SAND2010-1580C

Coulomb Blockade in Double Top Gated Silicon Nanostructures with Integrated Charge Sensing

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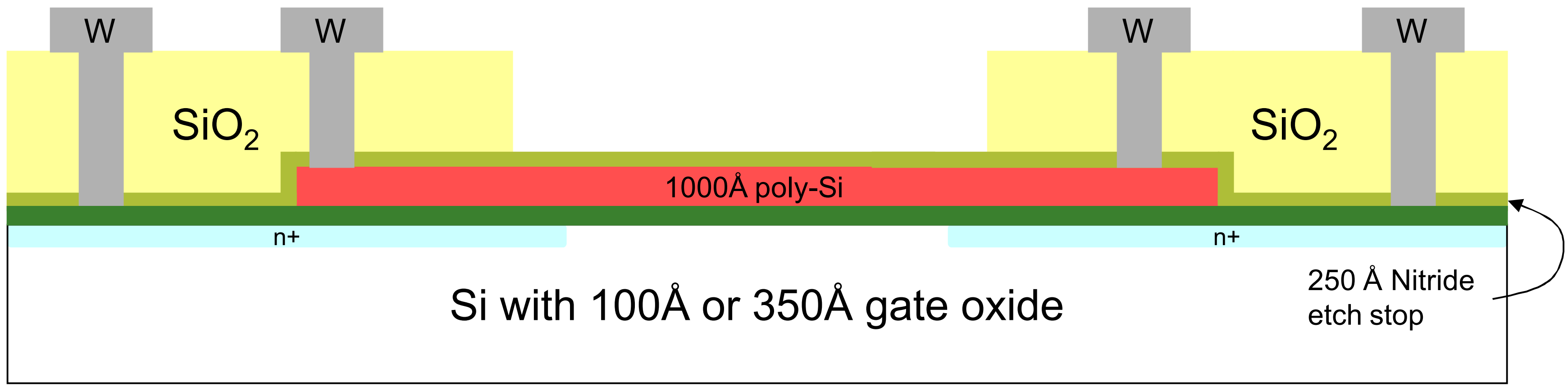
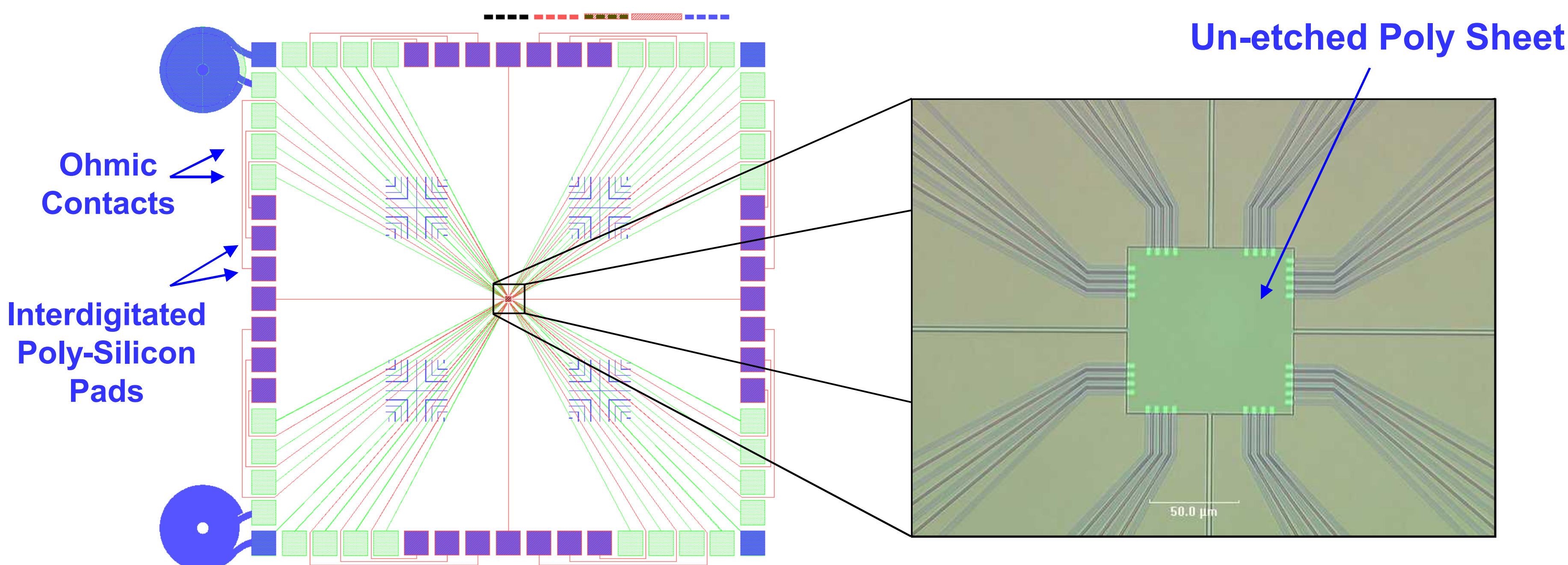
Eric Nordberg, Lisa Tracy, Greg Ten Eyck, Kevin Eng, Harold Stalford, Ralph Young, Kent Childs, Jeff Stevens, Robert Grubbs, Mike Lilly, Mark Eriksson, Malcolm Carroll

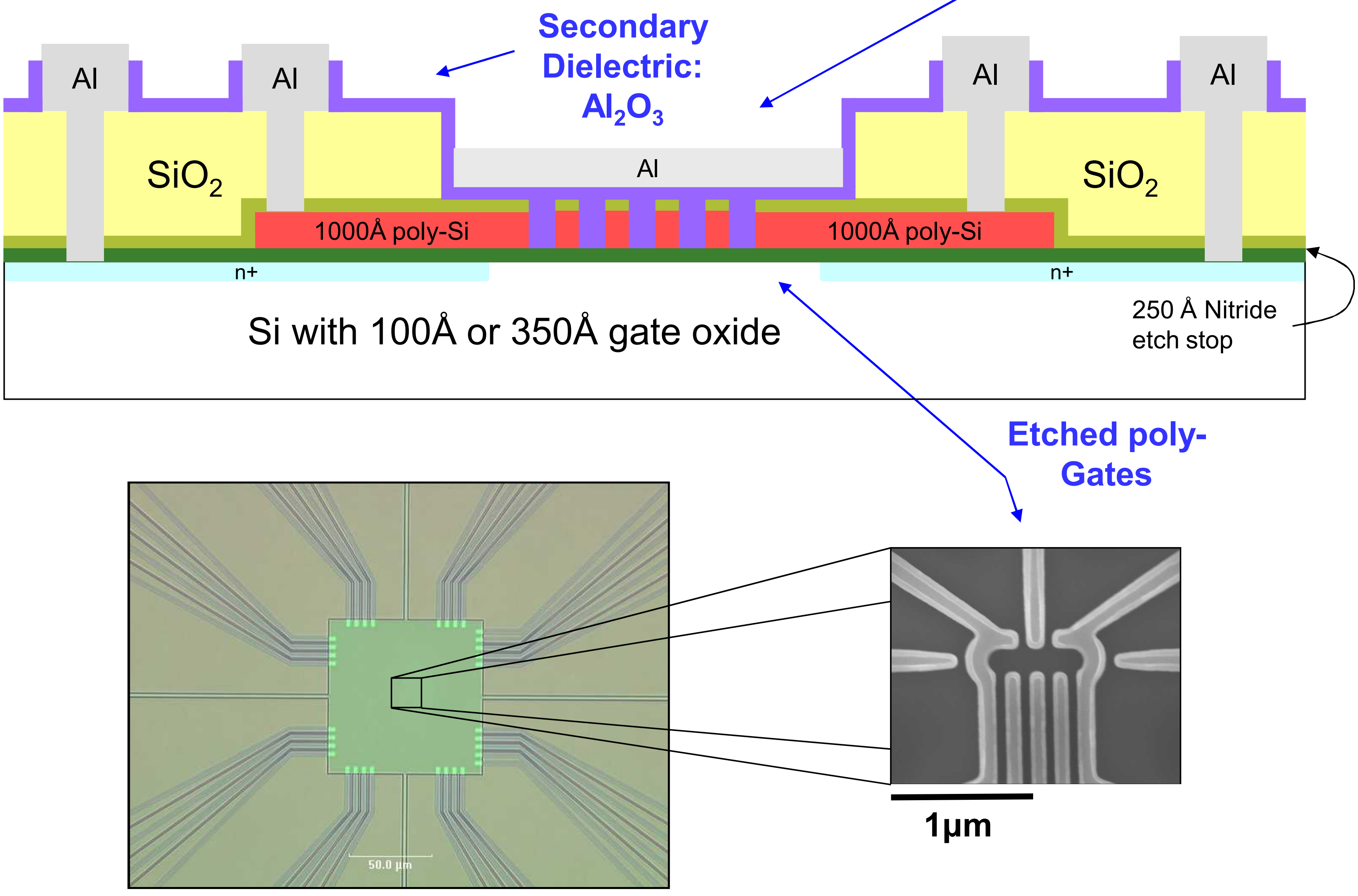
Initial Device Structure





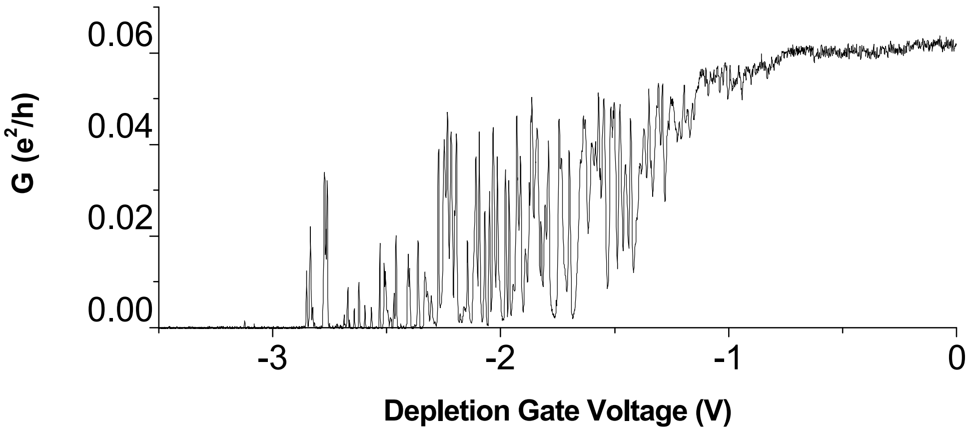
Peak Mobilities ~ 13000 cm^2/Vs before post processing @4K

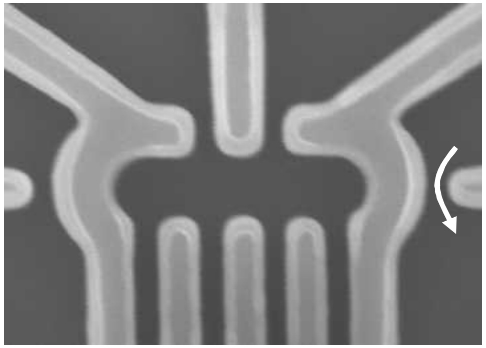
Final Device Structure



Process Induced Disorder

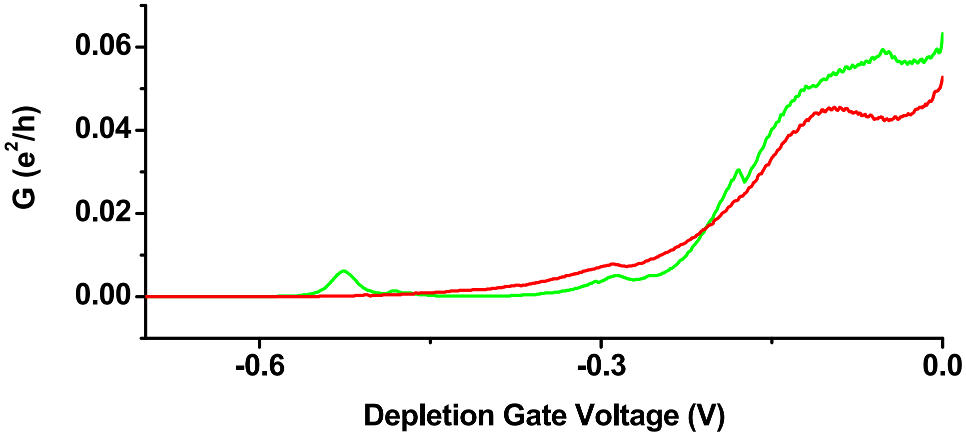
Disorder Dominated Conduction

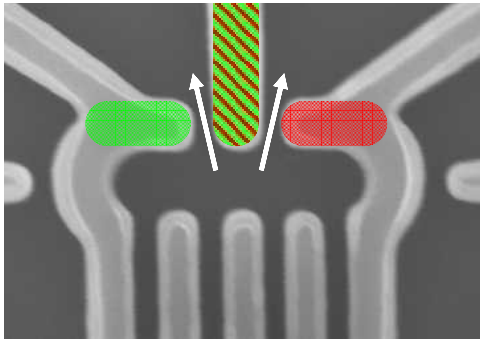




Top Gate Voltage: 8V

Constriction Dominated Conduction

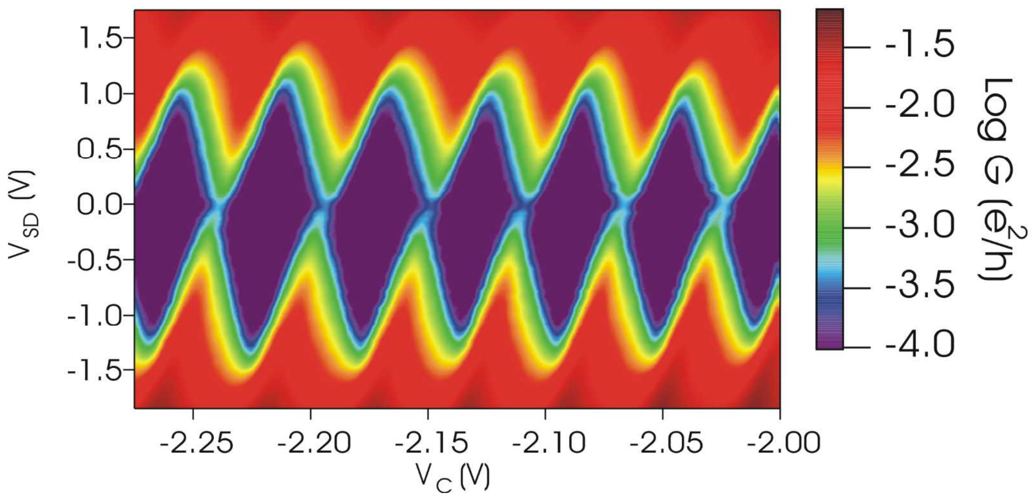


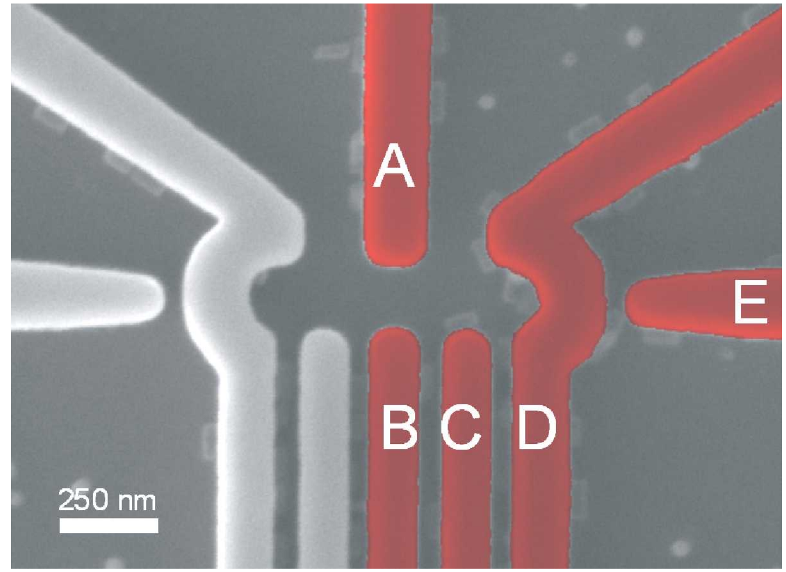


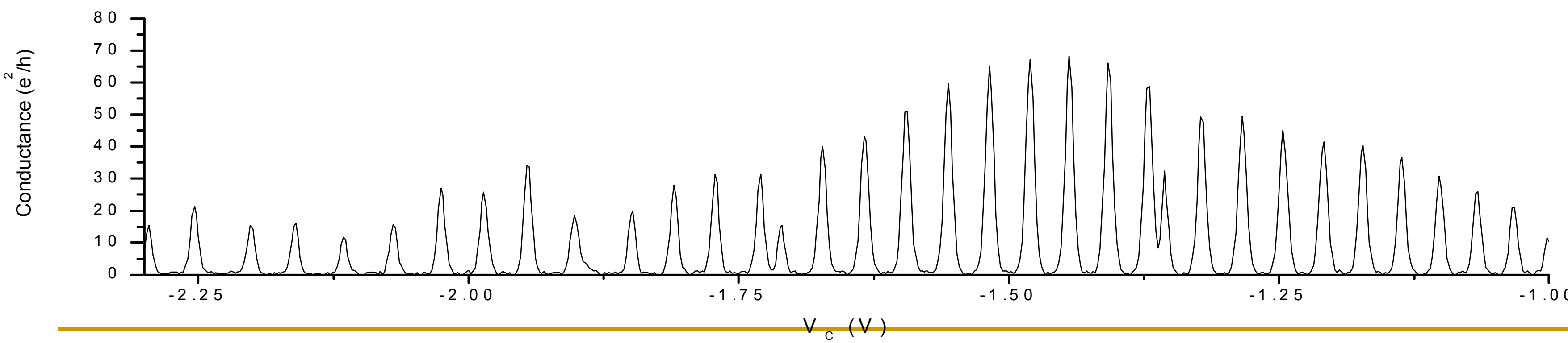
Top Gate Voltage: 25V

Data taken at 300mK

Coulomb Blockade within a Lateral Non-Collinear Geometry



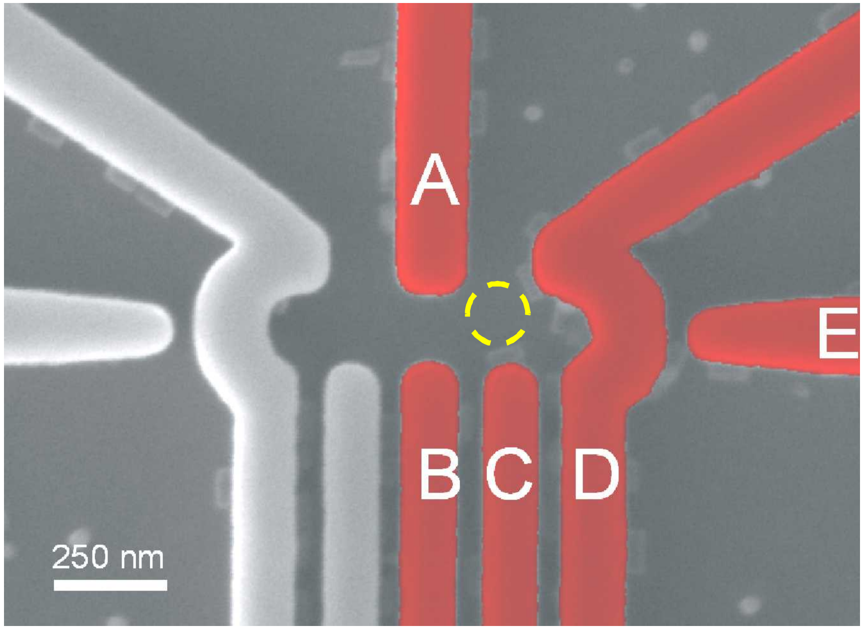




Data taken at 300mK

Quantum Dot Capacitances

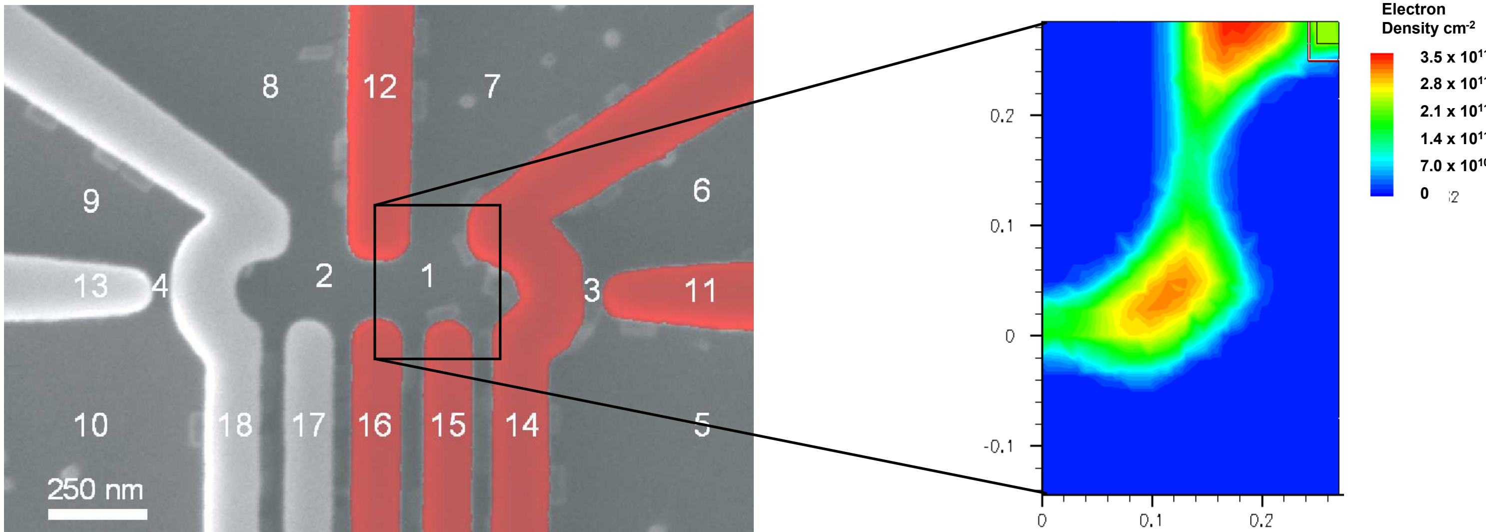
Gate:	C to Dot
Top Gate	14.7 aF
A	6.12 aF
B	3.24 aF
C	3.36aF
D	7.23 aF



- Capacitances can be extracted experimentally by measuring the period of the Coulomb blockade while each gate is swept
- These experimental capacitances can be compared to electrostatic simulations

Device Modeling

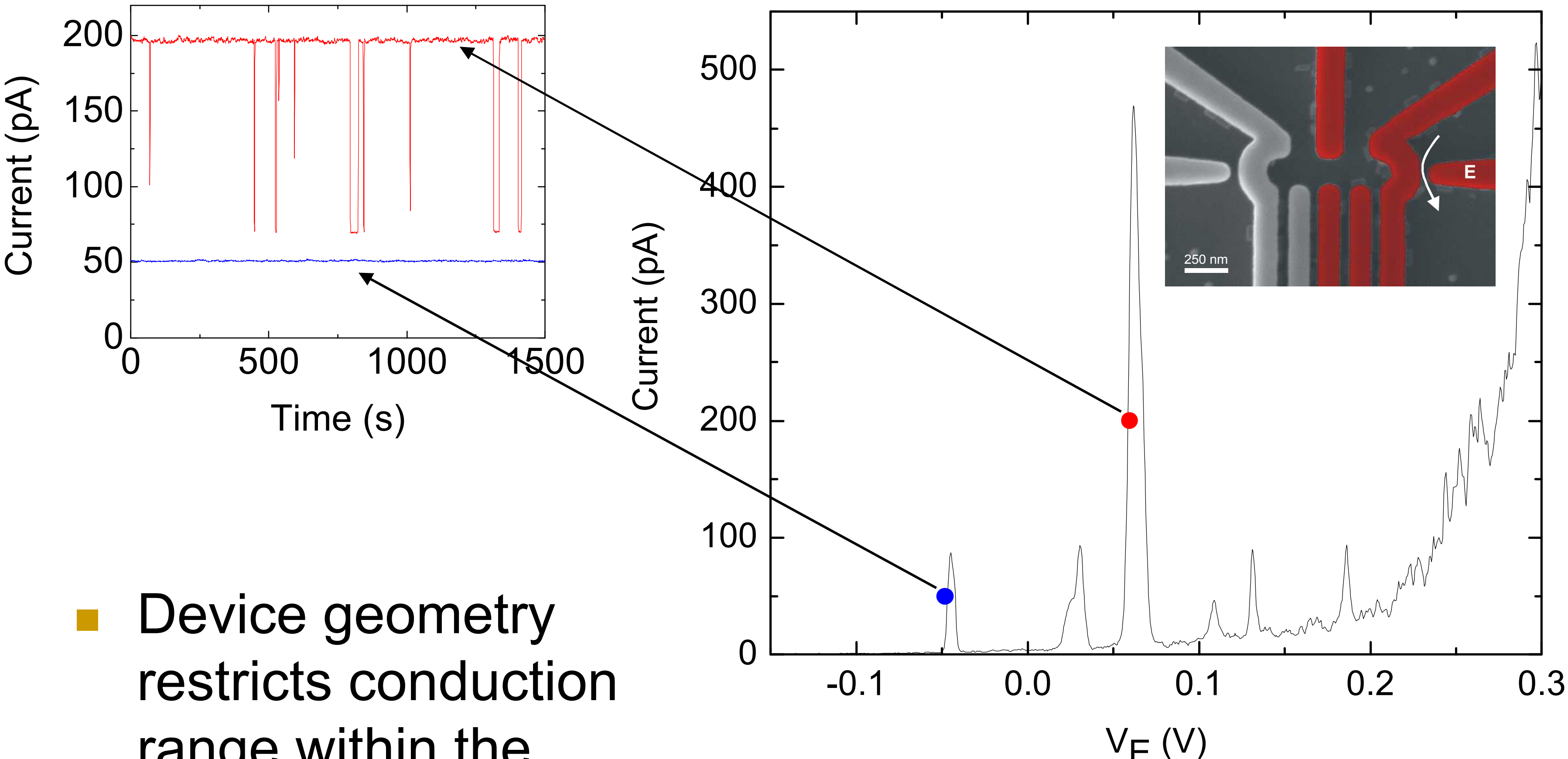
Simulated e⁻ density within QD



Capacitive Matrix:

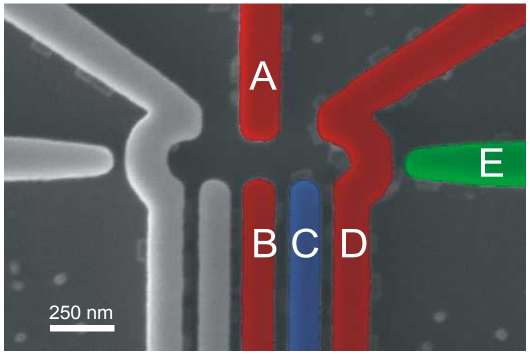
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	73.498	11.488	0.092	0.028	2.805	1.558	14.712	2.698	0.800	1.601	0.295	6.217	0.150	7.186	3.373	3.242	1.050	1.386	14.818
2	11.488	73.421	0.028	0.092	1.608	0.801	2.700	14.475	1.567	2.816	0.150	6.210	0.297	1.391	1.053	3.260	3.379	7.199	14.882
3	0.092	0.028	7.869	0.001	1.649	1.434	0.288	0.077	0.039	0.080	1.305	0.024	0.007	2.014	0.079	0.051	0.028	0.045	0.629
4	0.028	0.092	0.001	7.922	0.080	0.039	0.077	0.288	1.433	1.656	0.007	0.024	1.322	0.045	0.028	0.051	0.079	2.028	0.643
5	2.805	1.608	1.649	0.080	475.201	34.803	10.974	4.918	3.298	7.943	40.337	1.142	0.647	45.041	8.523	5.480	2.935	4.032	298.983
6	1.558	0.801	1.434	0.039	34.803	319.262	22.655	3.507	1.809	3.296	37.377	0.929	0.322	56.828	1.479	1.312	0.869	1.757	148.423
7	14.712	2.700	0.288	0.077	10.974	22.655	290.716	19.226	3.506	4.916	1.951	32.096	0.565	49.103	1.662	1.676	1.195	3.449	120.043
8	2.698	14.475	0.077	0.288	4.918	3.507	19.226	290.588	22.630	10.977	0.565	32.150	1.953	3.457	1.198	1.678	1.661	49.169	119.964
9	0.800	1.567	0.039	1.433	3.298	1.809	3.506	22.630	319.124	34.873	0.322	0.929	37.419	1.758	0.870	1.314	1.479	56.724	148.285
10	1.601	2.816	0.080	1.656	7.943	3.296	4.916	10.977	34.873	475.438	0.646	1.142	40.398	4.030	2.932	5.476	8.506	45.123	299.031
11	0.295	0.150	1.305	0.007	40.337	37.377	1.951	0.565	0.322	0.646	569.446	0.142	0.059	9.174	0.359	0.296	0.186	0.334	475.955
12	6.217	6.210	0.024	0.024	1.142	0.929	32.096	32.150	0.929	1.142	0.142	503.061	0.142	1.470	0.355	0.546	0.354	1.457	417.668
13	0.150	0.297	0.007	1.322	0.647	0.322	0.565	1.953	37.419	40.398	0.059	0.142	569.012	0.335	0.187	0.297	0.360	9.155	475.446
14	7.186	1.391	2.014	0.045	45.041	56.828	49.103	3.457	1.758	4.030	9.174	1.470	0.335	1350.500	110.369	4.914	1.980	2.398	1049.083
15	3.373	1.053	0.079	0.028	8.523	1.479	1.662	1.198	0.870	2.932	0.359	0.355	0.187	110.369	365.775	94.507	2.782	1.976	134.150
16	3.242	3.260	0.051	0.051	5.480	1.312	1.676	1.678	1.314	5.476	0.296	0.546	0.297	4.914	94.507	381.870	94.478	4.905	158.447
17	1.050	3.379	0.028	0.079	2.935	0.869	1.195	1.661	1.479	8.506	0.186	0.354	0.360	1.980	2.782	94.478	365.298	110.398	133.618
18	1.386	7.199	0.045	2.028	4.032	1.757	3.449	49.169	56.724	45.123	0.334	1.457	9.155	2.398	1.976	4.905	110.398	1351.939	1050.347
19	14.818	14.882	0.629	0.643	298.983	148.423	120.043	119.964	148.285	299.031	475.955	417.668	475.446	1049.083	134.150	158.447	133.618	1050.347	5060.414

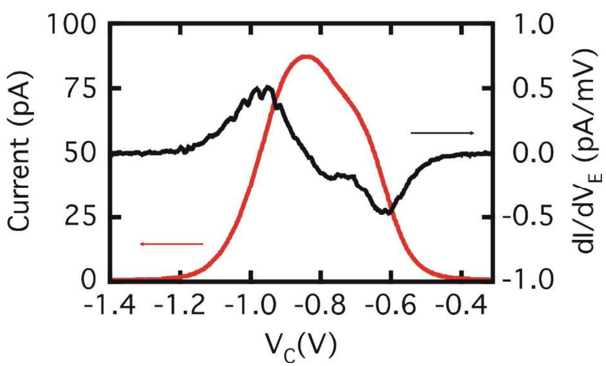
Charge Sense Channel Characteristics

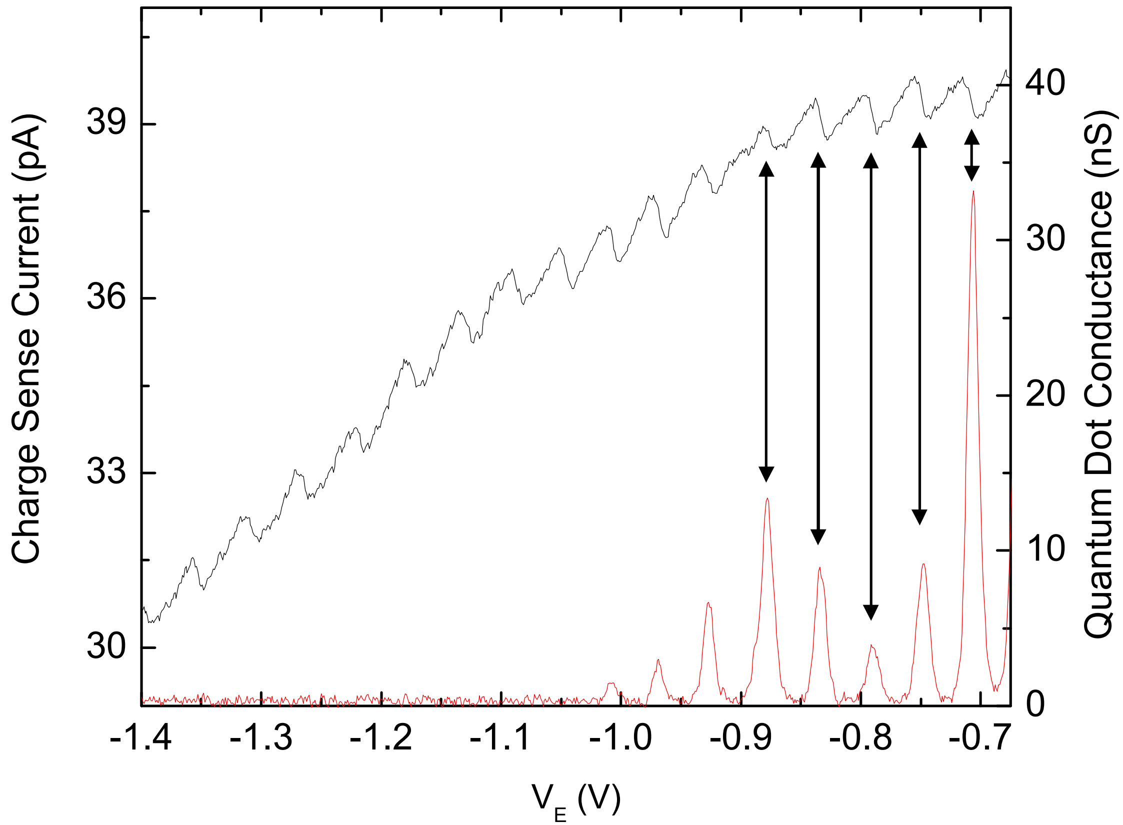


- Device geometry restricts conduction range within the charge sensor

Compensated Charge Sensing







- As V_C ramps from -0.7 V to -1.4 V, V_E is smoothly ramped from -50.57mV to -42.46mV.

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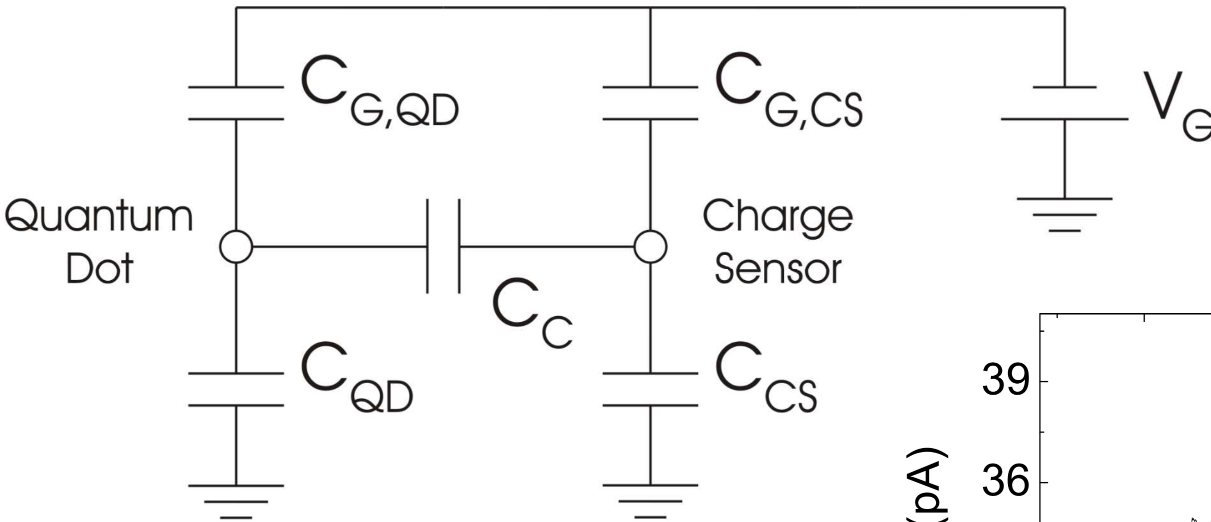
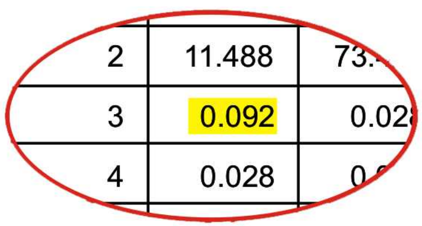
Capacitive Model – Expected Results

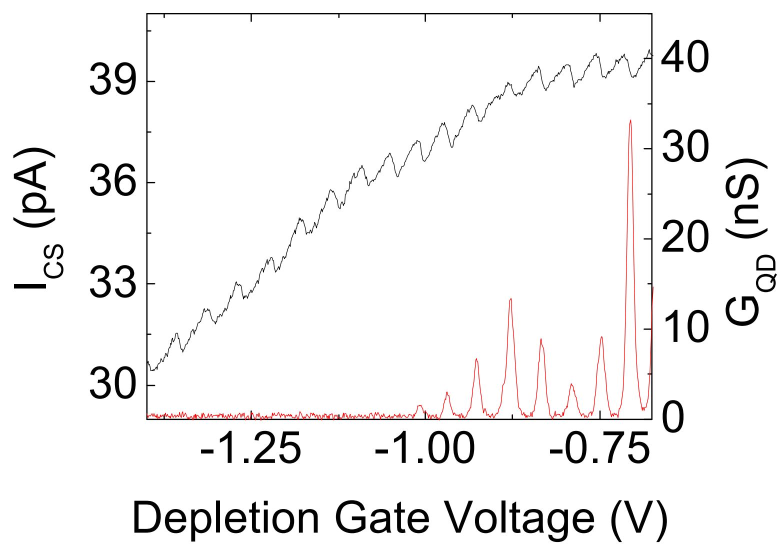


Experiment:
C_C = 0.09 ± 0.01 aF

Capacitive Model:
C_C = 0.092 aF

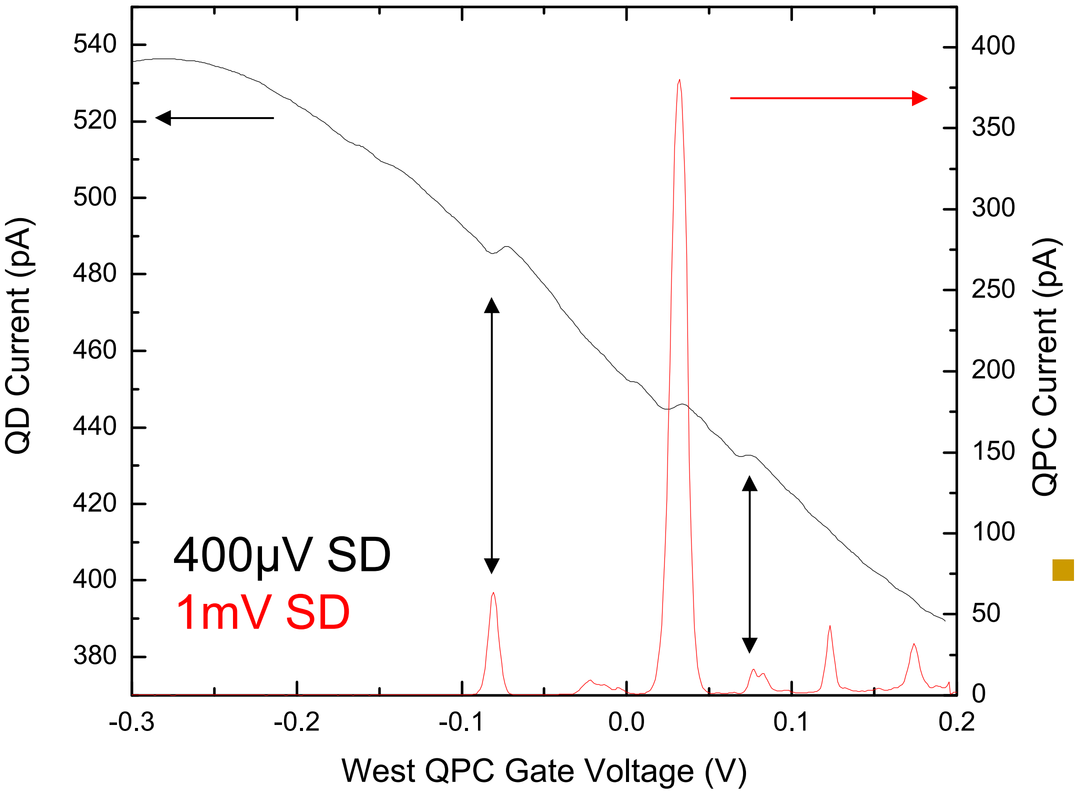


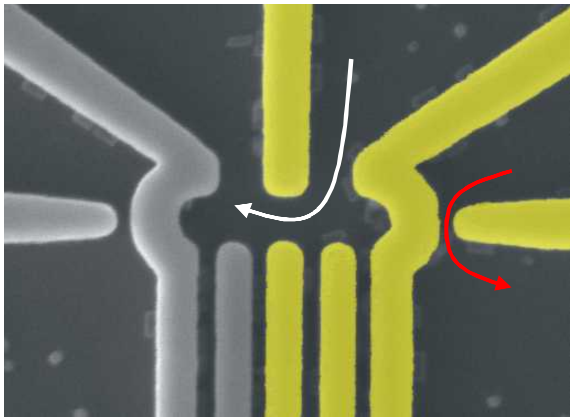
2	11.488	73.4
3	0.092	0.02
4	0.028	0.0



- Using measured gate capacitances, the charge sense signal magnitude, and dI/dV_G, C_C can be found experimentally
- Confidence exists that we can predict the magnitude of a charge sense signal in similar geometries with a capacitive simulation

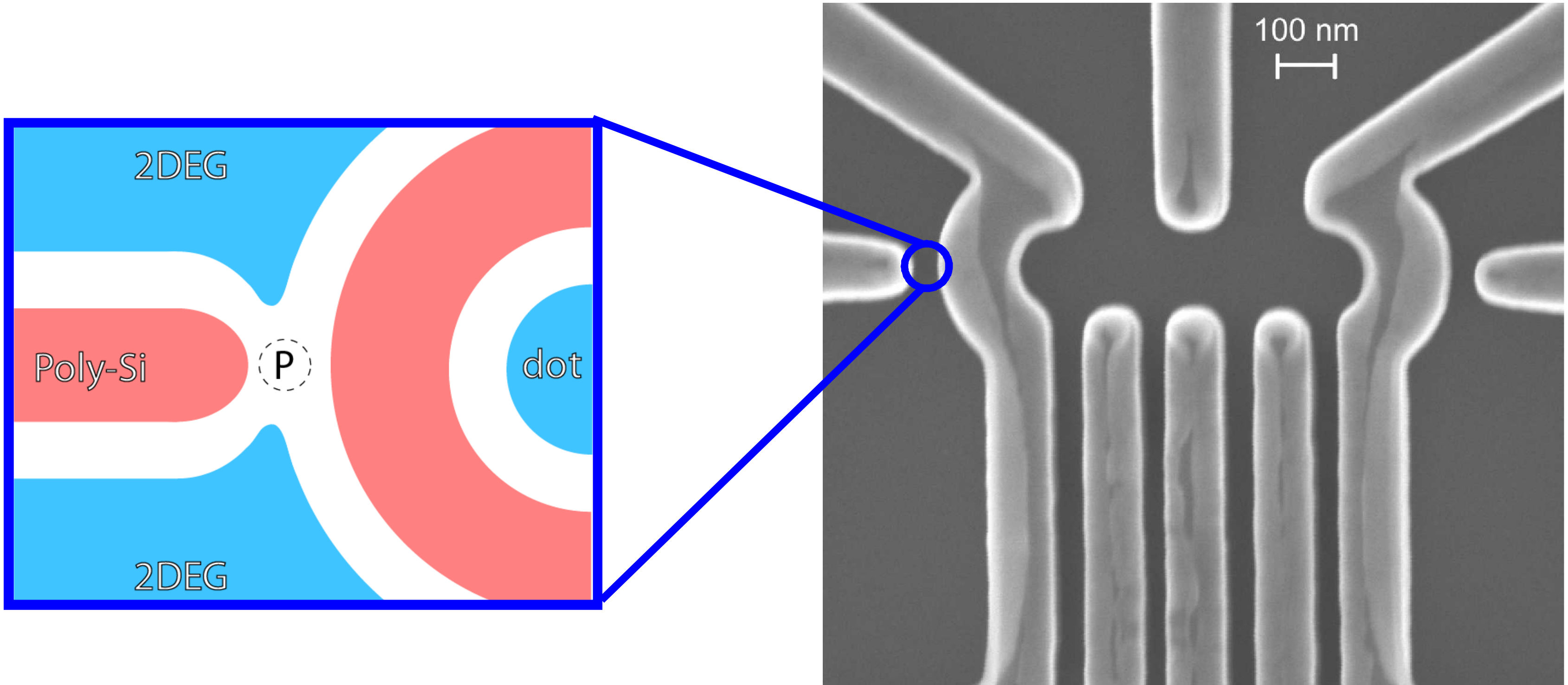
"Reverse" Charge Sensing





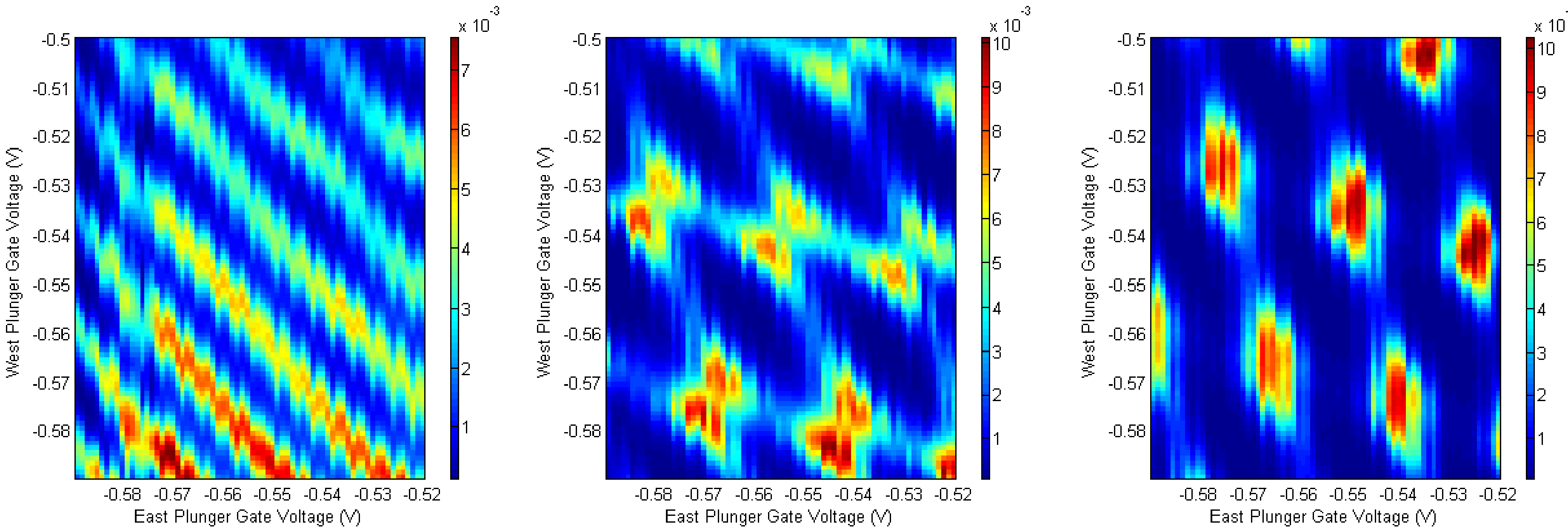
- While monitoring conduction through the main dot, current shifts are observed corresponding to charge transitions in the external constriction

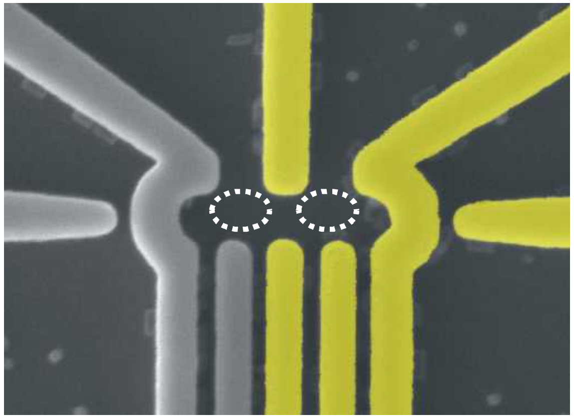
Donor Integration



- “Reverse” charge-sensing mimics a system where the occupation of a donor is monitored by a neighboring quantum dot

Double Dot





- Double-dots formed with single dots created on both sides of the device with variable coupling

Summary

- Stable, repeatable Coulomb blockade observed within a non-linear, tunable, Si-MOS structure with the possibility of donor integration
- Integrated, high visibility, charge sensing shown
- Capacitance simulations consistent with expected dot geometry, and observed charge sense signal
- “Reverse” charge sensing shows quantum dots of this geometry are sensitive to donor-like electrostatic fluctuations