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Electrical transport in dual-gate PN-junction nanowires

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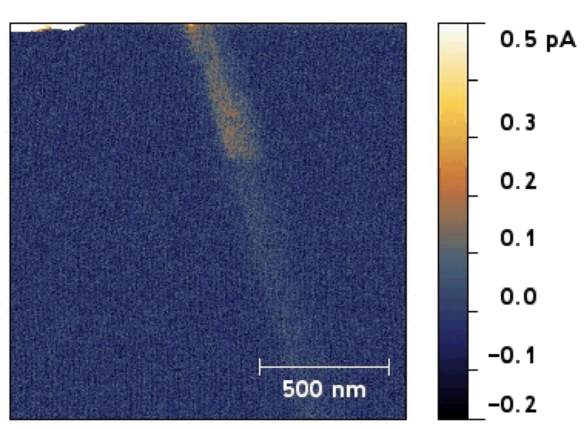
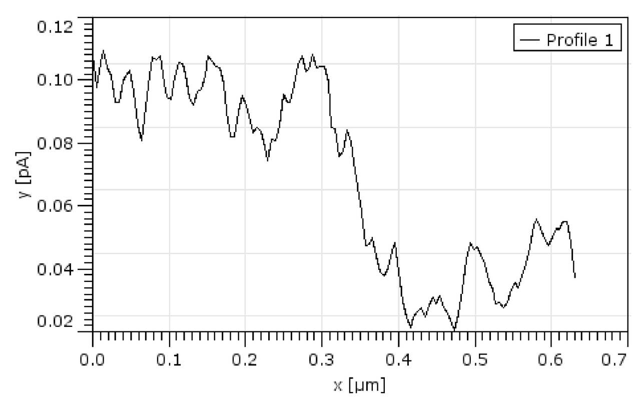
Axial Junction PN Nanowires

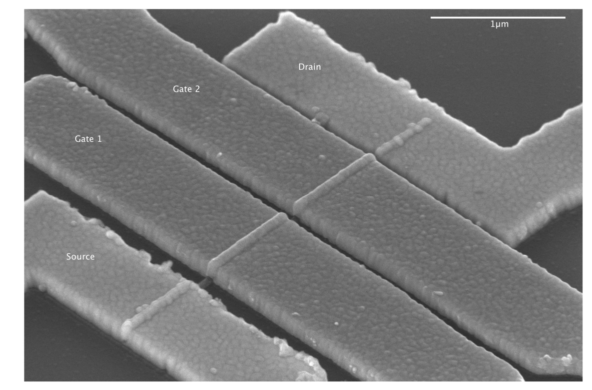
Silicon-Germanium alloy nanowires with an axial PN junction doping profile were placed onto substrates using a nanomanipulator tool. Observation of rectifying behavior in the electrical I-V measurements verify the presence of a PN junction. Using conductive-AFM, the location of the junction along the nanowire can be located.

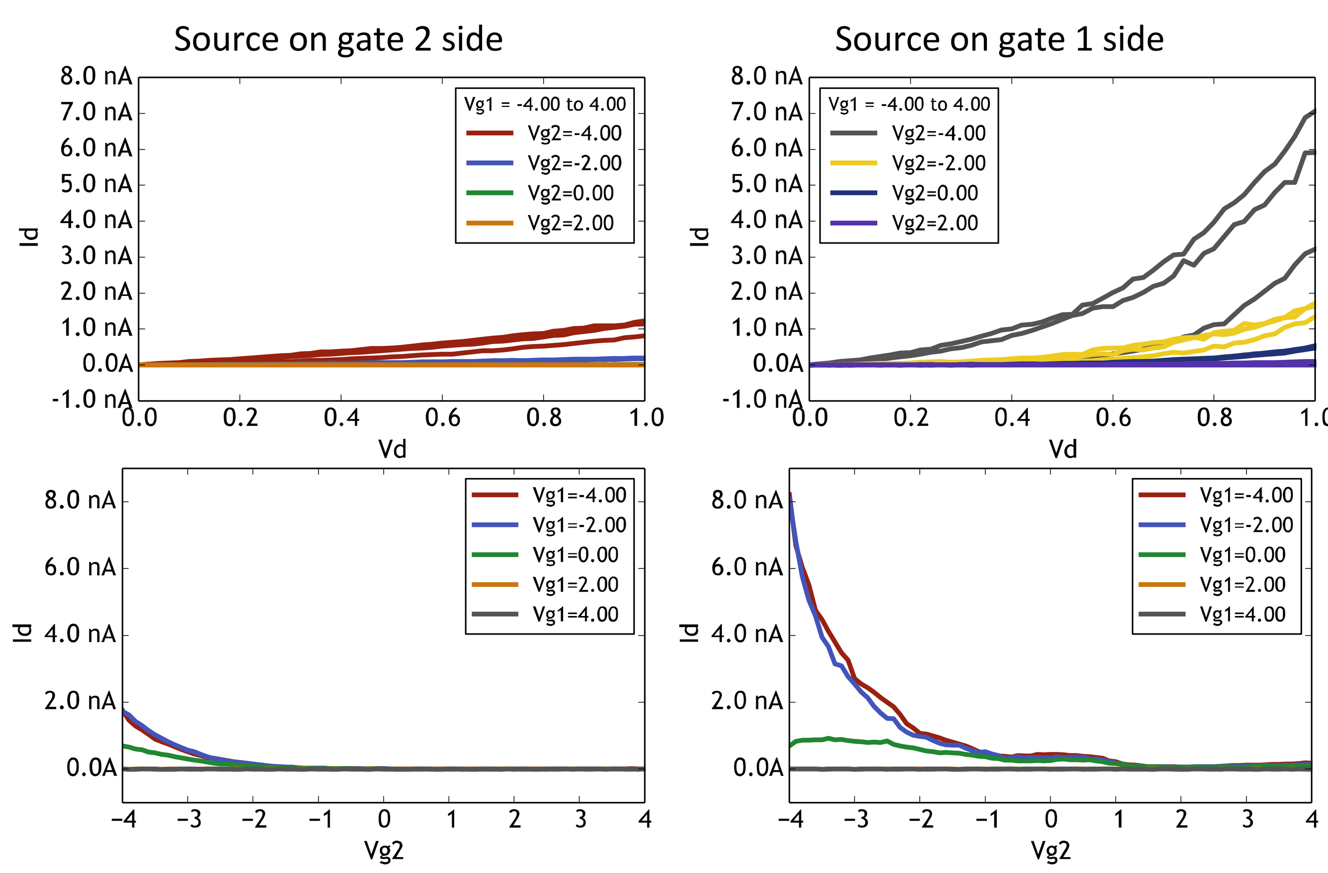




Dual Top-gate devices

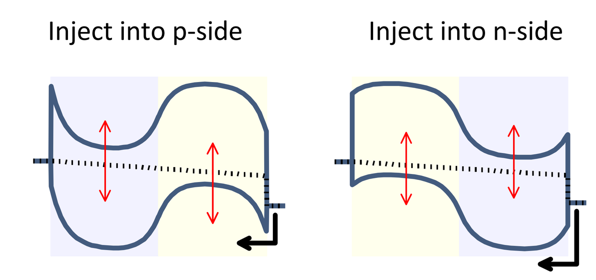
- 2 micron source-drain spacing
- Two independent gates, for N-side and P-side
- 10nm Al_2O_3 gate dielectric
- Asymmetric behavior





Qualitative Device Behavior

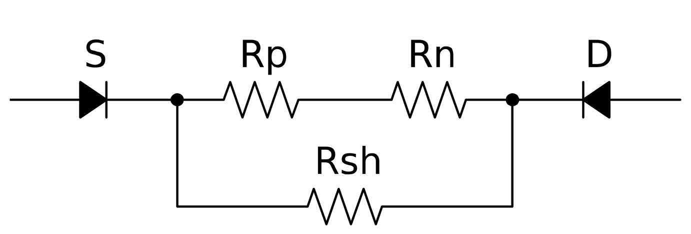
While the structure may look like an ordinary PN-diode, the contacts are not heavily or selectively doped and therefore form Schottky barriers limiting charge injection into the channel. Reversing the polarity of the device leads to asymmetric behavior in large part due to the relative difficulty of injecting holes into n-type or p-type nanowire. The line-up of the metal Fermi level near the valence bands determines that holes are the dominant charge carrier.

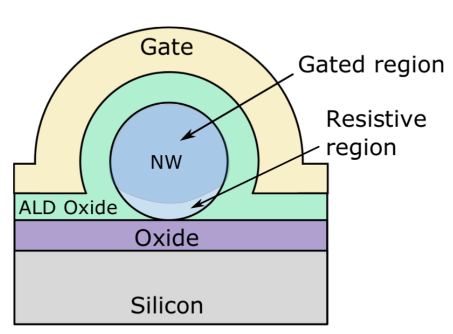


These band diagrams also reveal why the current saturates when sweeping the opposite gate voltage. Current becomes limited by the injection from the contact, so the opposite gate cannot increase the current any further. Both gates need to be enabled to get significant current levels.

Simple Model

The devices can be approximated using a simple model consisting of a Schottky diode in series with two channel resistances, one for the n-side and one for the p-side. A non-gated shunt resistance is included to account for the portion of the wire which is not well controlled by the gates, similar to a DIBL effect.





Resistance of the n- and p- sections of nanowire can be estimated from their charge density at a given gate voltage:

$$n = 2n_o \ln\left[1+\frac{1}{2}\exp\left(\frac{q(V_g - V_{th})}{\eta kT}\right)\right] \qquad R_{ch} = \frac{L_{ch}}{q\mu n W}$$

$$n_0 = \eta k T C_{ox}/2q$$

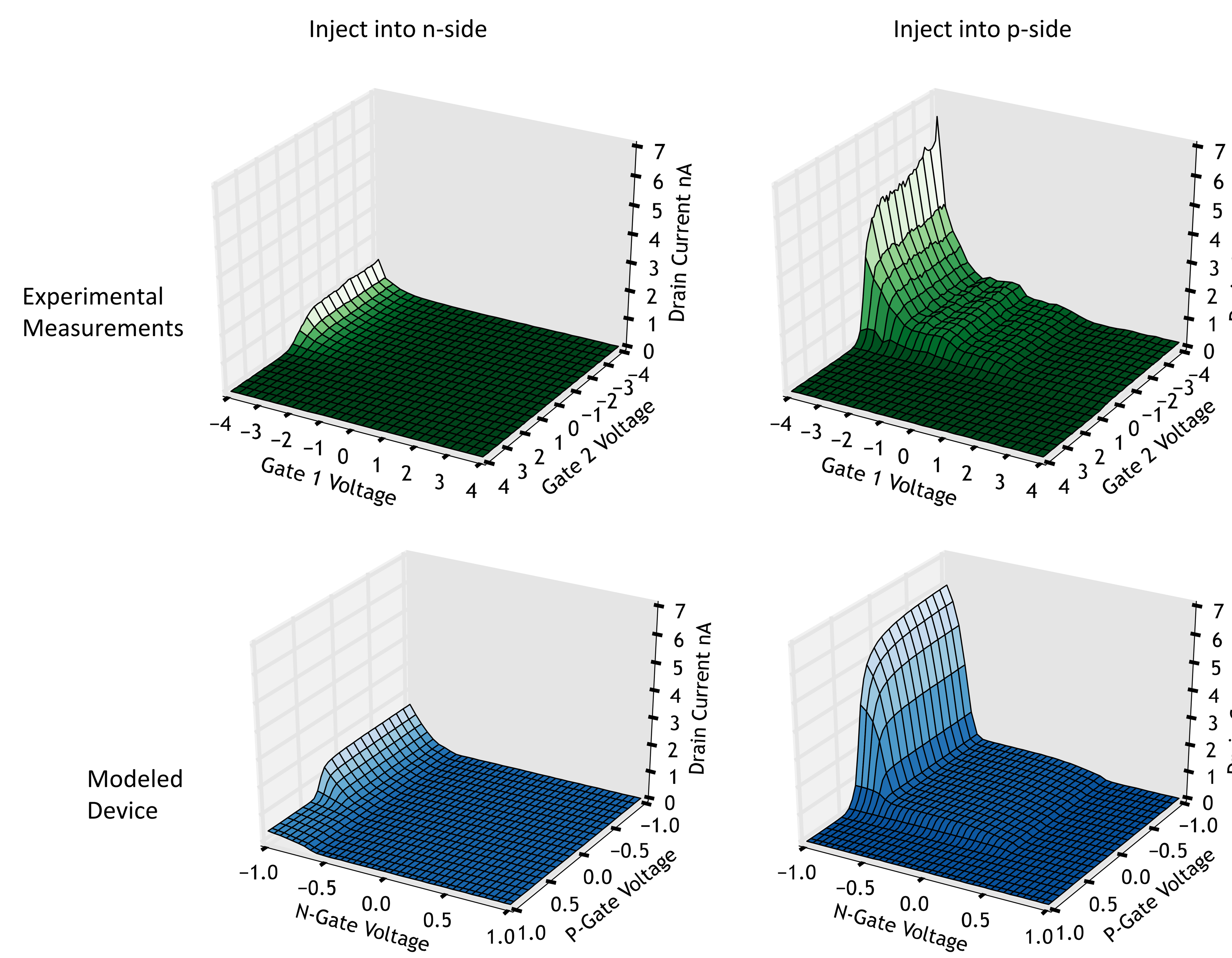
Current through the Schottky contact can be estimated using a WKB tunneling model, where the transmission probability T(E) captures the strength of the contact barrier:

$$J_s = \frac{4\pi m^* q k T}{h^3}\int_0^\infty T(E)(F_s - F_d)\mathrm{d}E$$

Measurements vs. Model

In the model, each channel resistance depends on its respective gate. Additionally, the Schottky barrier resistances depend on the direction of applied bias, whether charge is injected into the n-side or the p-side.

By choosing appropriate model parameters, a good fit between measurements and model can be achieved. The gate voltage ranges appear different due to the capacitive voltage division between oxide capacitance and semiconductor capacitance reducing the potential seen at the channel.



Summary:

- PN Junction verified by CAFM and electrical measurements
- Two independent gates can control the wire
- Behavior understood by band diagrams and SB + Rch model
- Characteristics strongly influenced by charge injection into nanowire from the contacts

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