Laboratories

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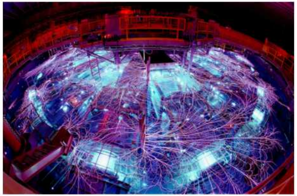

Design of an Experimental Platform for In-Situ Single Quantum Emitter Detection

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Outline

Introduction

- Single Quantum Emitters & Quantum Computing
- Deterministic Placement of Single Quantum Emitters
- Prior Work

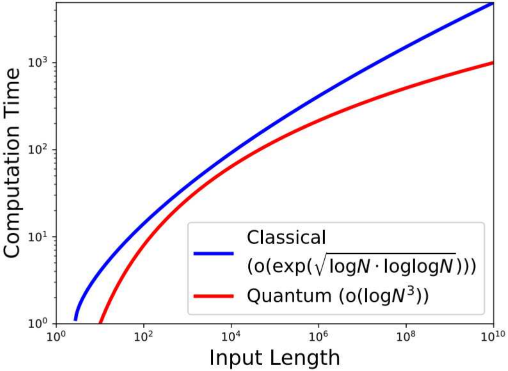
Experiment

- In-Situ Photoluminescence
- Instrument Design

Conclusion

Advantages of Quantum Computing

- Potential for easily breaking current encryption
- Ciritical speedup of computationally hard problems



The (still current) Challenge of Quantum Computing

- Many qubits are needed, but at the same time long coherence times are required
- Solid state systems ideal candidate for high qubit density
    - Single color centers (defect or donor) in wide-bandgap materials: Potential for high-density and long coherence time

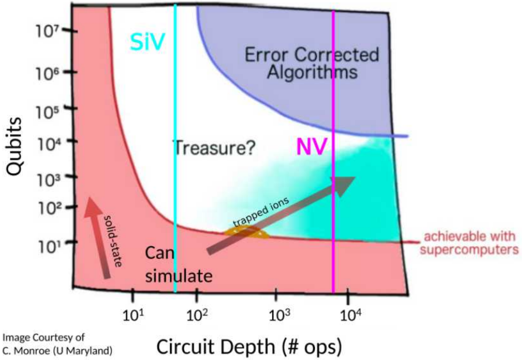
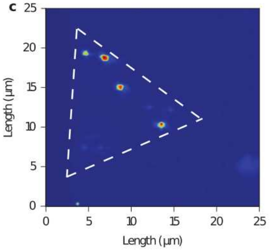


Image Courtesy of C. Monroe (U Maryland)

Deterministic Placement of Single-Quantum Emitters

- Coherent single photons are essential for transmitting quantum information
  - Single quantum emitters (SQE) are a source of coherent photons
- Currently SQE are mostly found, not made in samples
- To unlock the potential of SQE in solid state systems deterministic placement of SQE is necessary
  - Too close, interaction is too strong
  - Too far apart, hard to entangle

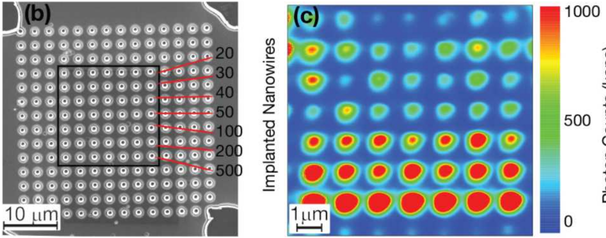


Y.M. He et al., Nature Nanotechnology 10, 497–502 (2015)

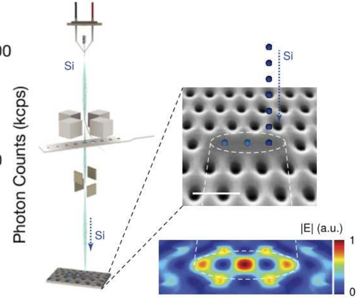
Focused ion beams allow precise (< 40 nm) implantation of defects in virtually any material and donors in materials such as diamond

Focused Ion Beams as a Route to Deterministic SQE Placement

- Focused Ion Beams (FIB) have focal spot sizes in the 10s of nm range



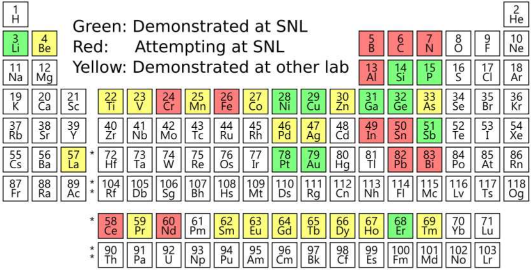
L. Marseglia et al., Opt. Express 26, 80 (2018)



T. Schröder et al., Nat. Comms., 8, 15376 (2017)

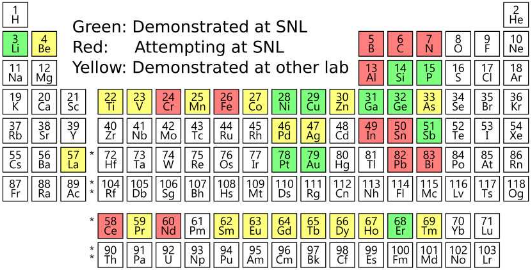
Focused Ion Beams from the nanoImplanter

- 100 kV accelerator using liquid metal alloy ion sources
- Access to ion species from approx. 1/3rd the periodic table



Focused Ion Beams from the nanoImplanter

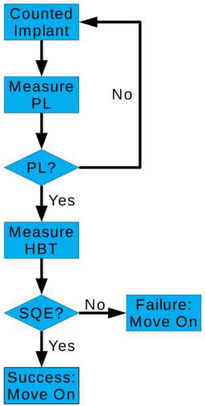
- Prior work has done timed and in-situ counted implantation but has not yet checked for in-situ SQE behaviour



BUT: None of this tells us if we have a SQE or not until after the fact

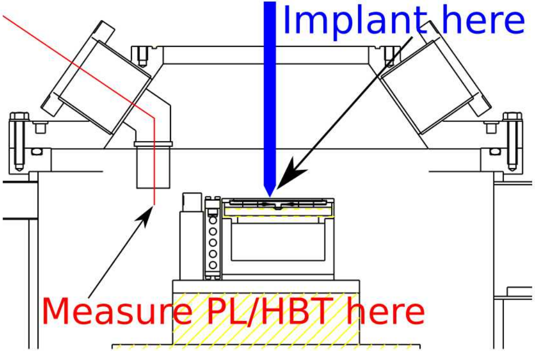
In-Situ Photoluminescence Detection for SQE Measurement

- Add a photoluminescence (PL) setup to the FIB column
- Use PL and Hanbury-Brown-Twiss (HBT) measurement to unambiguously determine SQE creation
- Implant, then check for PL immediately, if PL is visible, check for SQE with HBT
- Keep implanting until a SQE has been generated at the implant location, determined by HBT result



Design of the Custom In-Situ Microscope

- Microscope objective in vacuum chamber for in-situ PL detection
- z-axis movement to adjust for different focus of ion beam and optical microscope

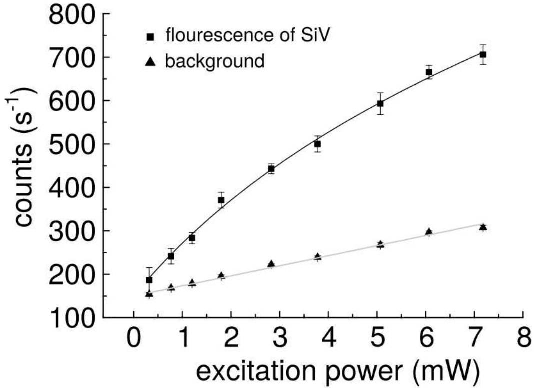


How Much Signal Can We Expect?

- Overall detection efficiency is estimated to be $\approx 10\%$

Component	Efficiency
BS Cube	45 %
Objective	80 %
NA	35 %
Dichroic	95 %

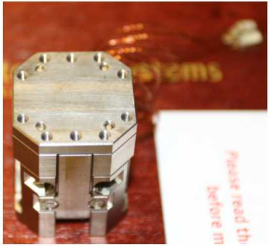
- To get $\geq 10^6$ cps, use ≥ 1 mW pump laser
  - Expected count rates from literature: $1 - 5 \times 10^5$ cps with 1 mW

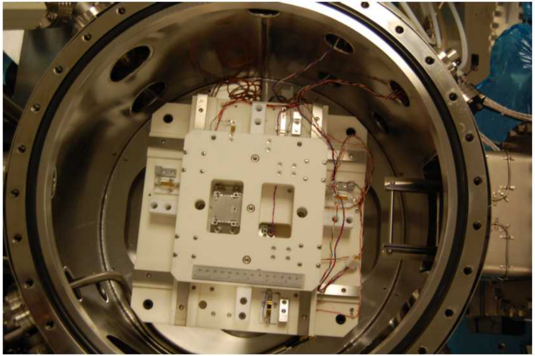


Wang et al., J. Phys. B: At. Mol. Opt. Phys., 39, 1 (2006)

Sample Holder Redesign

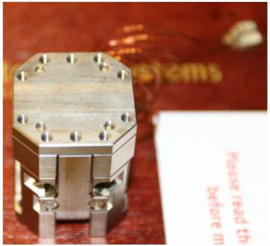
- Current sample holder does not have z-adjust
- Need to adjust sample height to focus in FIB and microscope

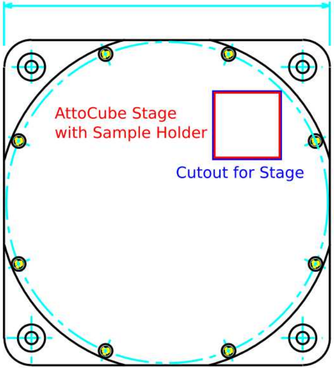


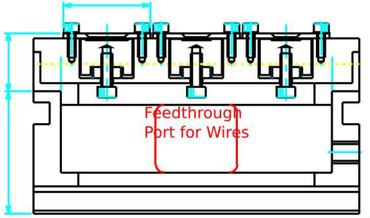


Sample Holder Redesign

- Current sample holder does not have z-adjust
- Need to adjust sample height to focus in FIB and microscope
- Add in capability to do counted implantation as well as in-situ PL

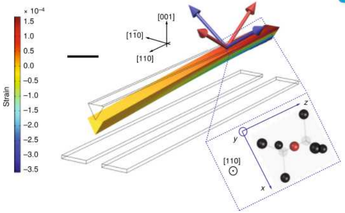




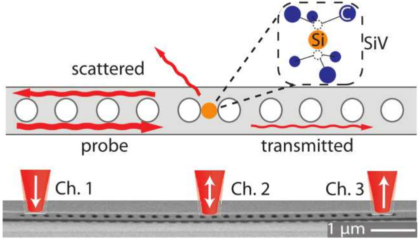


Conclusion

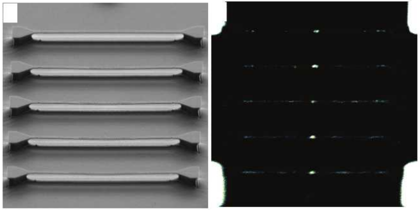
- Demonstrated the ability to perform high-resolution implantation (< 50 nm in x and y)
- Implantation depth accuracy (z axis) limited by straggle



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



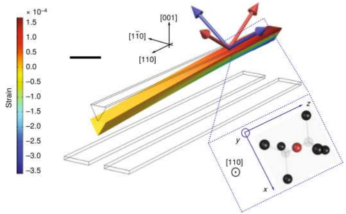
R. E. Evans et al., Science 362, 662–665 (2018)



A. Sipahigil et al., Science 354 (6314), 847-850 (2016)

Conclusion

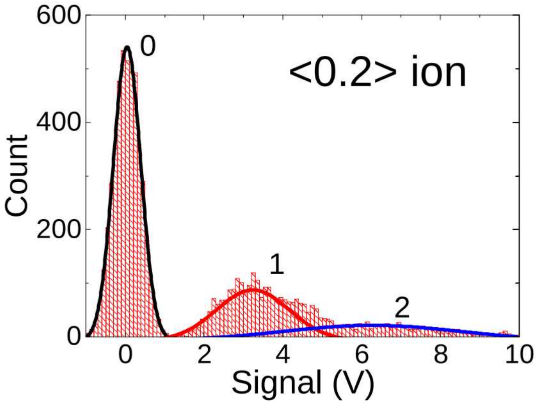
- Demonstrated the ability to perform high-resolution implantation (< 50 nm in x and y)
- Implantation depth accuracy (z axis) limited by straggle
- Currently silicon implantation into diamond is of limited use since the yield for optically active defect centers is low
  - Use the in-situ PL microscope on the nanoImplanter to deterministically create optically active defect centers with high resolution



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

Counted Implantation

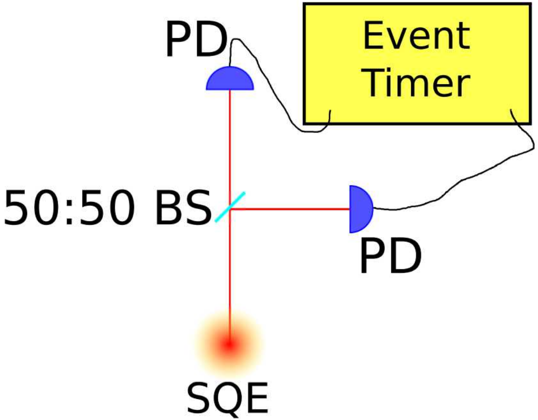
- Requires wire bondpads next to implantation region
- Does not confirm that implanted region is emitting light
- Problems arise with Si implantation into diamond where yield is only approx. 3%
  - Use SiC for testing of the microscope where yield is $10 - 20\%$, then move on to diamond



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

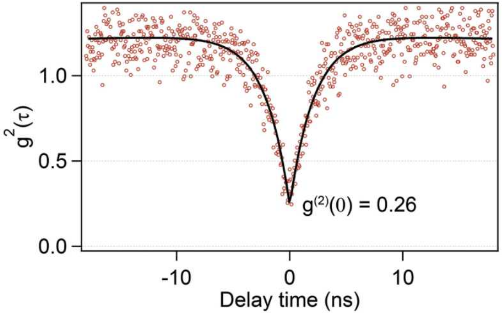
Hanbury-Brown-Twiss Measurement

- SQE can only emit one photon at a time
- Each photon will be transmitted or reflected at the beamsplitter being detected at only one of the two photodiodes



Hanbury-Brown-Twiss Measurement

- SQE can only emit one photon at a time
- Each photon will be transmitted or reflected at the beamsplitter being detected at only one of the two photodiodes
- Timed correlation measurement shows that within lifetime of SQE, correlation is close to zero



T. T. Tran et al., APL Photonics 2, 116103 (2017)