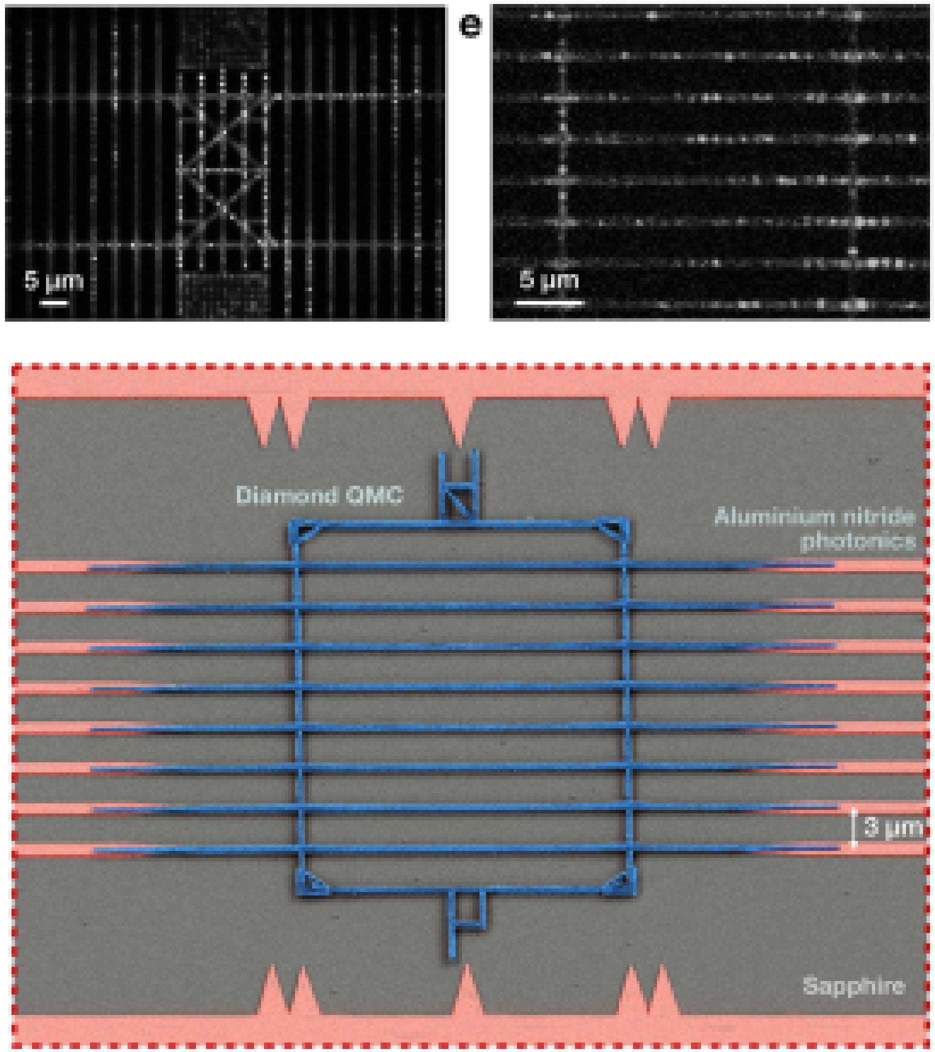
Examples of FIB Implantation



L. Marseglia et al., Opt. Express 26, 80 (2018)



Y.-I. Sohn et al., Nat. Commun. 9, 2012 (2018)



Noel H. Wan et al., arXiv 1911.05265 (submitted)