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Characterization of a Several Antimony Donor-SET System in Silicon

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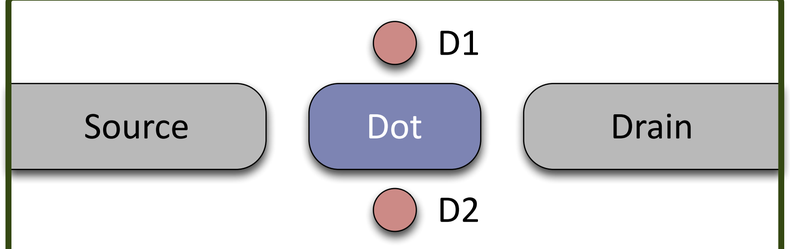
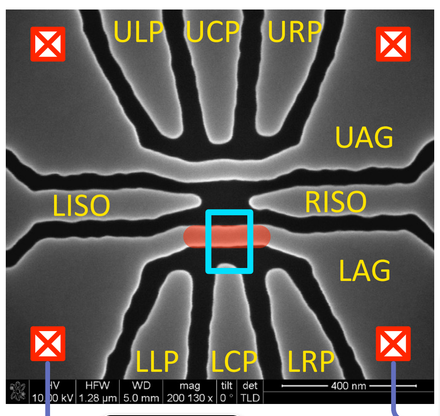
1. Motivation



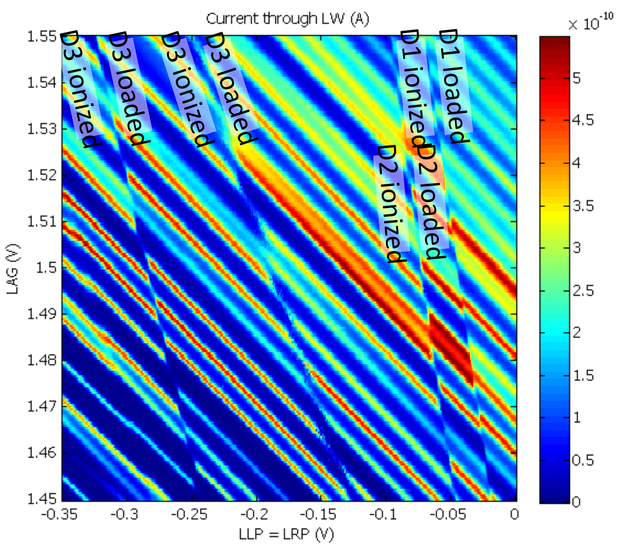
We are interested in controlling the interactions of electrons on two donors through a quantum dot. As a first step towards this goal, we are characterizing devices with many implants.

2. Device geometry and measurement setup



- Sample is a natural Si substrate with polysilicon gates.
- 35 nm Si oxide isolates the gates from the substrate.
- Sample is cooled in a dilution refrigerator to 26 mK.
- Ohmic contacts are represented by red squares.
- Dot position is highlighted in orange.
- The Sb implant window is defined by the blue square.
- There are donors implanted on either side of the lower wire (LW), but none near the upper wire (UW).
- Most measurements shown are low frequency (~130 Hz) transport measurements through the LW quantum dot.

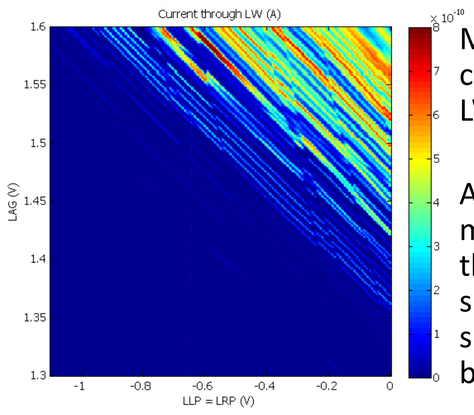
3. Detecting offsets



Ionizing a donor causes a change in the electric field felt by the LW dot. This can be observed by the shift in the LW Coulomb blockade lines. This shift is called an "offset".

4. Charge sensing

Transport measurement:



Measure the AC current through the LW.

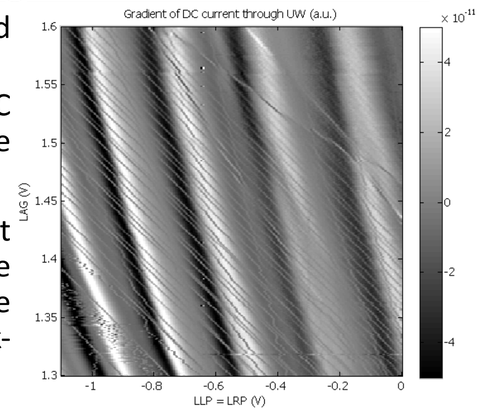
A charge sensing measurement using the UW as a charge sensor is taken simultaneously (see below).

Charge sensed measurement:

50µV DC is applied on UW source.

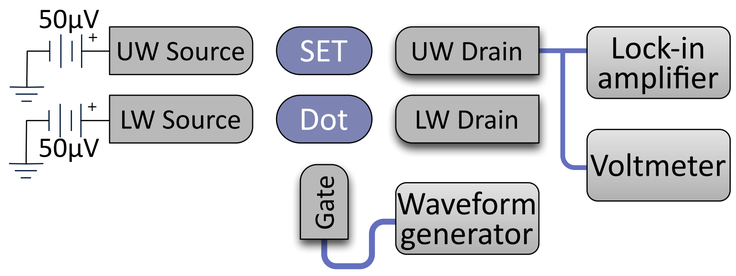
Measure the DC current through the UW.

The wide lines that are visible in the background are the UW Coulomb blockade peaks.

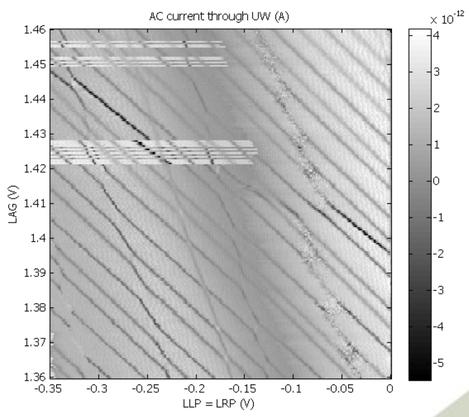


When the LW tunnel barriers become too opaque for transport measurements to be taken (see the lower left corner of the transport measurement), electron tunnelling events between the leads and the dot as well as between the dot and the donors can still be observed with the charge sensor.

Adaptive charge sensing:



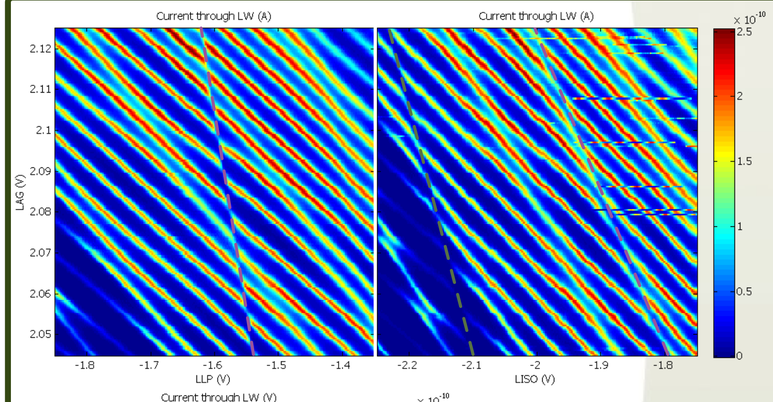
- Before each data point is taken, the DC current through the UW is measured to make sure that the charge sensor is in a region of high sensitivity (on the edge of a CB peak).
- If the UW has shifted away from its region of high sensitivity, the UW gates are adjusted.
- Once the UW is properly adjusted, the AC current through the UW is measured.

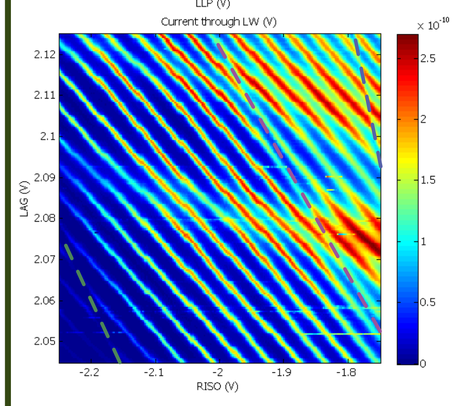


The plot to the left was taken using adaptive charge sensing.

Several donor offset lines are clearly visible.

5. Attempts at donor position triangulation

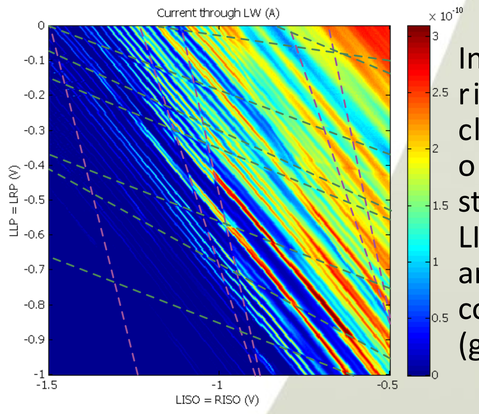




In all three plots, the offset traced in purple is caused by the same donor. It is clear that the slope of this offset depends on which pairs of gates are swept.

The slope of a donor offset is related to the ratio of the capacitances of the donor to the two gates that are swept. Measuring this ratio for different pairs of gates may allow triangulation of the donor's position.

In the example shown above, the purple offset is most likely situated below the LW and slightly to the left of LCP.



In the plot to the right, there are clearly 2 sets of offsets: Those strongly coupled to LISO=RISO (purple) and those strongly coupled to LLP=LRP (green).

It is safe to assume that the former are those implanted above the LW and the latter are implanted below it.

Work is currently underway to use capacitance ratios extracted from similar data to determine the position of the donors with higher precision.

6. Future goals

- Measure the tunnelling times of different offsets.
- Reach the low electron regime in the LW dot while staying in a parameter region where offsets are visible.
- Implement pulsing experiments where electrons from donors implanted above and below the LW can tunnel onto the dot. Show that interaction between the donors' electrons can be obtained using this scheme.
- Characterize the interaction between the electrons situated on two separate donors.

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