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Si quantum dots with focused ion beam implanted phosphorus donors

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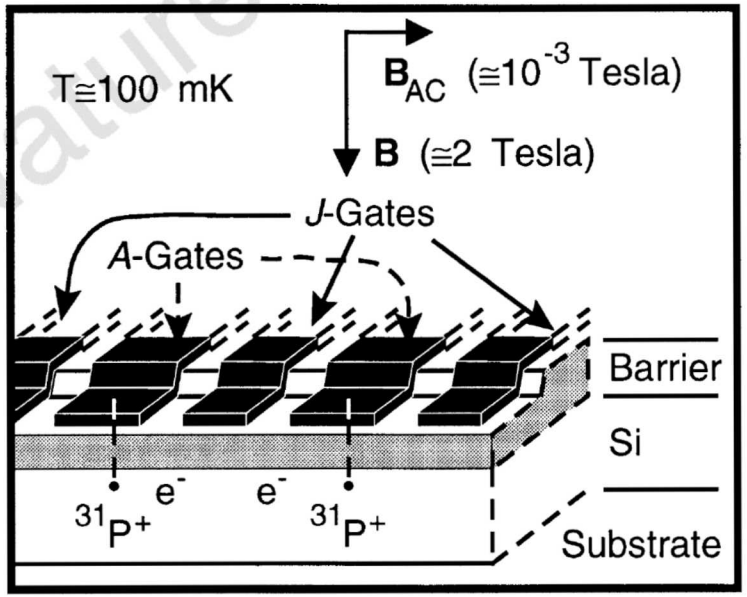
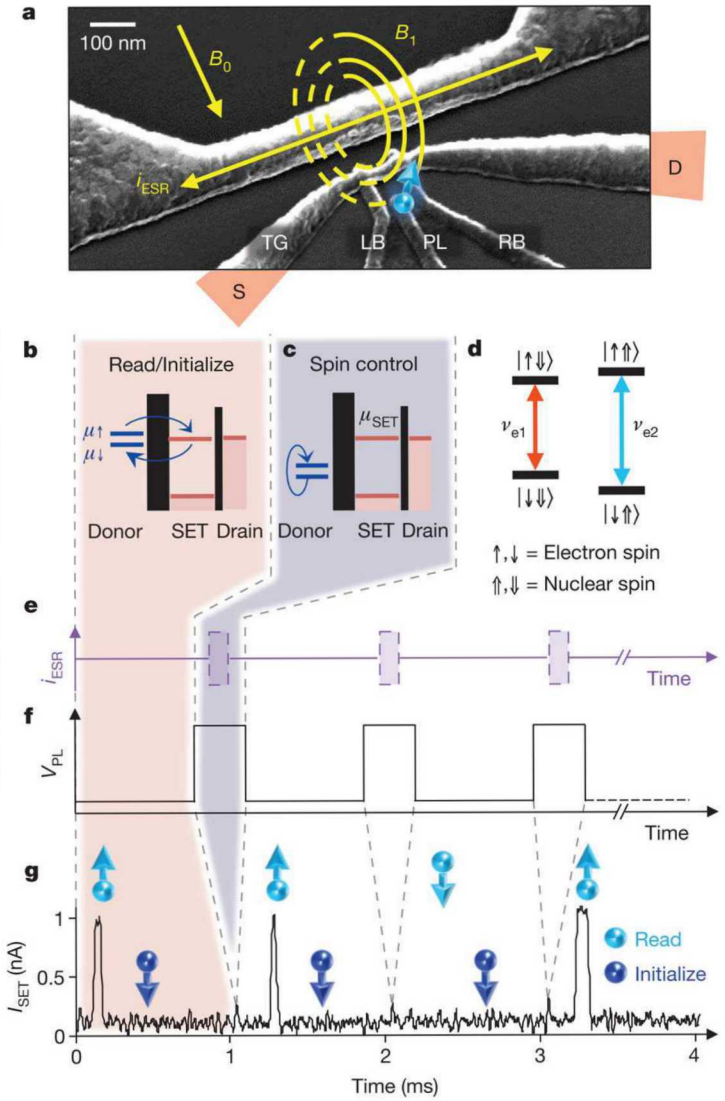
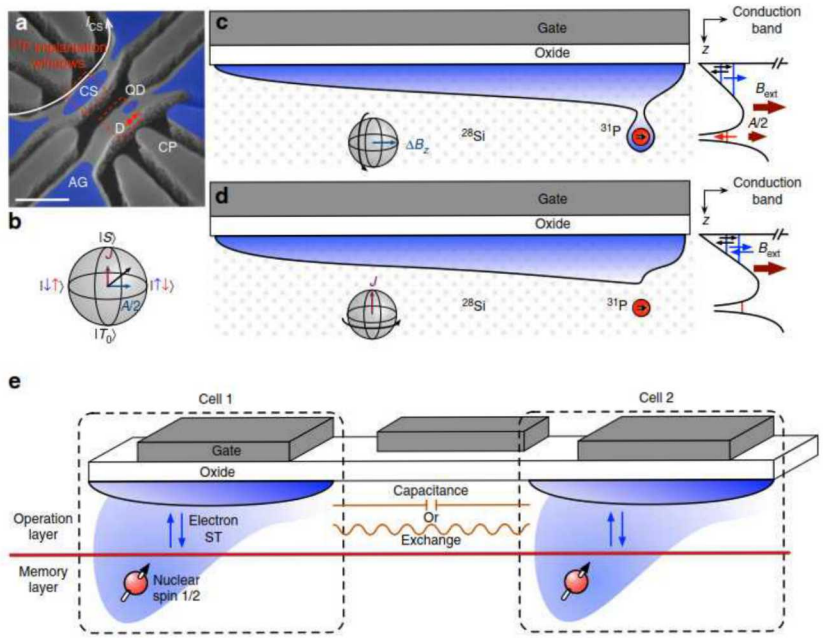
Single Donor Devices for Quantum Computing



B. E. Kane, Nature 393, 133 (1998)

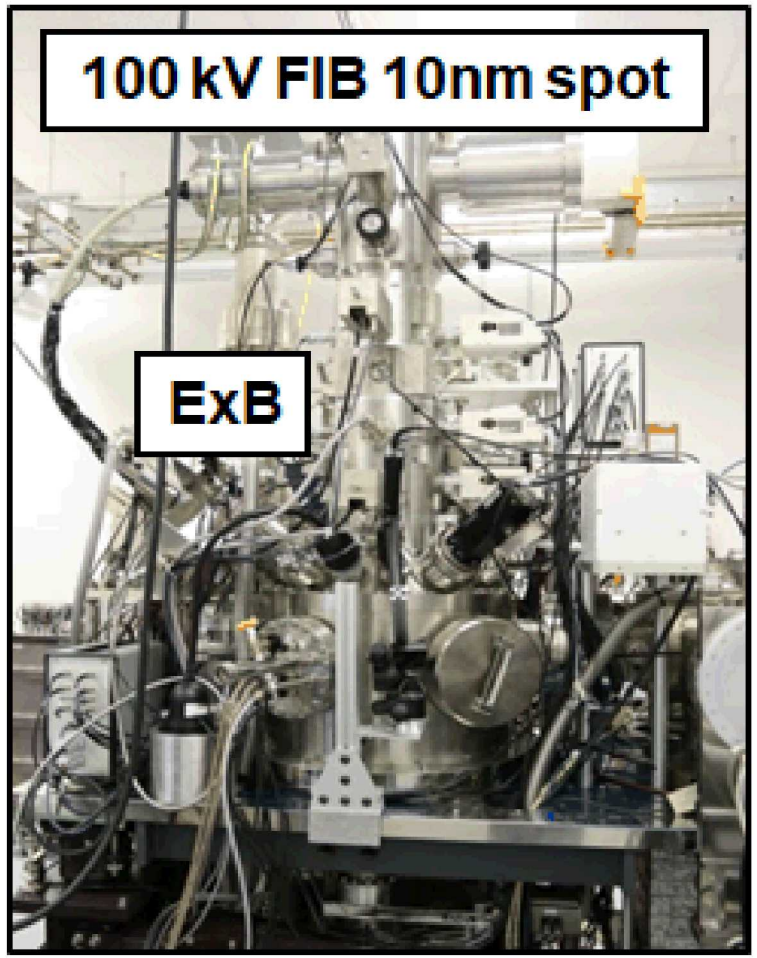


J. J. Pla et al. Nature 489, 541 (2012)

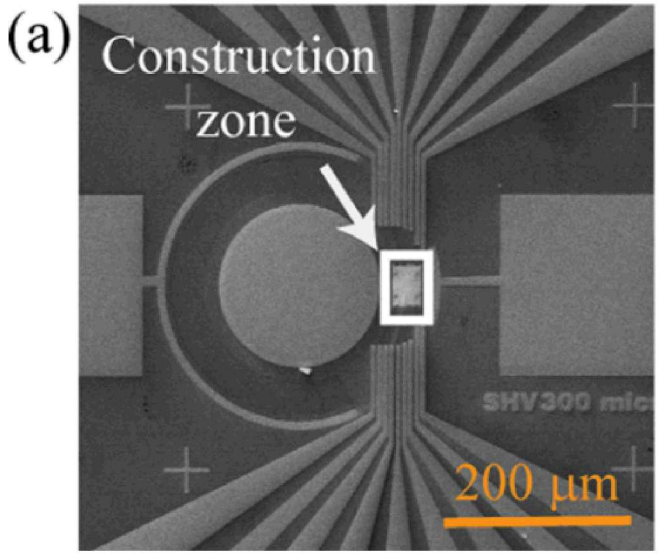


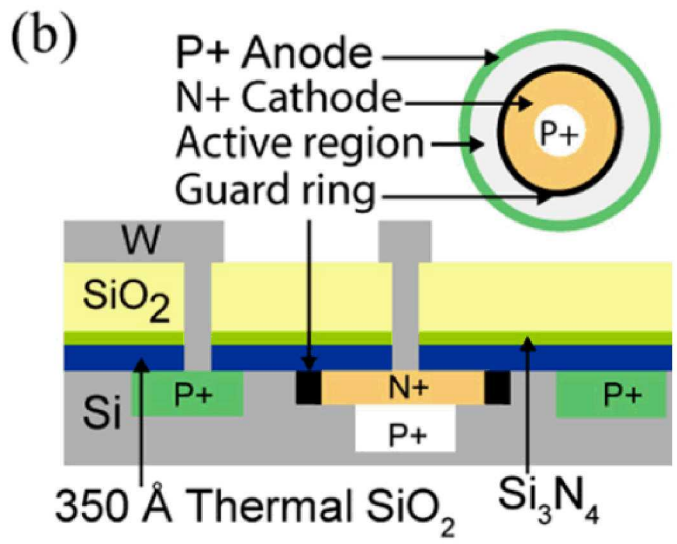
P. Harvey-Collard et al. Nat. Comm. 8, 1029 (2017)

Direct-write nanoImplanter at Sandia



Donor qubit fabrication on a *Si-MOS platform with integrated* ***single ion detectors*** *and* ***nanostructures for transport***



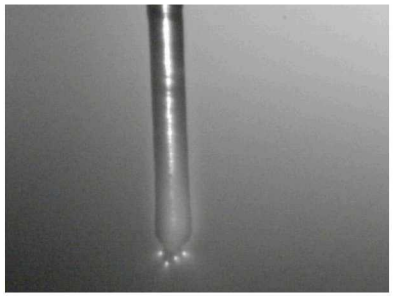


M. Singh et al. Appl. Phys. Lett. 108, 062101 (2016)

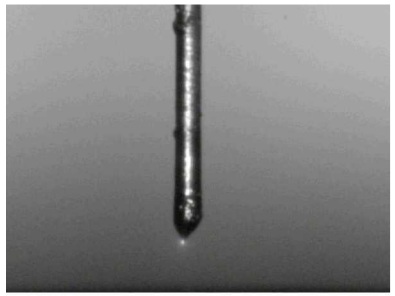
Counted Sb ions at 120 keV

nanoImplanter: Sb → P

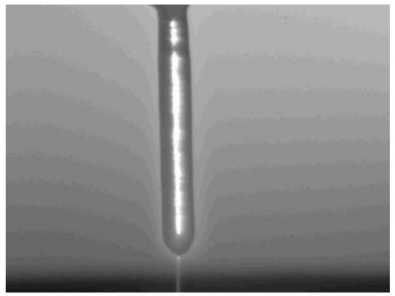
P tip development



Ugly with multiple emission points

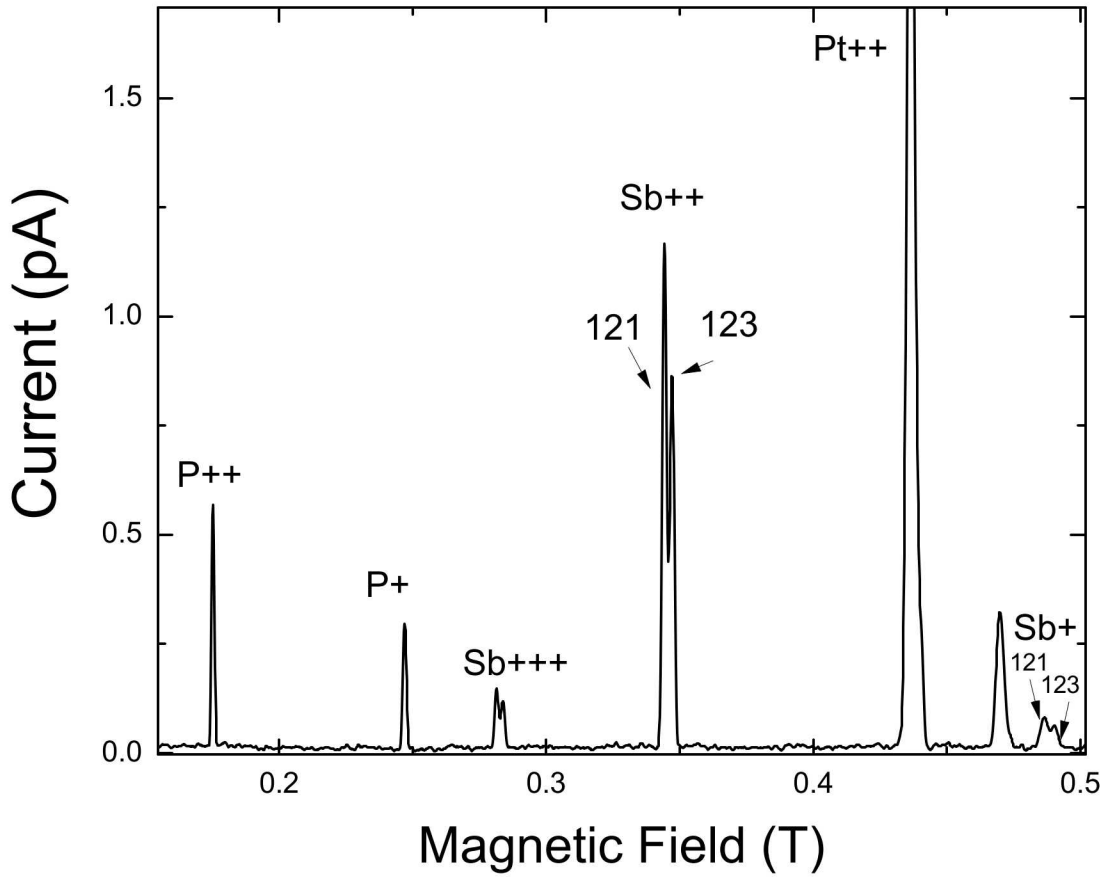


Bad off-axis emission

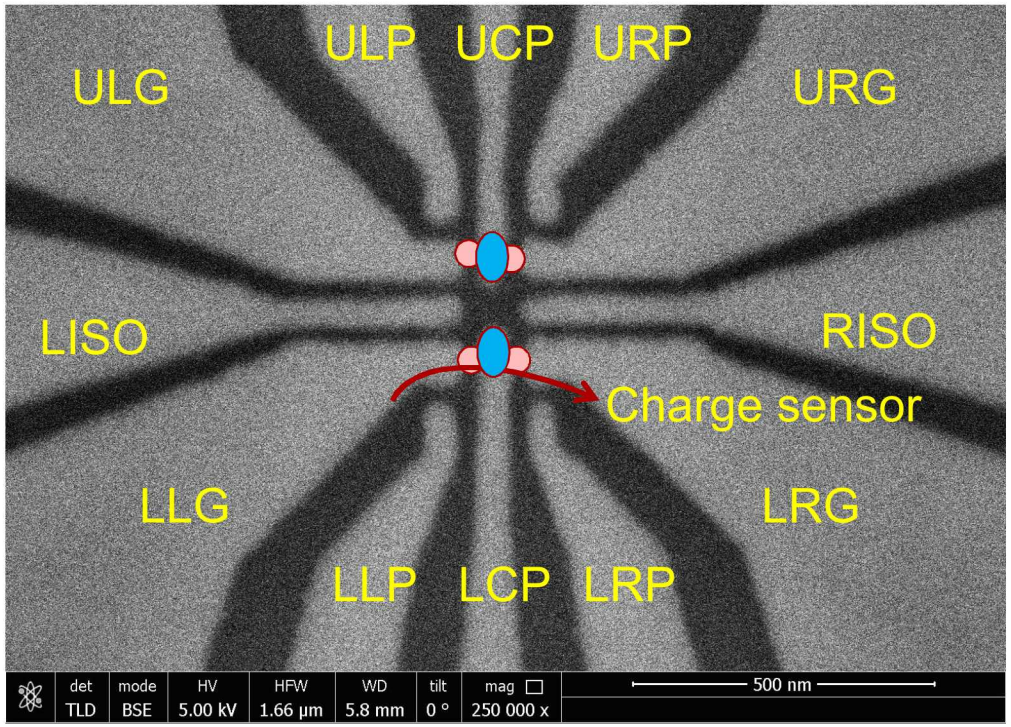


Good Emission

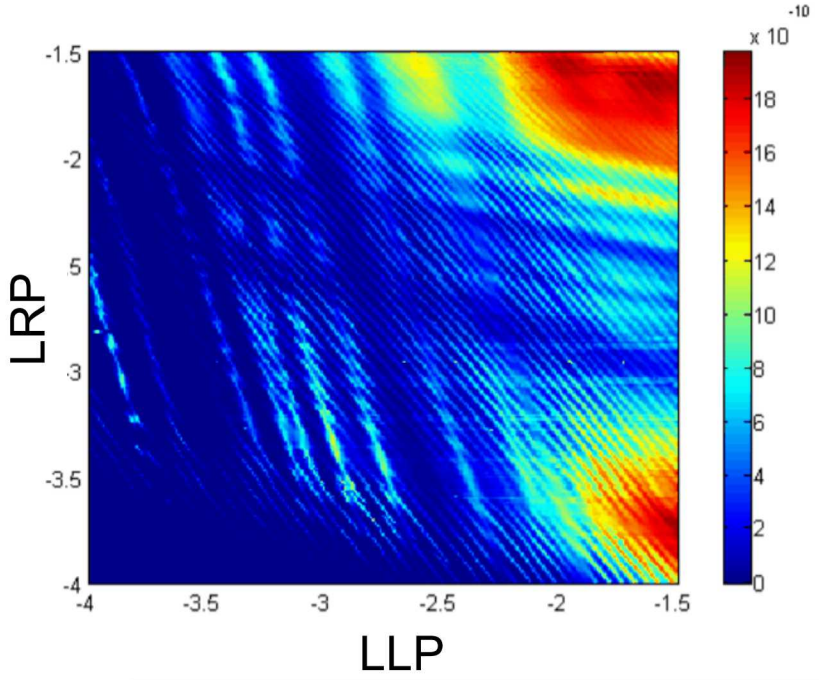
- Stable operation up to 1200 uA*hr observed ☑
- Small spots sizes possible, observed <30 nm ☑
- ***BUT***, significant tip to tip variation observed



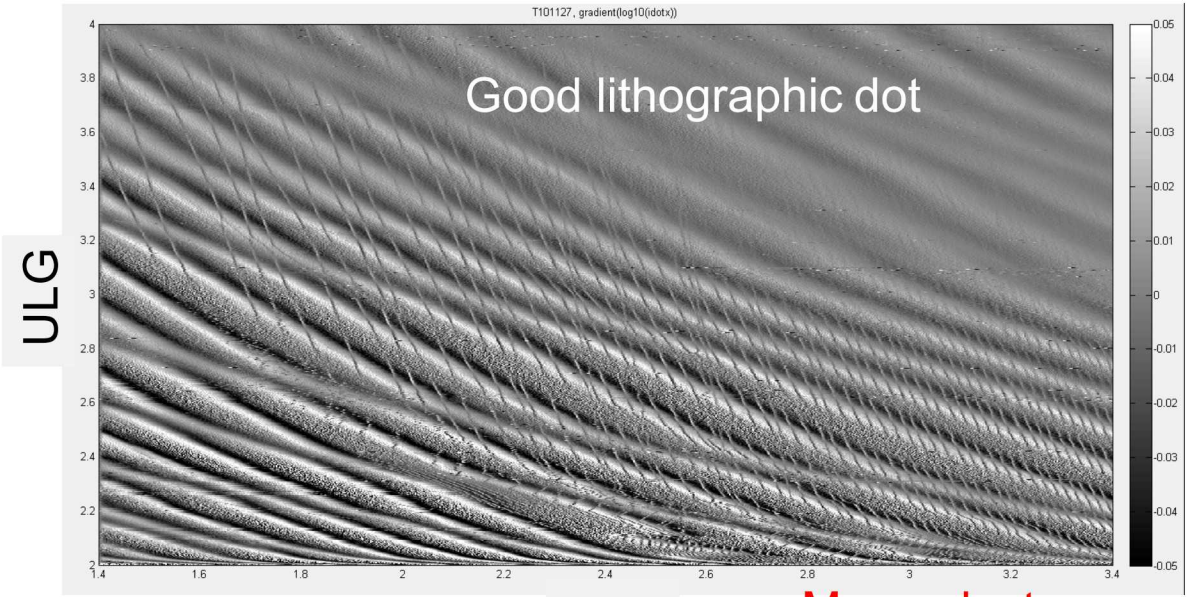
Transport and charge sensing in a device with timed P implant (fluence 4E11/cm2)



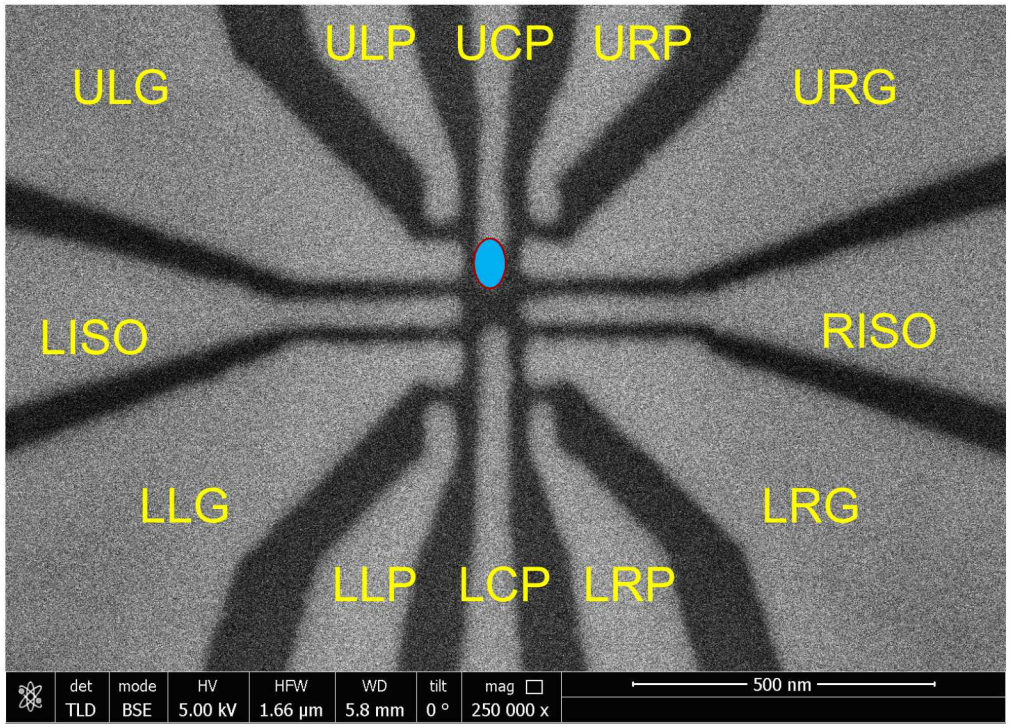
Lithographic dot
Donor(s)



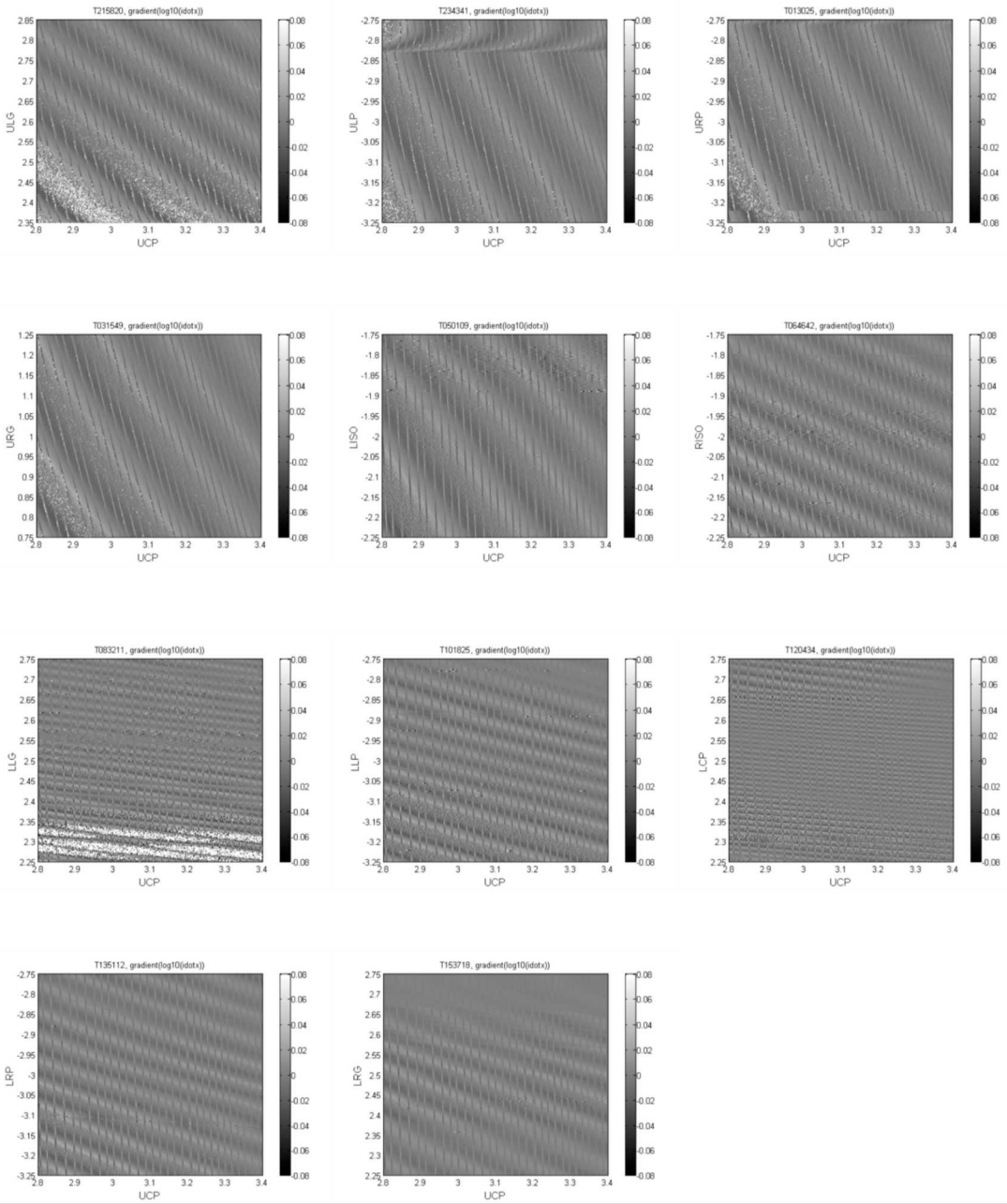
Reasonably good dot transport (charge sensor)



Good lithographic dot behavior in the many-electron regime



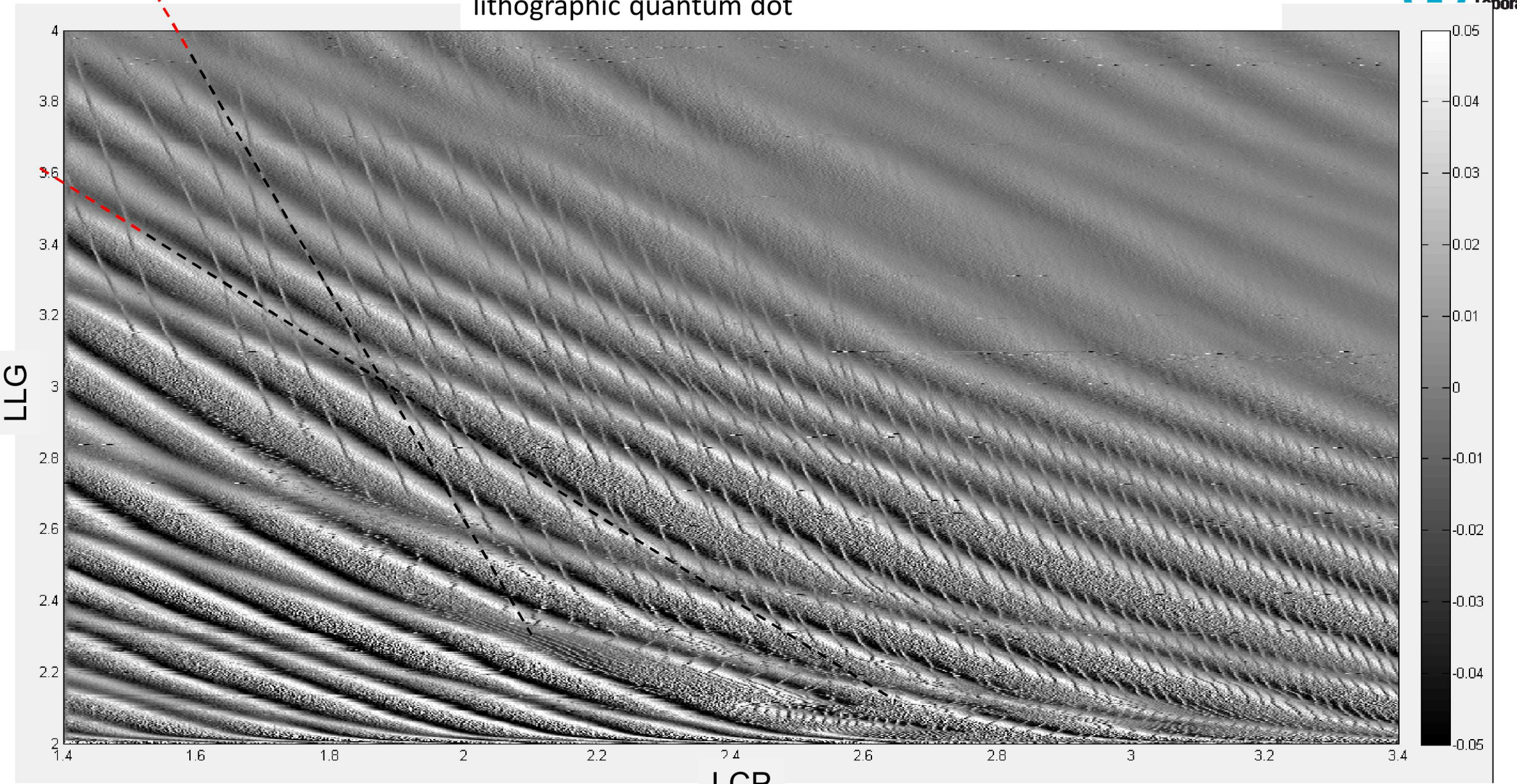
Lithographic dot



Gate	Capacitance (aF)
ULG	1.88
ULP	1.59
UCP	7.63
URP	1.59
URP	2.09
LISO	0.33
RISO	1.28
LLG	0.44
LLP	0.25
LCP	0.63
LRP	0.28
LRP	0.19

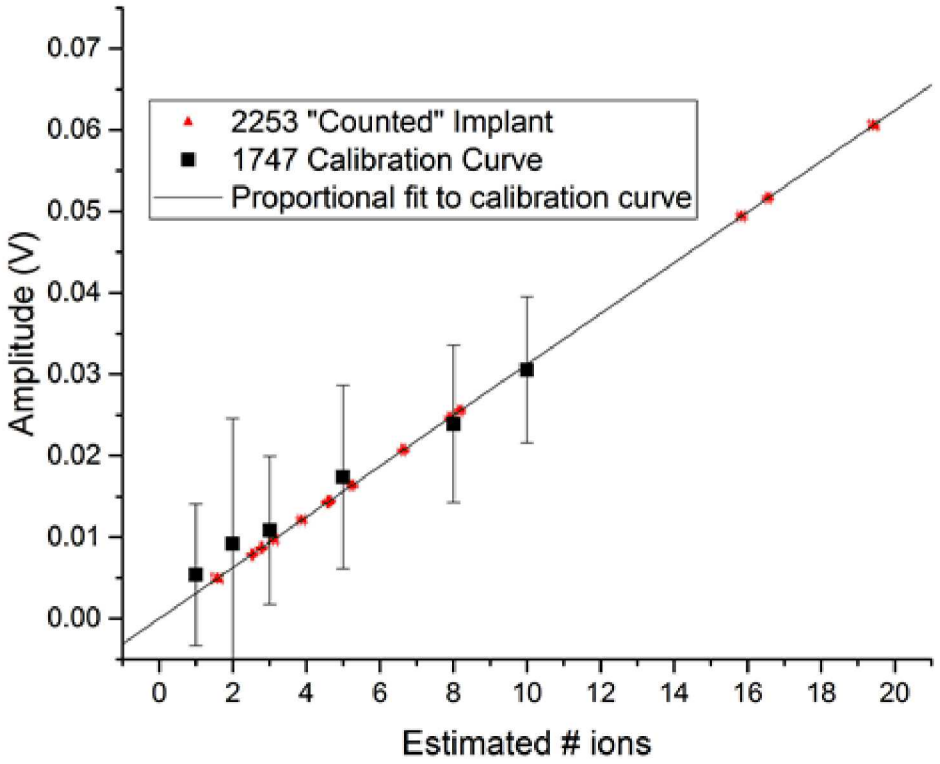
Potential Donors

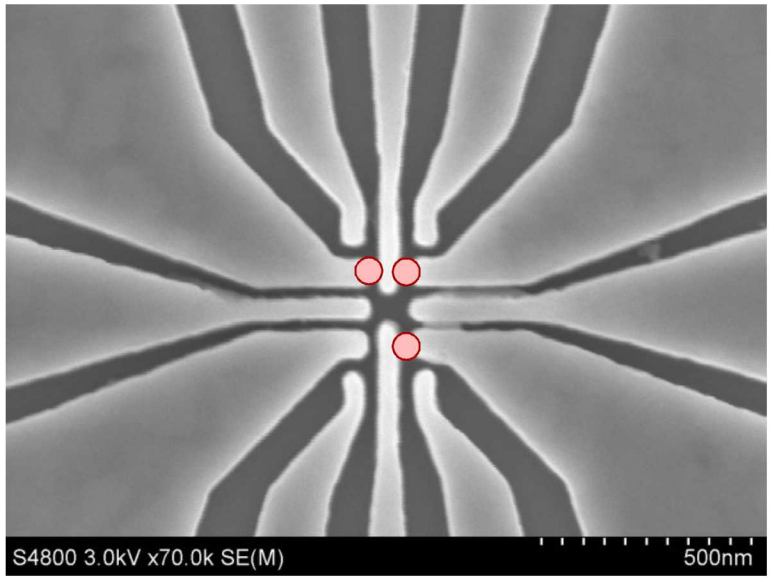
Timed P implant produces donor-like objects coupled to a lithographic quantum dot

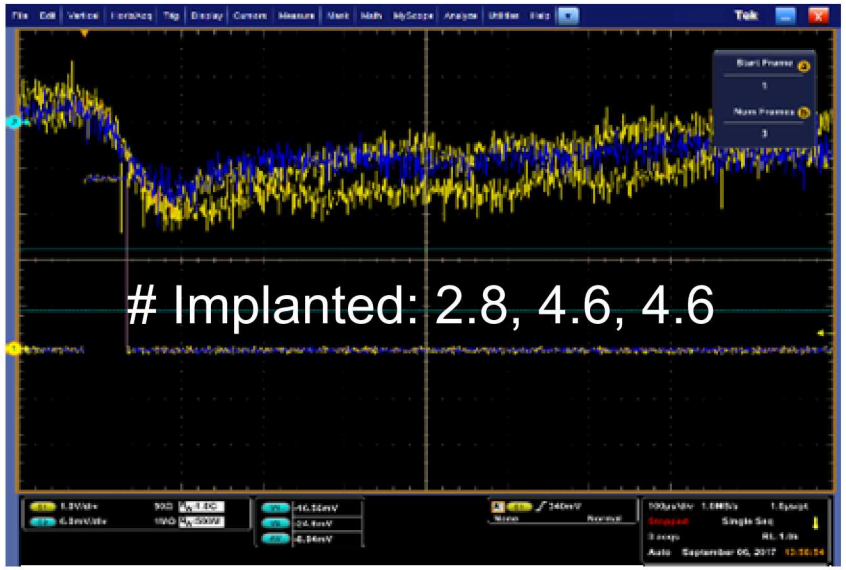


Detector response and calibration for counted P implant

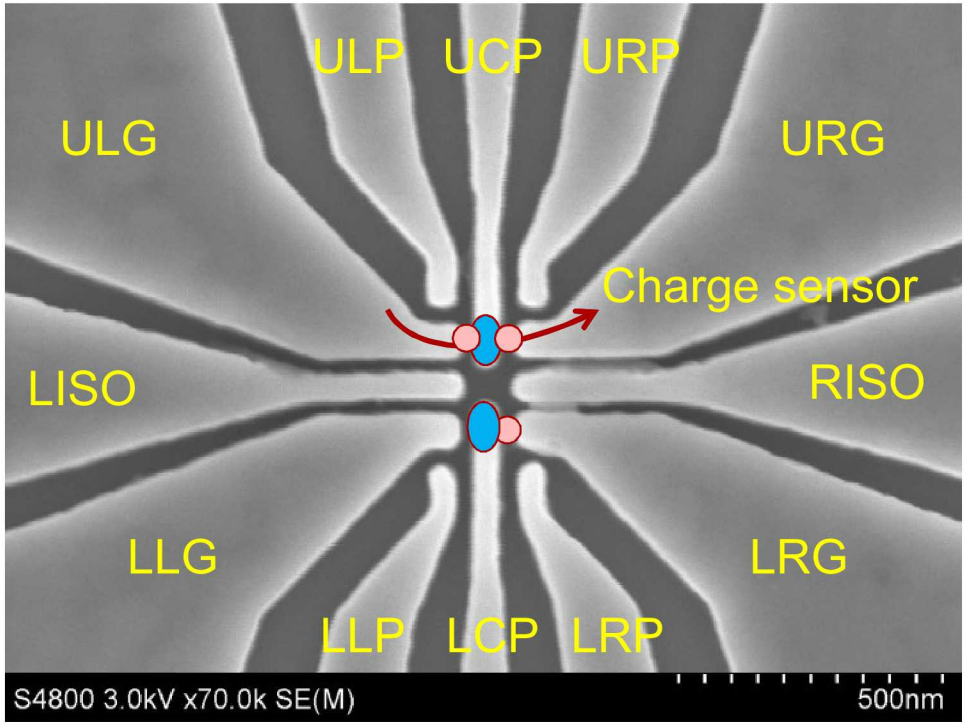
PtPSb tip
45 keV P+
Spot size ~ 63 nm



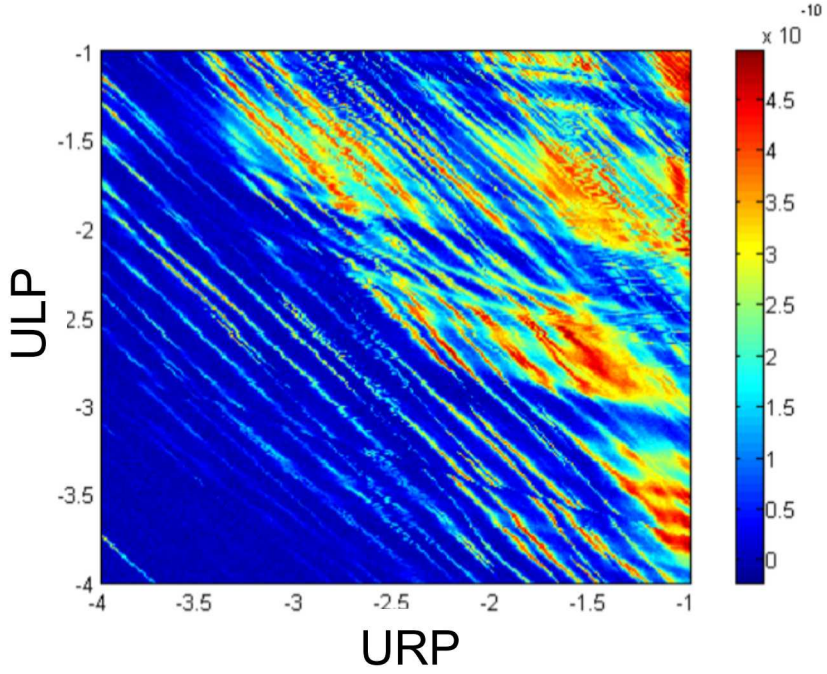




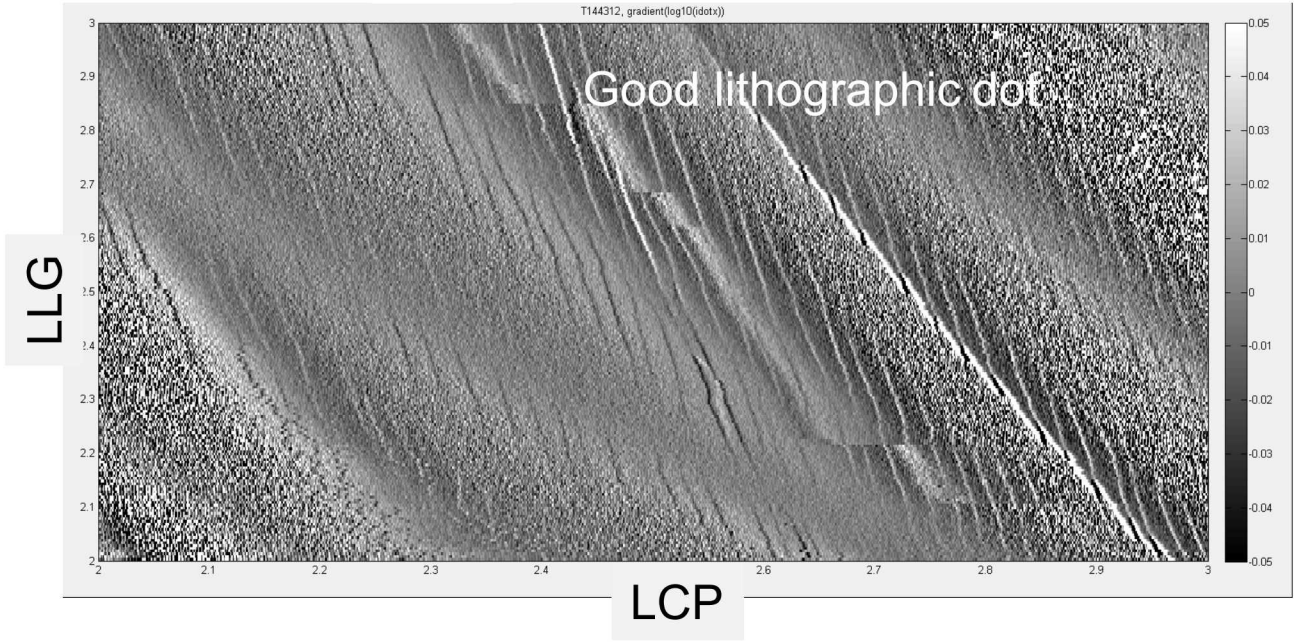
Transport and charge sensing in the device with counted P implantation



Lithographic dot
Donor(s)



OK dot transport (charge sensor)



Potential Donors

Counted P implant produces donor-like objects similar to timed implant.

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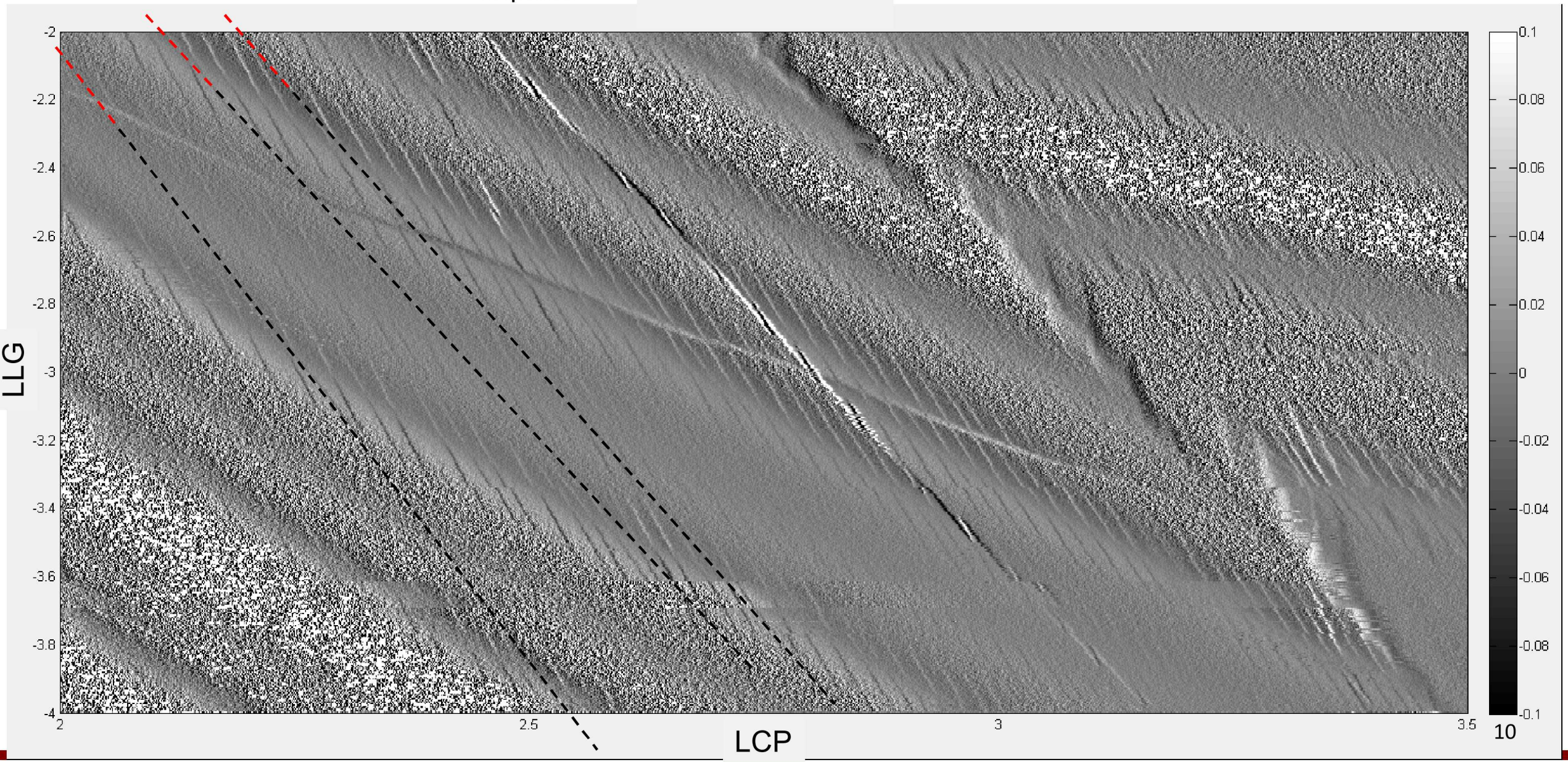

Summary

- SNL's nanoImplanter enables direct, counted implant of P donors into Si MOS quantum dot devices.
- Good quantum dot behavior is consistent with the nanostructure design.
- Charge sensing measurements reveal donor-like objects in implanted regions.

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