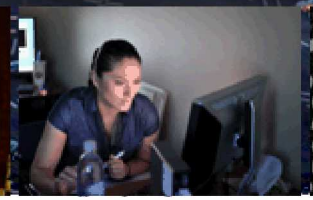
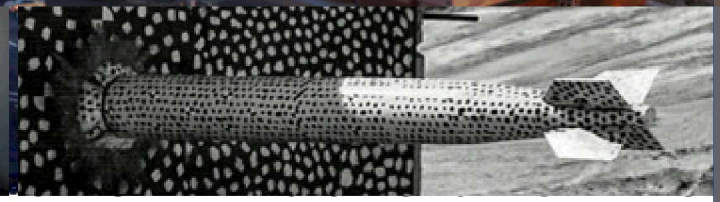
SAND2020-2654C

An in-situ Single Photon Source Detection Platform for Deterministic Nanometer Resolution Ion Implantation





PRESENTED BY

Michael Titze

Vignesh Chandrasekaran, Kulturansingh Hooghan, Han Htoon, Edward Bielejec

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Why Solid-State Defects

- Many approaches to quantum communication, sensing and computation
- Solid-state defects have benefit of scalability
- Downside is solid-state is 'dirty'
  - Long coherence times are hard to accomplish in materials such as Si, 2D-TMD, etc.
- Color centers in wide-bandgap materials are relatively clean solid-state systems
- Here, focus on SiV in diamond and VSi in SiC

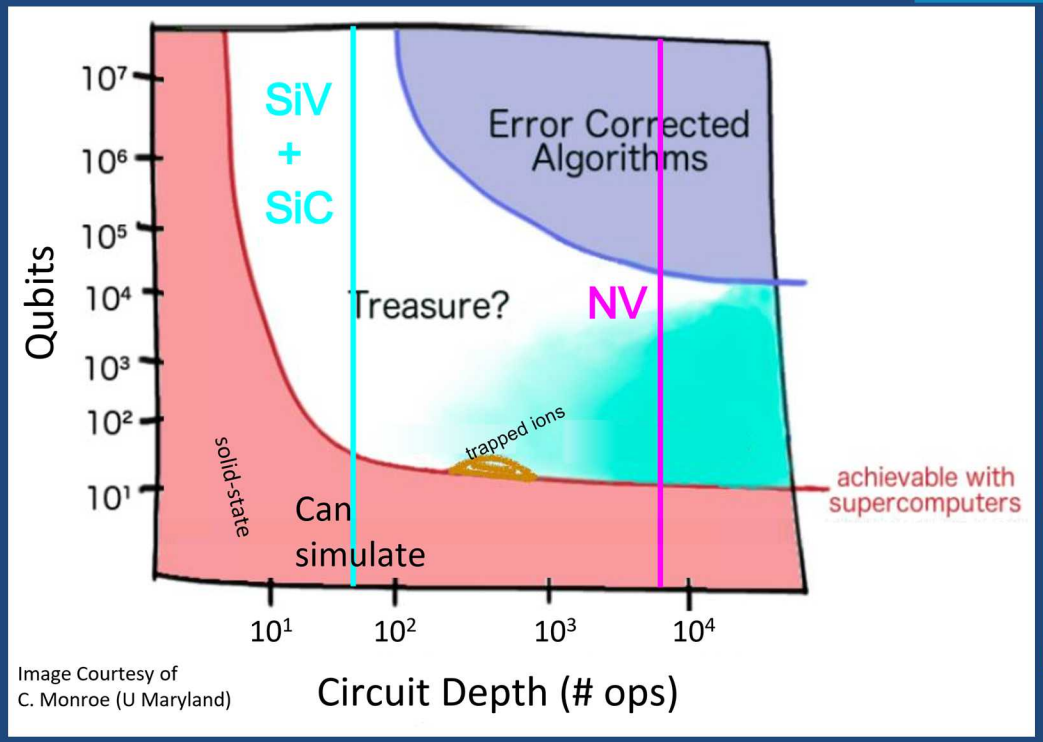
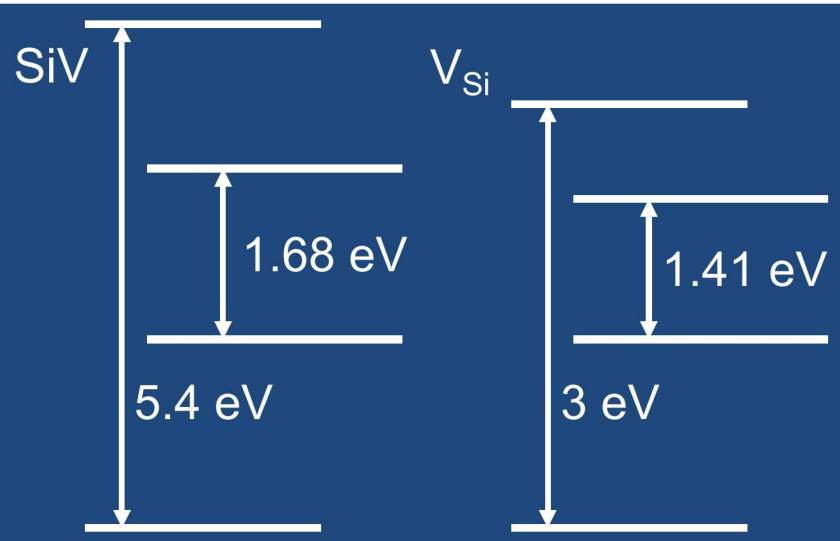
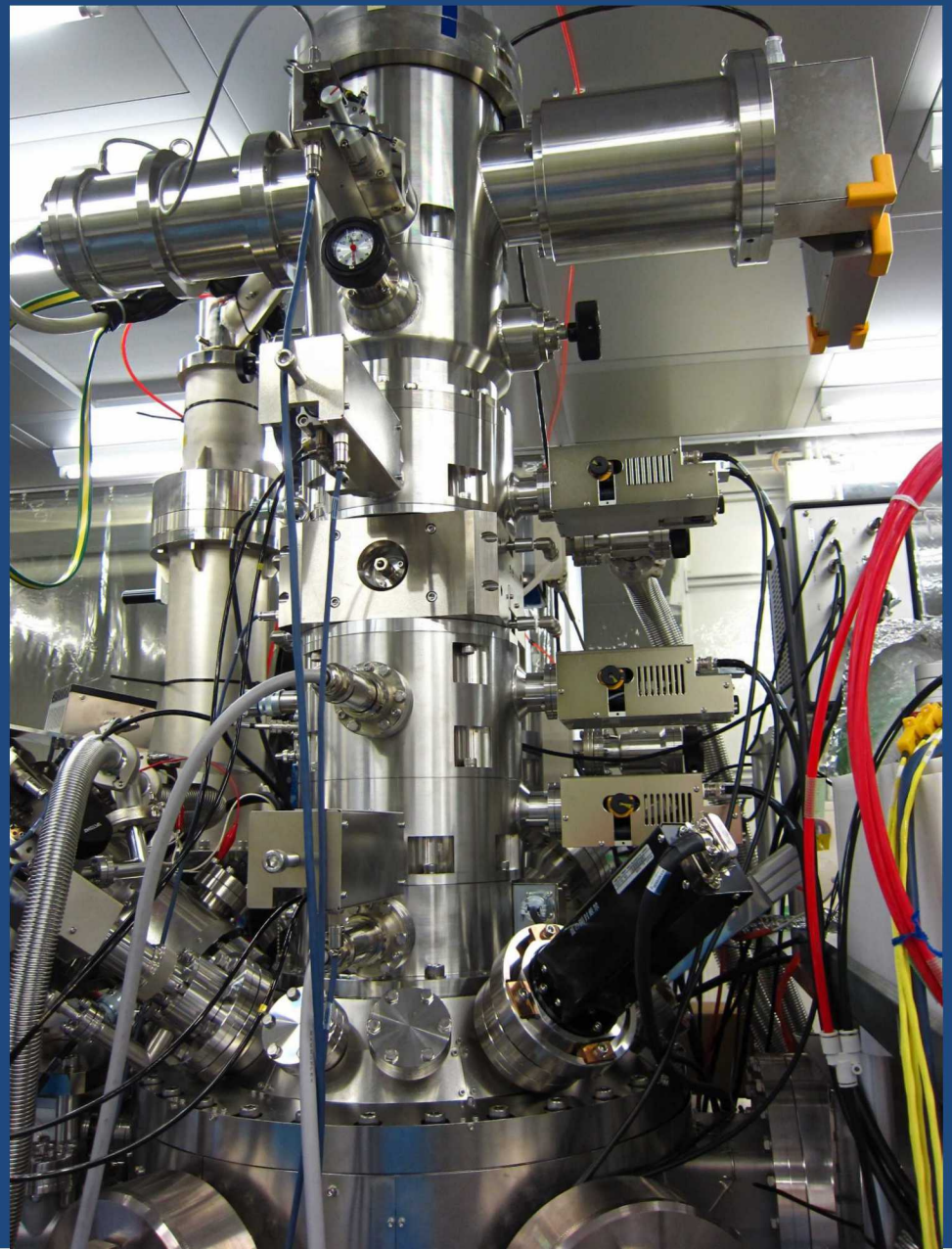


Image Courtesy of
C. Monroe (U Maryland)

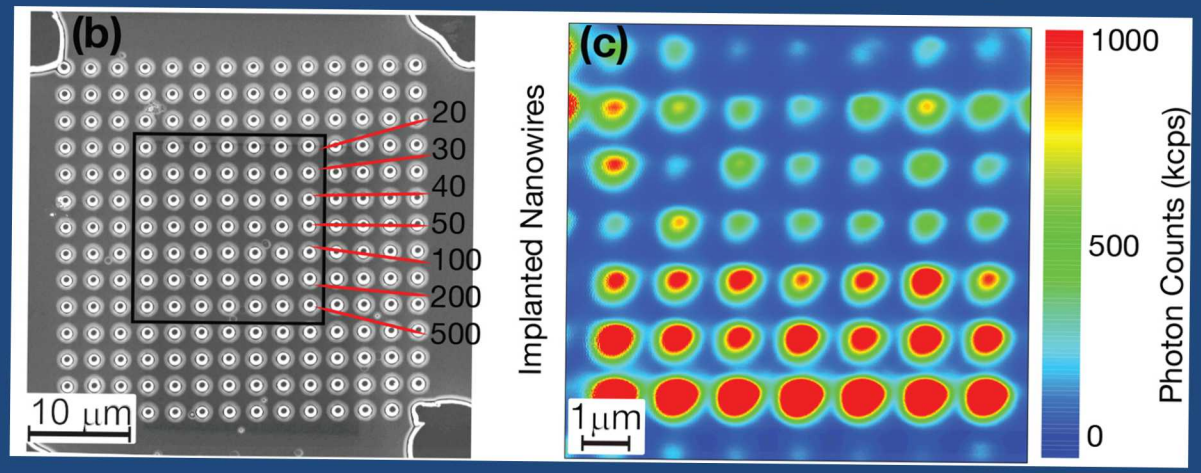


Ion Implantation for Defect Creation

- Ion Implantation is uniquely suited for deterministically generating defect centers in solid state materials
- High-Energy (up to 200 keV) focused ion beam (FIB) implantation allows for targeting accuracy <50 nm and focal spot sizes <30 nm
- Direct-write principle can easily be scaled up to large devices and arbitrary structures
- Crucial roadblock is the low yield of optically active defects
  - ~3% in diamond and SiC

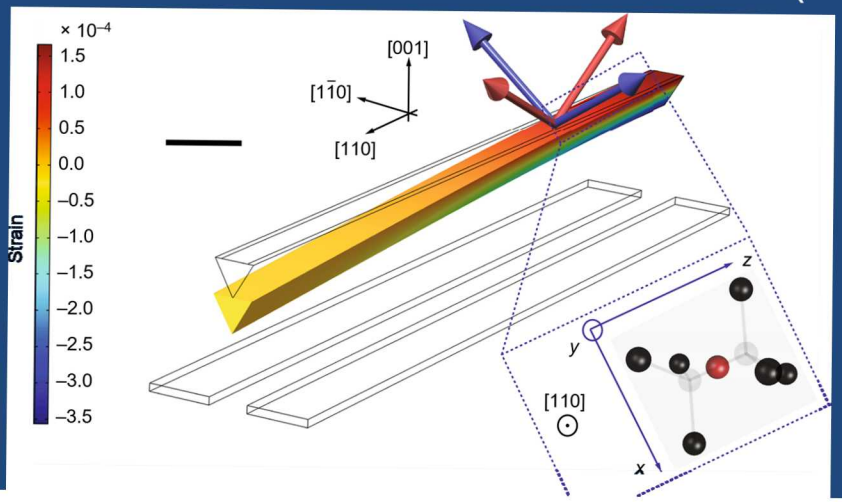


Examples of FIB Implantation



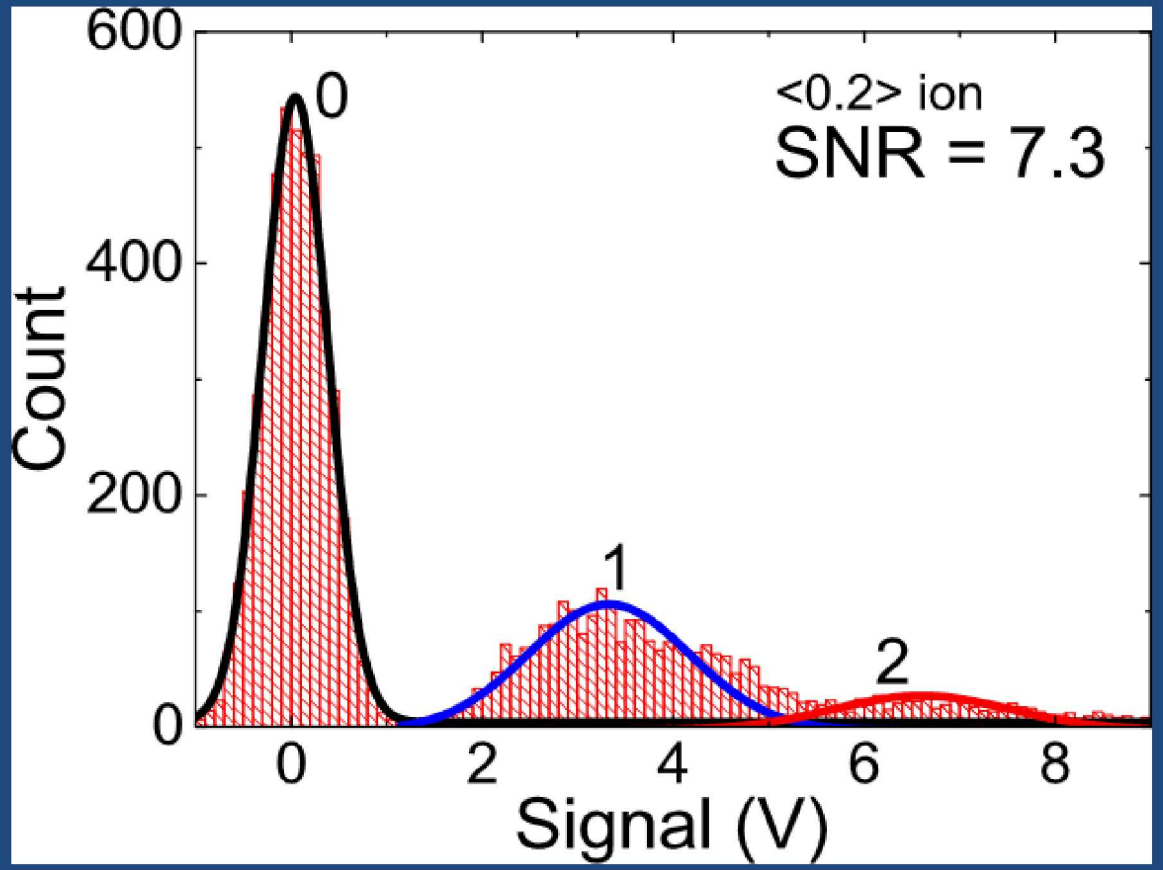
L. Marseglia et al., Opt. Express 26, 80 (2018)

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



Problems When Using Deterministic Defect Creation

- Two main issues with ion implantation for defect creation
  1. Low yield of optically active defects
  2. For few-ion implants, dominated by the Poisson distribution
- In-situ ion counting was demonstrated in our lab enabling deterministic single ion implantation

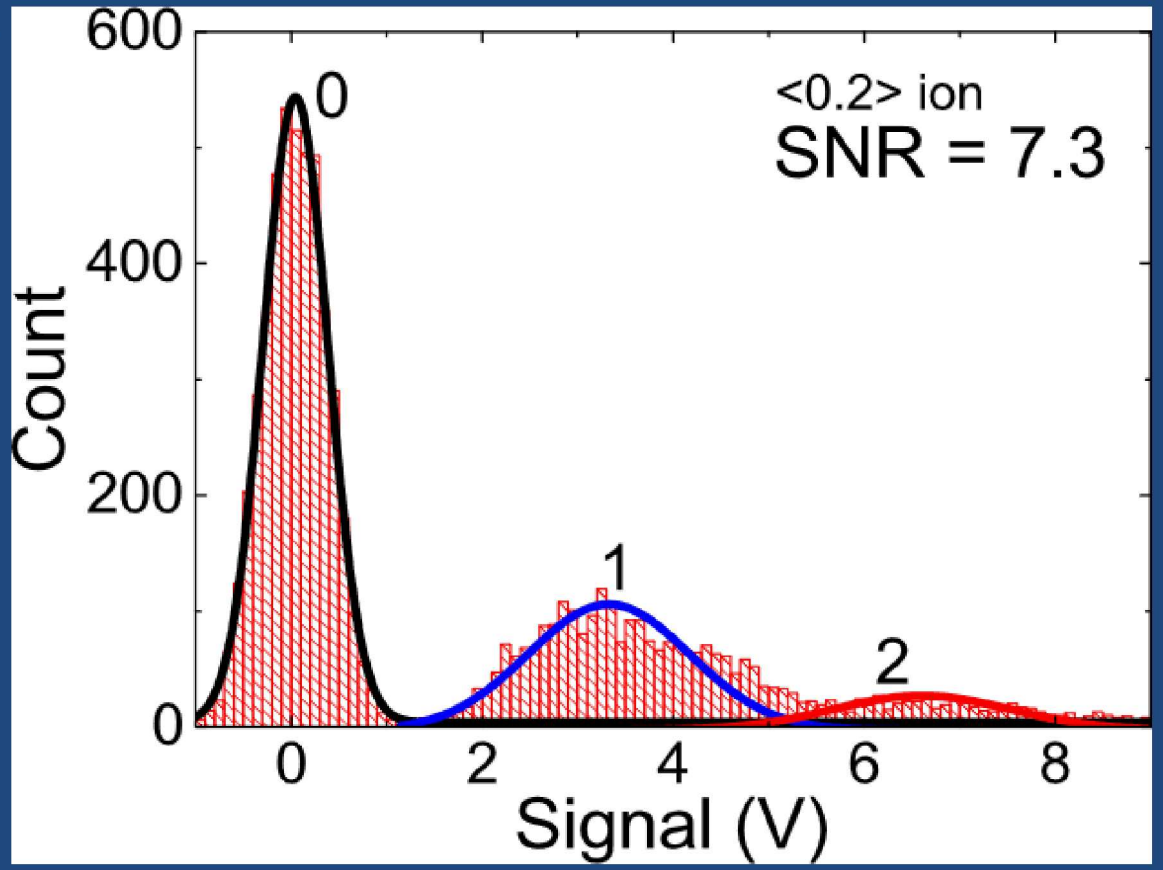


JBS Abraham et al., Appl. Phys. Lett. 109, 063502 (2016)

Problems When Using Deterministic Defect Creation

- Two main issues with ion implantation for defect creation
  1. Low yield of optically active defects
  2. For few-ion implants, dominated by the Poisson distribution
- In-situ ion counting was demonstrated in our lab enabling deterministic single ion implantation

To deterministically create single photon centers, need to detect the photoluminescence (PL) from implanted ions in-situ



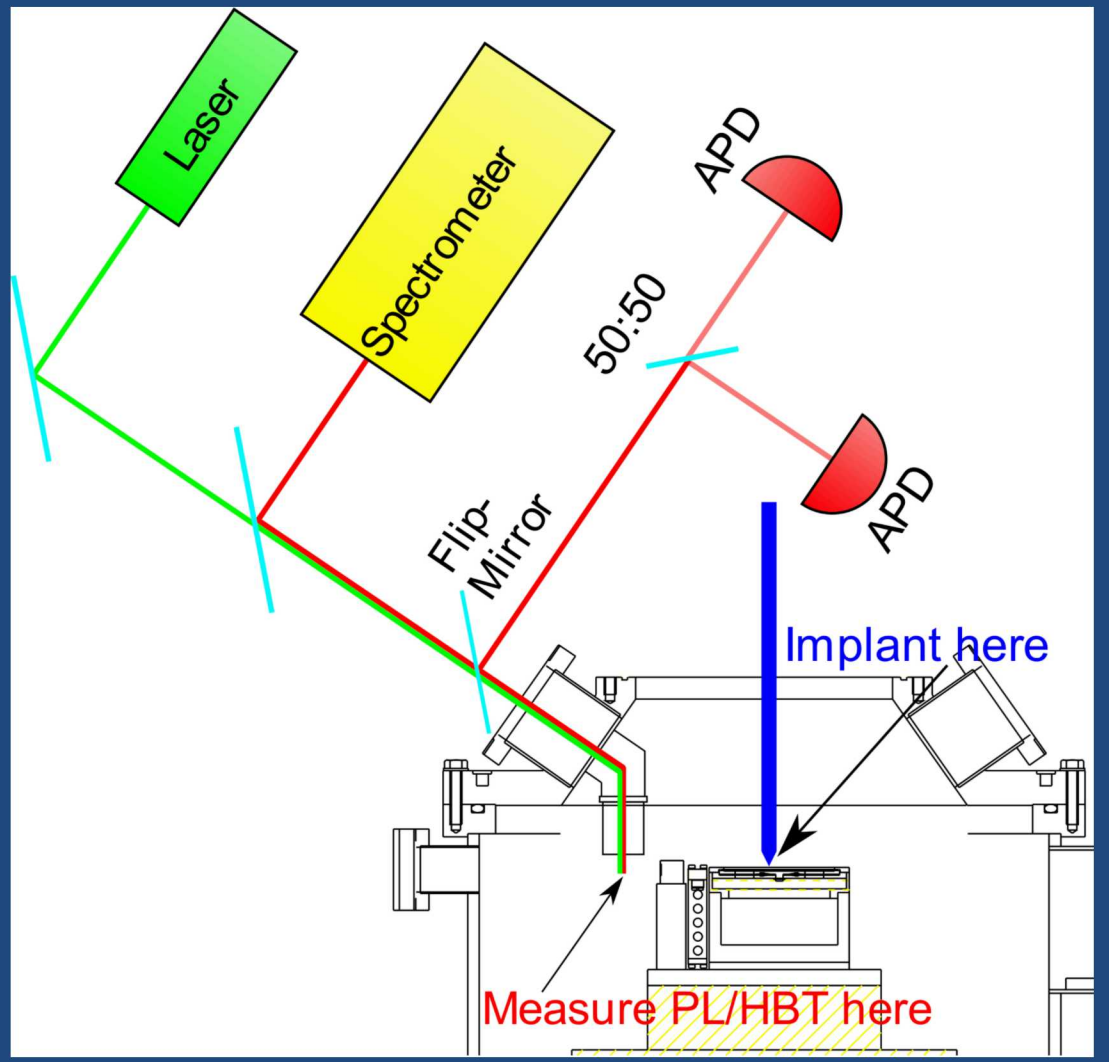
JBS Abrahams et al., Appl. Phys. Lett. 109, 063502 (2016)

In-Situ Photoluminescence Setup

- Two-Step Process, enabled by high-resolution interferometry stage
  - Implant in one location
  - Detect PL with high-NA objective at another location

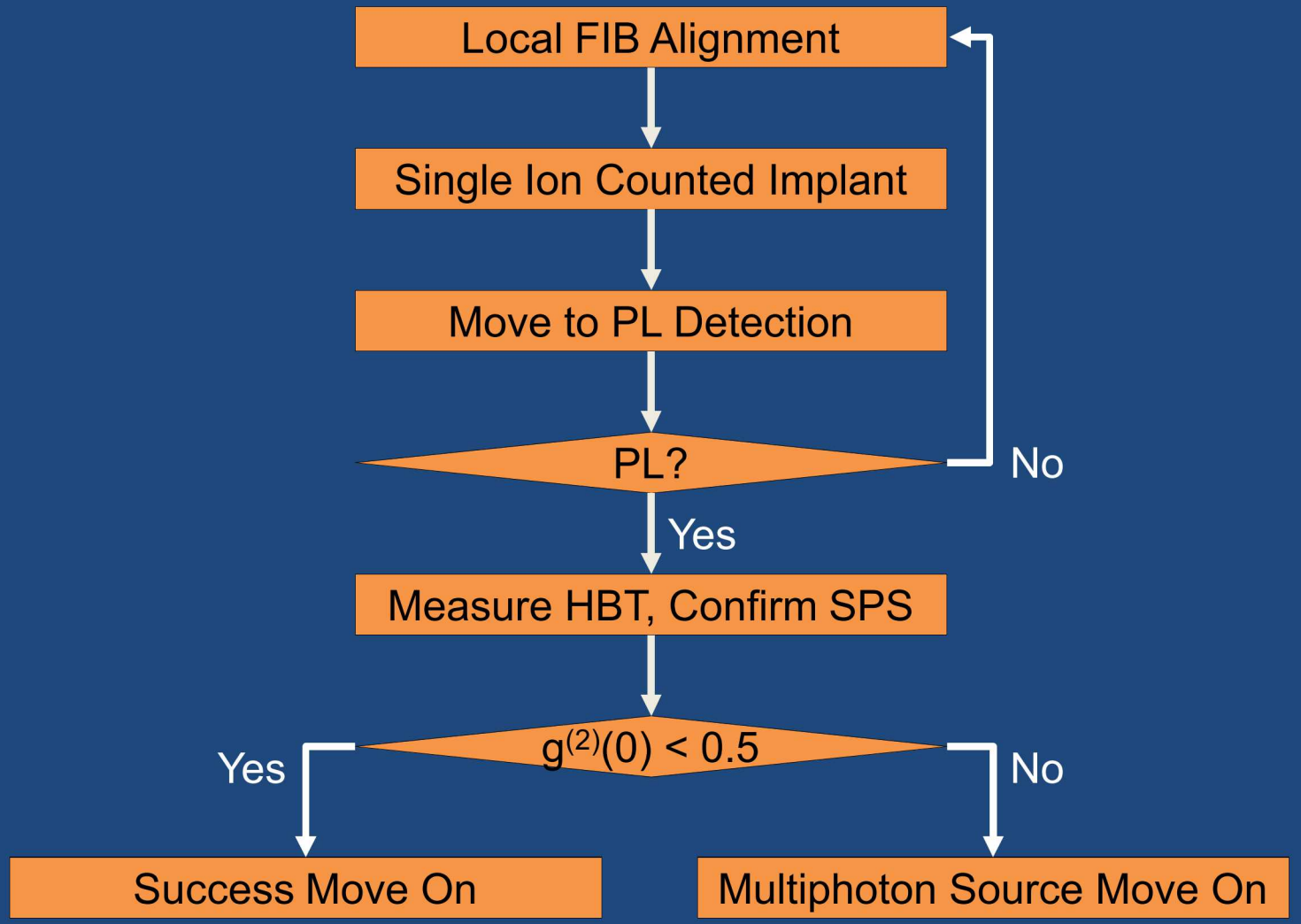
- Vsi is used for in-situ PL, no need for high-temperature anneal

Insert photo of in-situ microscope



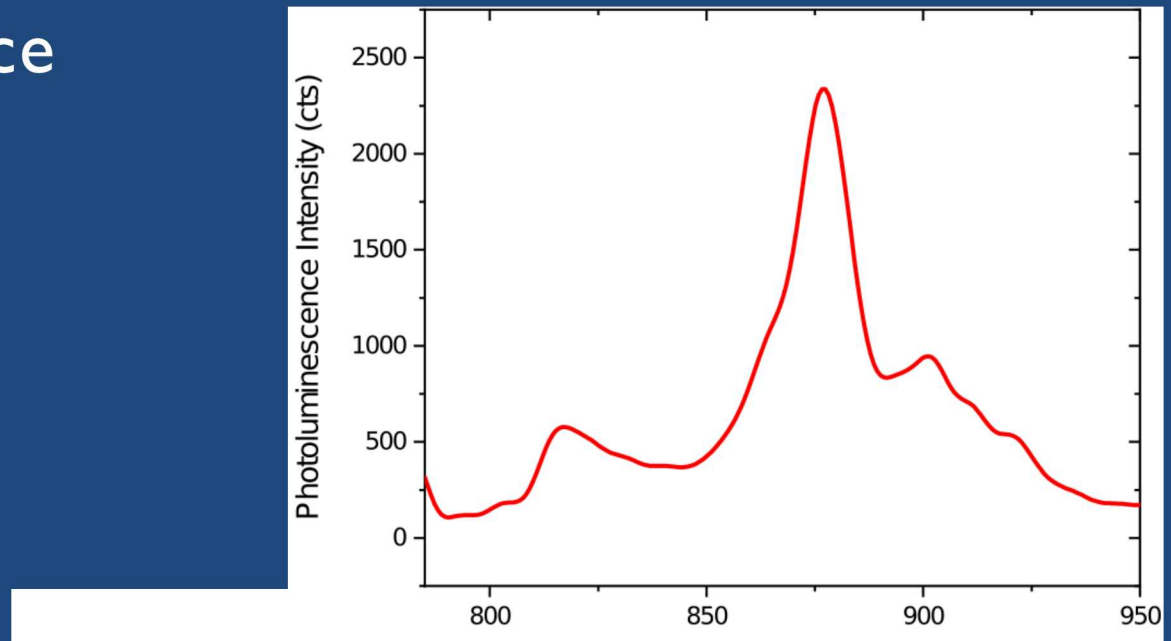
In-Situ SPS Detection Process Flow

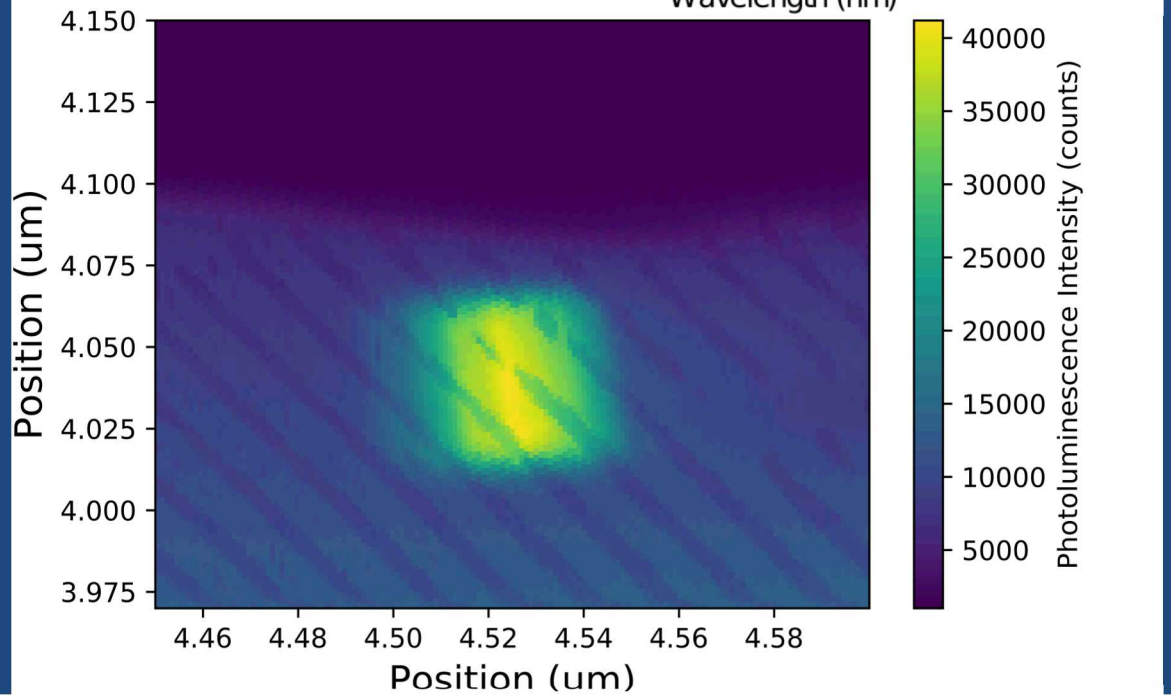
- Movement repeatability between implant location and PL detection ~ 5 um
- Local alignment allows for correction of the ion beam implantation location between ion beam exposures
- Targeting accuracy down to ~50 nm has been previously demonstrated
- Expect to reduce using automatic alignment based on edge detection



Ex-Situ Vsi Photoluminescence

- SiC FIB implantation with 300 keV He to generate V_{Si} defects
  - Implantation fluence 10^12 ions/cm^2
  - Emission from Vsi observed





Conclusion

- Demonstrated high-resolution implantation for scalable quantum applications
- Roadblock so far was low yield
- In-situ detection of SPS enables high yield creation of deterministic defects or color centers
- Future work will allow in-situ detection of defects in diamond (SiV, NV, ZnV, ???)