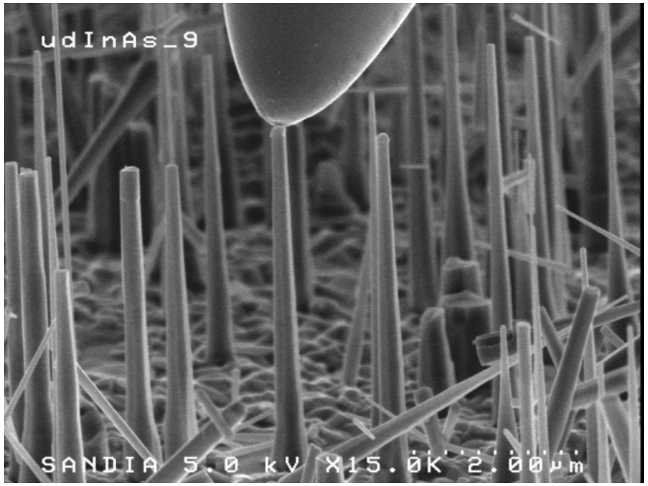
SAND2009-2216C

Extracting Carrier Concentration and Mobility from Space-Charge-Limited Transport in InAs Nanowires



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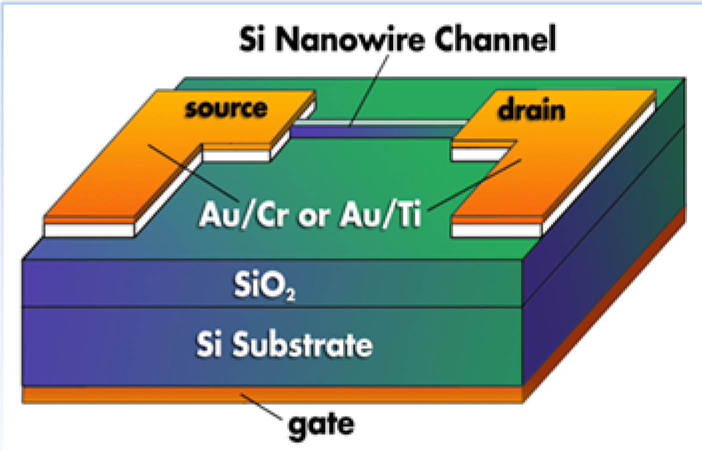
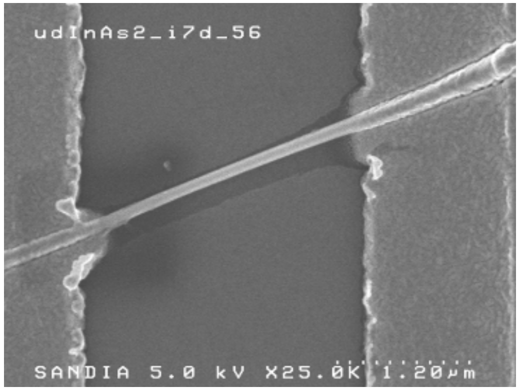
Motivation for Experiments





$$\mu = \frac{L^2}{V_{SD} C}\left(\frac{dI_{SD}}{dV_G}\right) \qquad n = \frac{CV_{TH}}{e}$$

•Fabrication intensive

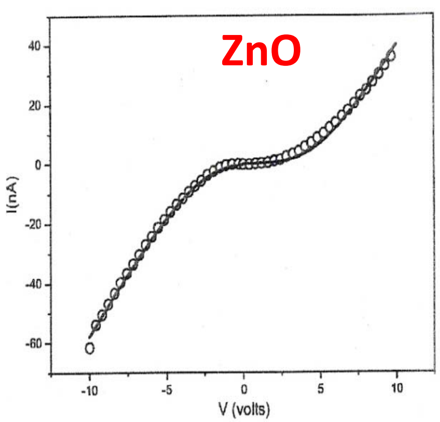
•Surface chemistry affects dI/dVg, source of variability in μ

Space-Charge-Limited Current

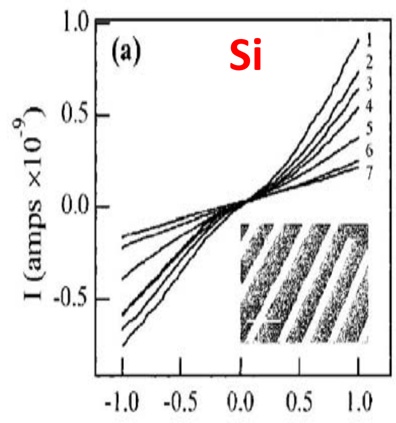
- Occurs when injected charge density exceeds thermal carrier concentration

$$J = \frac{9}{8}\frac{\varepsilon\mu V^2}{L^3}$$ (Mott-Gurney; low aspect ratio)

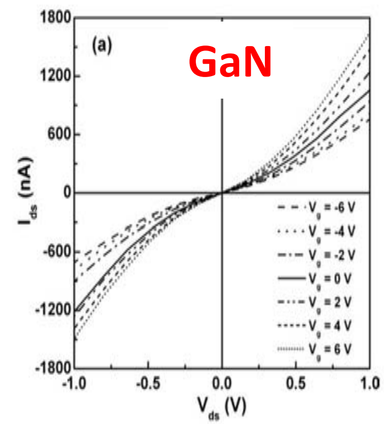
- Accounts for non-linear I-V in many nanowire experiments



Zhang et al, APL

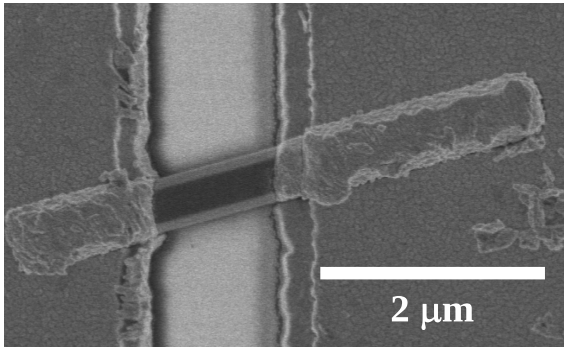


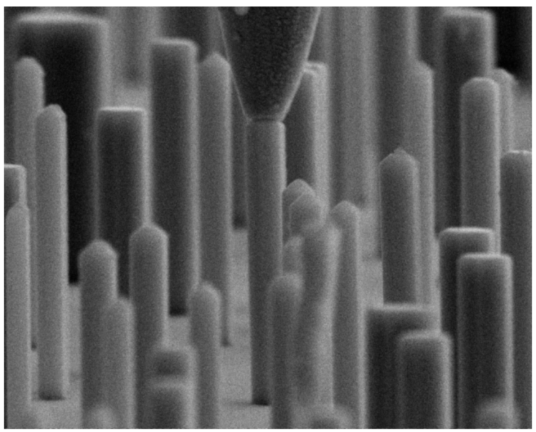
Cui et al, JPC B



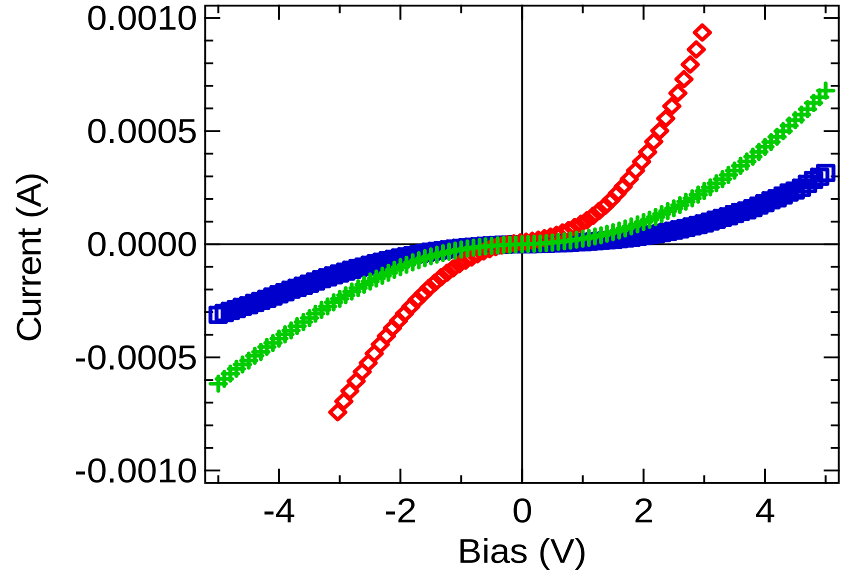
Ham et al, Nanotech.

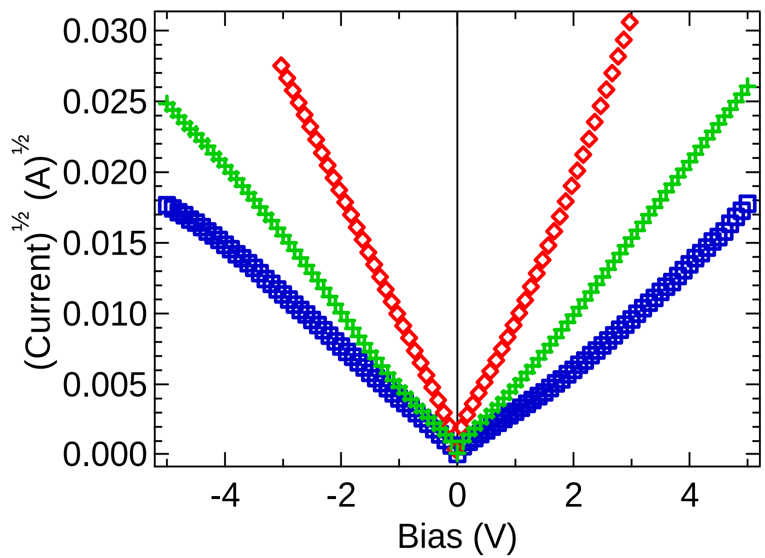
SCLC in NWs





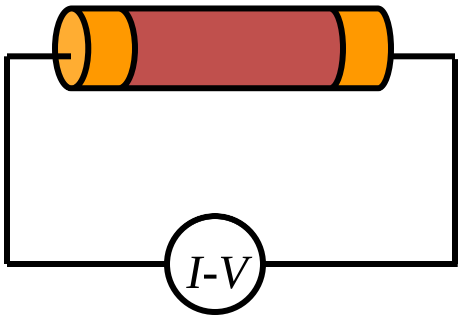
$$J_{nw} \approx J_{bulk}\left(\frac{Radius}{Length}\right)^{-2}$$





A.A. Talin, F. Léonard, B.S. Swartzentruber, X. Wang, S.D Hersee, *P.R.L.* **101**, 076802 (2008).

For nanowires SCLC scaling is I~(R/L)$^{-2}$ × bulk



$$J = \frac{2}{R^2}\int_0^R rj(r)\,dr = \frac{2e\mu}{R^2}\int_0^R rn(z,r)E_z(z,r)dr$$

$$\frac{\partial^2 V}{\partial r^2} + \frac{1}{r}\frac{\partial V}{\partial r} + \frac{\partial^2 V}{\partial z^2} = -\frac{en(z,r)}{\epsilon}$$

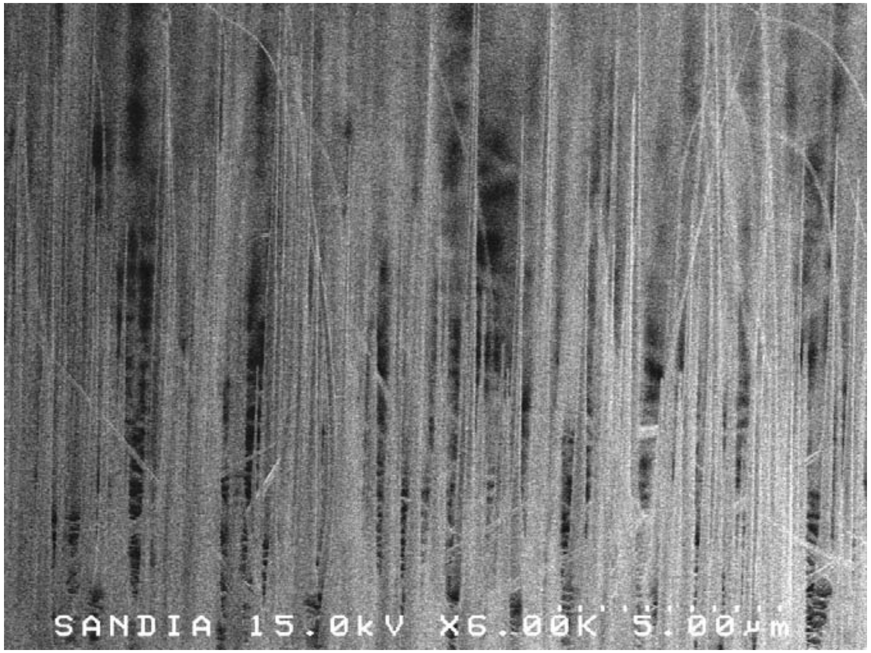
$$I_{sc}(nanowire) = f\left(\frac{R}{L}\right)\frac{A\varepsilon\mu}{L^3}V^2$$

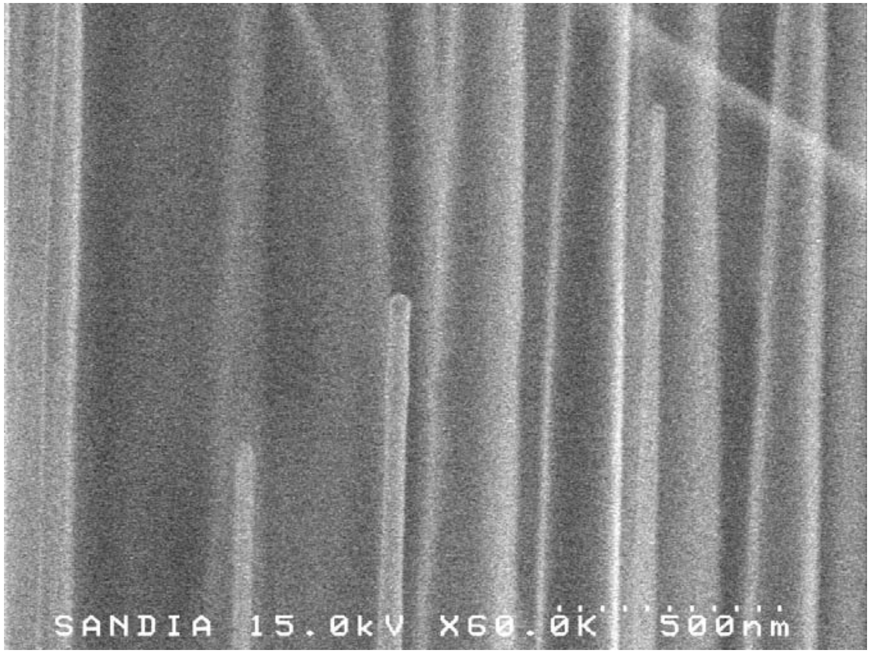
$$f\left(\frac{R}{L}\right) \sim \left(\frac{R}{L}\right)^{-2}$$ **for R/L<<1;** $$f\left(\frac{R}{L}\right) = \frac{9}{8}$$ **for R/L>>1;**

Thin films: Grinberg, Luryi, Pinto, Schryer, IEEE Trans. Electron Devices 1989

Nanowires: Talin, Leonard, Swartzentruber, Wang, Hersee PRL 2008

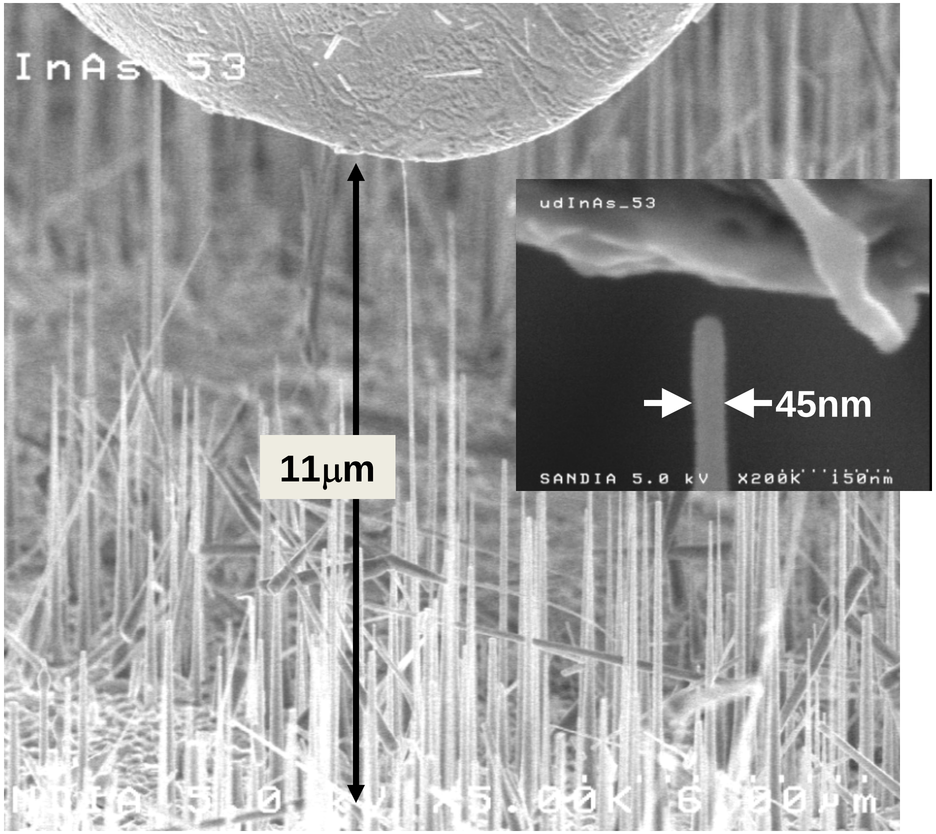
InAs NWs

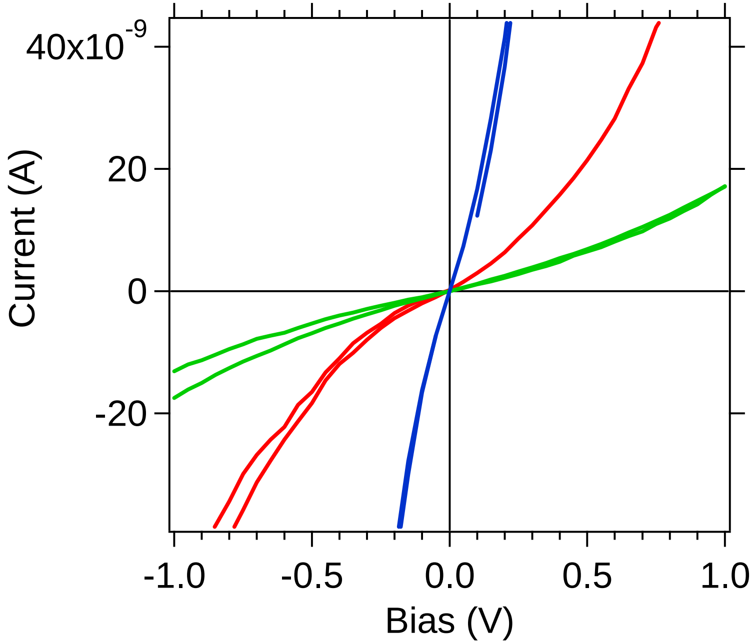




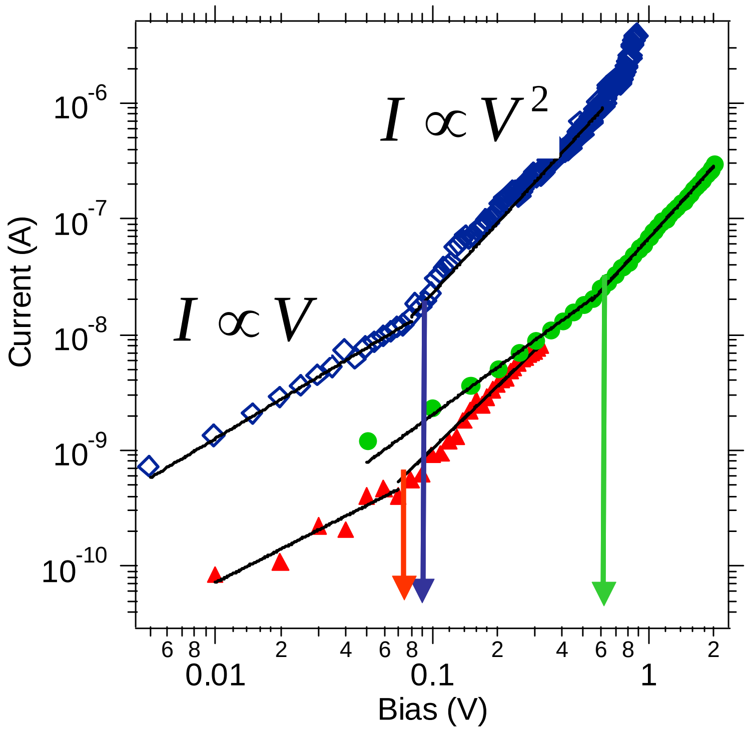
VLS growth, nominally undoped

Space charge limited conduction in InAs Nanowires





At low bias, conduction is Ohmic; from crossover voltage can estimate n

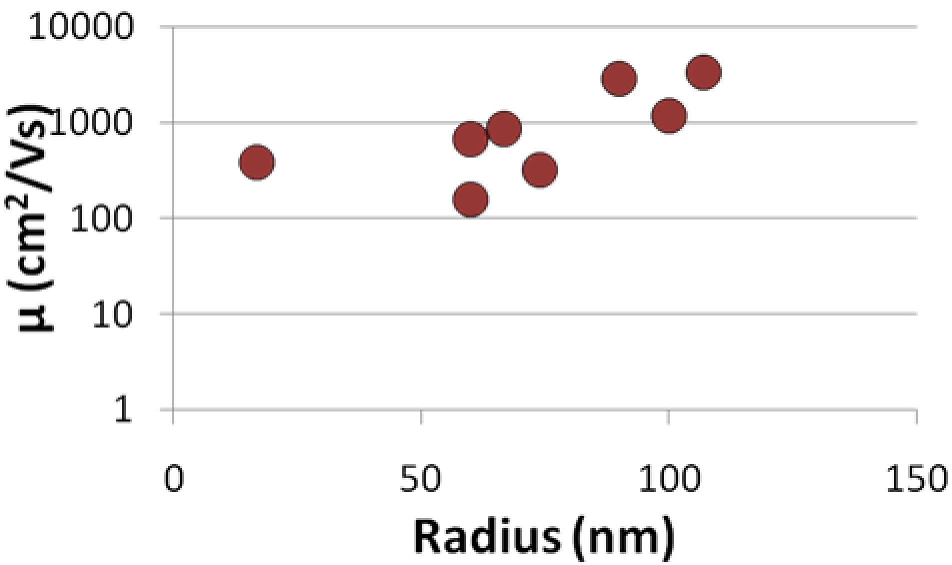


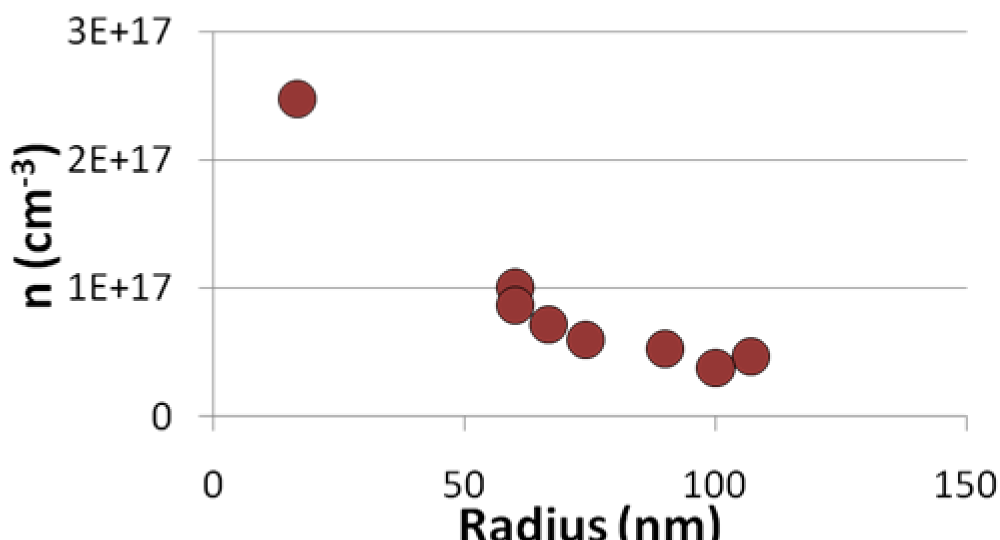
$$J_{Ohmic} = J_{SCLC}$$

$$en\mu \frac{V_c}{L} = \left(\frac{L}{R}\right)^2 \varepsilon\mu \frac{V_c^{\ 2}}{L^3}$$

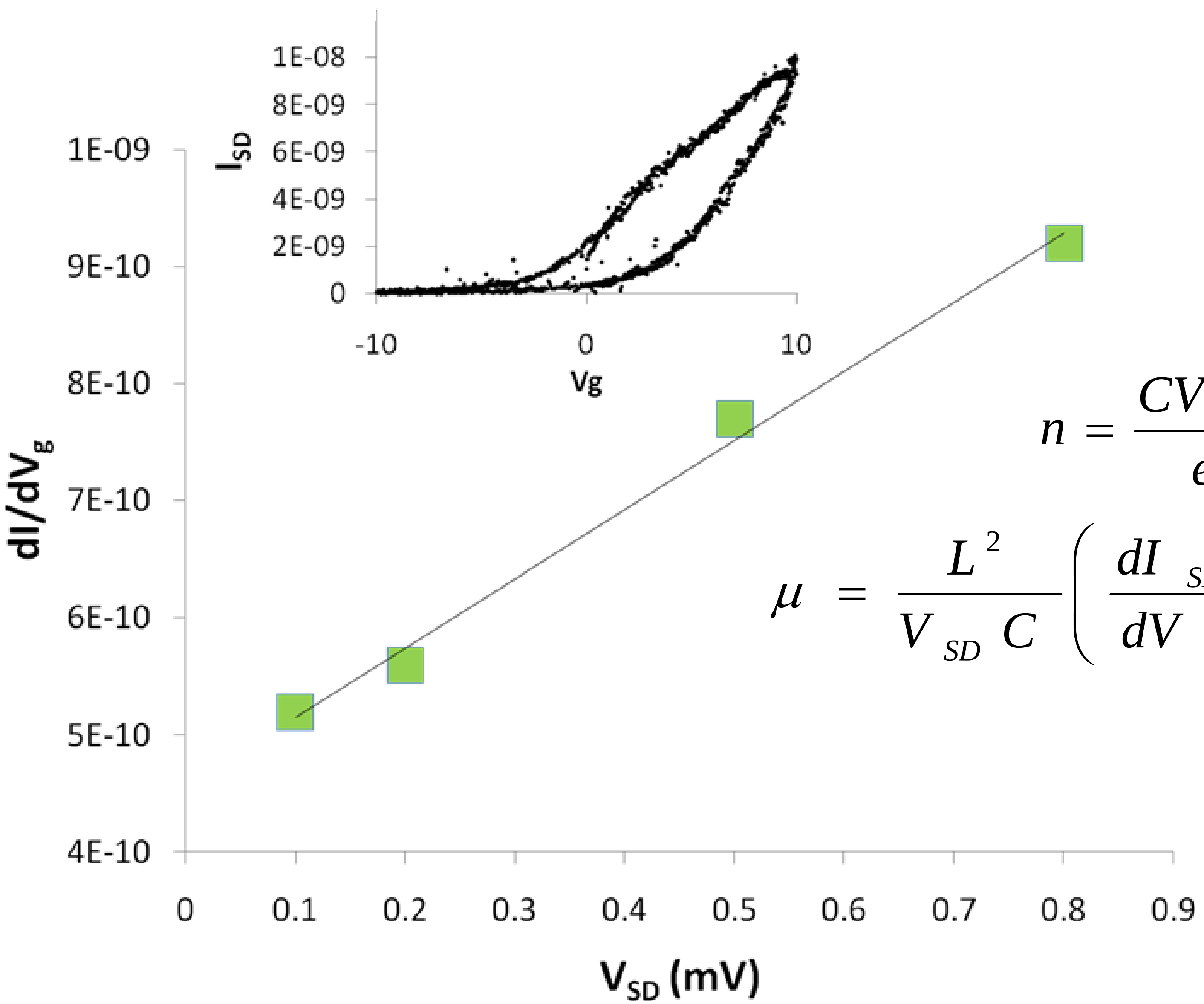
$$n = \frac{\varepsilon V_c}{eR^2}$$

SCLC Characterization Results





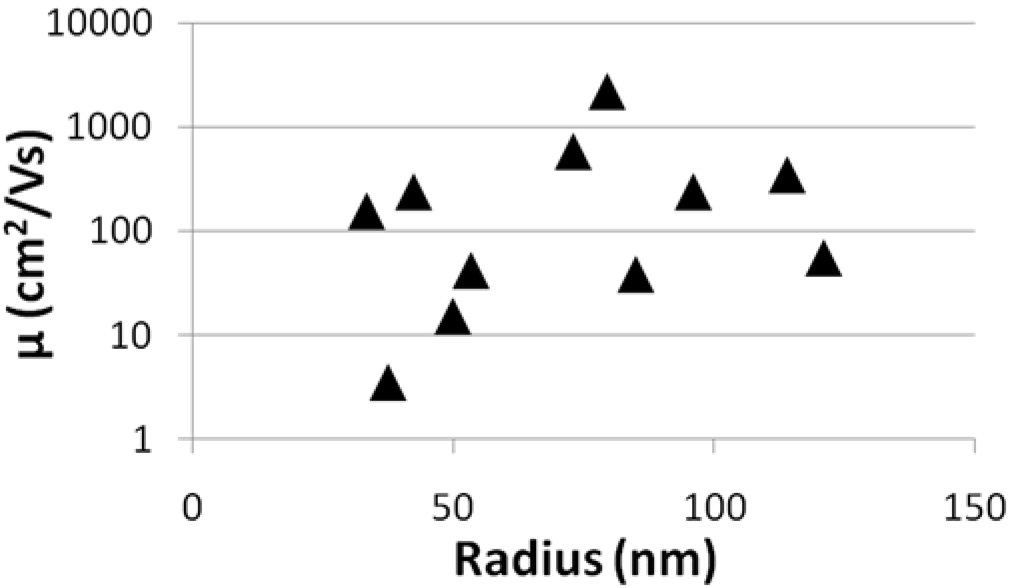
NWFETs – Obtaining μ and *n*

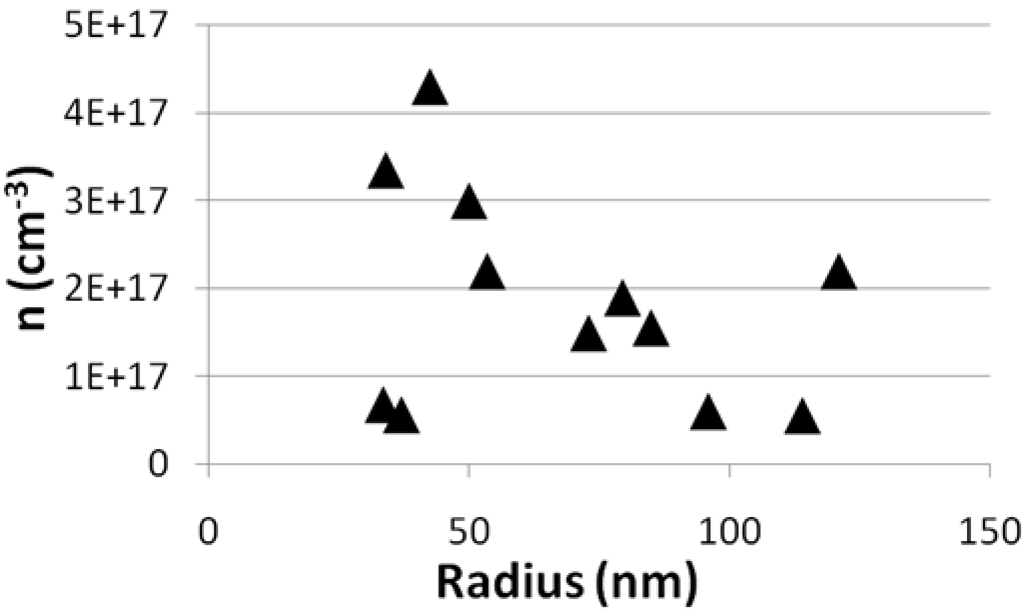


$$n = \frac{CV_{TH}}{e}$$

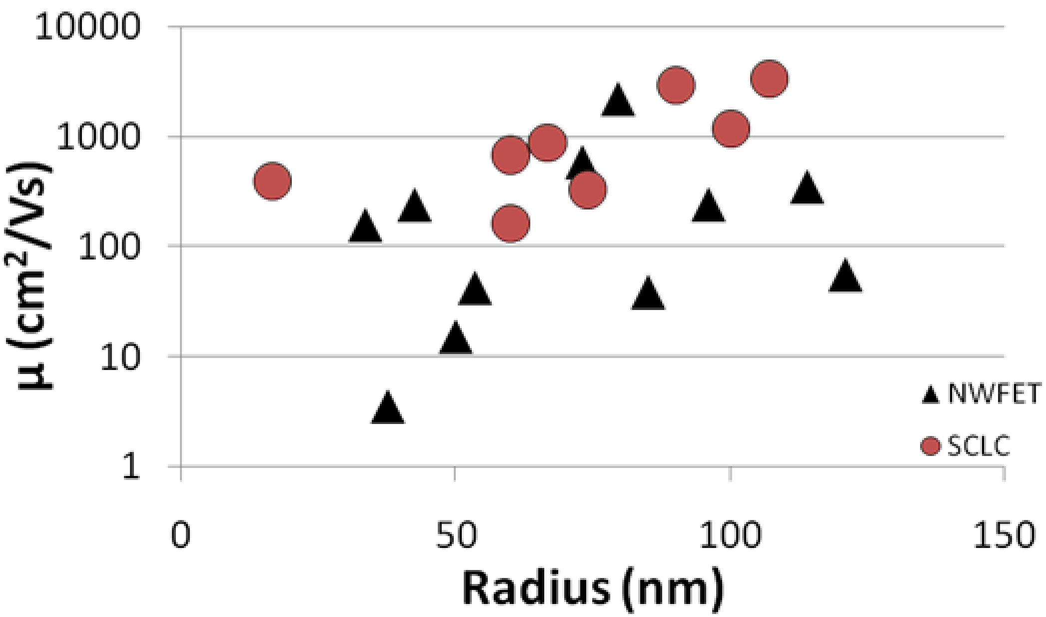
$$\mu = \frac{L^2}{V_{SD}\,C}\left(\frac{dI_{SD}}{dV_G}\right)$$

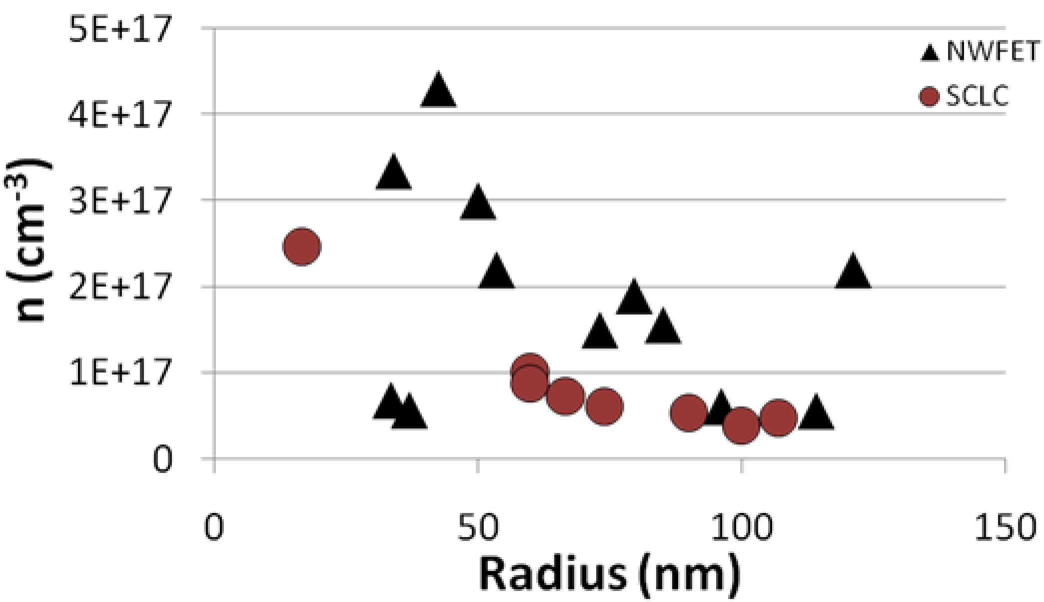
NWFET Results





Comparison of Techniques





Summary

•Space-charge-limited current enhanced in nanowires

•2-probe on-wafer technique effective in characterizing transport

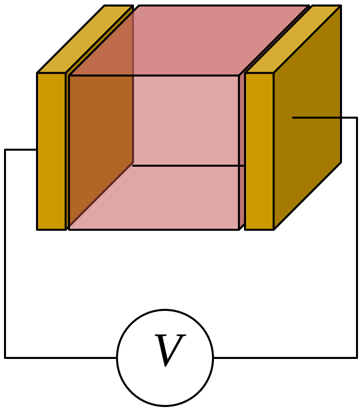
•Crossover from Ohmic to SCLC provides carrier concentration

•Carrier concentration decreases, mobility increases with radius in InAs nanowires (consistent with previous results)

Growth Details

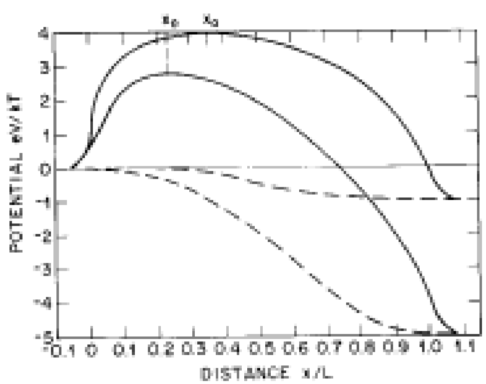
- In the growth chamber the template was annealed for 10 min in arsine (AsH_3) ambient at 650°C and then cooled to 400°C for growth.
- The nanowires were grown by low-pressure (60 Torr) metal-organic CVD using AsH_3 and trimethyl indium (TMIn) with the Au serving as the collector for the VLS mechanism.
- The growth occurred for 10 min using a TMIn partial pressure of 2.42E-3 Torr and an AsH_3 partial pressure of 0.336 Torr.
- The resulting nanowires are n-type, with diameters between 50 and 300 nm and lengths above 10 µm. Planar growth rates under these conditions were below 0.04 µm/min.

Combining 1D Poisson and drift equations leads to correct expression for bulk SCLC



$$J(x) = \underbrace{qn(x)}_{\text{electrons/cm}^3}\underbrace{\mu E(x)}_{\text{cm/s}}$$

Low mobility or low carrier concentration can limit J, create electron pile up at cathode



$$\frac{dE}{dx} = \frac{qn(x)}{\varepsilon}$$

$$Jdx = \varepsilon\mu E dE$$

$$Jx = \frac{\mu\varepsilon}{2}E^2 \qquad E = \sqrt{\frac{2J}{\mu\varepsilon}}x^{1/2}$$

$$\frac{dV}{dx} = -E$$

$$V(x) = \sqrt{\frac{2J}{\mu\varepsilon}}\frac{2}{3}x^{3/2}$$

$$\boldsymbol{I_{sc}(bulk) = \frac{9A\varepsilon\mu}{8L^3}V^2}$$