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the foundation of an impending revolution

Meenakshi Singh

Sandia National Laboratories

Image from http://3.bp.blogspot.com/_y7rfKiUrBlY/TOvZ1wZSNBI/AAAAAAAADCk/dH6Pi5PtLiU/s1600/spinning_top.gif


#FeelTheBern
Bernie
2016
Feel The Bern
Bernie


the silent majority
STANDS WITH
TRUMP
MAKE
AMERICA
GREAT
AGAIN
Vote
Can't

the foundation of an impending revolution

in electronics

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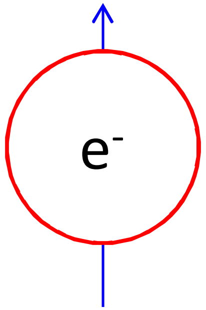
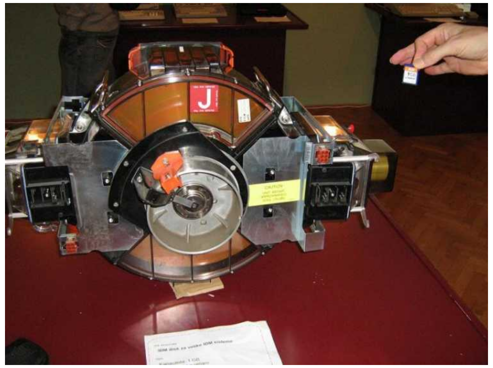
Image from http://3.bp.blogspot.com/_y7rfKiUrBlY/TOvZ1wZSNBI/AAAAAAAADCk/dH6Pi5PtLiU/s1600/spinning_top.gif

Prologue: do we want a revolution?

Conventional electronics rely on the charge of an electron

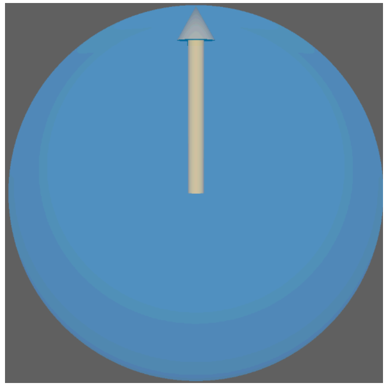
Electron has another property - spin





- End of ‘Moore’s Law’ is coming
- Multiple functionality
- …
- …

Donor Spin Qubits in Silicon



Proximity Effect in Ferromagnetic Nanowires

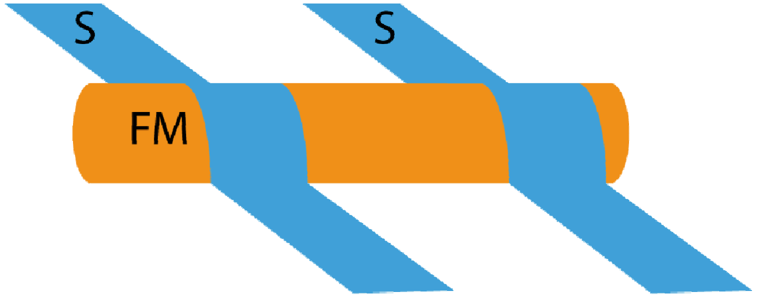
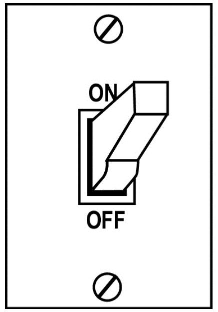


Image from gizmodo.com/302856/this-is-what-1gb-of-storage-looks-like-now-and-20-years-ago

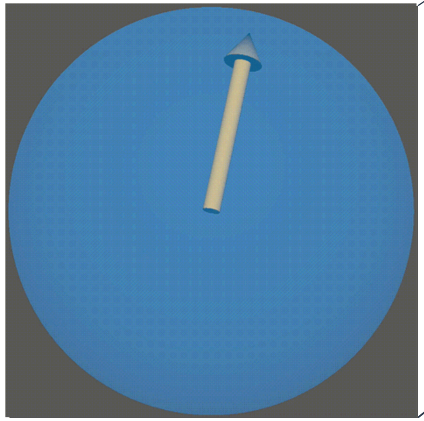
Donor Spin Qubits in Silicon

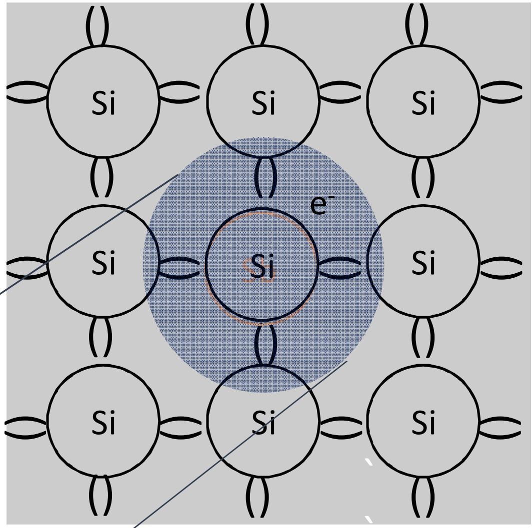
Donor Spin Qubits in Silicon

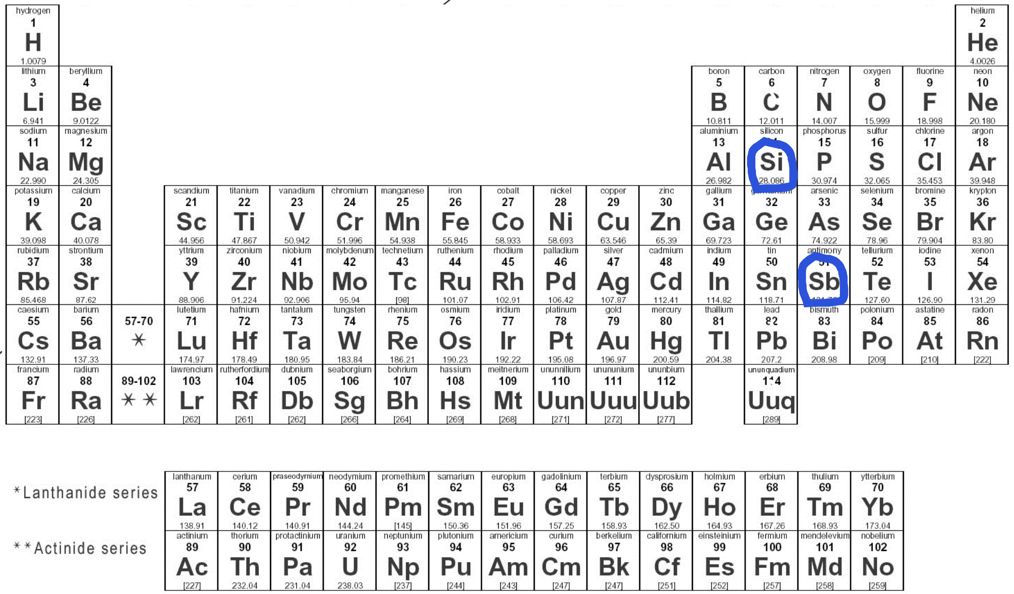
A bit



An electron spin

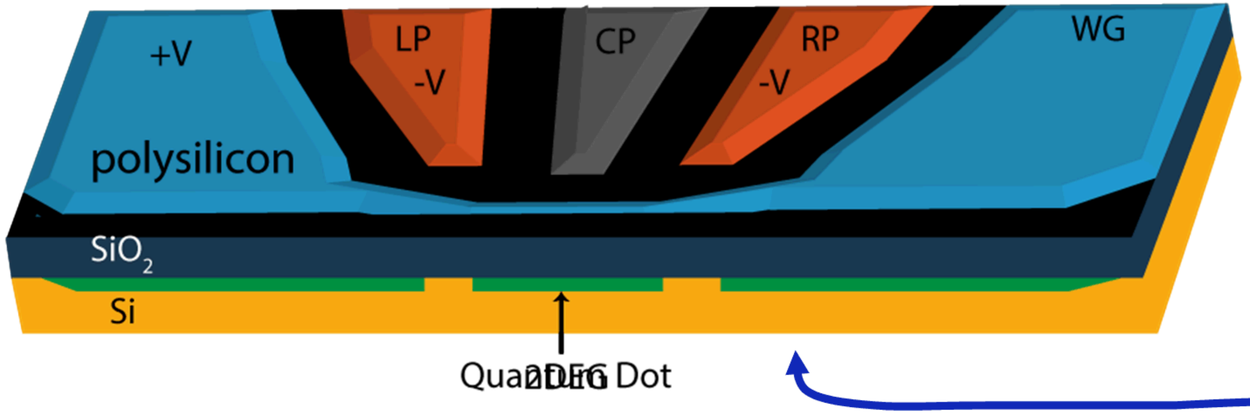


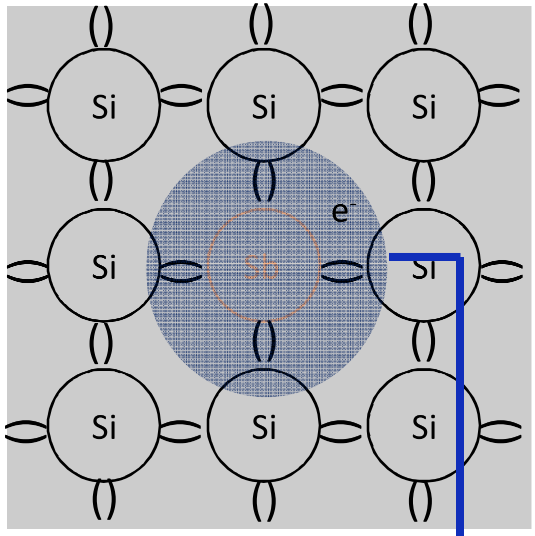




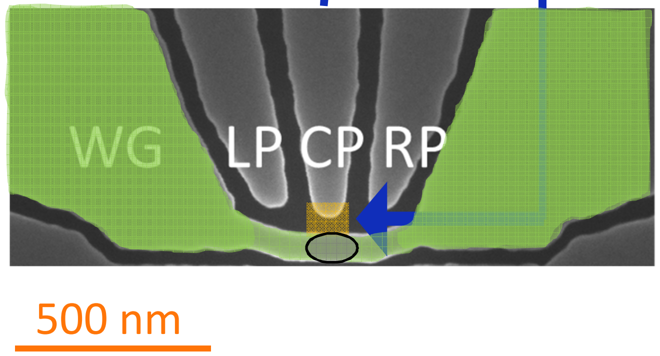
What is a spin to do? (to be a viable qubit)

1. Take orders from and give information to user: single qubit





2. Work with other spins: two qubit gates

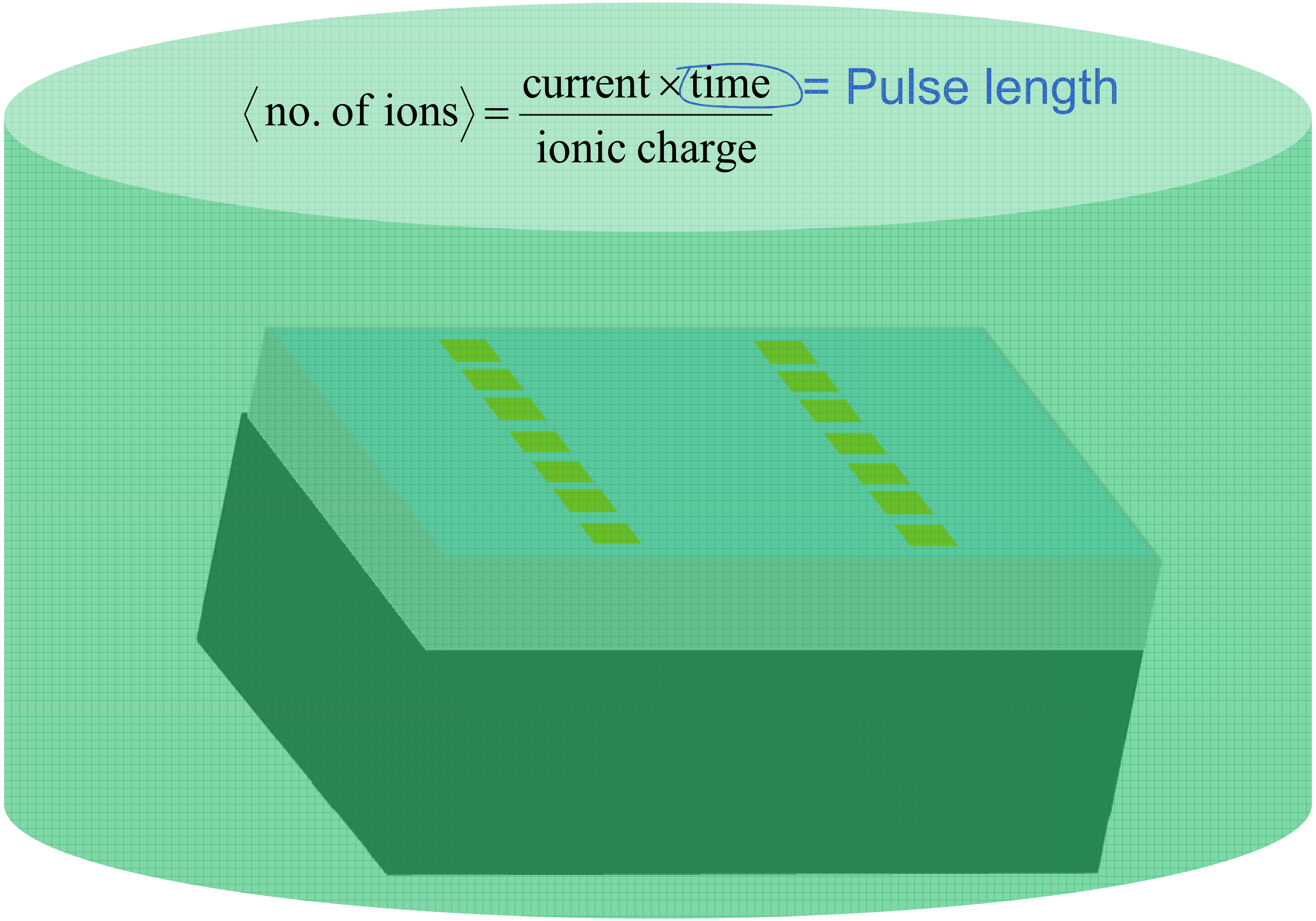


Deterministic control over:

1. Placement of donors
2. Number of donors

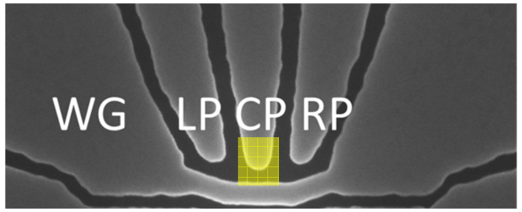
How the location/”counting” was done till now

$$\langle \text{no. of ions} \rangle = \frac{\text{current} \times \text{time}}{\text{ionic charge}}$$ = Pulse length

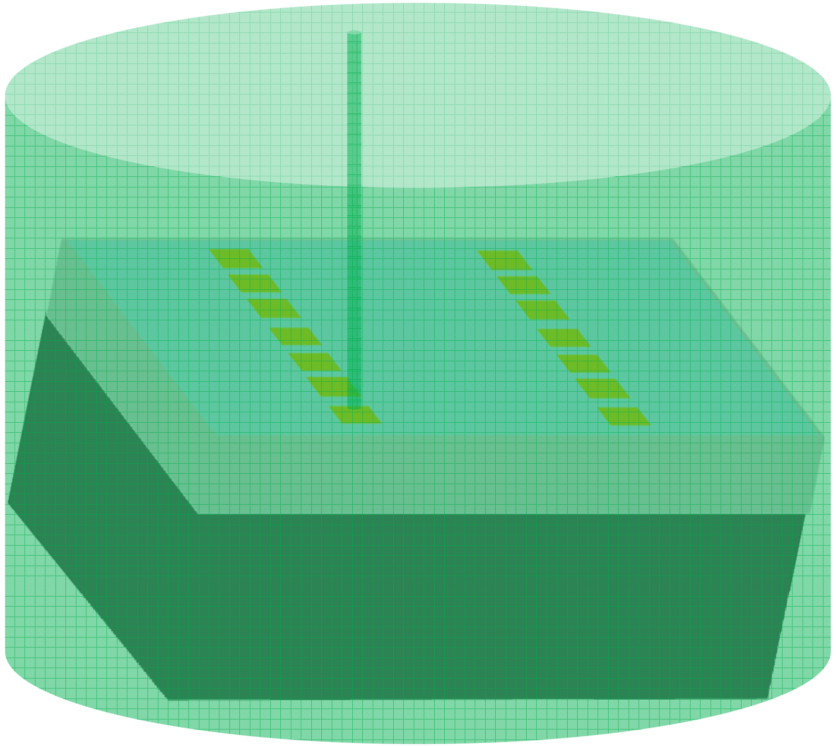


How we control donor location

Defining lateral position

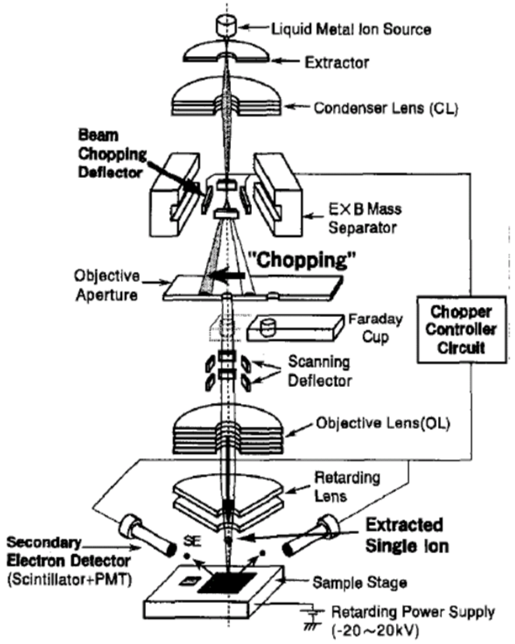


Use PMMA mask to define implant position



Deterministic control over:

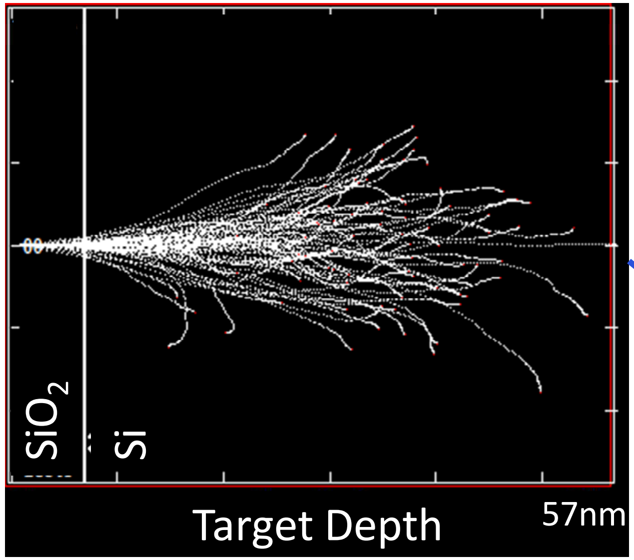
1. Placement of donors
2. Number of donors



Use a focused ion beam nano-implanter to limit implant to one lithographic site

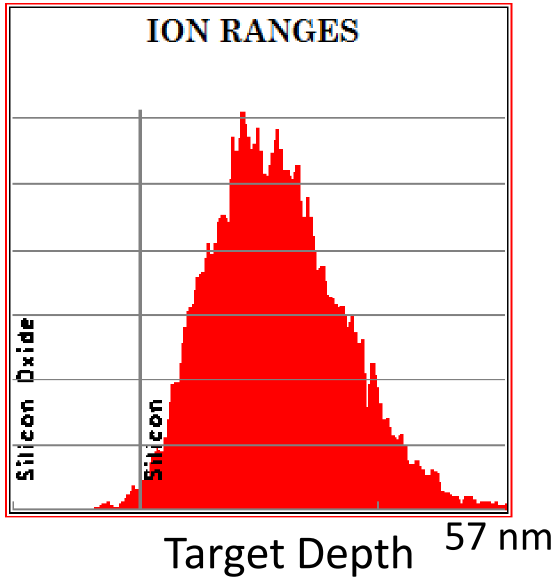
How we control donor location

Defining vertical position



SRIM simulation

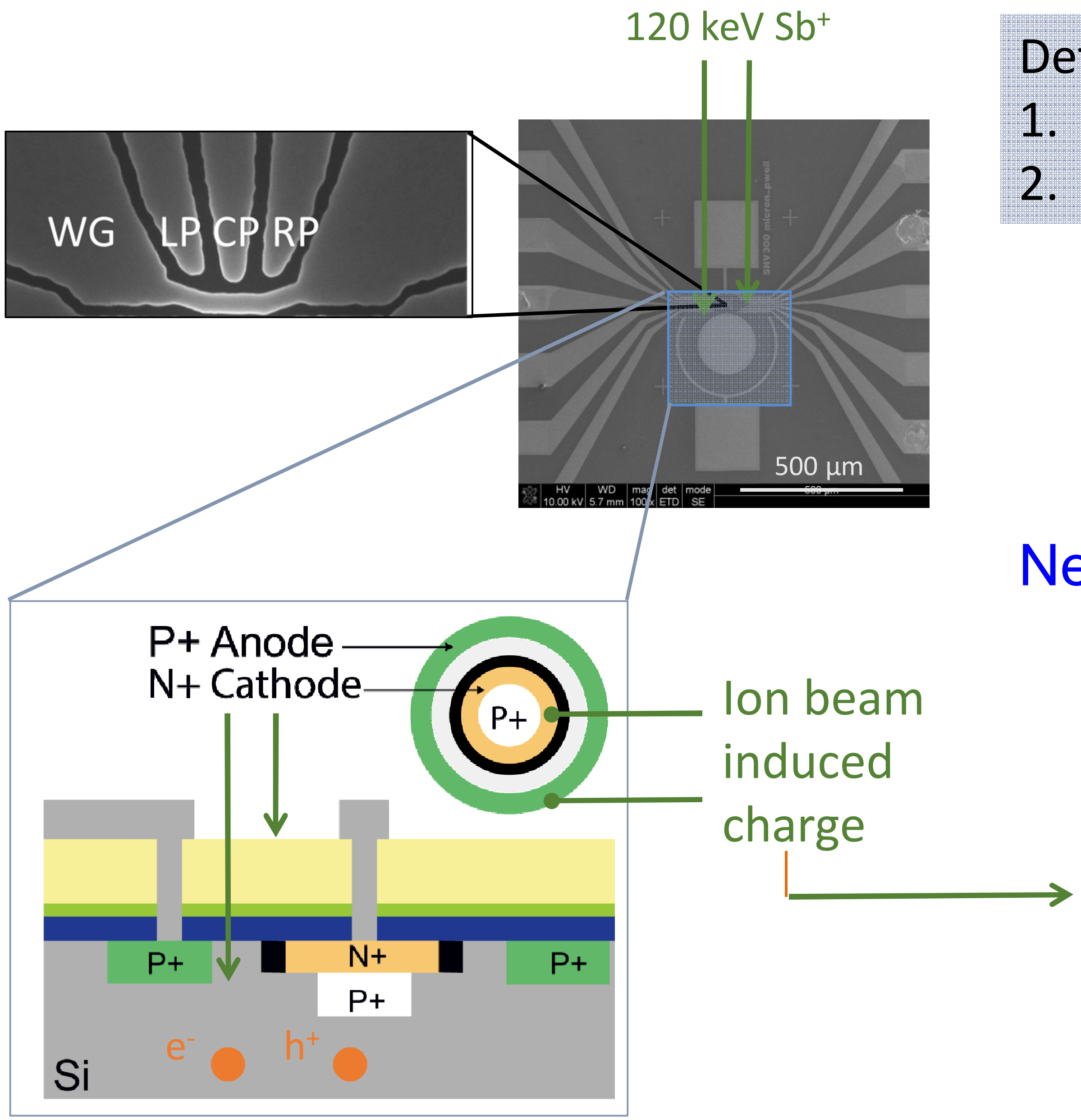
Deterministic control over:
1. Placement of donors ~15nm ✓
2. Number of donors



Low energy, heavy ion (120 keV Sb) used to minimize depth straggle

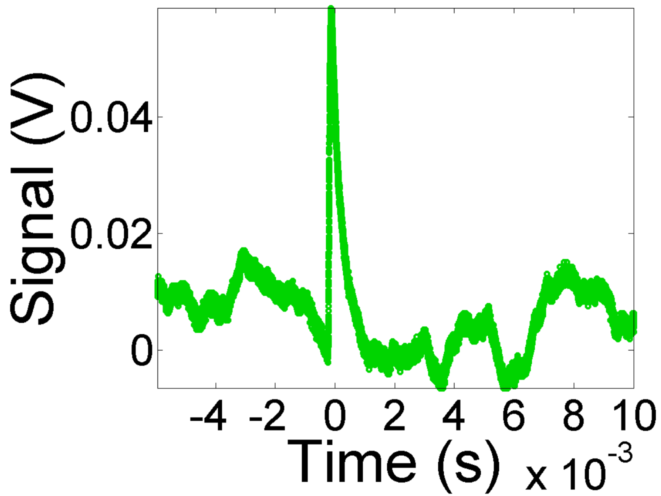
How we control the number of donors

Deterministic control over:
1. Placement of donors ✓
2. Number of donors



Need to detect single ions

Response to <25> ions



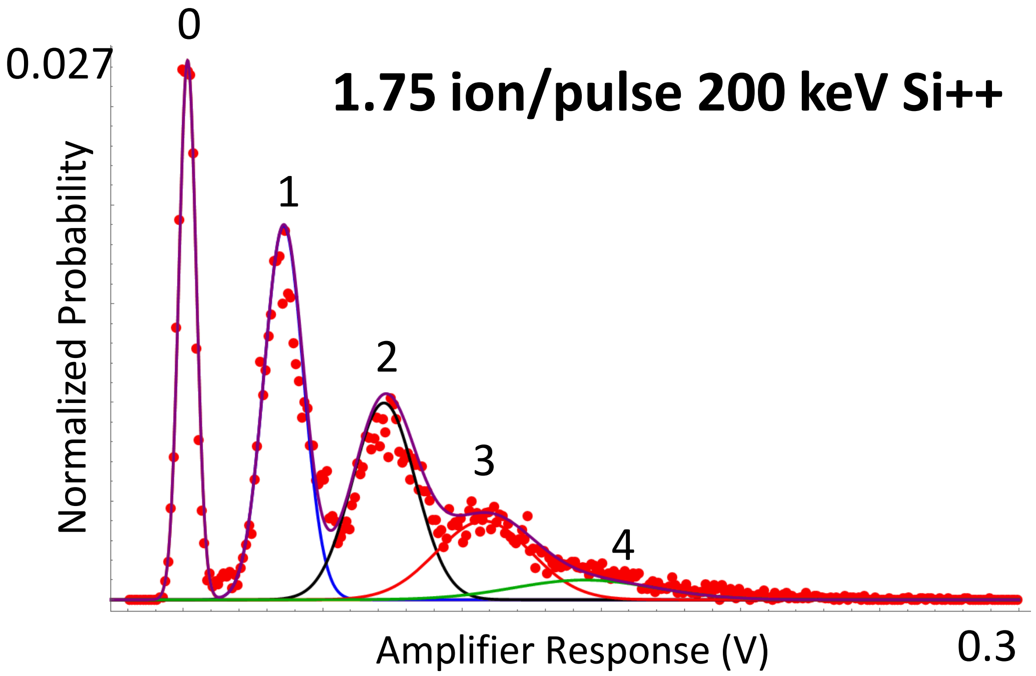
Detecting a single ion

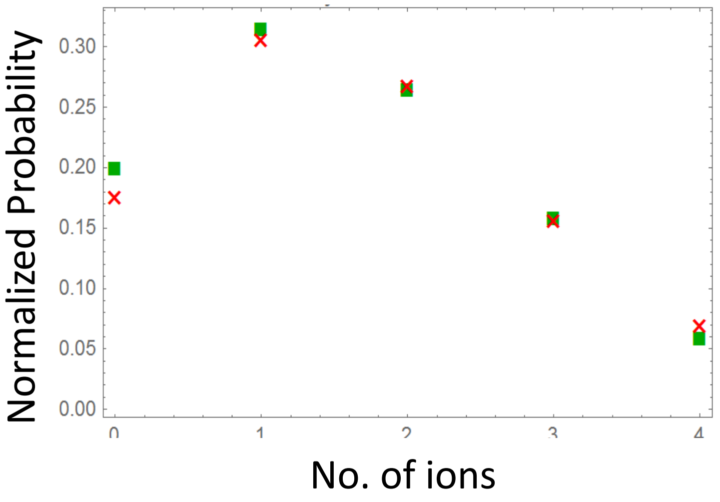
Recall

$$\langle \text{no. of ions} \rangle = \frac{\text{current} \times \text{time}}{\text{ionic charge}}$$ = Pulse length

Poisson Statistics:

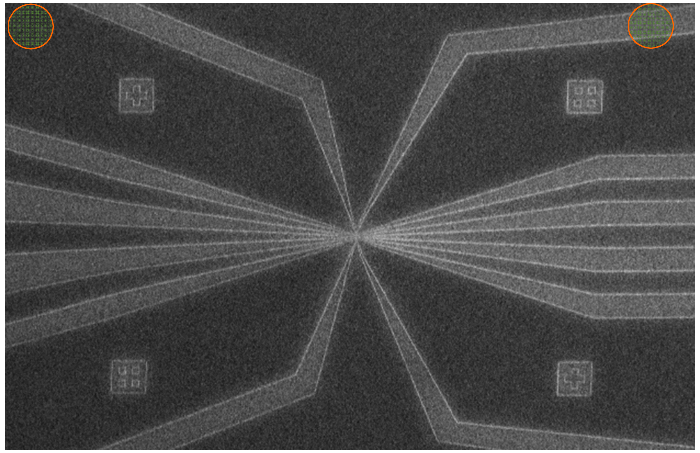
$$\text{actual no. of ions} = \langle \text{no. of ions} \rangle \pm \sqrt{\langle \text{no. of ions} \rangle}$$





Detecting single ions

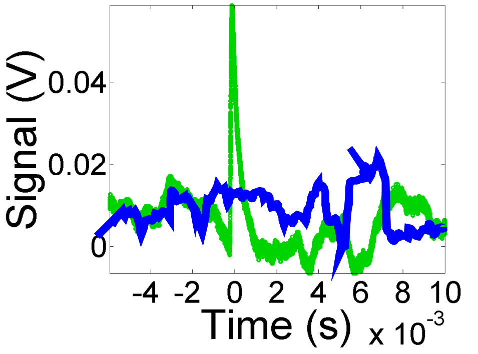
120 keV Sb+, <1> ion/pulse

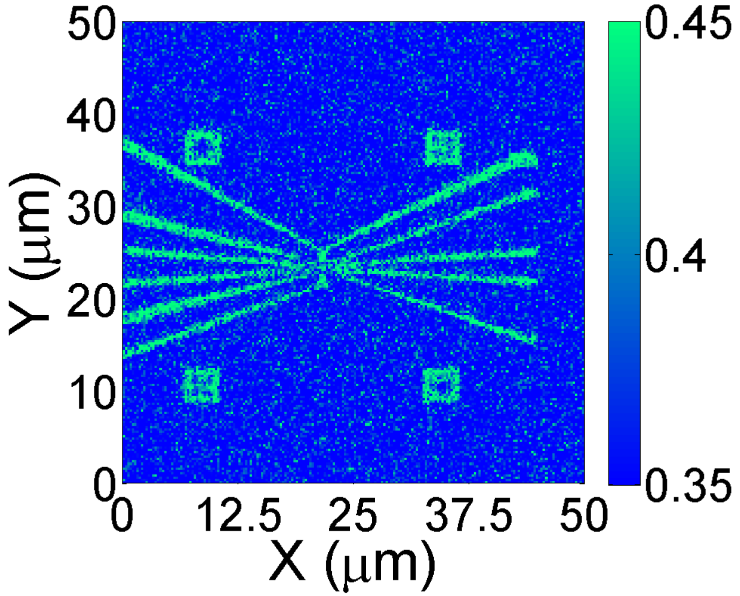


Deterministic control over:

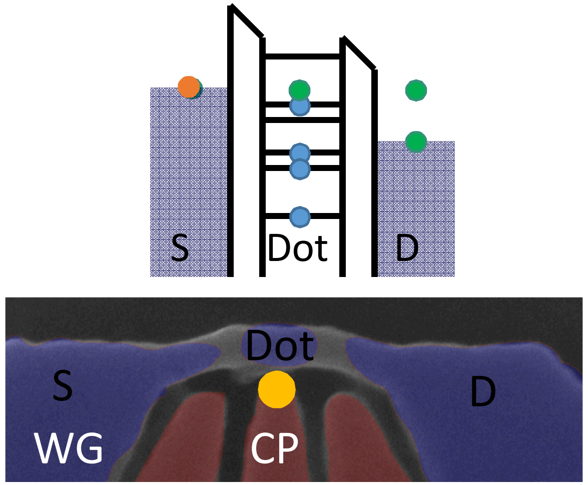
1. Placement of donors ✓
2. Number of donors ✓

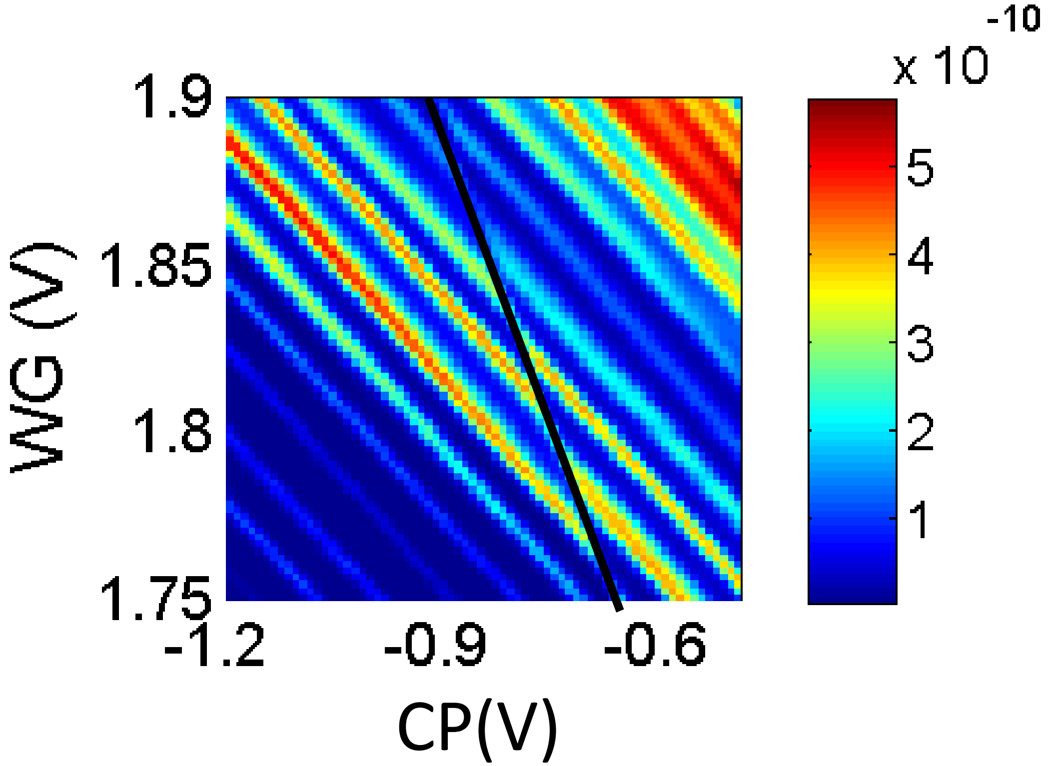
Recall





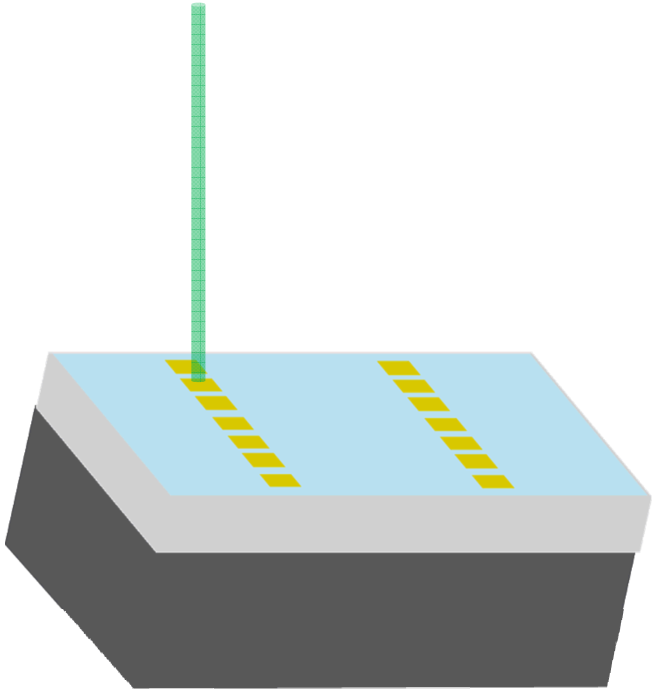
Do the donors work? (Can the dot ‘see’ them)

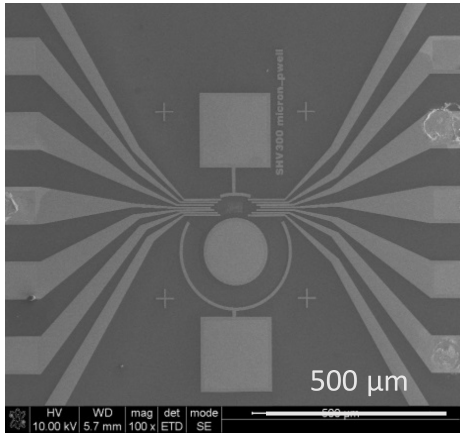


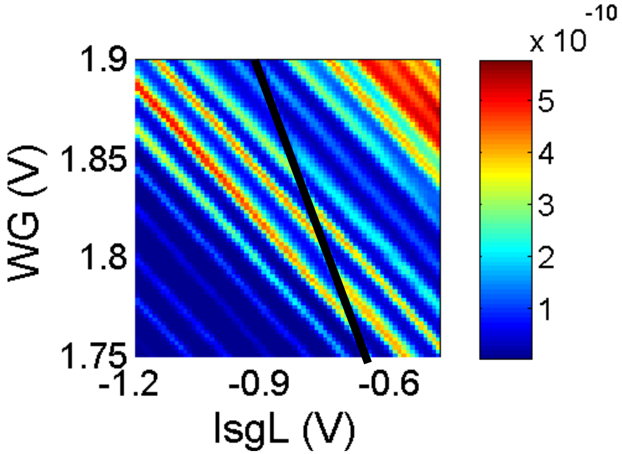


In 6 implanted devices measured, 10-50% of implanted donors were seen

In summary: what is the technology and what it can do







CP(V)

Can implant within a 15 nm radius

Can count single donors in situ

Can detect motion of the donor electron in transport

Immediate path forward to fabricating two qubit devices

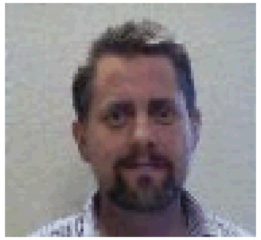
APL **108**, 062101 (2016) – **Editor's pick** and in **AIP News** at the end of this month

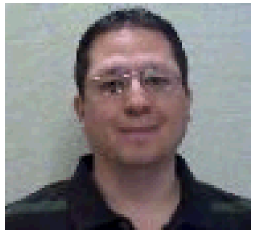
Sandia National Laboratories

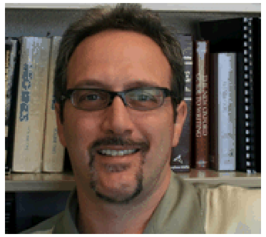
CINT

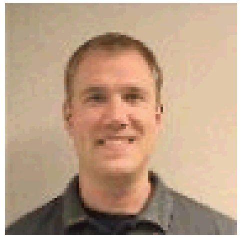

Jose Pacheco


C. Bureau-Oxton


Daniel Perry


J. Dominguez


Ron Manginell

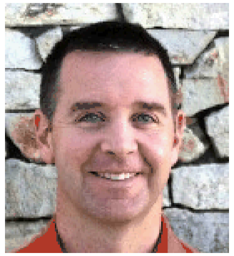

Greg Ten Eyck


Joel Wendt


Tammy Pluym


Dwight Luhman


Ed Bielejec


Mike Lilly


Malcolm Carroll

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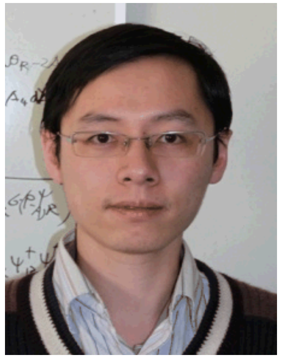
Jian Wang


Mingliang Tian


Chaoxing Lu

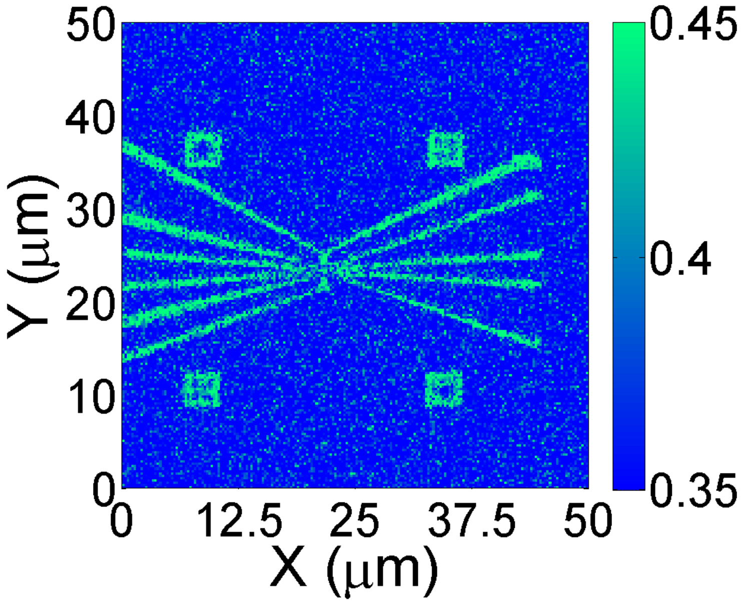

Jainendra Jain


Nitin Samarth

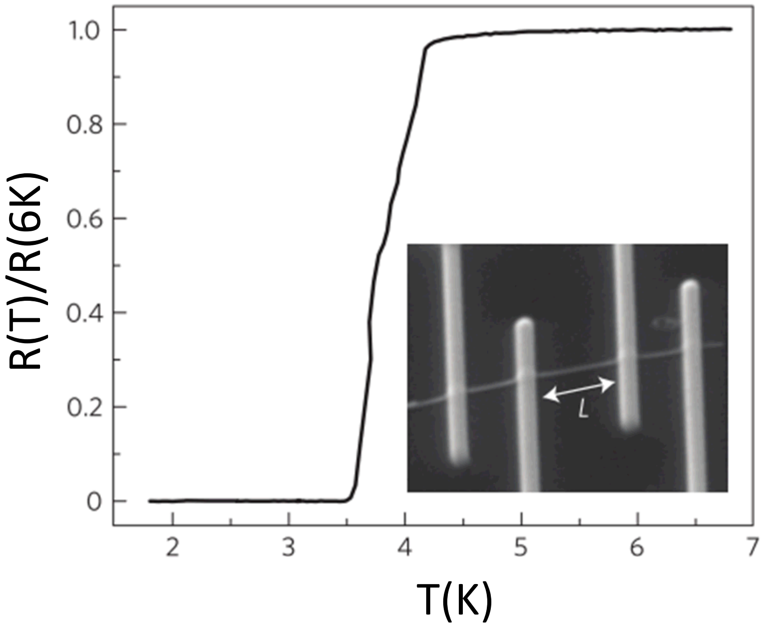

Tom Mallouk


Moses Chan

Overview – results, plans, Q&A



Development of a new technology enabling implant of a counted number of donors into a specific location – spin qubits



Discovery of a long-range superconducting proximity effect in ferromagnetic nanowires

Superspintronics

Thank You