Single ion doping for spin readout transistors

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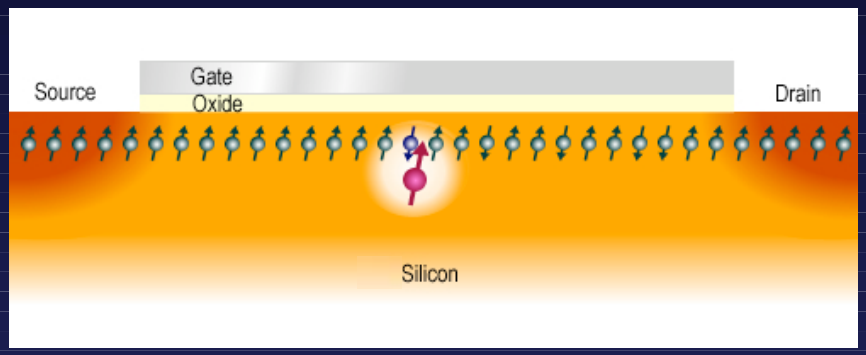
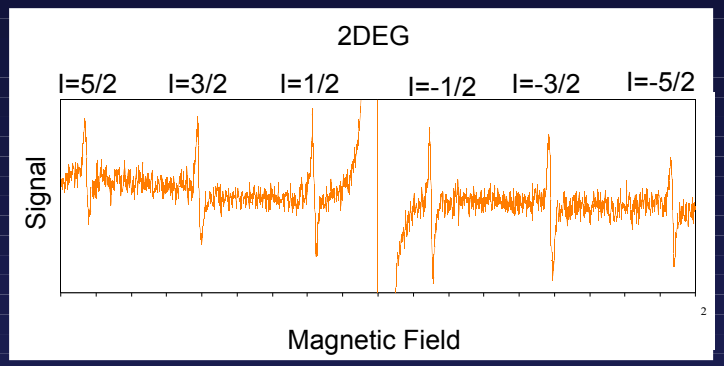
Berkeley, August 25, 2009

Outline

1. Motivation
2. Scanning probe setup
3. Ion placement progress
4. Summary & Outlook

Donor based quantum computer development





Electrically Detected Magnetic Resonance – Read out

Cheuk Lo, Spin-dependent scattering off Neutral Donors in Silicon Field-Effect Transistors

Kevin Young, Optimal experiment design for parameter estimation as applied to dipole- and exchange-coupled qubits

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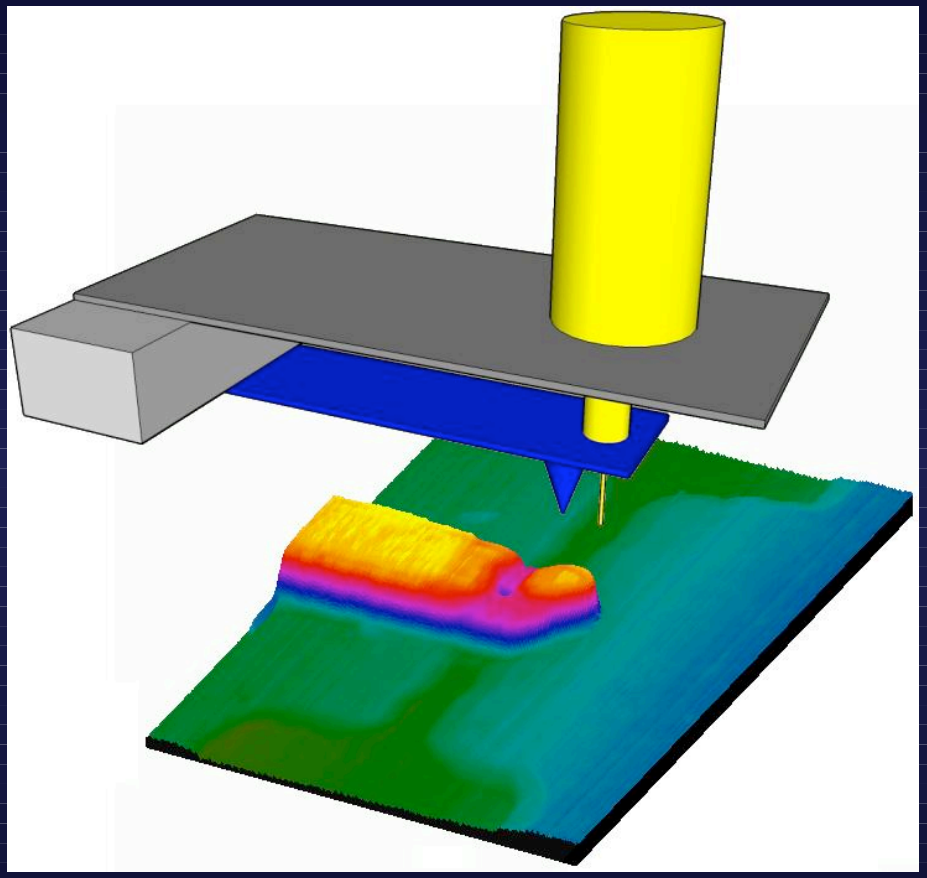
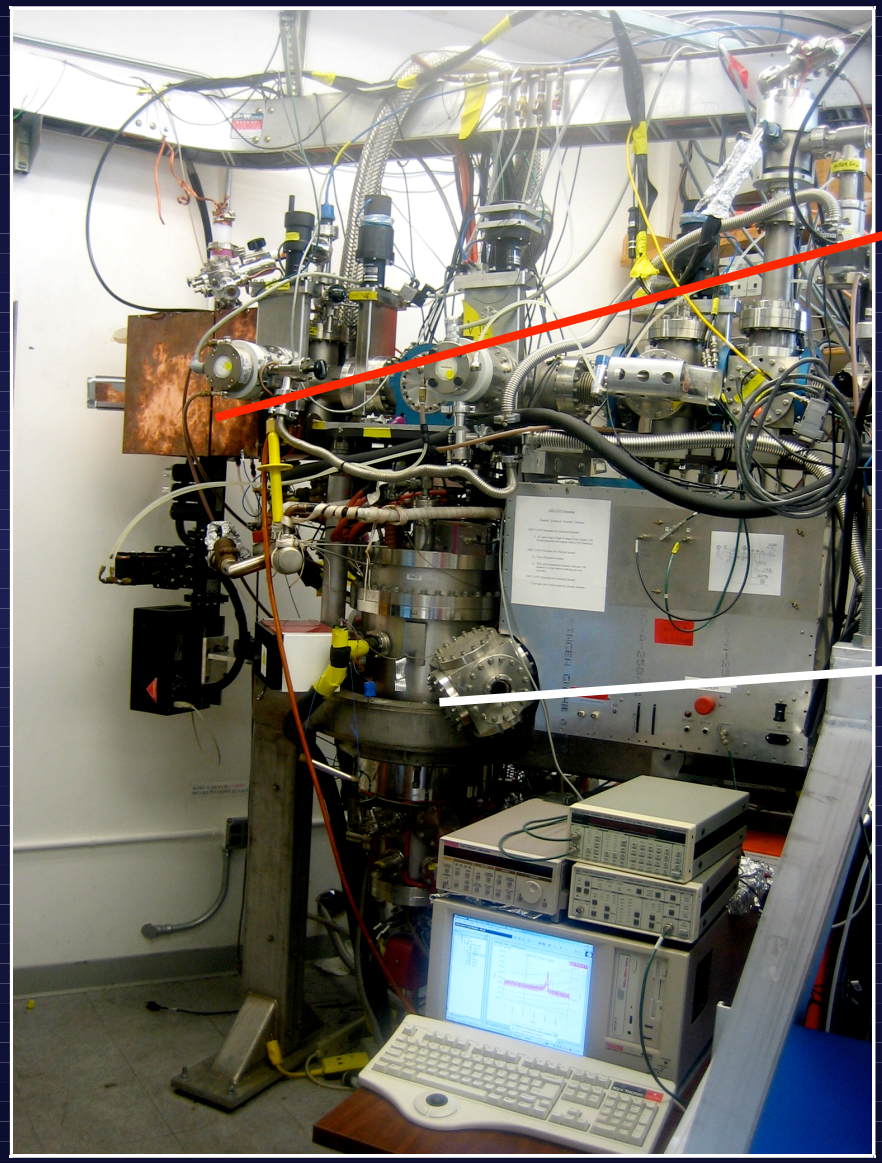
Implantation with scanning probe alignment



A. Persaud, et al., Nano Letters 5, 1087 (2005)

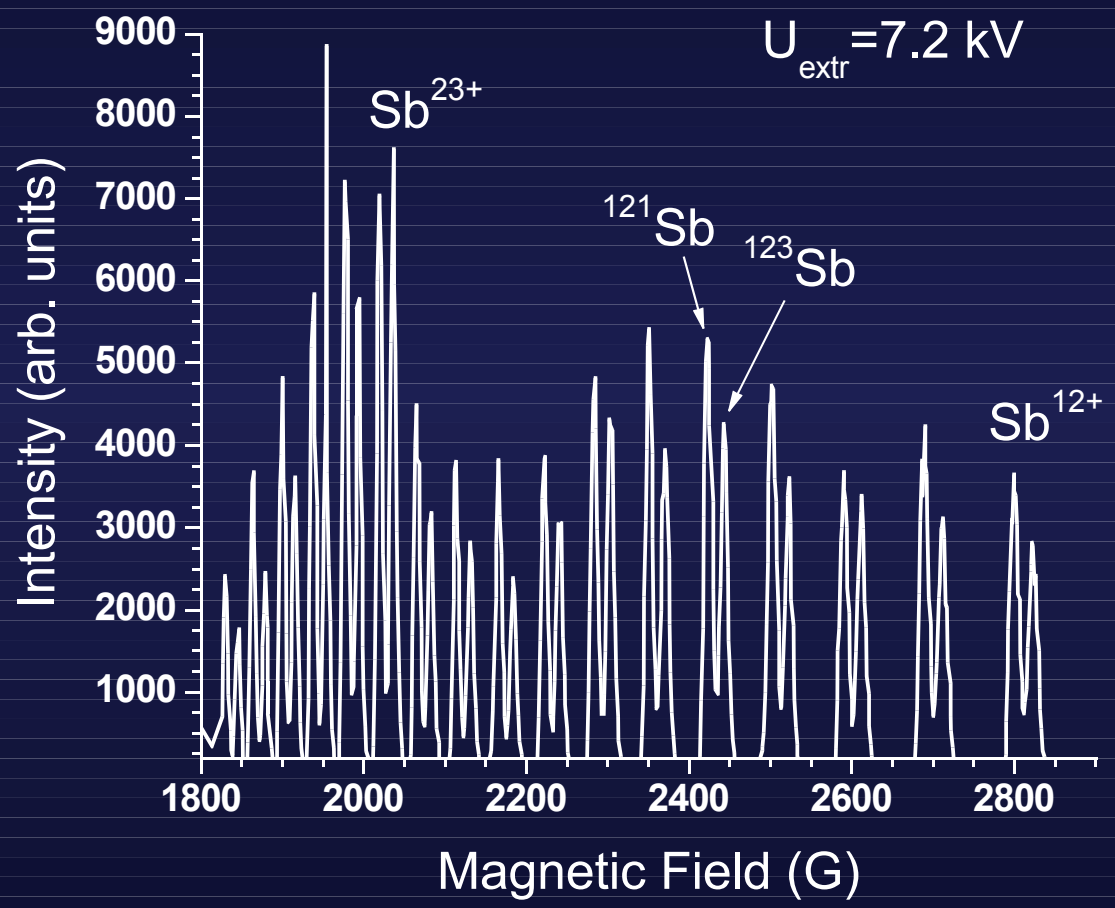
Ion beam generation



ECR (Electron Cyclotron Resonance Source), 2.5 GHz micro waves, low to medium ion charge states and molecules, max. U_{ext}~ 15kV

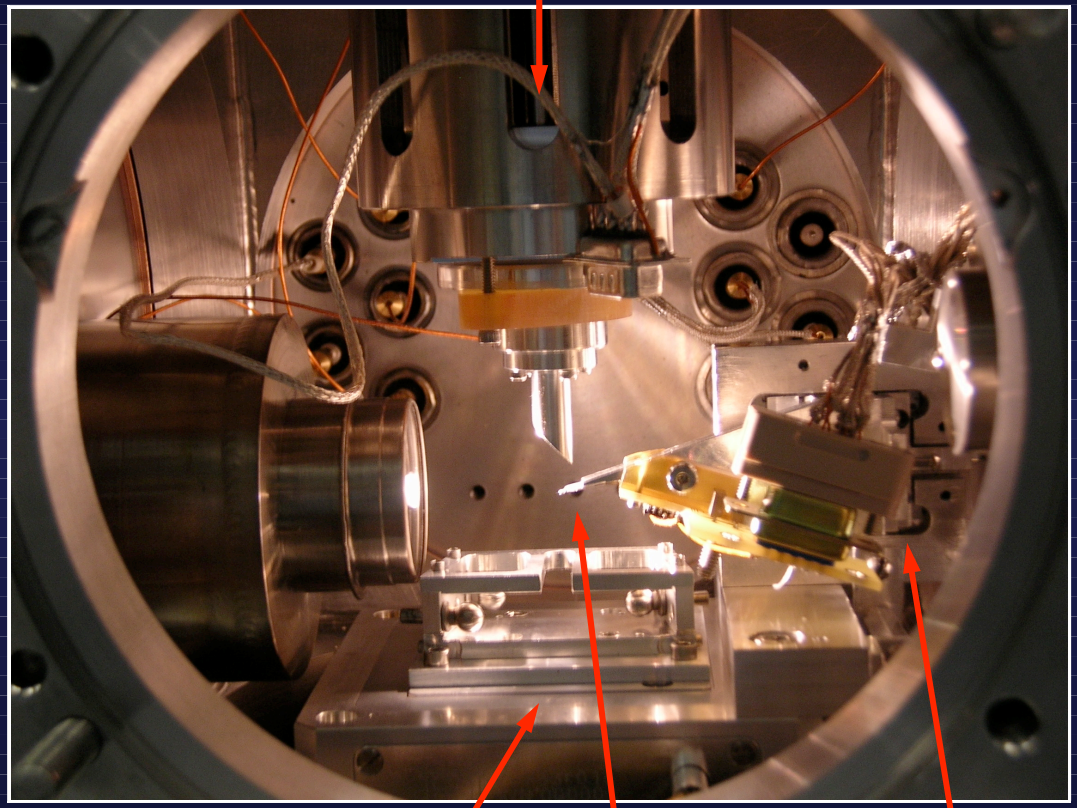
EBIT (Electron Beam Ion Trap) for medium to high ion charge states, e. g. Sb [4 to 40+], 10 to 500 keV

Selection of implant species



Scanning probe setup

Ion travel direction

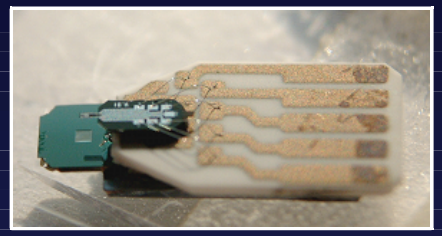


AFM stage

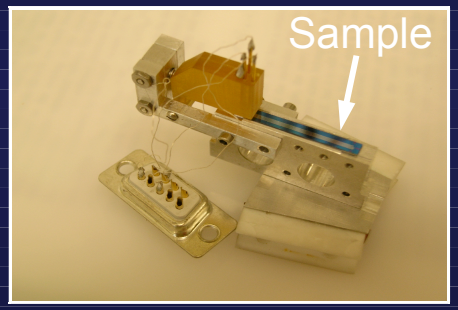
Tip

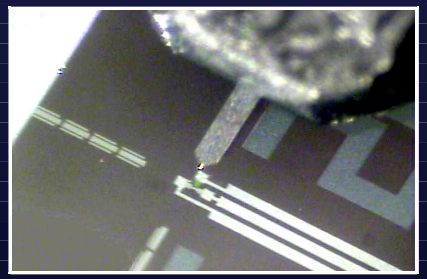
x-y-z flexure stage for tip movement

AFM tip with pre-collimator



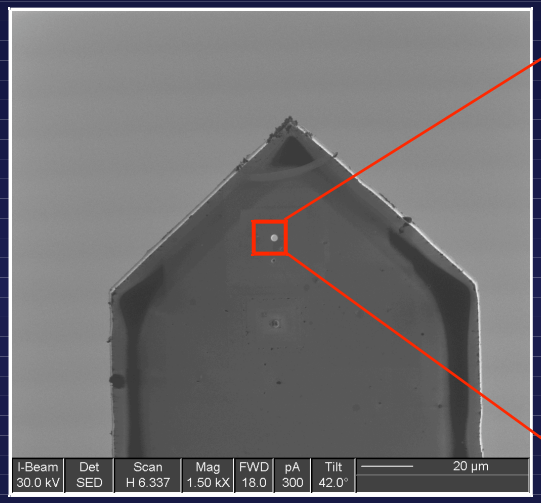
Piezo-resistive AFM tips



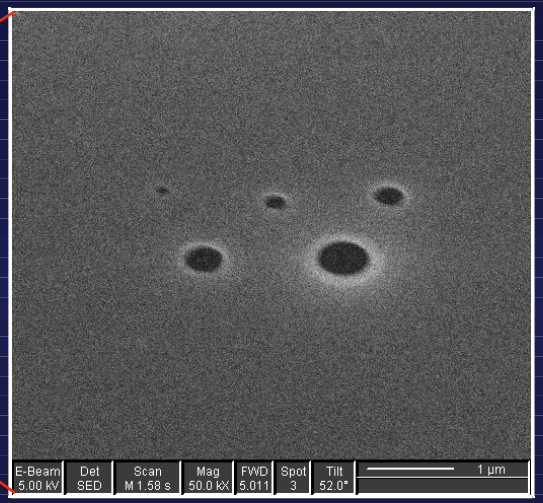


Implant aperture fabrication

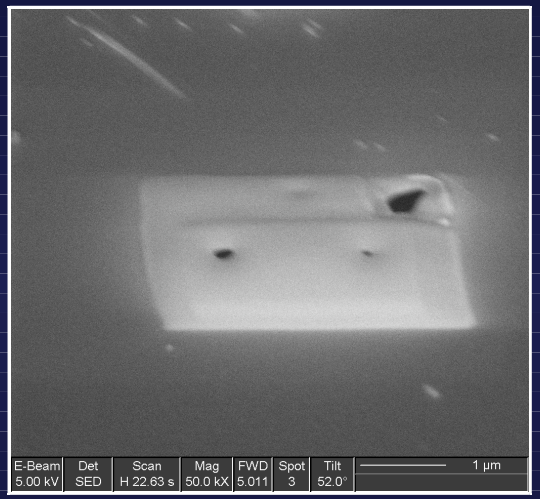
AFM tip



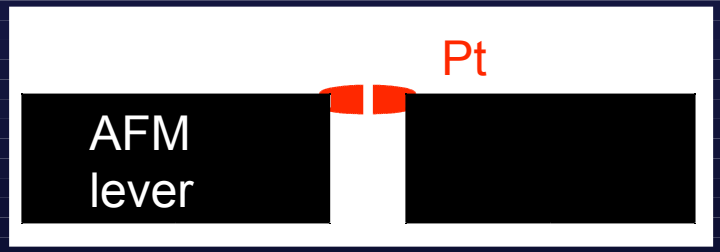
FIB drilling



Pt deposition

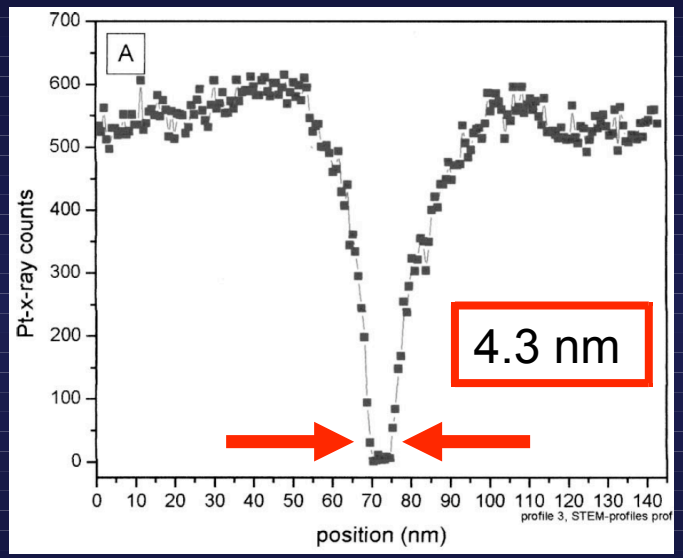


Schenkel et al., J. Vac. Sci. Technol. B, 21 (6), 2720 (2003)



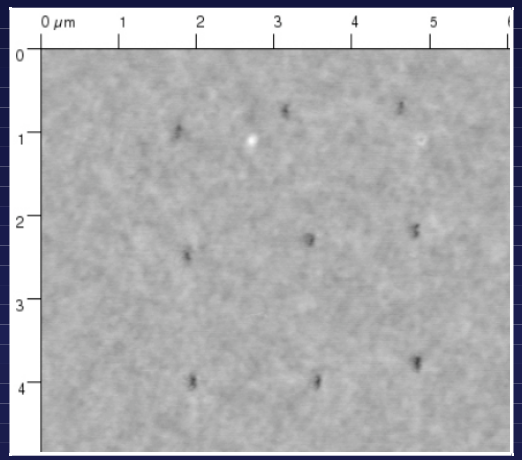
Ion placement accuracy

STEM scan



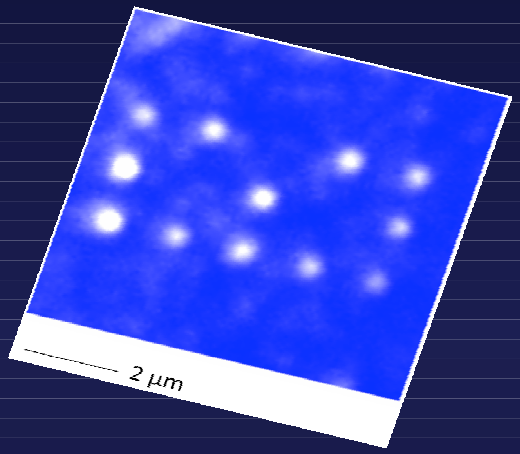
Schenkel et al., J. Vac. Sci. Technol. B, 21 (6), 2720 (2003)

90nm hole

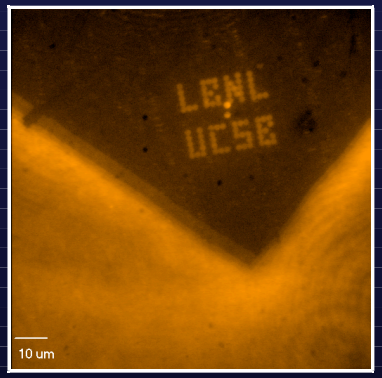


Pattern in PMMA

80nm hole



5-10 NV centers/spot

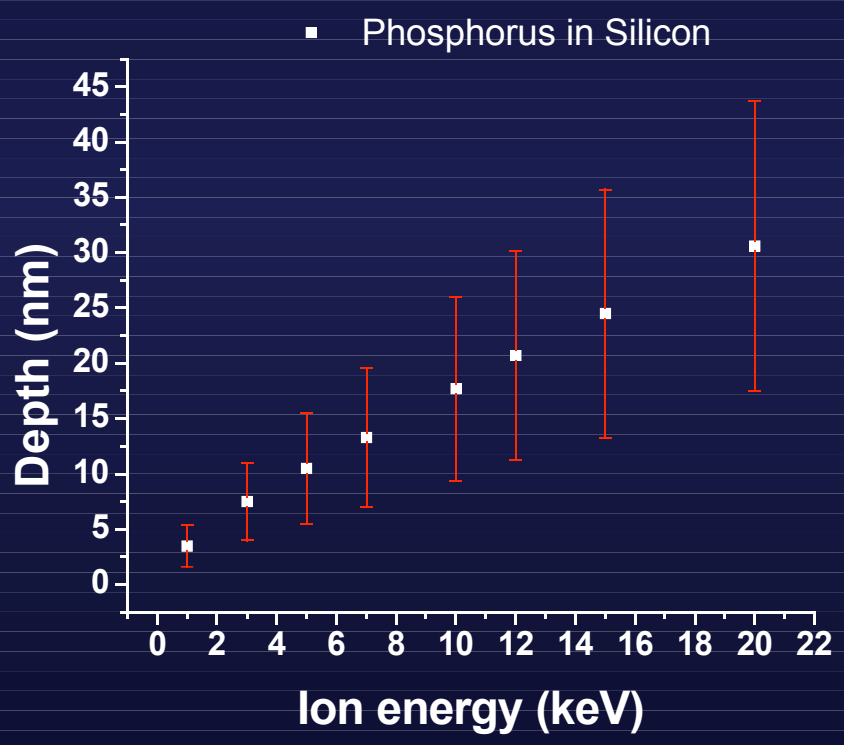


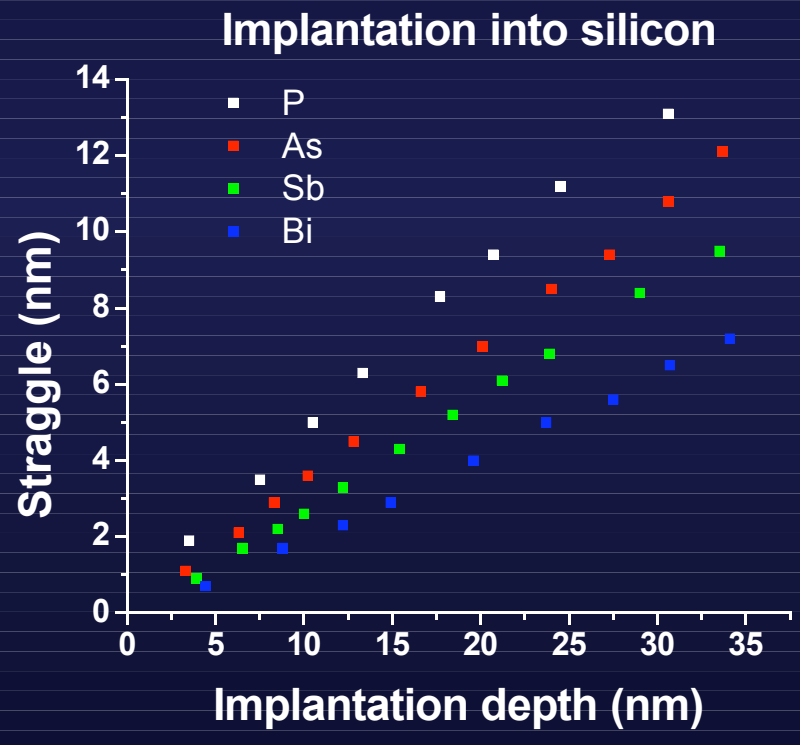
Greg Fuchs et al. (UCSB)

Ion placement accuracy - Straggling

Δx = hole size + straggling + diffusion

SRIM Simulations





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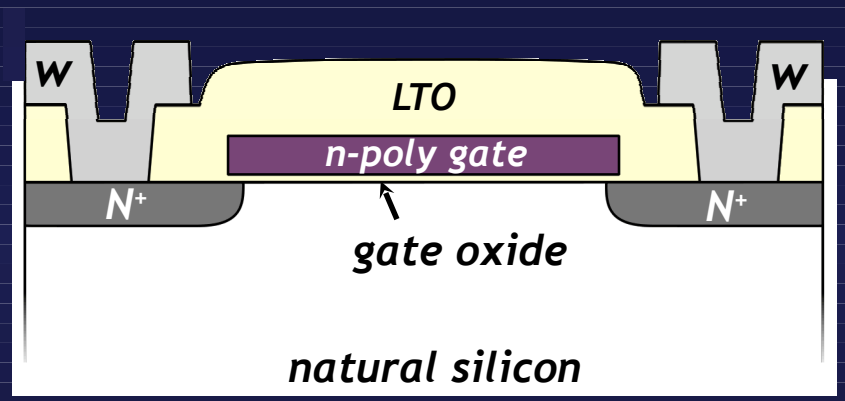
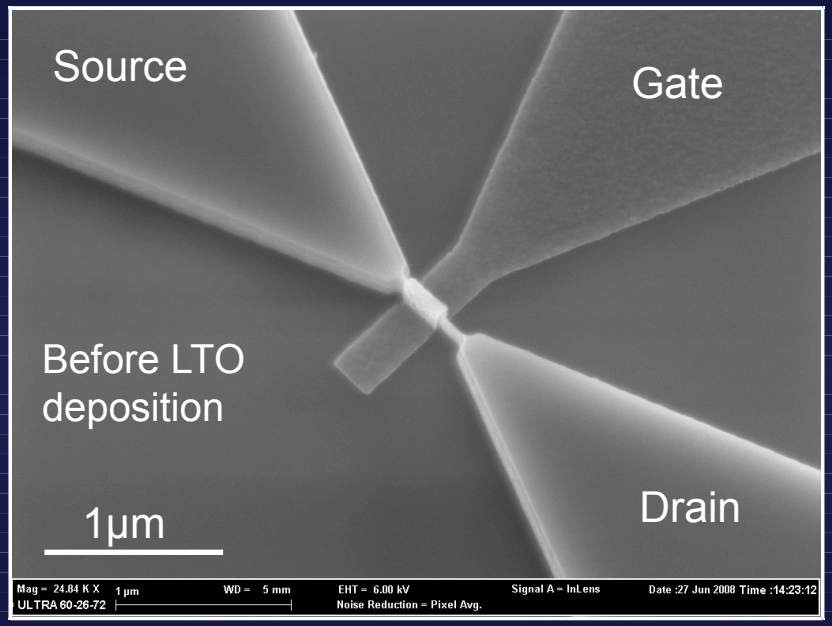
Field Effect Transistor (FET) devices in silicon



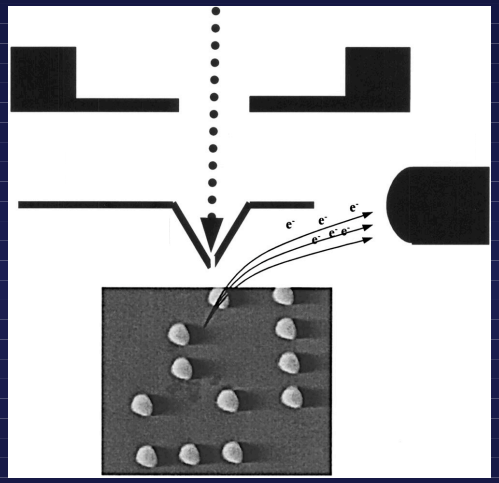
n-type or p-type
2x2μm² channel region



(50nm-300nm channel width)

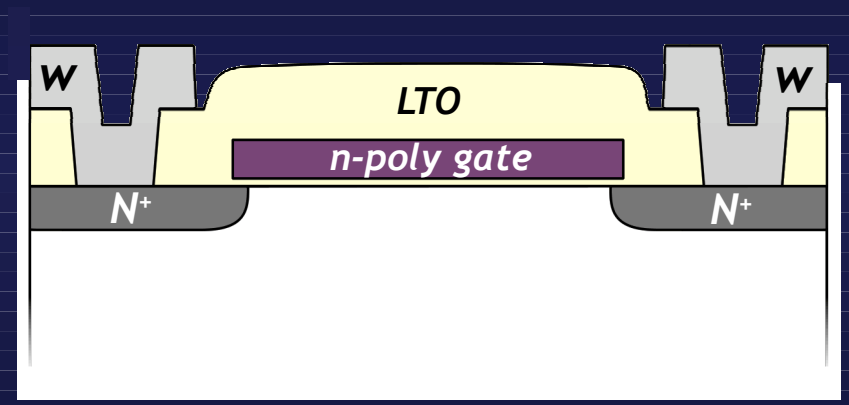
Mechanisms for ion detection

Detection of secondary electrons

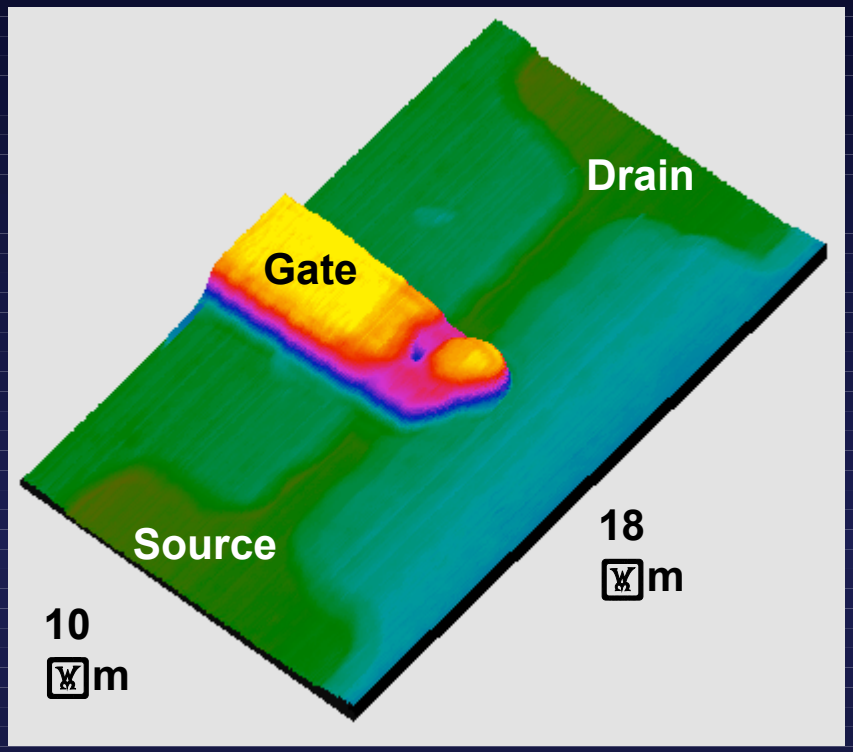


A. Persaud, et al., J. Vac. Sci. Technol. B 22(6) (2004)

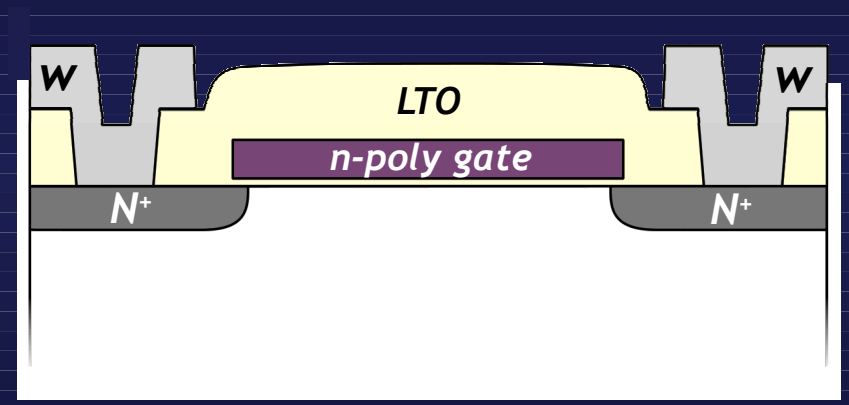
Detection via source-drain current



Aperture drilling for ion detection



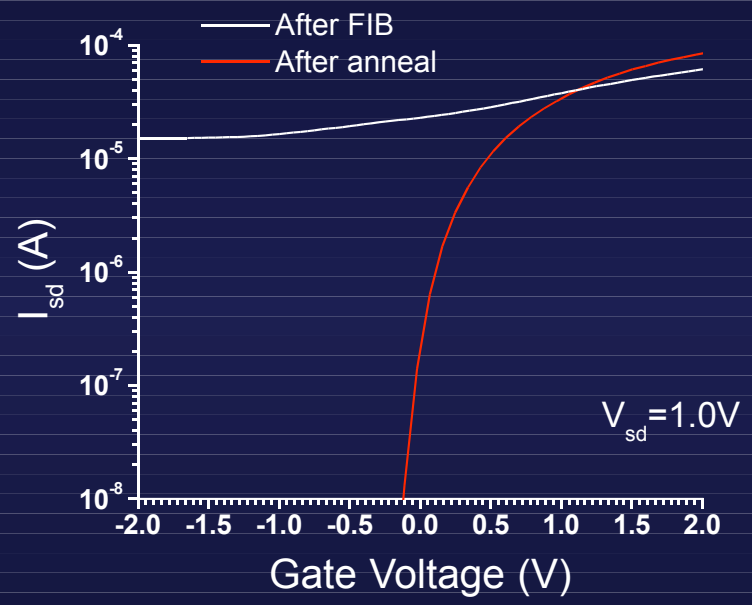
A. Batra et al, *Appl. Phys. Lett.* **91**, 193502 (2007)

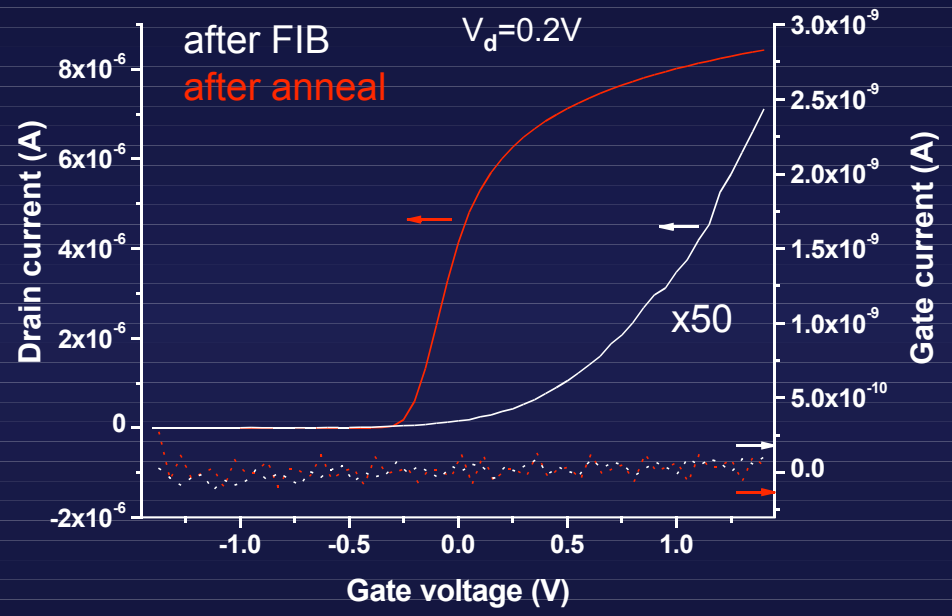


Dual beam focused ion beam:

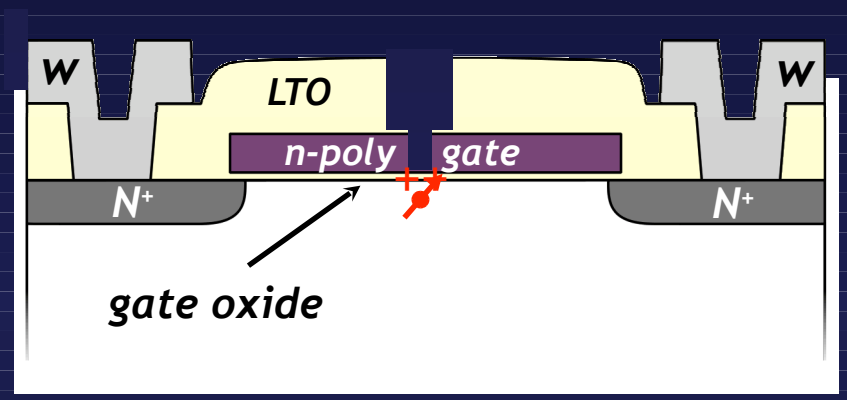
- 30keV Ga^+ ion beam
- 5keV electron beam
- XeF_2 gas supply

FIB damage recovery





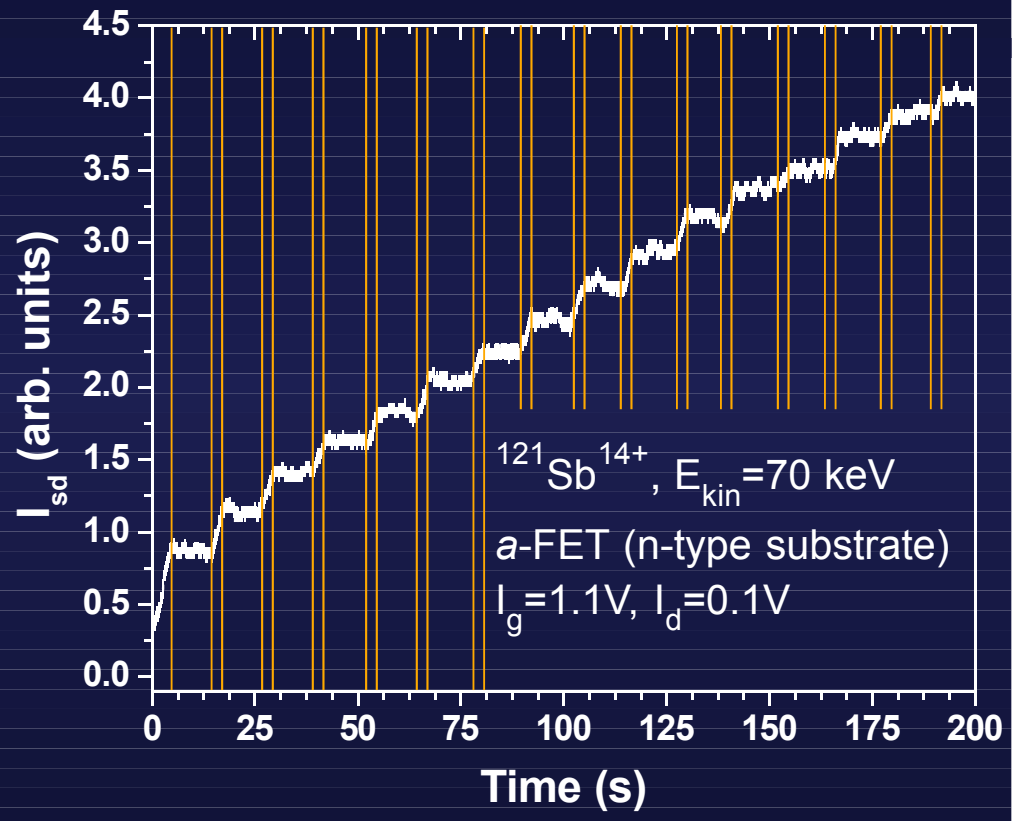
Effect of ion impact on source drain current



Positively charged defects in the gate oxide

→ ΔV_{gate}

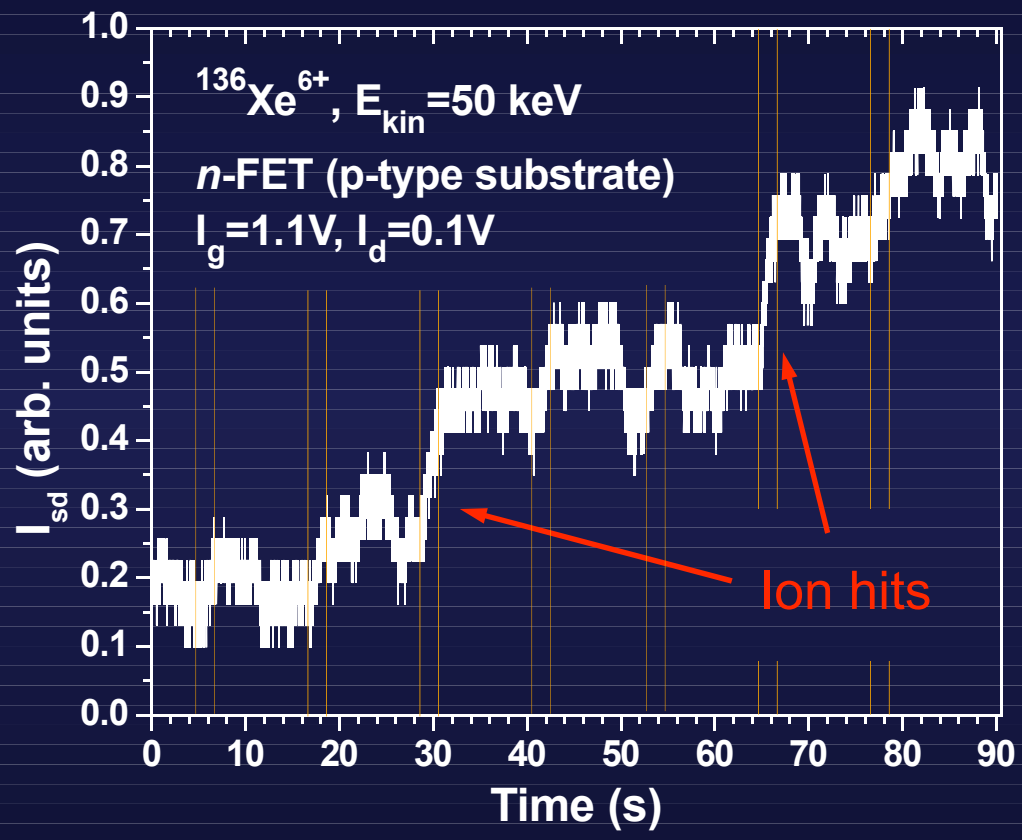
~ 3 ions/interval



A. Batra et al, *Appl. Phys. Lett.* **91**, 193502 (2007)

Single ion impact detection in planar FETs

~0.2 ions/ interval

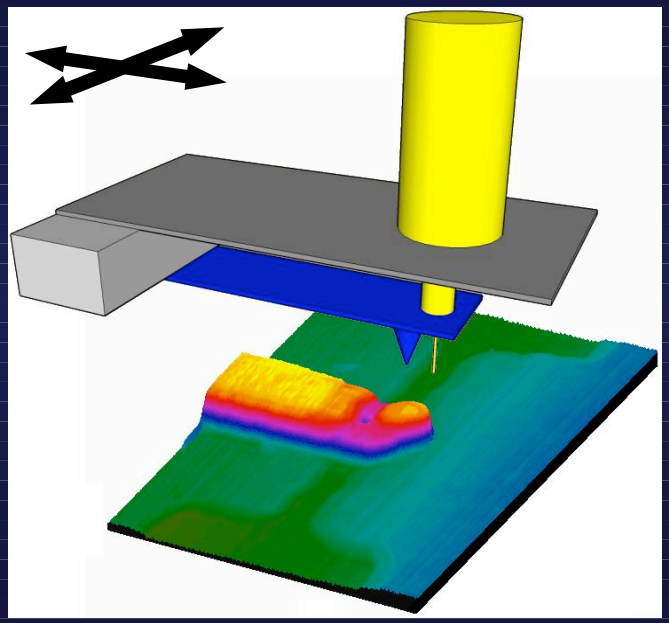


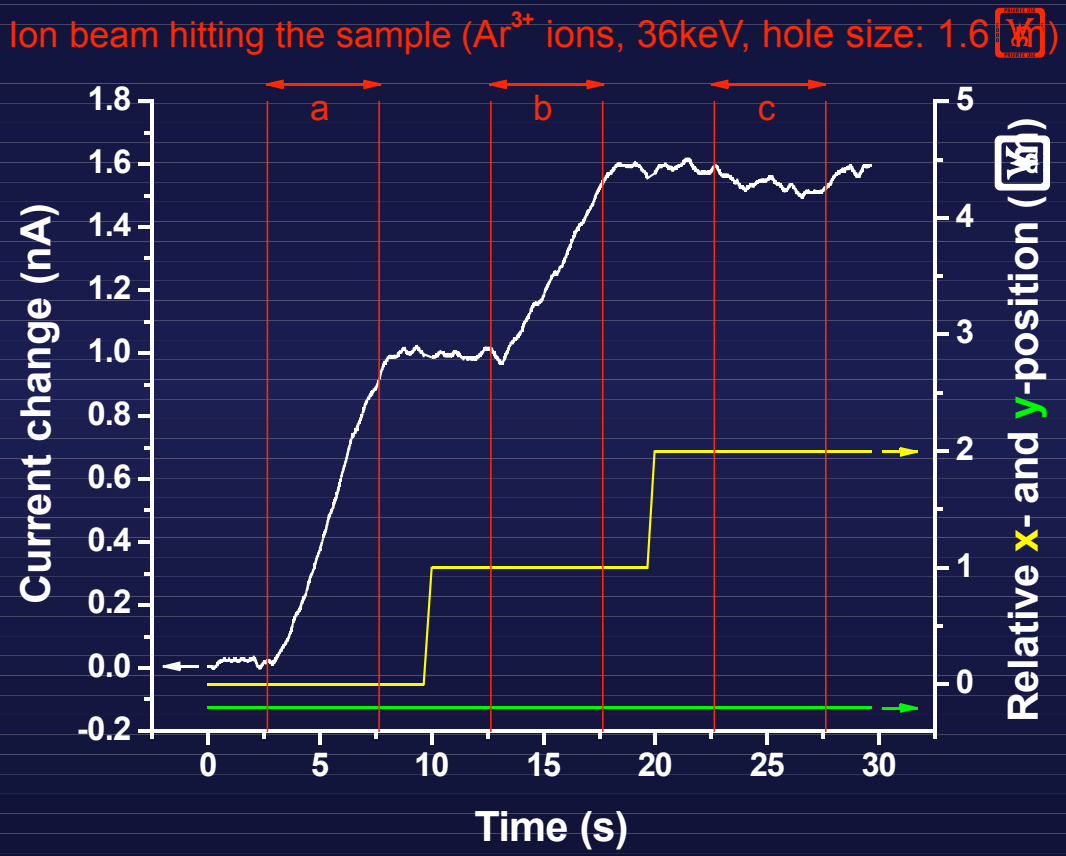
I_{sd}~ 200µA, Ion effect ~ 20nA (10^{-4})

Channel area: 2µm x 2µm

Mapping the "active area" (local detector)

Ion beam induced current changes





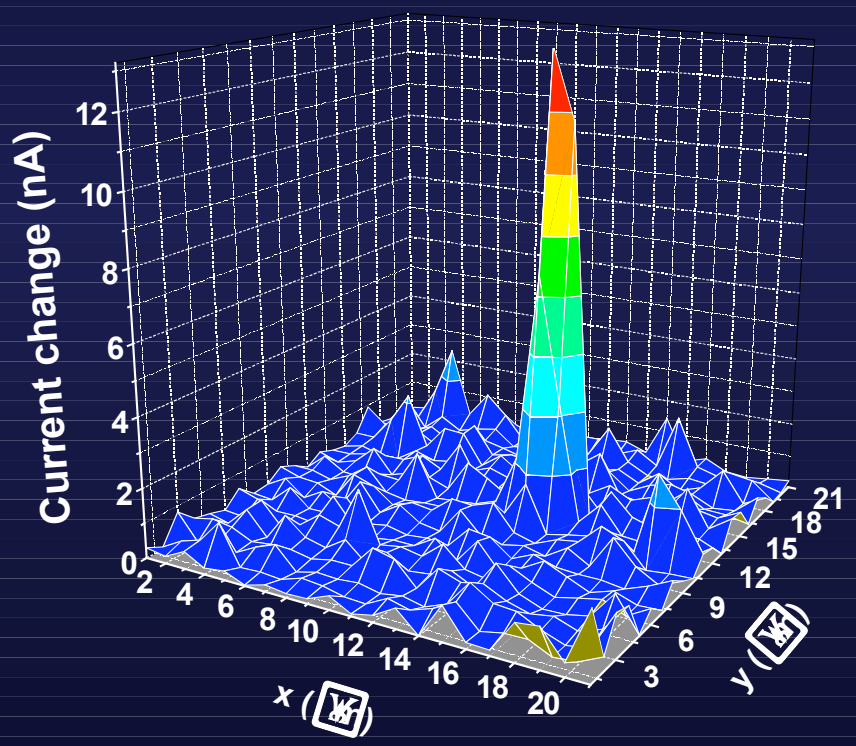
Weis et al., Nuc.Inst.Meth.Phys.Res.B 267, 1222 (2009)

Mapping the "active area" (local detector)

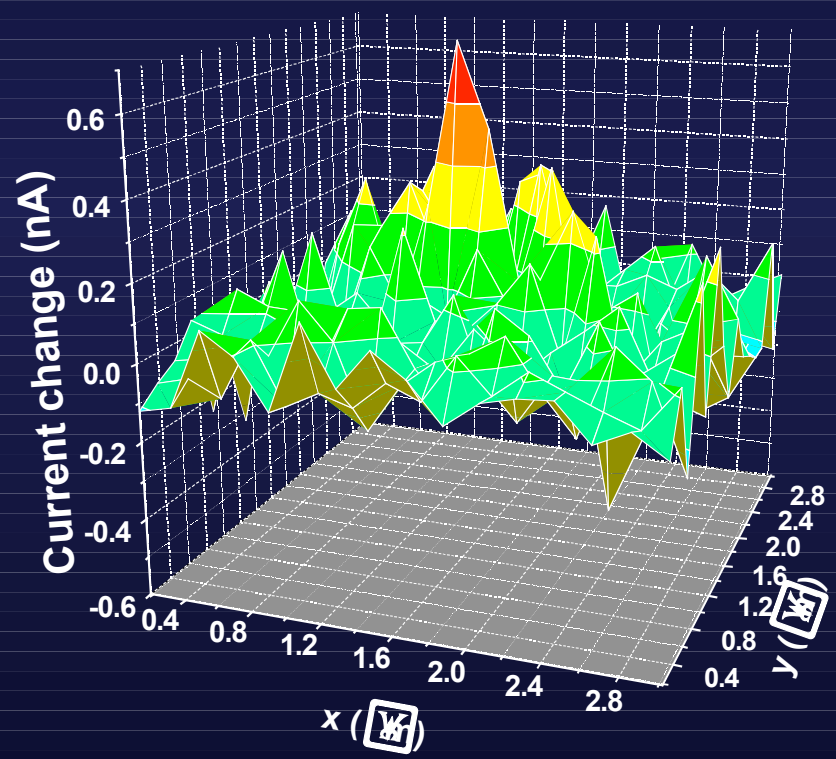
I_{sd}~10µm

(V_g=1.0V, V_d=0.8V)

Collimator size: d ~1.6µm



Collimator size: d ~100nm



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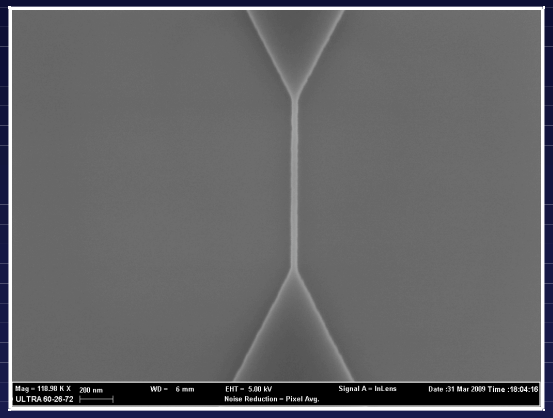
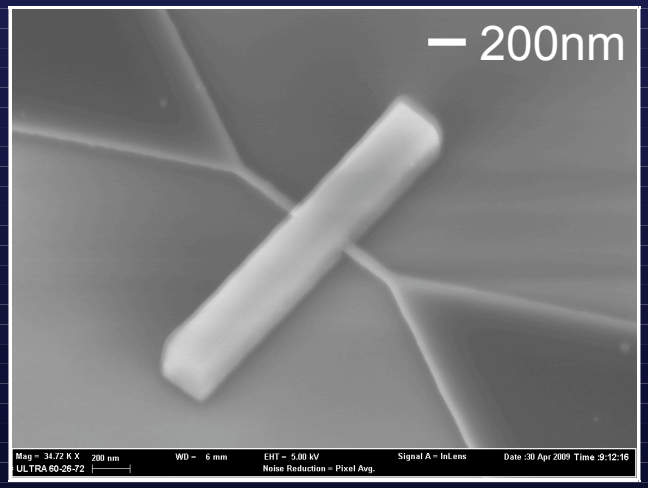
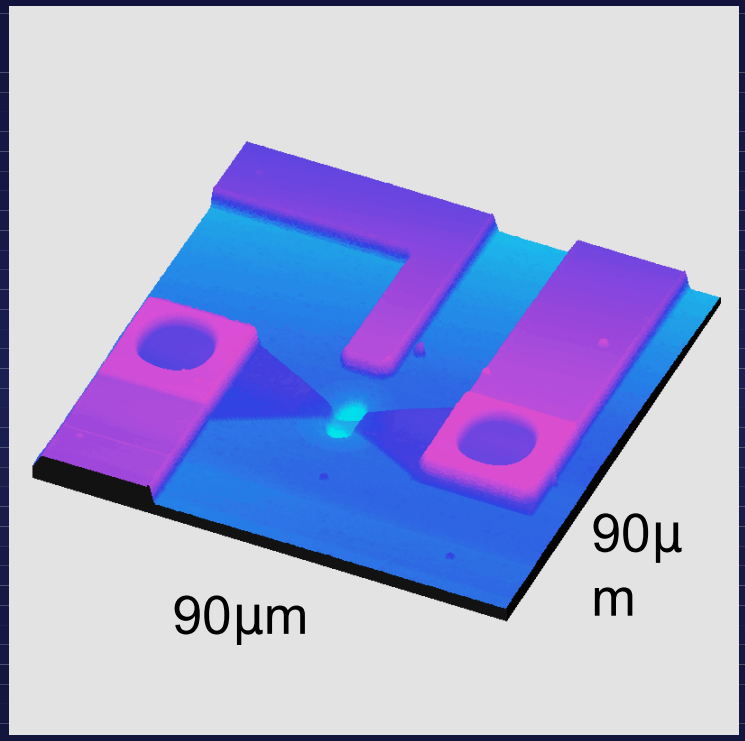
Sub-100nm implantation test devices

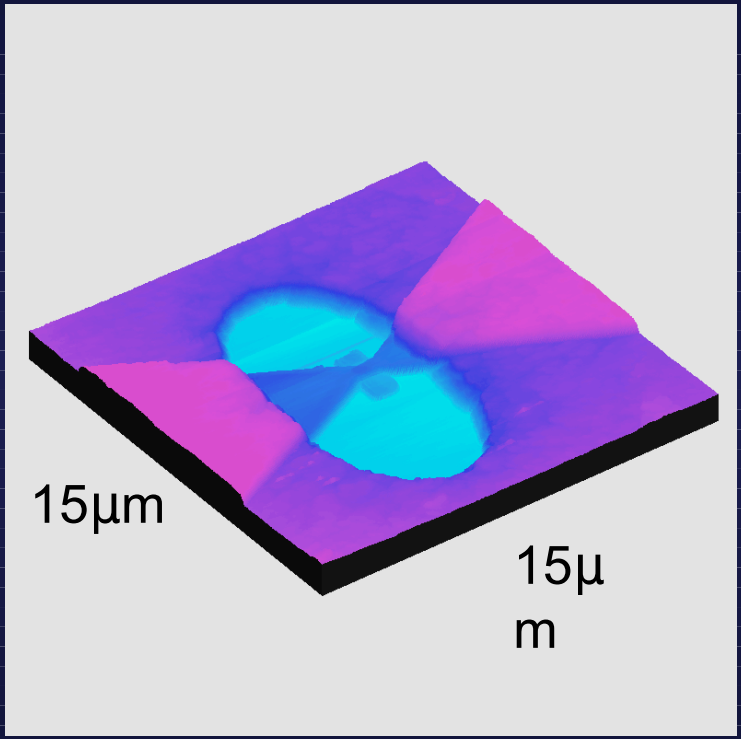


Width: 50nm - 200nm
Length: 300nm



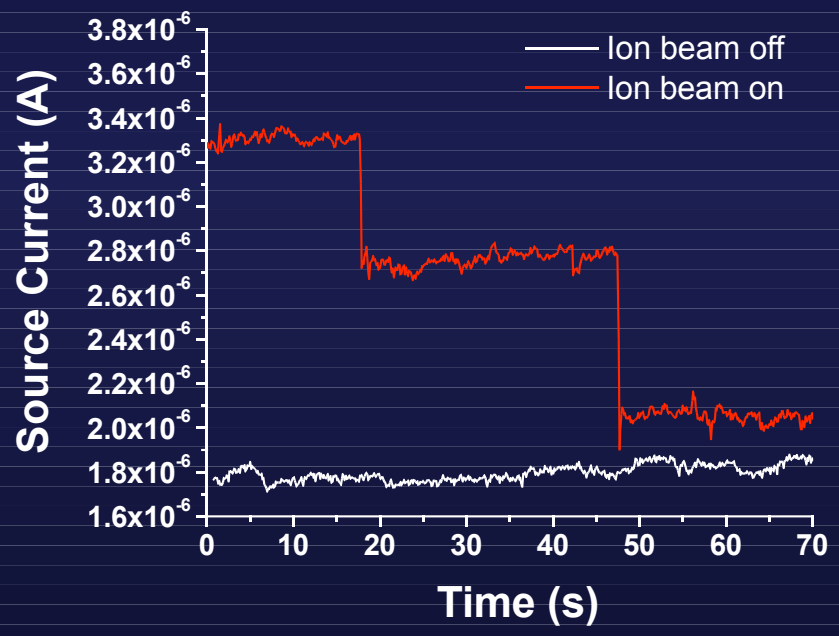


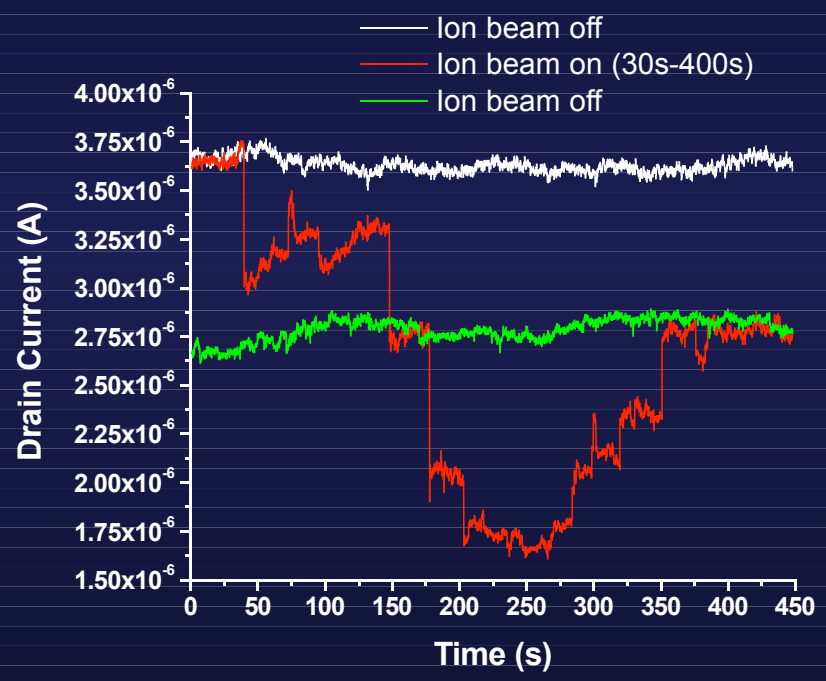
Sub-100nm implantation test devices



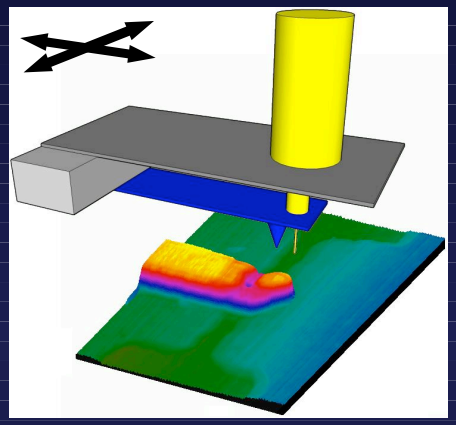
Sub-100nm implantation test devices

Xe^{6+}, 56keV, room temperature, 100nm x 300nm





Summary & Outlook



- Detection of single ion impacts
- Use of dynamic implantation mask
- Full device recovery

Improvement of implantation precision (apertures & beam alignment)

EDMR/ transport studies of single donor devices ($V_{th}=V^{i}_{th}-eN_D/C_{tot}$)

Acknowledgements

Microlab at UC Berkeley

Molecular Foundry at LBNL

Funding Agents:

Q&A

… is waiting!