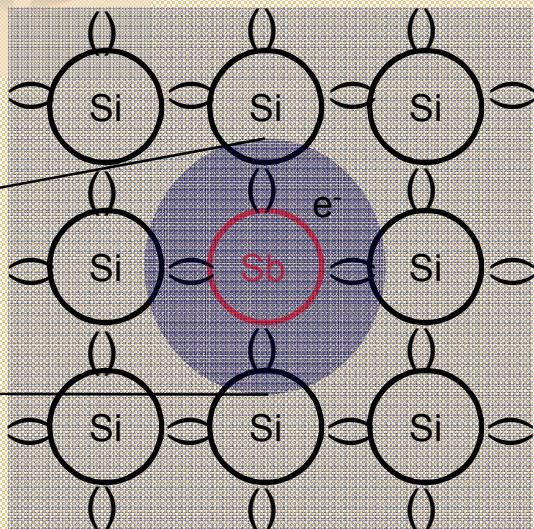
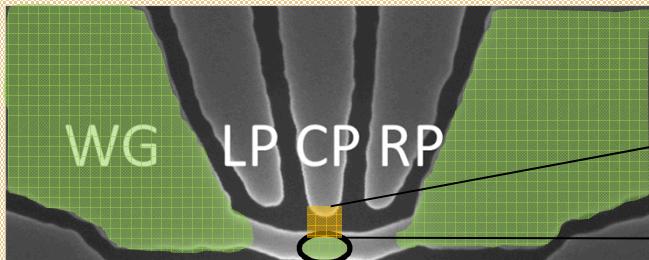


Silicon Quantum Dots with Counted Antimony Donor Implants



M. Singh, J. L. Pacheco, D. R. Luhman, E. S. Bielejec, M. P. Lilly and M. S. Carroll

This work was performed, in part, at the Center for Integrated Nanotechnologies, a U.S. DOE Office of Basic Energy Sciences user facility. The work was supported by Sandia National Laboratories Directed Research and Development Program. Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a Lockheed-Martin Company, for the U. S. Department of Energy under Contract No. DE-AC04-94AL85000.

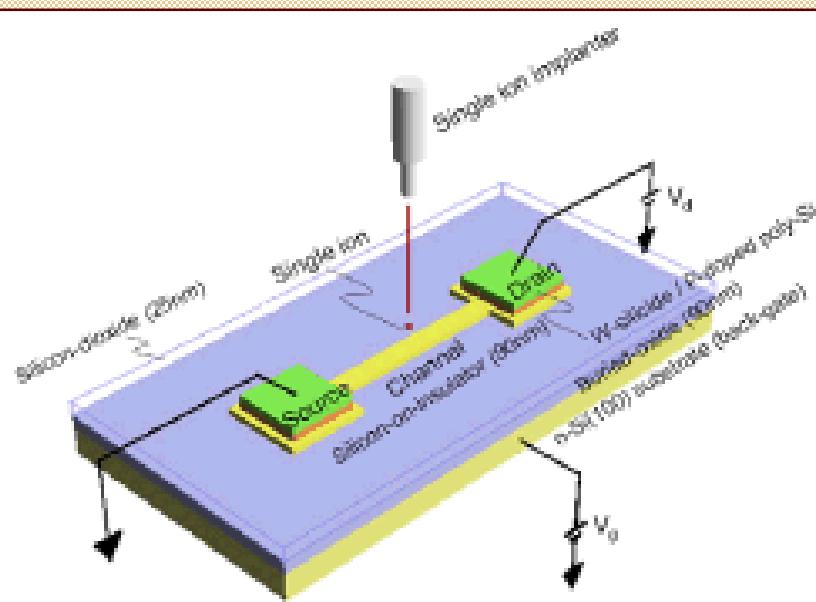
Why count donors?

Two qubit experiments require deterministic control over number of donors

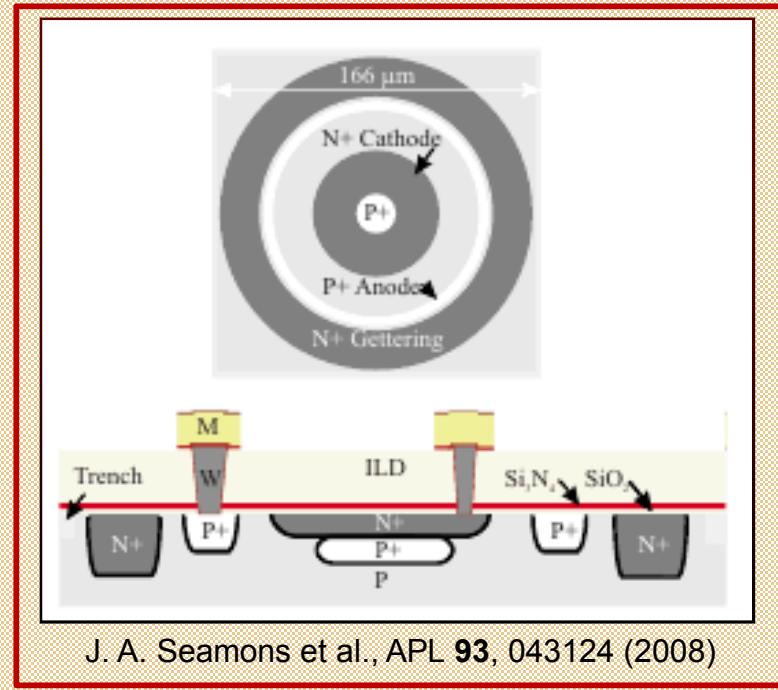


B.E. Kane, Nature 393, 133 (1998)

How to count donors:

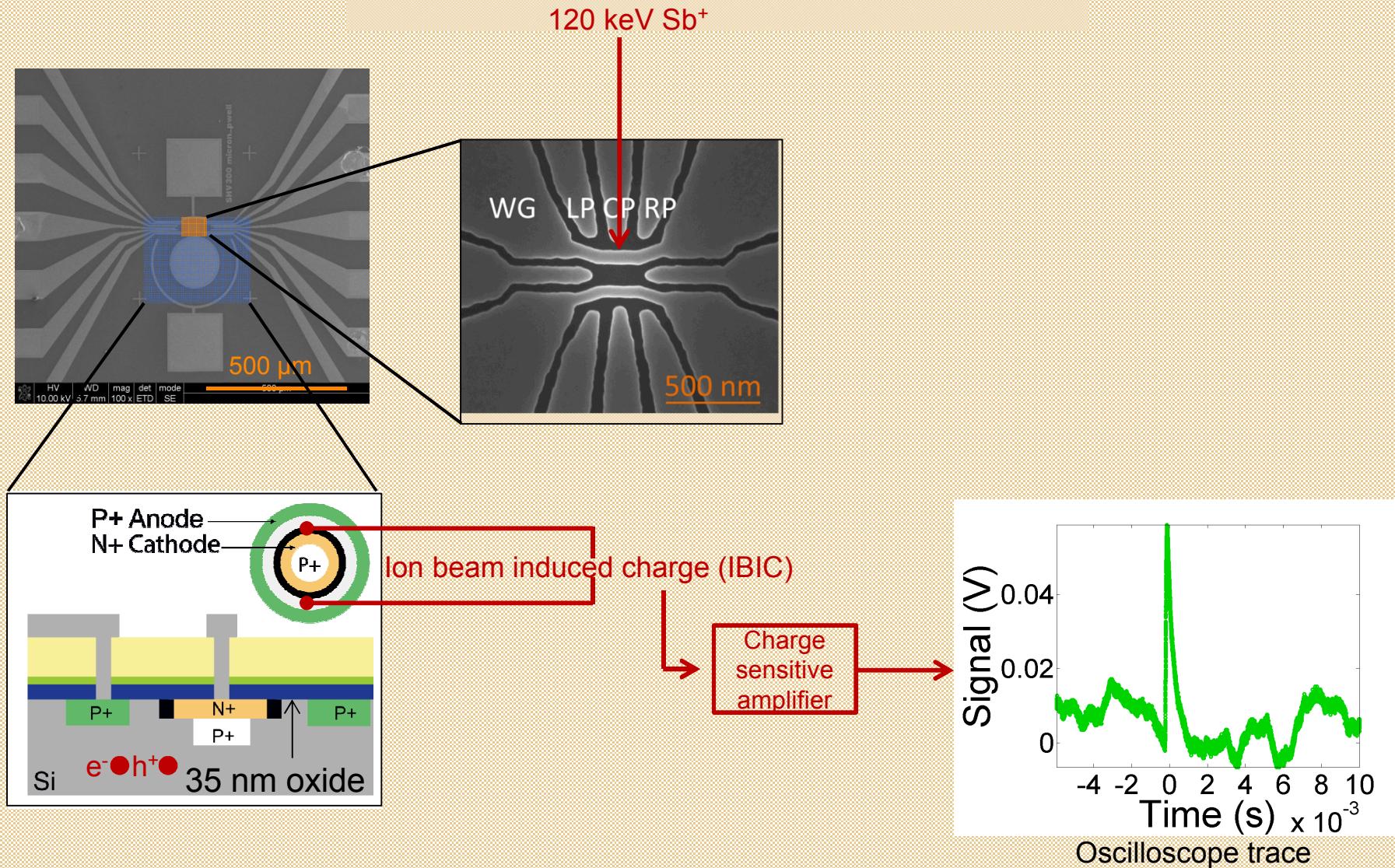


T. Shinada et al., Nanotechnology 19, 345202 (2008)



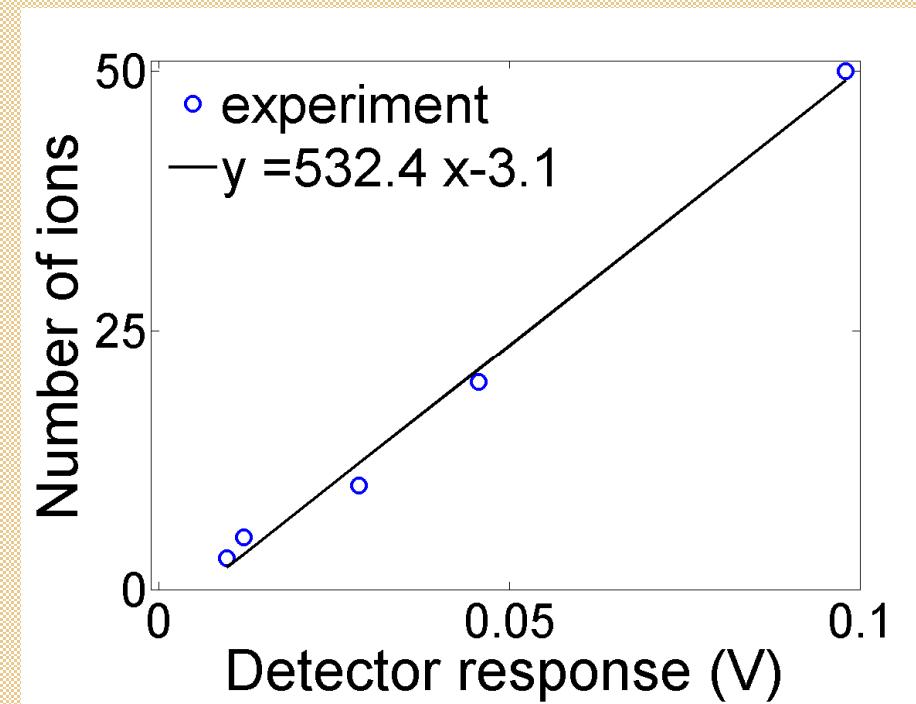
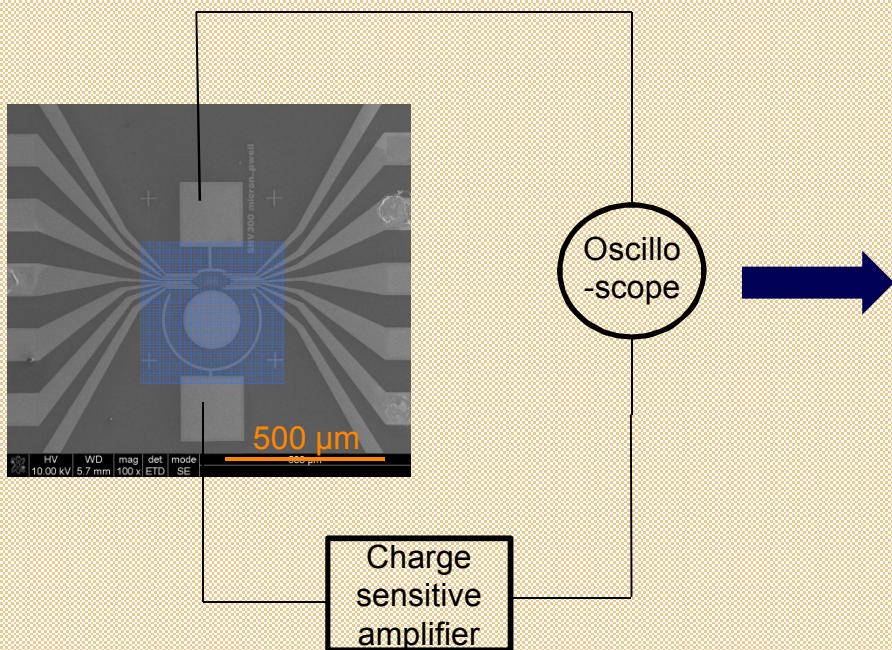
J. A. Seamons et al., APL **93**, 043124 (2008)

How do we count

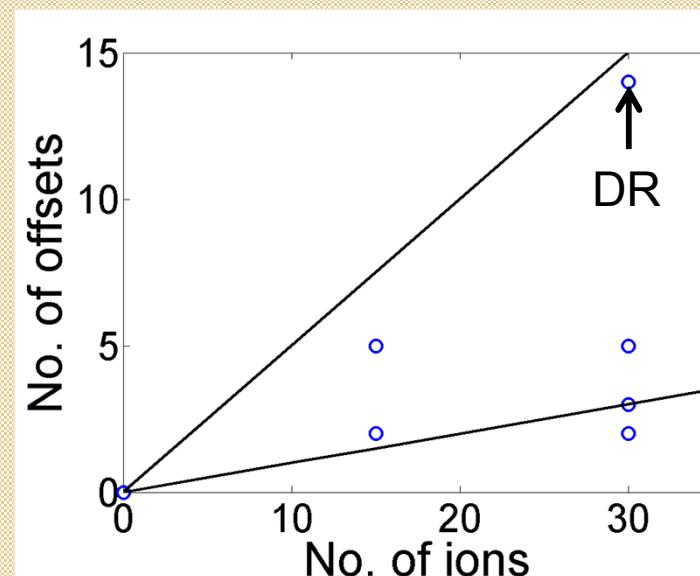
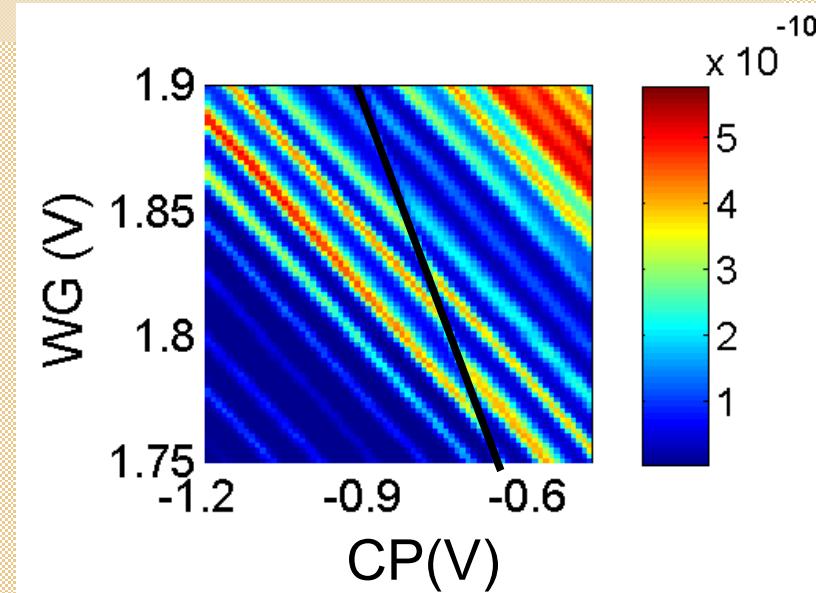
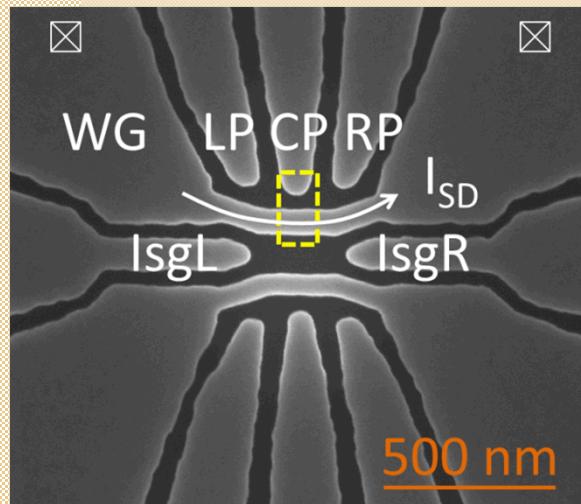


Making devices with counted no. of donors

Counting the ion implants

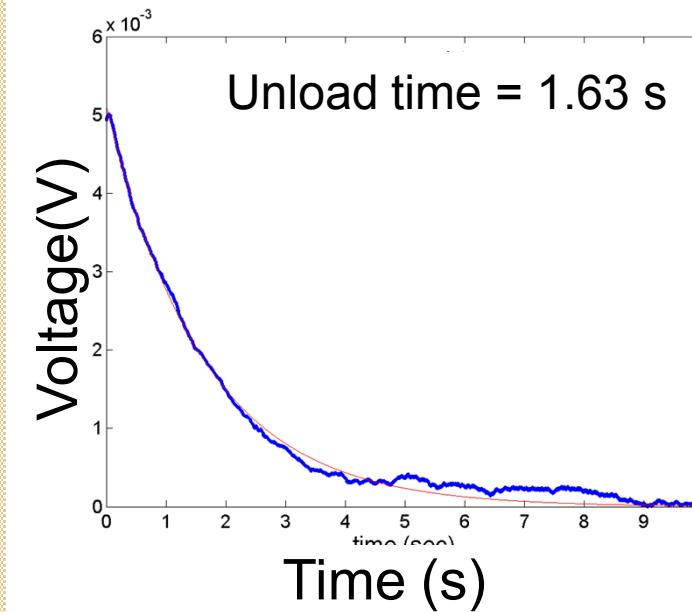
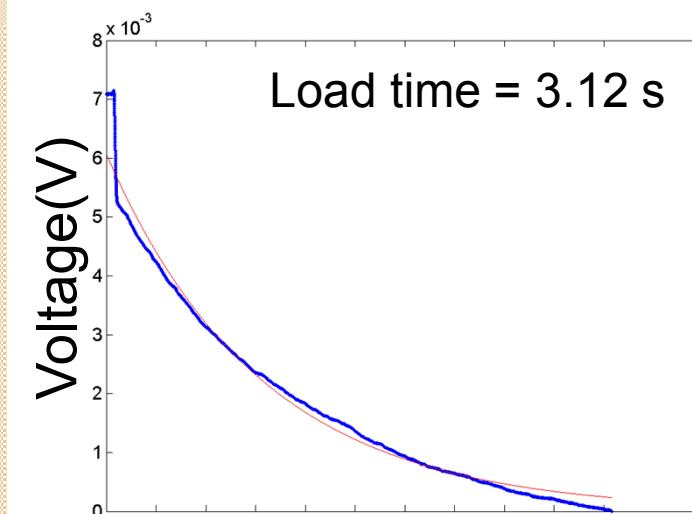
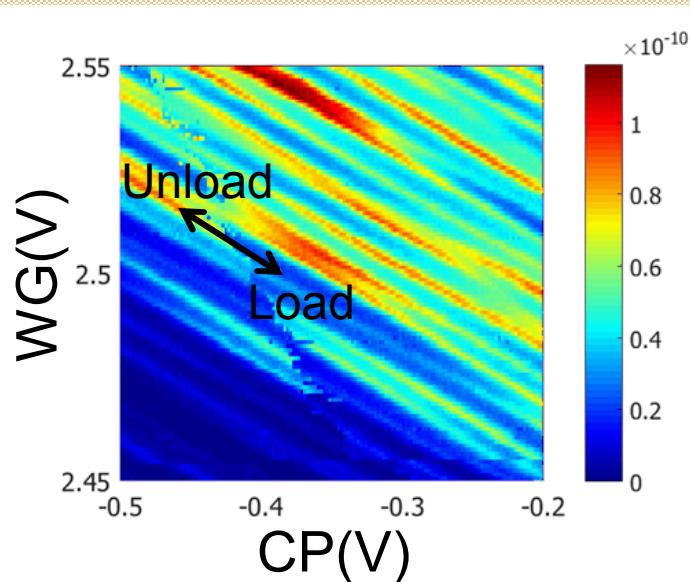


Does the SET work/see the donors?

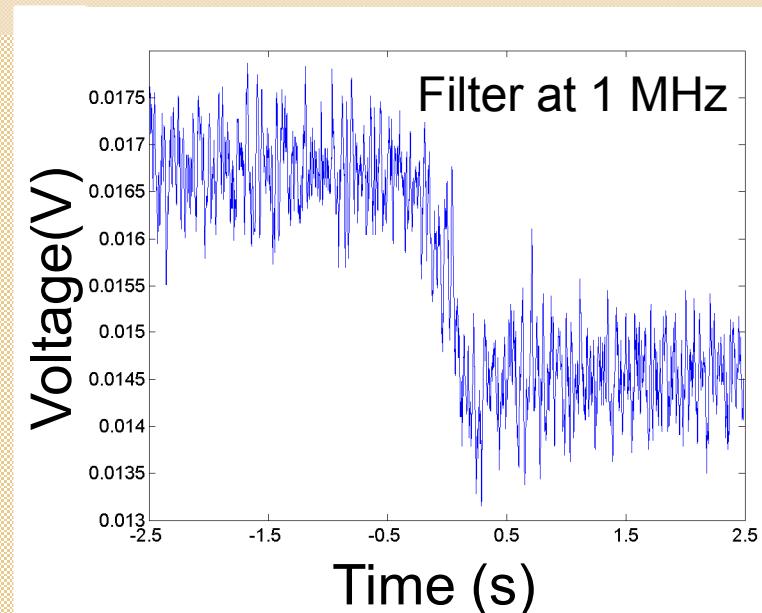
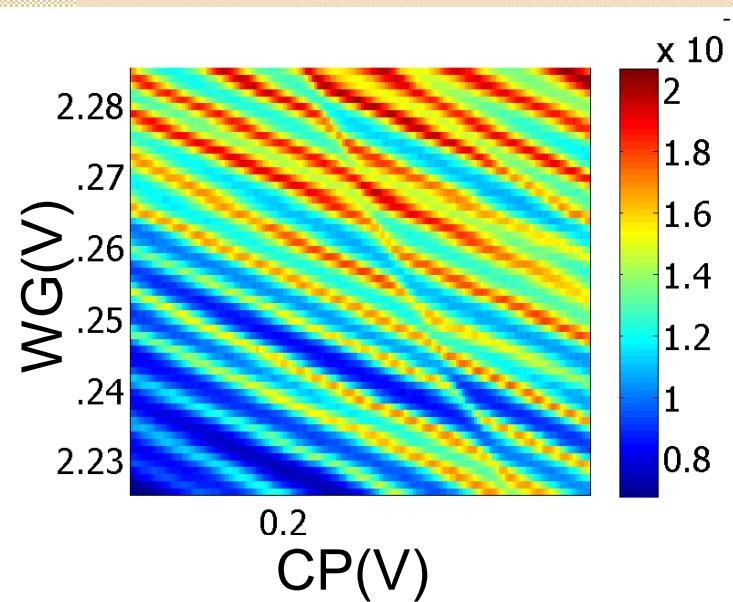


Tunneling Time Measurement on Counted Donors

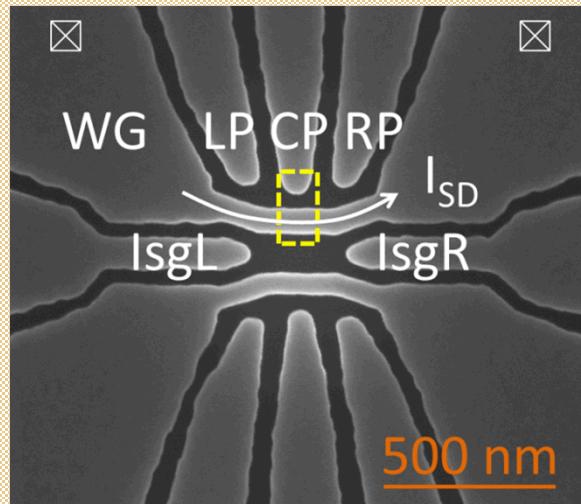
Some offsets are very slow



Tunneling Time Measurement on Counted Donors



Others are very fast

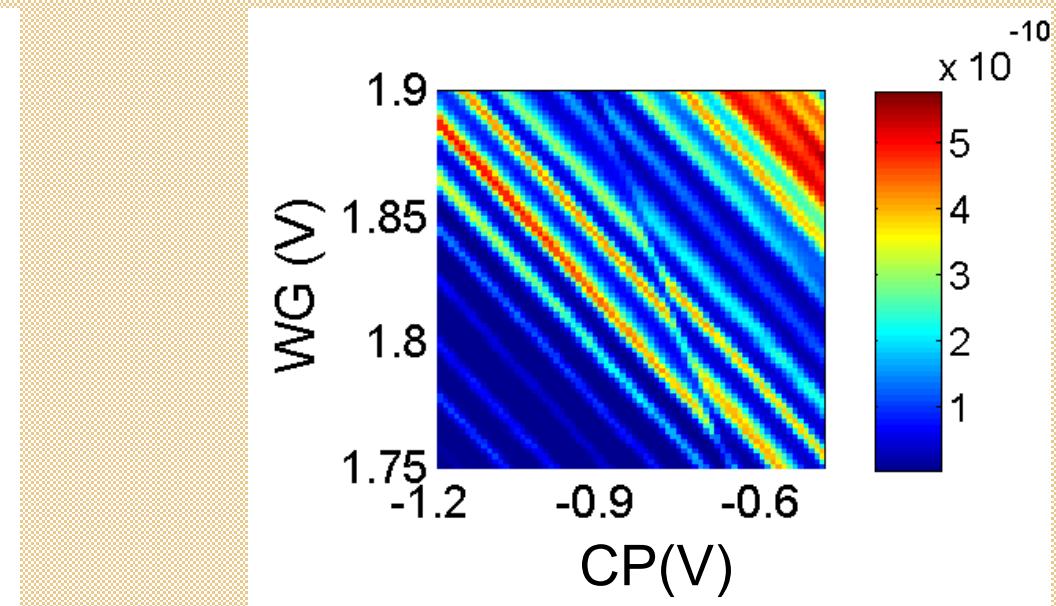
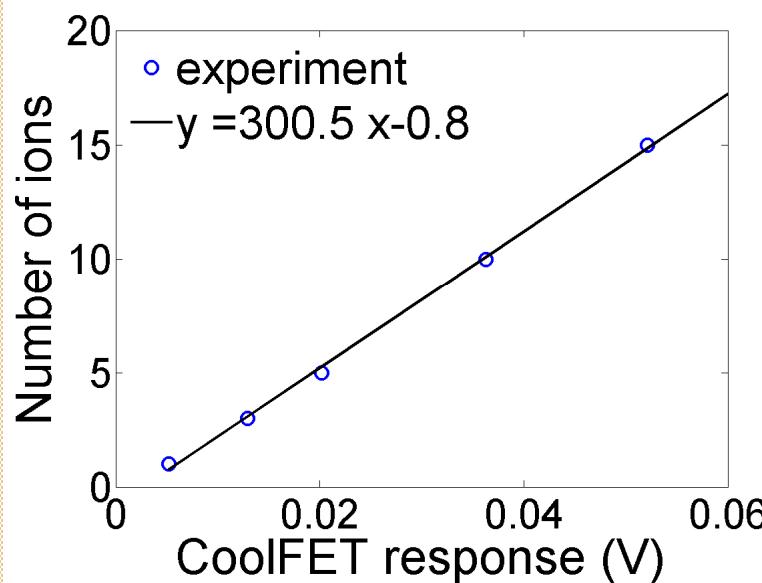


1. With focused ion beam system and lithography, we can control lateral position to ~ 10 nm
2. By thinning oxide to 7 nm in the implantation region, we can use lower energy ions and reduce depth straggles

Results

THIS WORK:

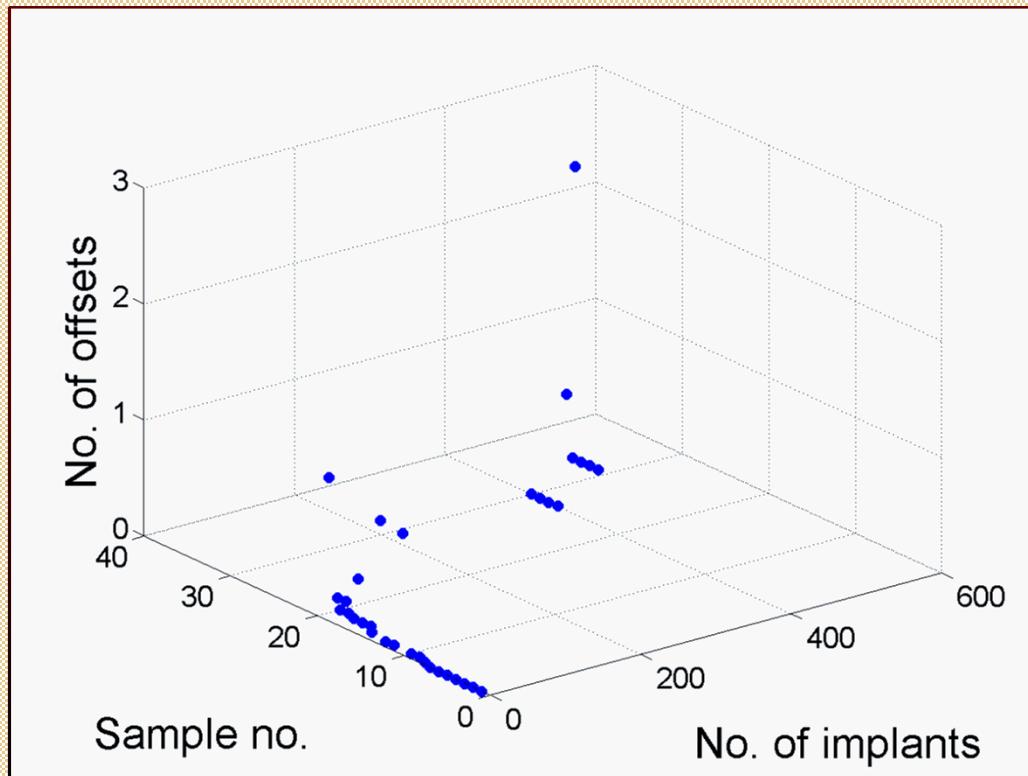
Correlation between no. of donors implanted and no. of charge offsets in transport measurement is seen (APL 108, 6, 062101 (2016))



Thank you

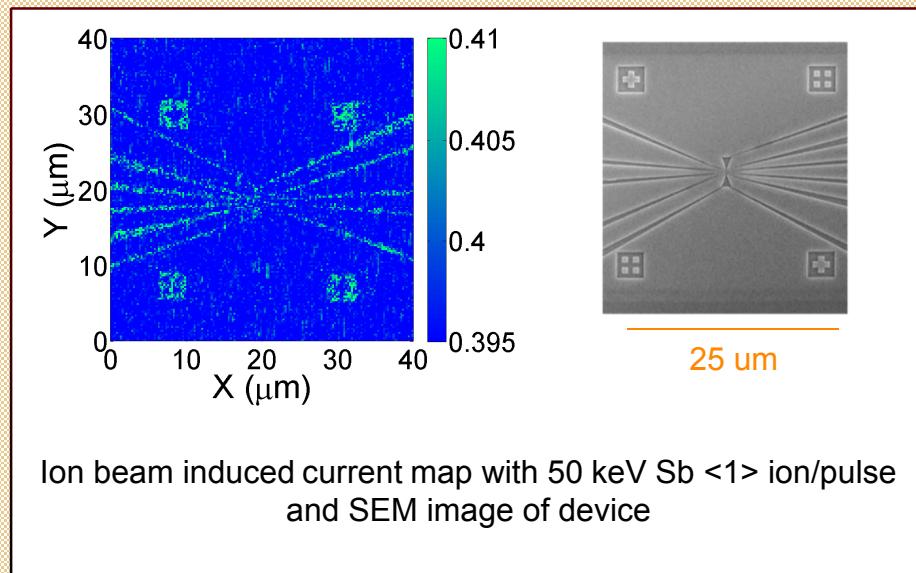
Additional Information

7 nm counted implants

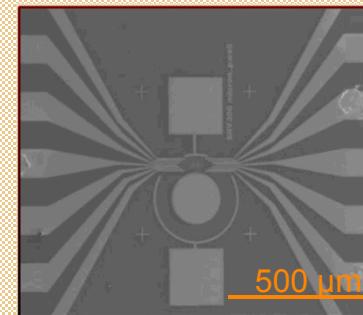


Single ion detection and functional SET

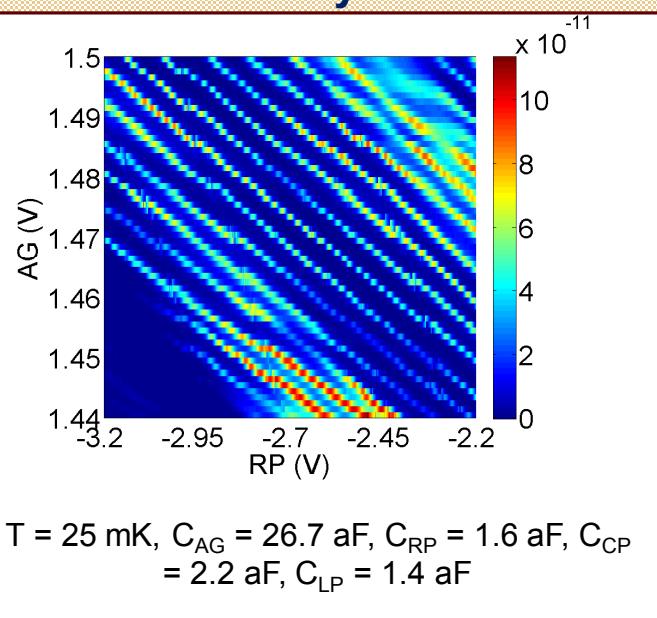
Single ion detection



Diode detectors that can detect a single ion integrated with functional SETs.



SET with capacitances agree with simulations of an electrostatically defined dot

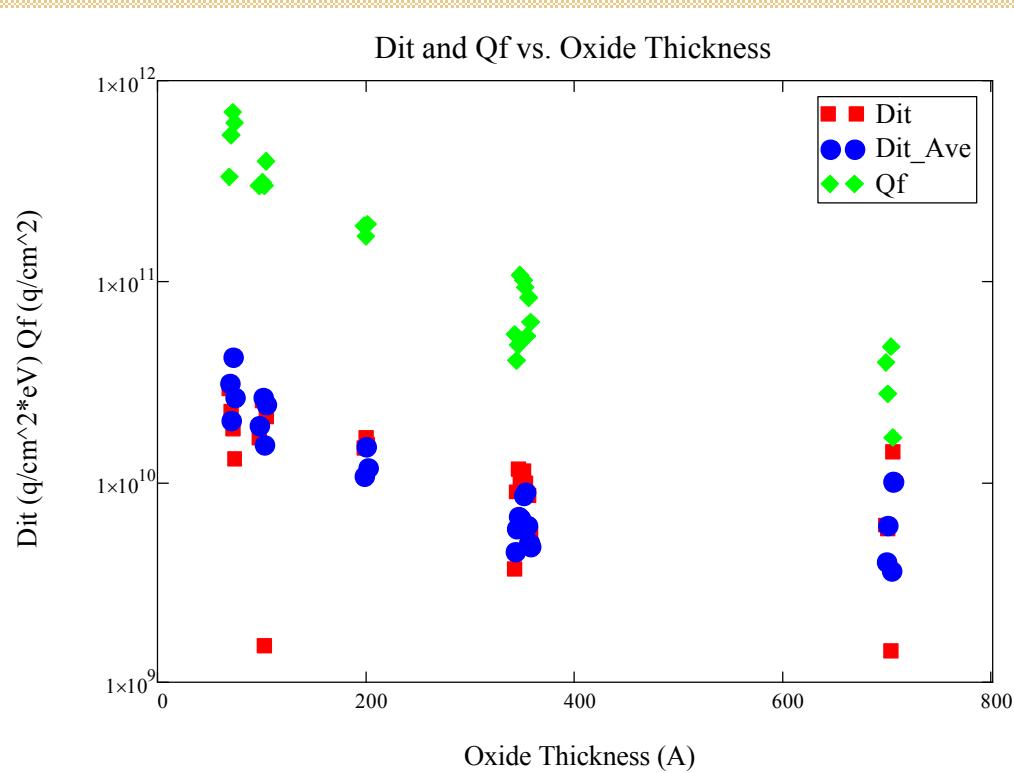


Sample Synthesis: 7 nm oxide

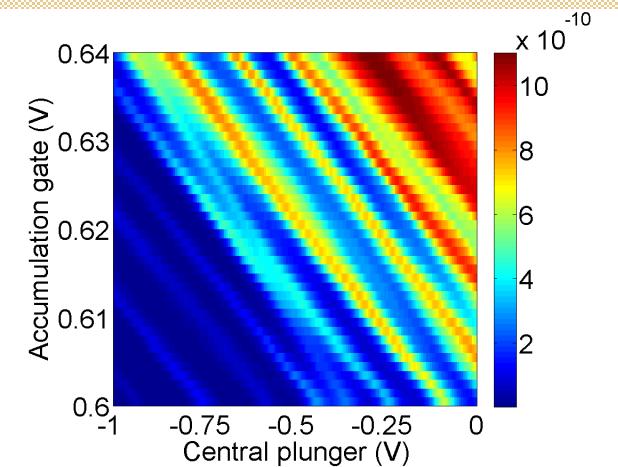
1. Interface trapped charge (D_{it}) and fixed charge (Q_f) are concerns for dots and donors near the SiO_2/Si interface
2. Thinner oxides lead to higher fixed charge

We require deterministic control over:

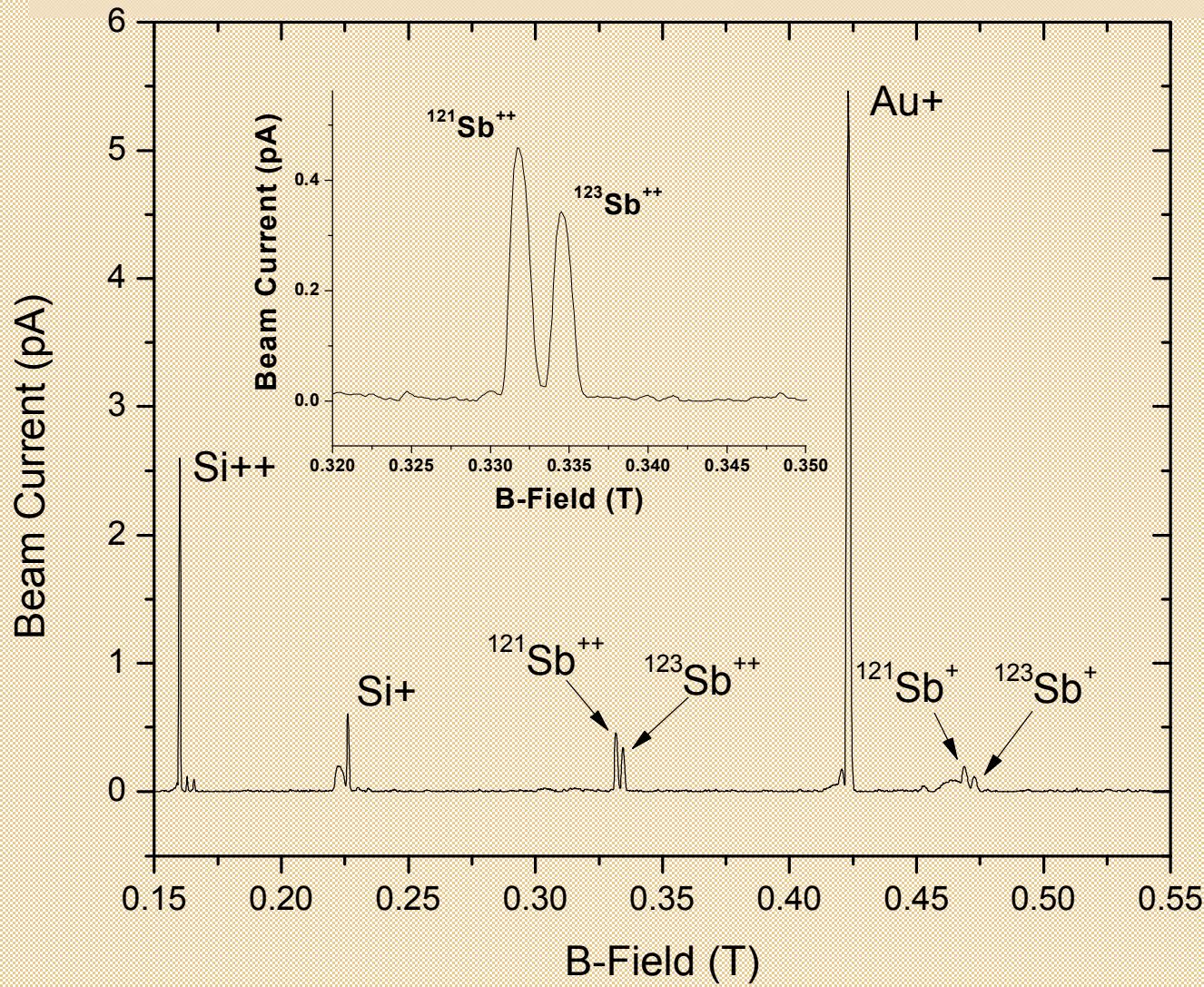
1. Placement of donors: needs thin oxide
2. Number of donors



However, we are able to obtain stable single dots in these systems



AuSiSb Mass Spectrum



hydrogen	1	
	H	
1.0079		
lithium	3	beryllium
	Li	4
6.941		Be
sodium	11	magnesium
	Na	12
22.990		Mg
		24.305



scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 0.5 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.322	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununtrium 110 Uun [270]	ununpentium 111 Uuu [271]	ununhexium 112 Uub [272]		ununquadium 114 Uuq [289]				

* Lanthanide series

**Actinide series

Capable of Generating Ion Beams from $\sim \frac{1}{3}$ of the Periodic Table