Characterization of a lateral double quantum dot in a silicon MOS device

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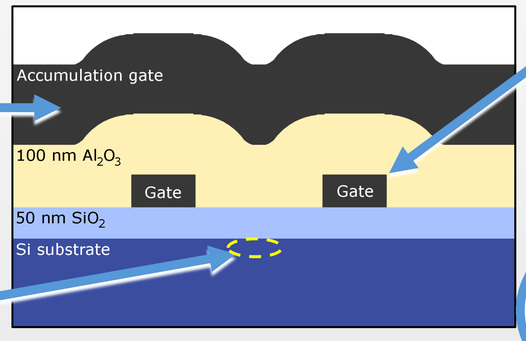
Background

- Over the past two years we have been investigating quantum dots (QD) formed by depletion gates in silicon MOS structures [Xiao, *et al.*, PRL **104**, 096801 (2010); Xiao *et al.*, APL **97**, 032103 (2010)].
- Our present effort, in collaboration with Irfan Siddiqi's group at UC Berkeley, is to couple two states of a silicon double quantum dot (DQD) charge qubit to a microwave co-planar stripline resonator. Working towards that goal we have fabricated a DQD device and are in the early stages of evaluating its performance as a charge qubit (in terms of controllability, coherence).

Device design

Schematic device cross-section



Positive voltage applied to the "top" gate forms a global 2D accumulation layer of electrons at the Si-SiO_2 interface.

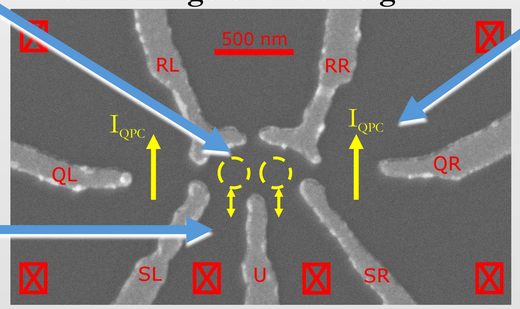
"Side" gates patterned in the middle layer are held at lower voltages to deplete the 2DEG locally.

Quantum dot(s) are formed where electrons may sit in potential wells between depletion gates.

Point-contact-like channels on each side are used as charge sensors: their conductance is changed by the presence of DQD electrons.

Electrons may tunnel to/from the dots into the 2DEG spaces (leads) between the SL, U, and SR gates

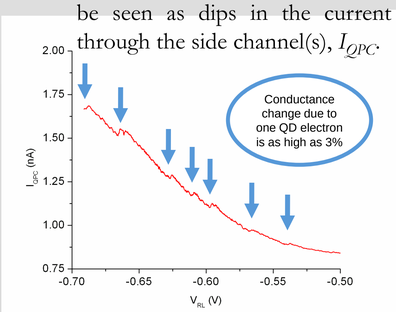
SEM image of the side gates



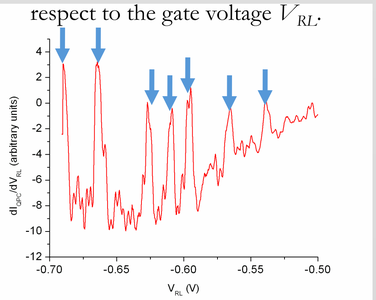
- Gates RL and RR are designed to control the chemical potential of each QD.
- SL, U, and SR control the tunnel coupling between dots and external leads.
- QL and QR tune the sensitivity of the charge sensing channels.

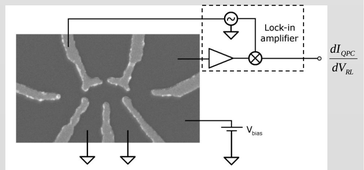
Charge sensing method

Changes in the number of electrons on the quantum dot can be seen as dips in the current through the side channel(s), I_{QPC}.



The transitions are clearer if we plot the derivative of the current with respect to the gate voltage V_{RL}.

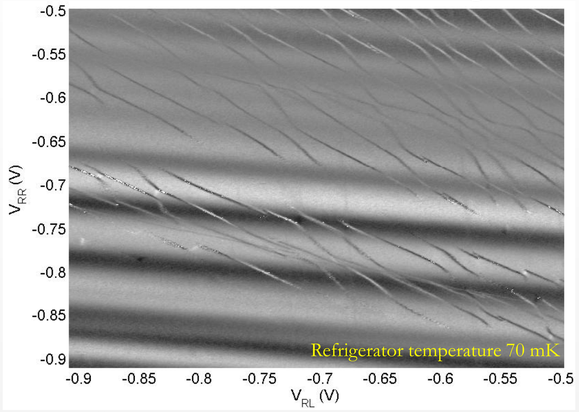




We can measure the charge sensor current differentially by applying a small oscillating voltage to gate RL and monitoring I_{QPC} with a lock-in amplifier. The output signal is proportional to dI_{QPC}/dV_{RL}.

Preliminary results

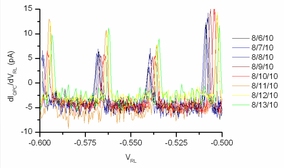
Charge stability diagram



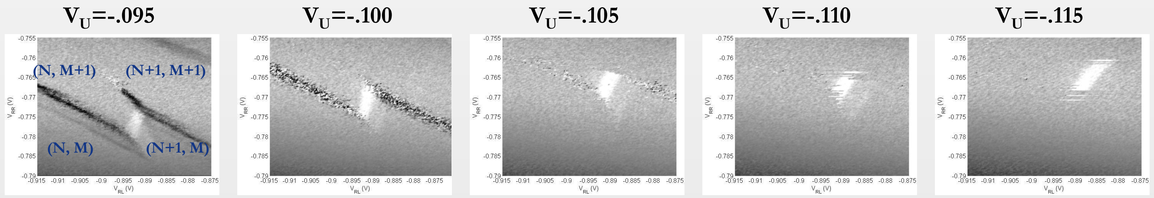
Differential conductance of the right charge sensor channel as a function of the voltages on gates RL and RR.

- Broad, nearly horizontal features are fluctuations in the conductance of the charge sensor itself; the narrower diagonal lines indicate changes in the DQD configuration.
- This diagram shows the evolution of the system from a single large QD or strongly coupled DQD (upper right) to a weakly coupled DQD (mid-lower left), to where the tunnel barriers with the leads close off (lower left).
- In the lower-left, inter-dot electron transitions are visible even when the external tunnel barriers are closed.

The system has a small drift of <2 mV per day, no long-term instability seen.

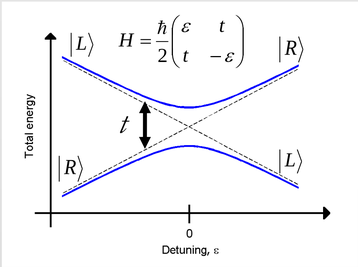


Tuning tunnel barriers to isolate the DQD



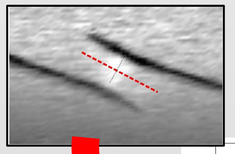
As the voltage on gate U is made more negative, the transition lines that indicate electron transfers between the DQD and the leads disappear, indicating that the DQD becomes (nearly) isolated from the leads. The inter-dot transition remains visible.

DQD as a charge qubit



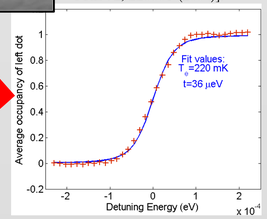
- Such a qubit in silicon may have T_2 coherence time as long as 220 ns [Gorman, *et al.*, PRL **95**, 090502 (2005)].

- The DQD can be operated as a highly tunable "charge" qubit, near a point where one electron transitions between dots. The two qubit states $|L\rangle$ and $|R\rangle$ correspond to the extra electron being localized on the left dot or on the right dot.
- Qubit Hamiltonian parameters can be controlled by voltages on the side gates: the detuning energy ε is mainly influenced by gates RL and RR; the inter-dot coupling energy t is influenced by gate U. The states $|L\rangle$ and $|R\rangle$ can be read out by the charge sensor.



The tunnel coupling t can be estimated from the shape of the inter-dot transition line: the broader the line, the stronger the coupling [following DiCarlo *et al.*, PRL 92, 226801 (2004)].

We can readily tune t to a value of 24 μeV for coupling to a 6 GHz microwave resonator.



Conclusions and outlook

- The device we have constructed forms a tunable double quantum dot system with integrated charge sensing channels.
- These early results are promising for our efforts to couple the DQD to a microwave resonator. Work is ongoing to fully understand the DQD behavior in this device.