Quantum Technologies (generic)
Utilizing defects in crystals for quantum information application (specific)

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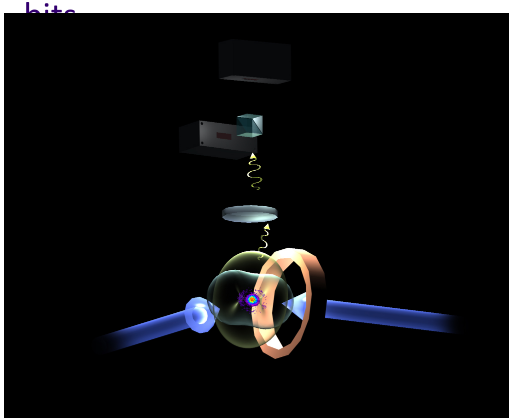
Monday, July 30th, 2018
UW Physics REU program

UNIVERSITY of WASHINGTON

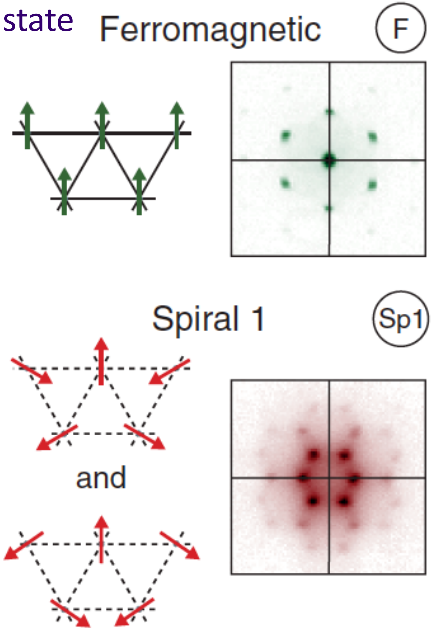
Atoms are the quintessential quantum system

Trapped ions as quantum bits



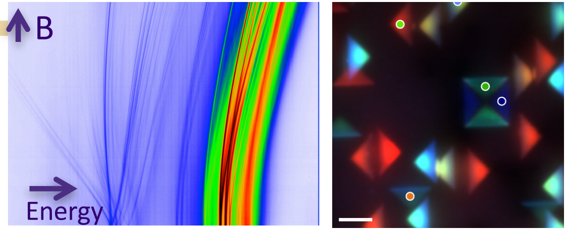
Schematic of a single trapped ion
Blinov group, UW

Cold atoms used to simulate magnetic effects in solid state

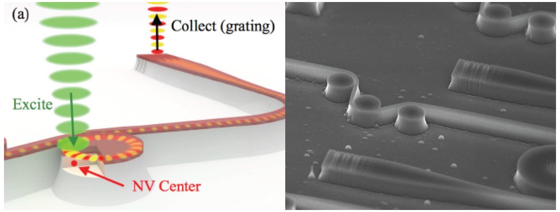


Sengstock group, Hamburg

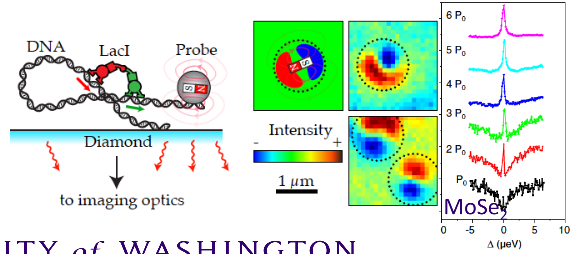
Quantum-enabled technologies



Fundamental properties of carriers bound to defects in direct band gap semiconductors



With “less-than-perfect” defects, building an on-chip network of spins



Collaborative efforts:
Sensing nanomagnet probes
(Paul Wiggins, UW)
Excitonic and magnetic properties in 2D materials (Xiaodong Xu, UW)

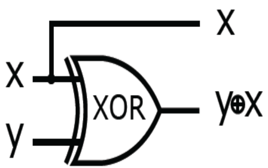
Quantum Information (brief diversion)

Classical Information

Bit

0, 1

Gate, Reversible XOR



Classically tractable problems

"Quantumly" tractable problems

Quantum Information

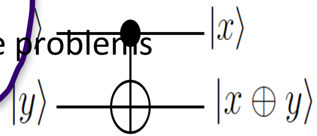
Qubit:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

$$|\alpha|^2 + |\beta|^2 = 1$$

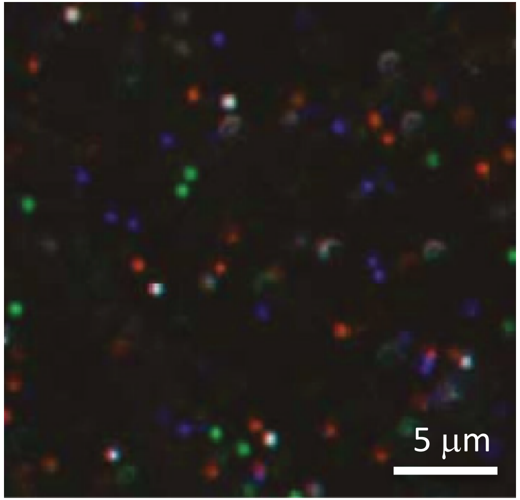
$$\hat{H}|\psi\rangle = i\hbar\frac{\partial}{\partial t}|\psi\rangle$$

Gate, CNOT



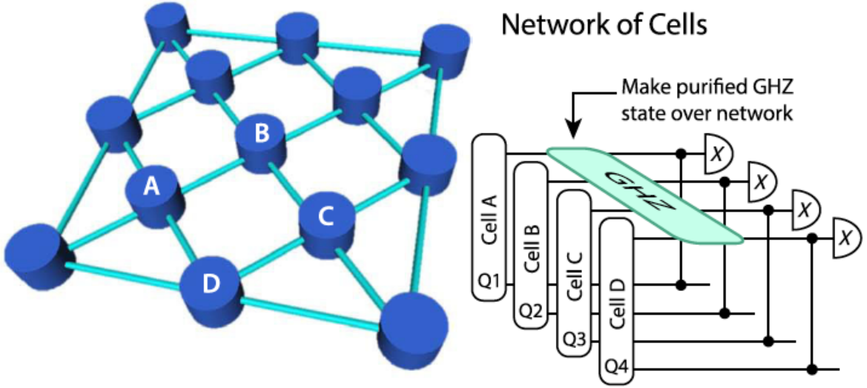
Defect-based quantum networks

Single defect experiments



Optical image of single defects in commercial diamond substrate[1].

Measurement-based quantum entanglement



Distributed model of quantum information processing[2,3]

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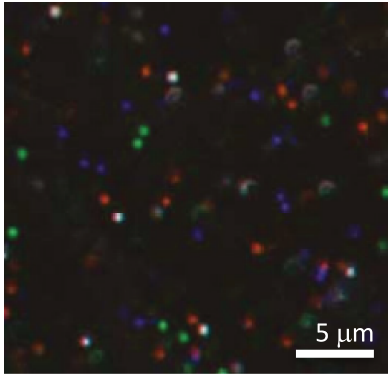
[1]Edmonds *et al. PRB* (2012) [2]Nickerson, Fitzsimons, Benjamin *PRX* 4 041041 (2014) [3]Raussendorf, Briegel, *PRL* (2001)

Enabling developments for defect-based quantum information

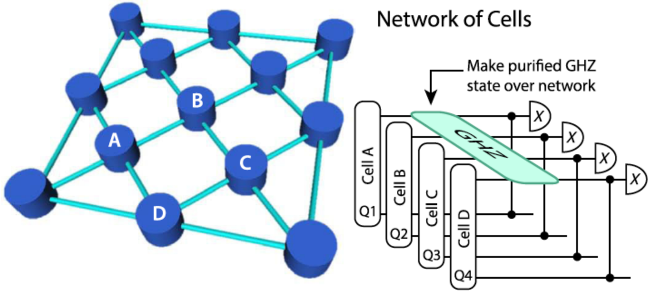
Single defect experiments



Optical image of single defects in commercial diamond substrate[1].

(Not just in diamond!)

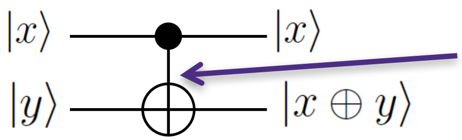
Measurement-based quantum entanglement



Distributed model of quantum information processing[2]

[1]Edmonds *et al.* (Warwick, UW, HP) *PRB* 86, 035201 (2012)
[2]Nickerson, Fitzsimons, Benjamin *PRX* 4 041041 (2014)

Removing the need for local interaction

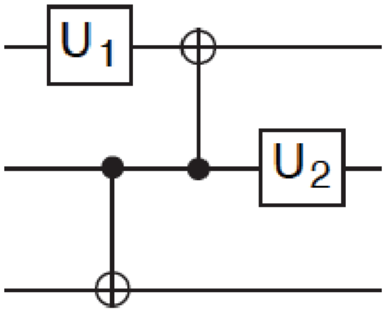


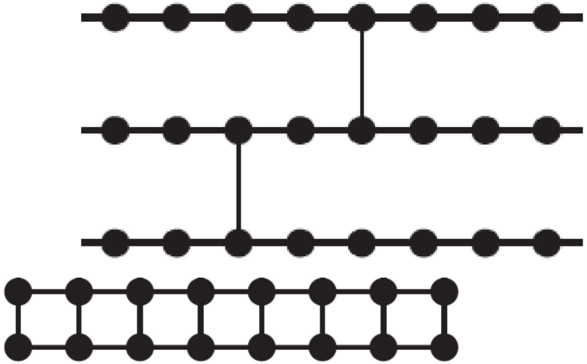
Looks like a local
interaction that needs
high level of control

qubit

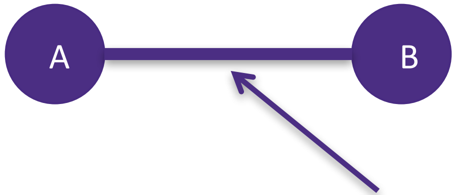
glement

Alte
“clu
sing





Raussendorf, Briegel, *PRL* 86, 5188 “A one-way quantum computer”

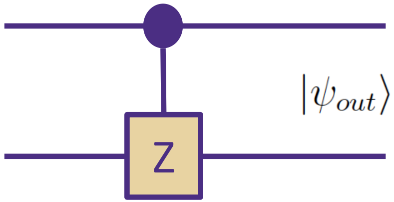


(Significant portion of my research)

This edge is created when a c-phase gate is applied to the following input states.

$$\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$$

$$\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$$

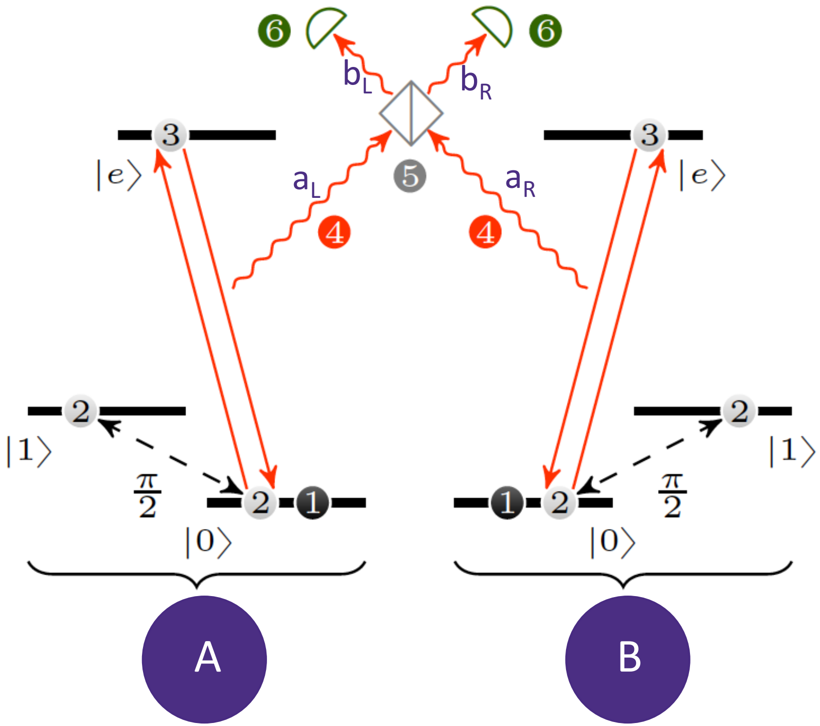


$$|\psi_{out}\rangle = \frac{1}{2}(|00\rangle + |01\rangle + |10\rangle - |11\rangle)$$

$$|\psi_{out}\rangle = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} \langle 00|\psi_{in}\rangle \\ \langle 01|\psi_{in}\rangle \\ \langle 10|\psi_{in}\rangle \\ \langle 11|\psi_{in}\rangle \end{bmatrix}$$

(Output state is local unitary equivalent to a Bell state.)

Edge can be created via measurement on emitted photons from A and B.



1 $[|0\rangle \otimes |0\rangle]\,|\mathrm{vac}\rangle$

2 $[(|0\rangle + |1\rangle) \otimes (|0\rangle + |1\rangle)]\,|\mathrm{vac}\rangle$

3 $[(|e\rangle + |1\rangle) \otimes (|e\rangle + |1\rangle)]\,|\mathrm{vac}\rangle$

3‘ $[|e1\rangle + |1e\rangle]\,|\mathrm{vac}\rangle$

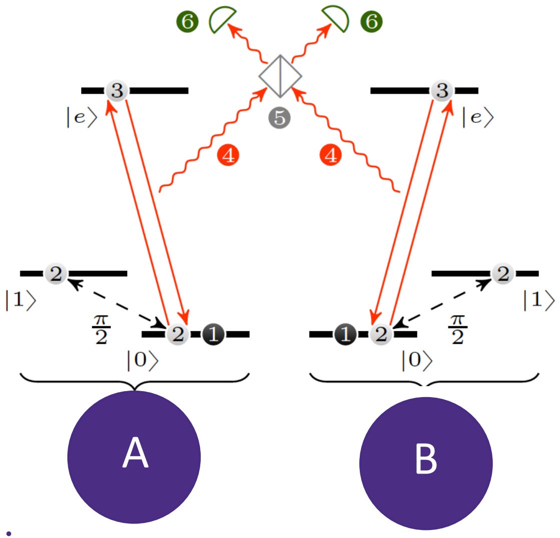
4 $\left[|01\rangle a_{\mathrm{R}}^{\dagger} + |10\rangle a_{\mathrm{L}}^{\dagger}\right]|\mathrm{vac}\rangle$

5 $\left[(|01\rangle + i|10\rangle) b_{\mathrm{L}}^{\dagger} + (i|01\rangle + |10\rangle) b_{\mathrm{R}}^{\dagger}\right]|\mathrm{vac}\rangle$

6 $(|01\rangle + i|10\rangle)$

Barrett and Kok *PRA* 71, 060310, Experimental demonstration with NV centers- TU Delft

System requirements (subset)



> **Two atoms must emit identical photons**

> **Photon must be detected**
  - Described protocol scales linearly with detection efficiency
  - Protocols robust to loss error scale as square of efficiency

> **At least 2 qubits per node with local operations**

> **Entanglement rate should be significantly faster than decoherence time.**

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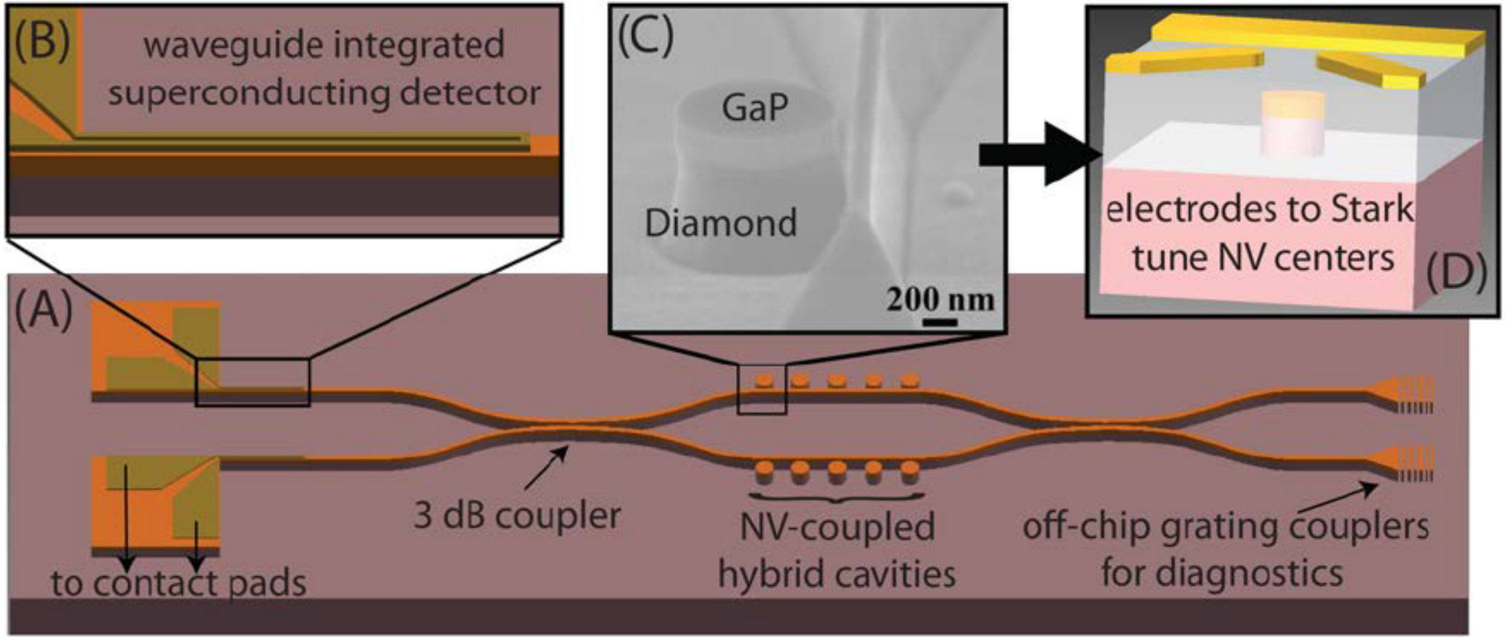
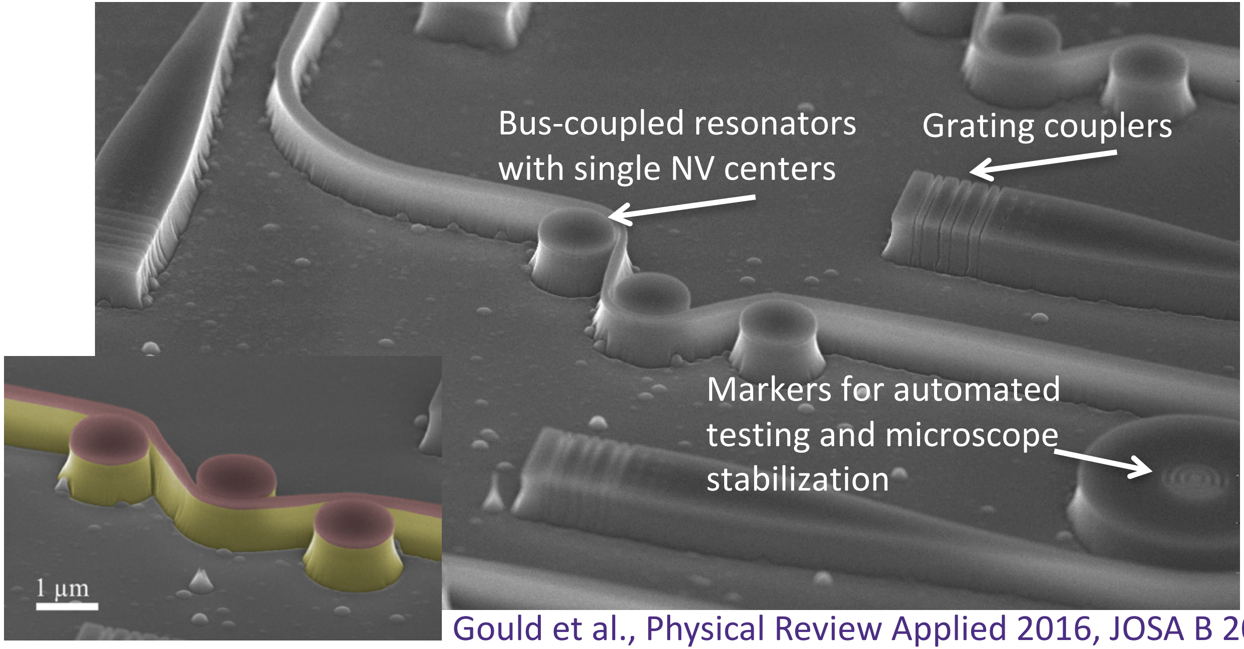
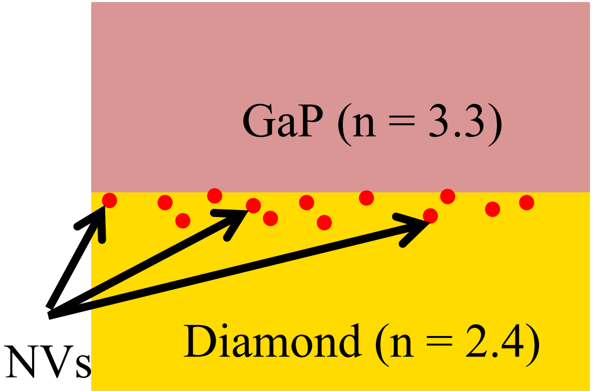
The lure of a solid-state platform



Efficient photon collection and routing

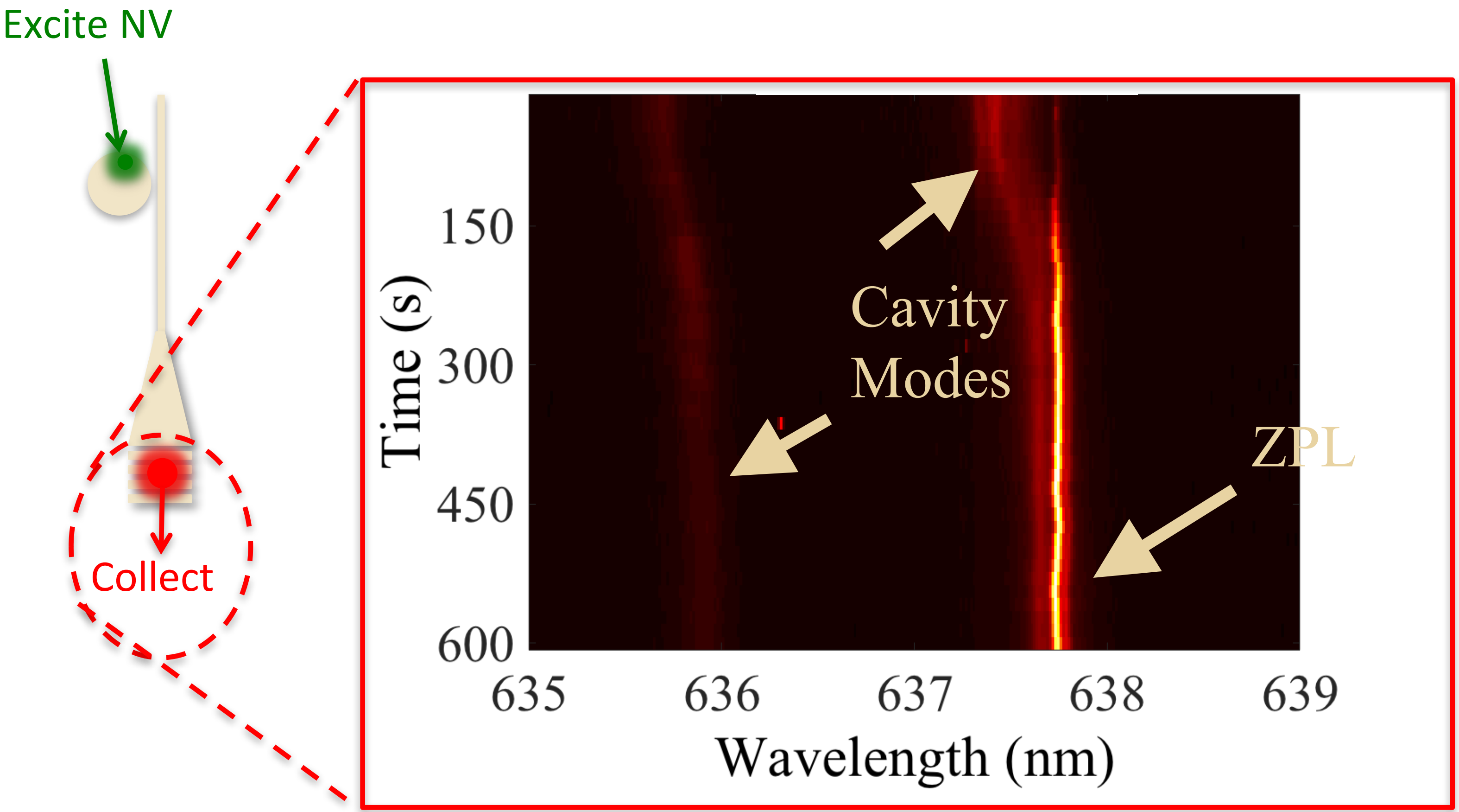




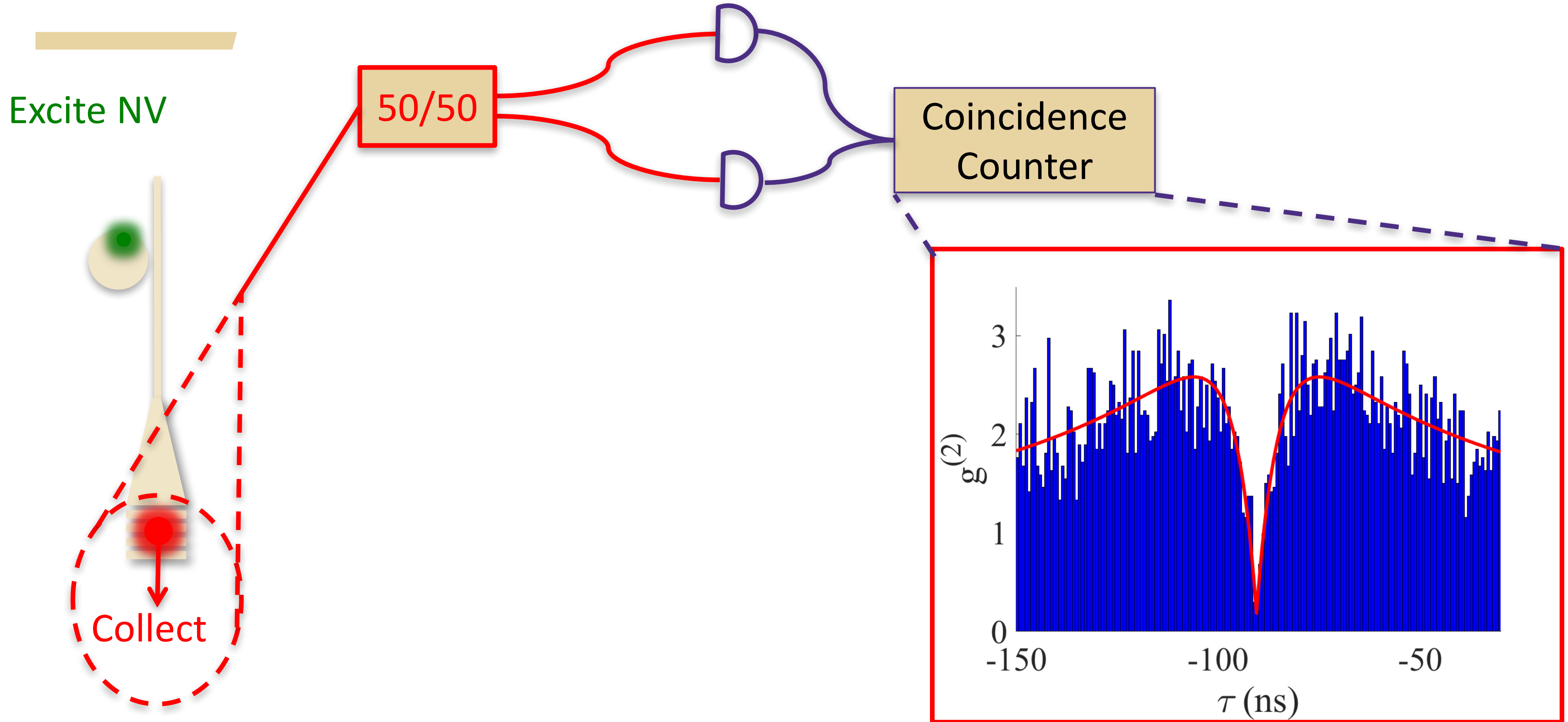
Gould et al., Physical Review Applied 2016, JOSA B 2016

GaP growth: Fariba Hatami, Humboldt University

Collecting photons from a single defect

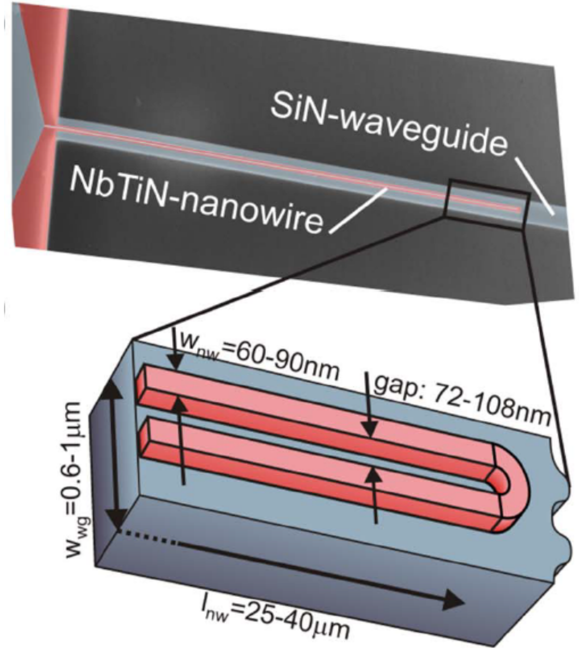


Statistics of a single photon source



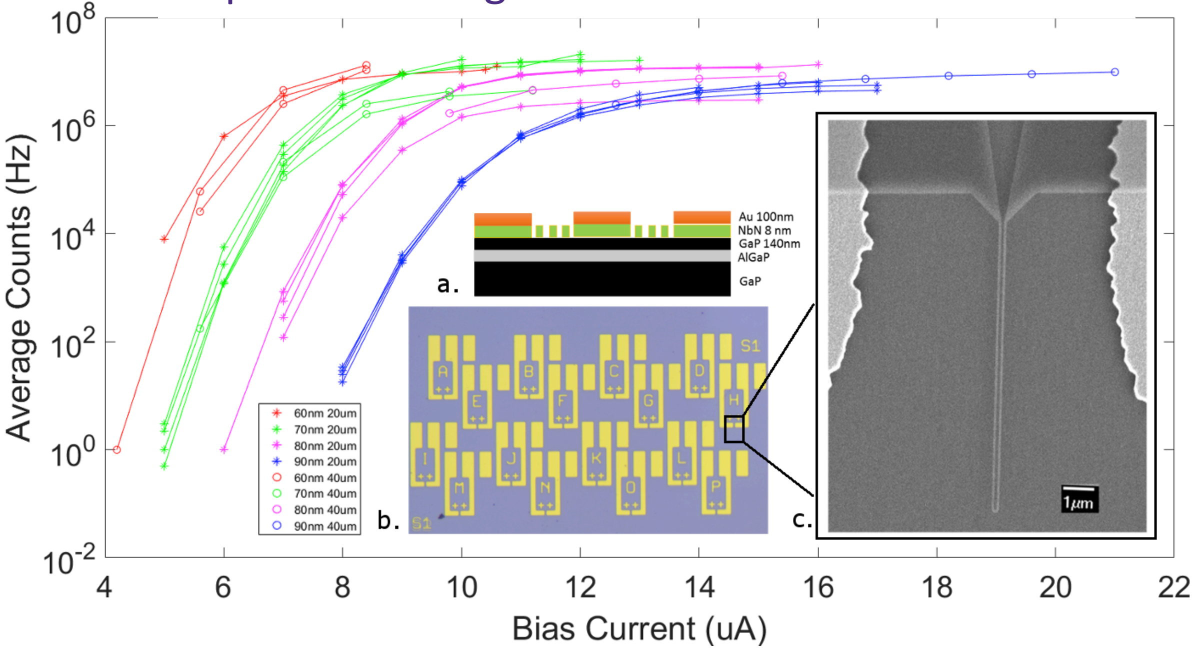
Prospects for on-chip detection

Srivatsa Chakravarthi



Hong Tang group, Yale

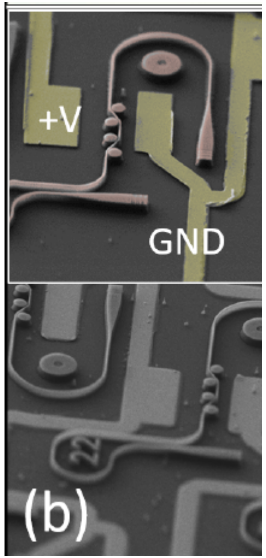
Superconducting NbN detectors on GaP at UW



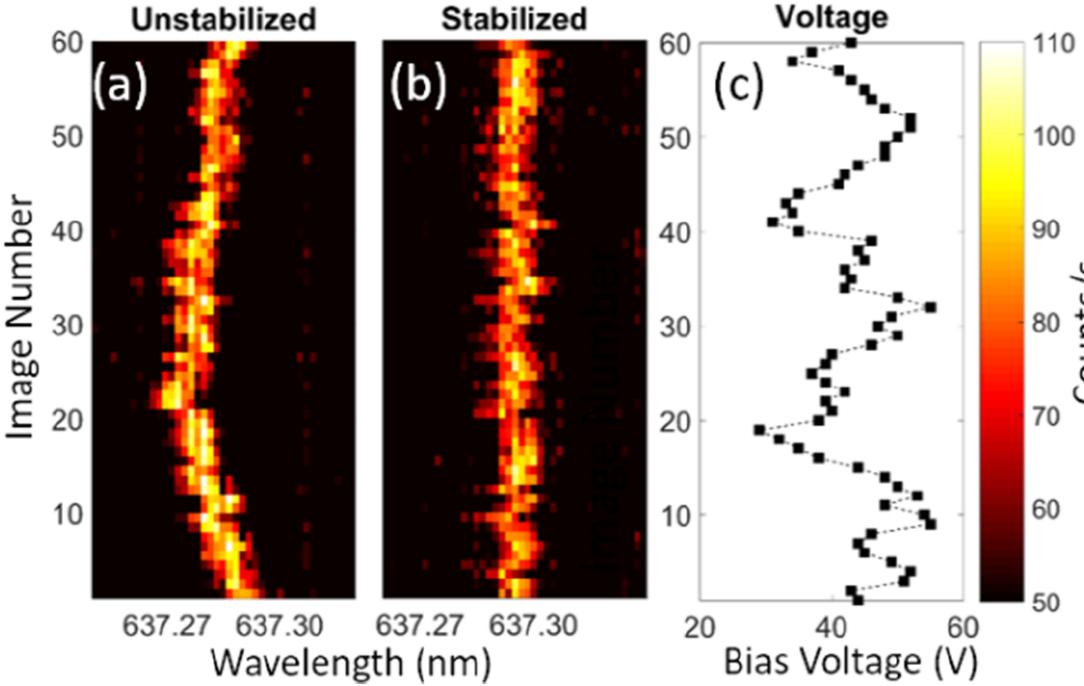
NbN sputtering: Andrea Fiore, TU Eindhoven

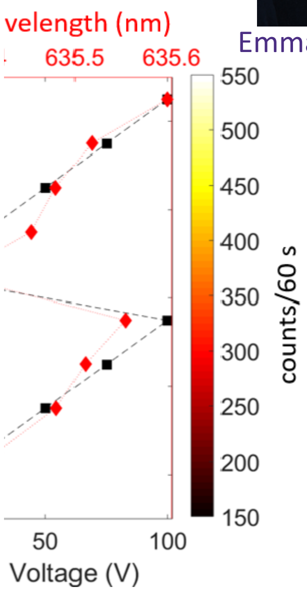
Prospects for active control of defect properties

Emma Schmidgall



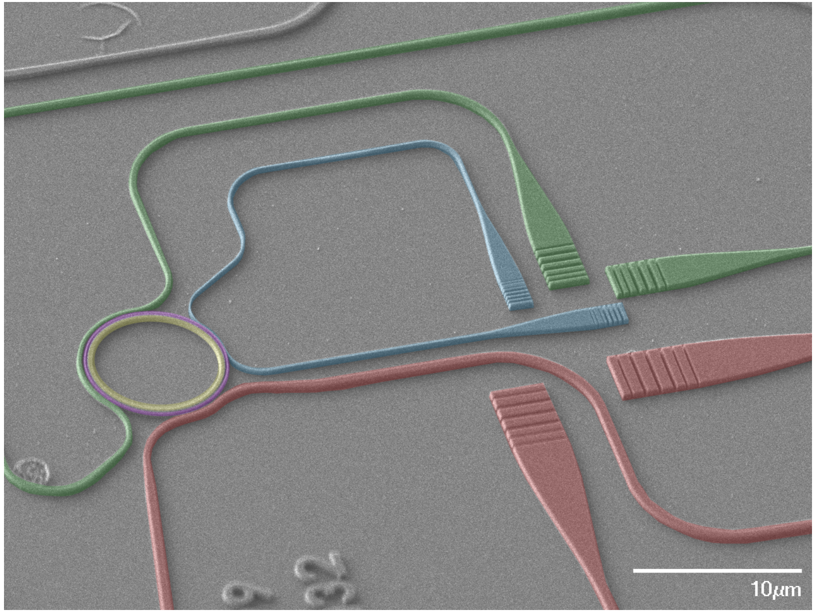
Schmidgall, Chak





Disclaimer: level of stabilization is still orders of magnitude off for quantum applications.

Low energy frequency conversion



Alan Logan

GaP transferred to oxide

Difference frequency conversion:
637 nm + 1080 nm -> 1550 nm

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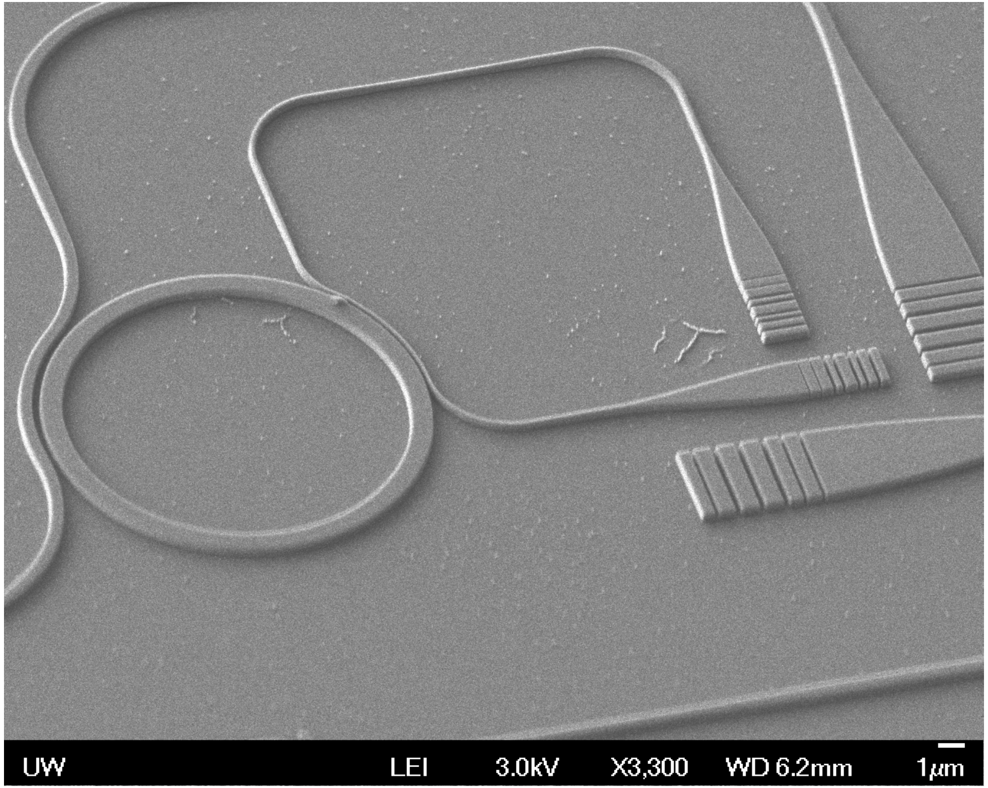
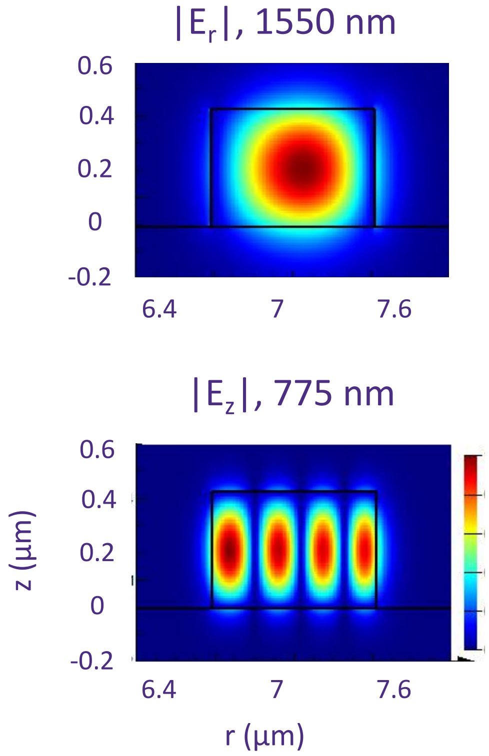
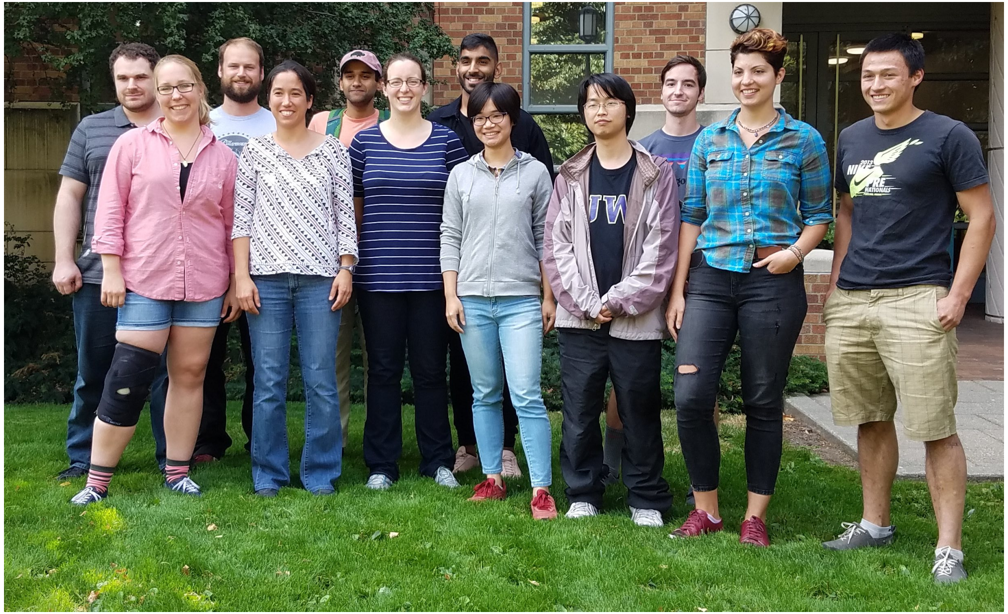
Nonlinear photonics design: Alejandro Rodriguez, Princeton

Low energy frequency conversion: Current working devices 1550 nm -> 775 nm







Semiconductor Spins

*Todd Karin, PhD
Xiayu Linpeng, grad
Maria Viitaniemi, grad
*Cameron Johnson, undergrad
Colin Stanley, Glasgow (GaAs growth)
Satoru Seto, Ishikawa (CdTe growth)
Simon Watkins, Simon Fraser (InP growth)
Y. Kozuka, M.Kawasaki, U. Tokyo (ZnO growth)
Mikhail Durnev, Ioffe (theory)
Mikhael Glazov, (theory)

Diamond Photonics

Michael Gould*, PhD
Emma Schmidgall, postdoc
Srivatsa Vardaraj, grad
Alan Logan, grad
Ian Christen, undergrad
Fariba Hatami, Humboldt (GaP growth)
Andrea Fiore (NbN growth)

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NSF DARPA

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*former members