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Assembly and electrical transport characterization of nanostructures

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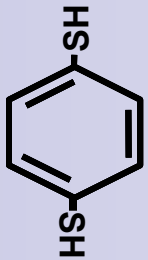
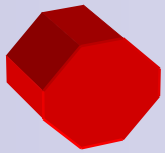
Outline

1. Introduction
2. Semiconductor nanowires
3. Carbon nanotubes
4. Molecule-metal nanosphere assembly

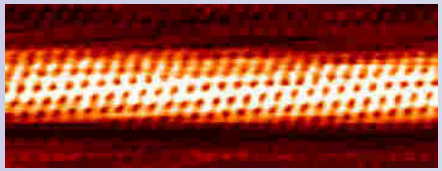
What do we want to know?



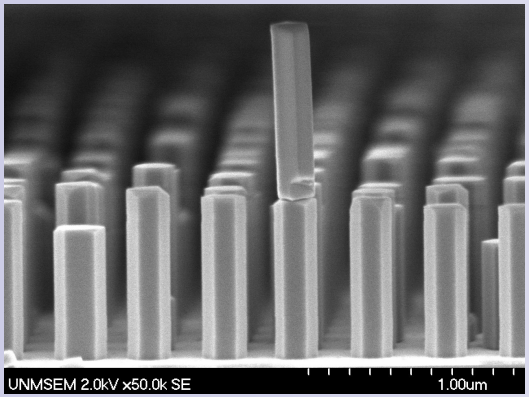
molecules



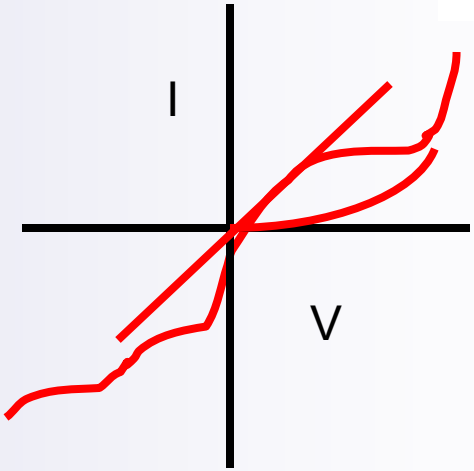
quantum dots

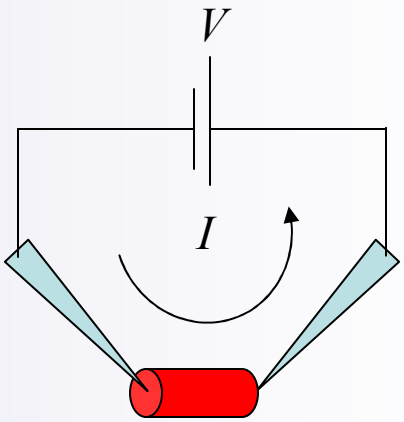


carbon nanotubes
(and graphene)



nanowires





Beyond I/V, want to understand how dimensions, composition, contacts, etc affects transport

Nanowire device assembly using the Discovery Platform

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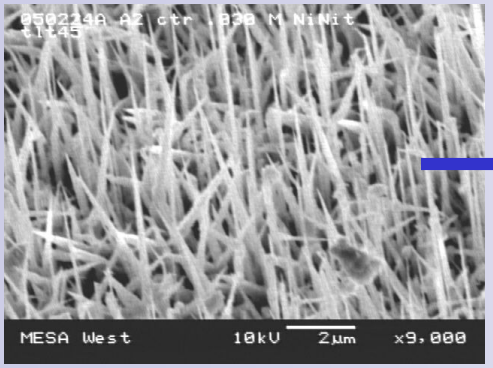

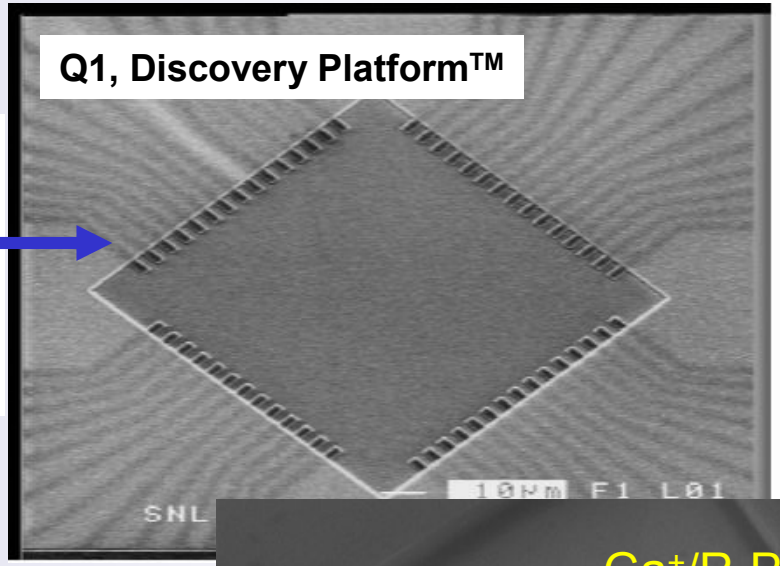

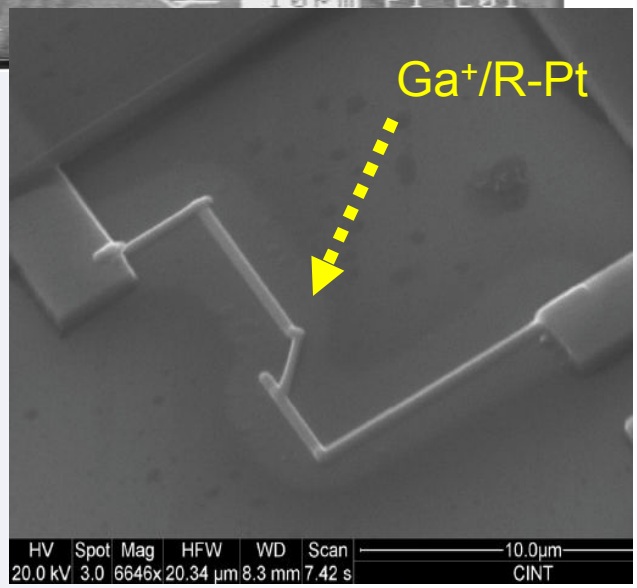

This step requires electron beam or focused ion beam

Nanowire device assembly using optical lithography: works well for nanowires >2 μm in length

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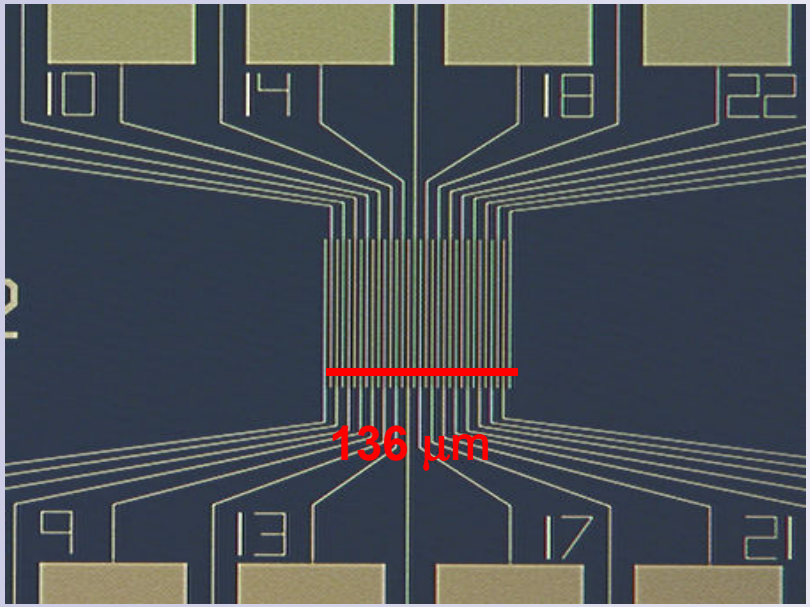
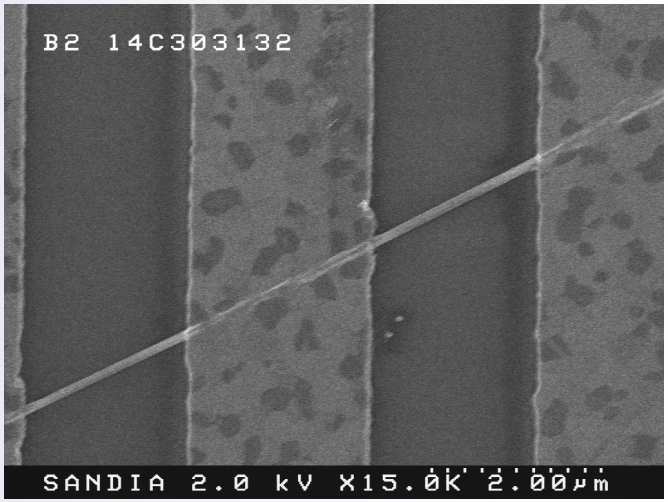
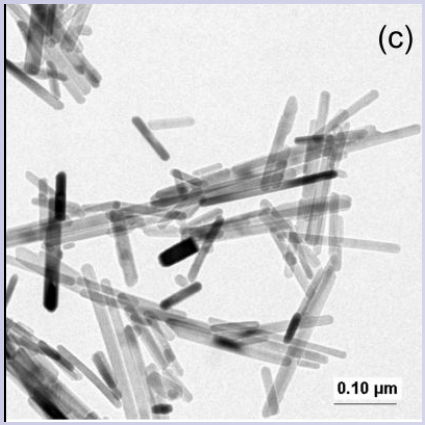
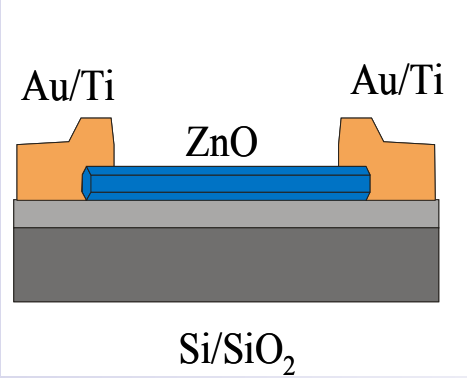
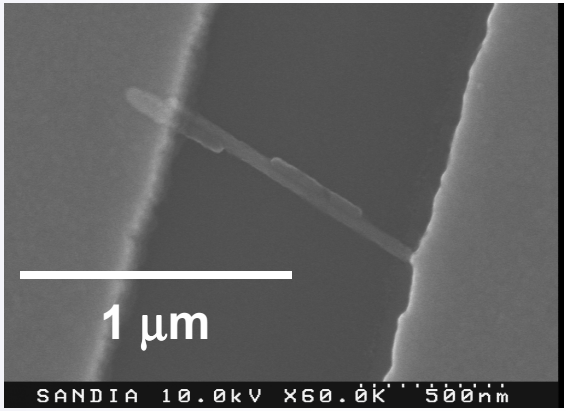


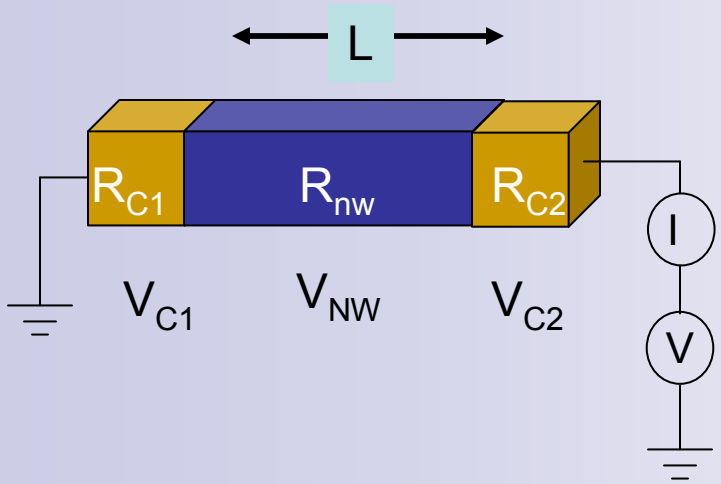


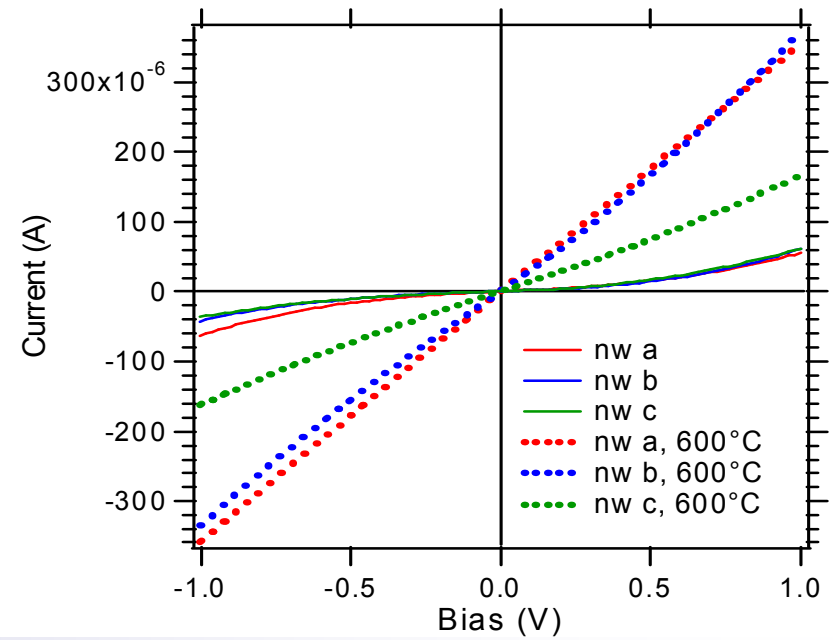






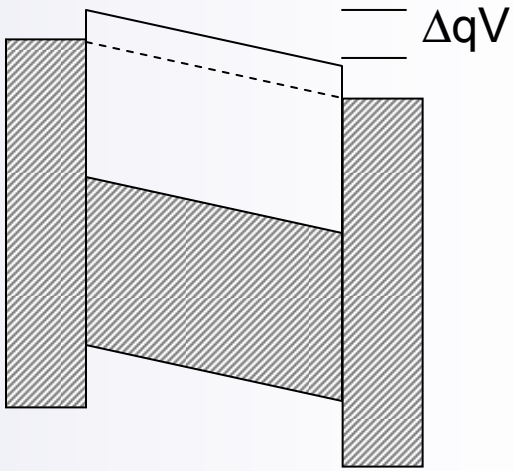
Ohmic conduction in a nanowire



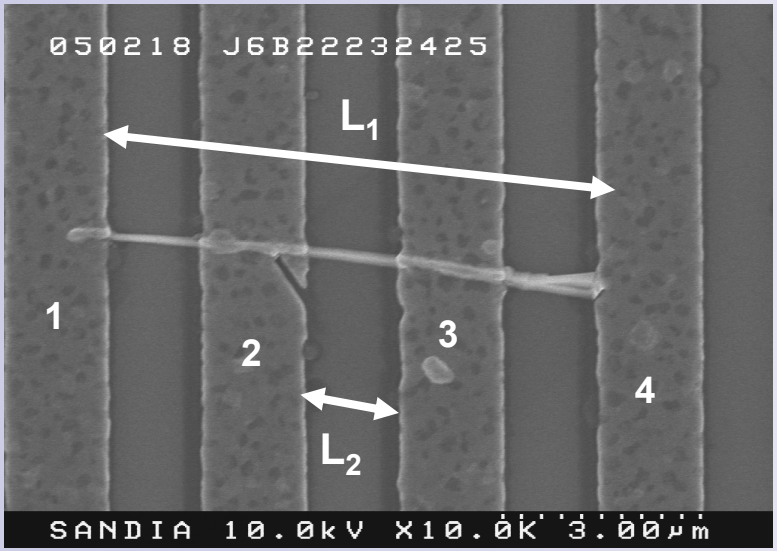


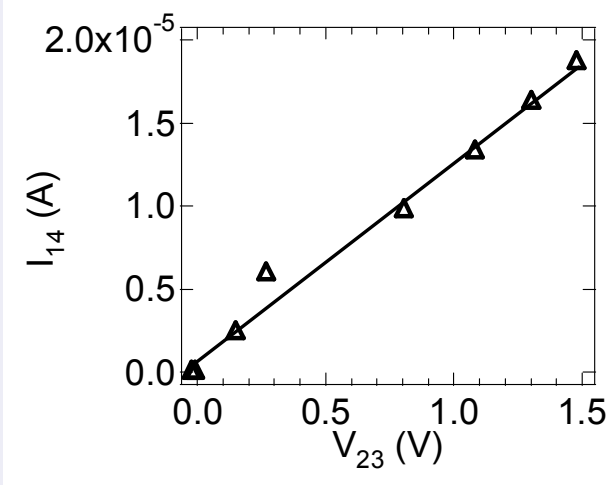
$$R_T = \frac{V_T}{I} = \frac{V_T}{AJ} = 2R_C + R_{NW}$$

$$J = qnv = qn\mu E = qn\mu \frac{V_{NW}}{L}$$



Even with ohmic I-V, need 4-point probe (or TLM) for reliable nanowire resistivity measurement





$\rho_s=(V_{23}/I_{14})\pi r^2/L_2=0.27\ \Omega\text{cm}$

$$\rho_s = \frac{1}{qn\mu}$$

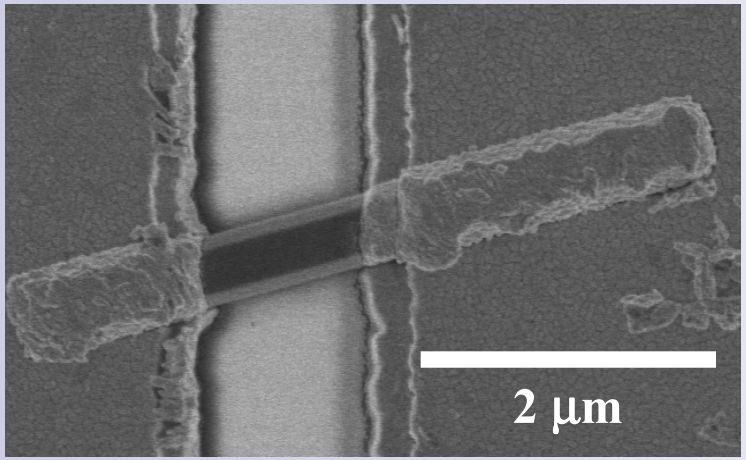
$R_T=2R_c+(\rho_s/\pi r^2)\,L_1$

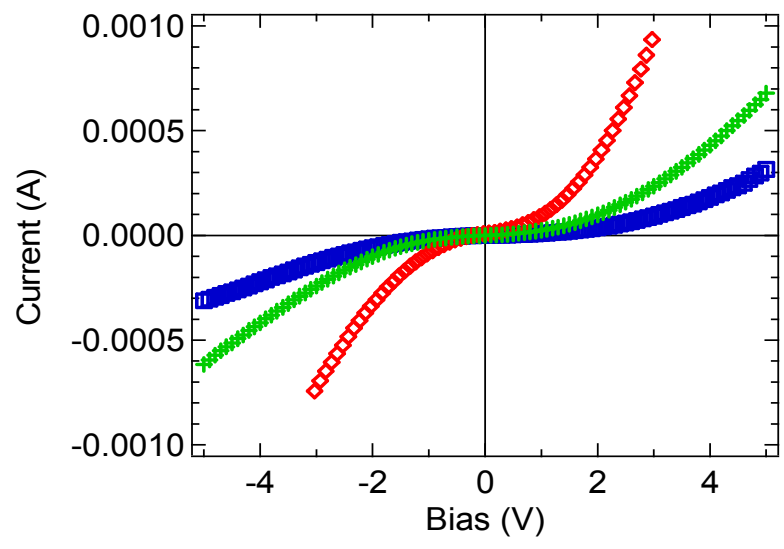
n, μ are constants

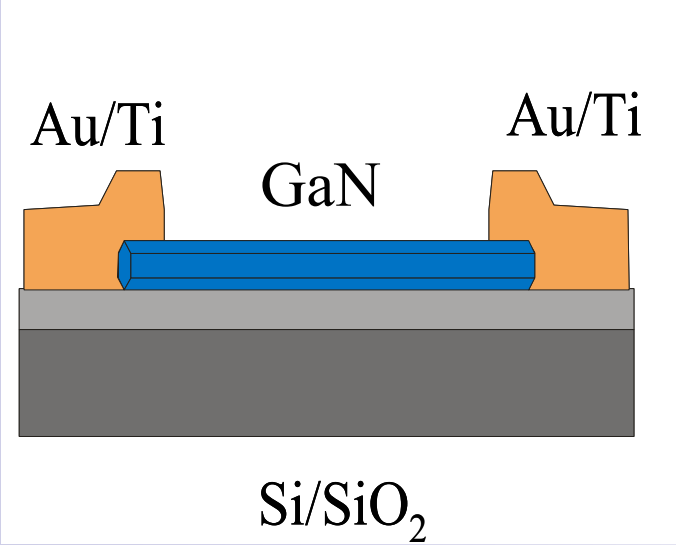
$R_c \approx 1.4\times10^5\Omega$, or
$\rho_c \sim 5.6\times10^{-5}\ \Omega\text{cm}^2$

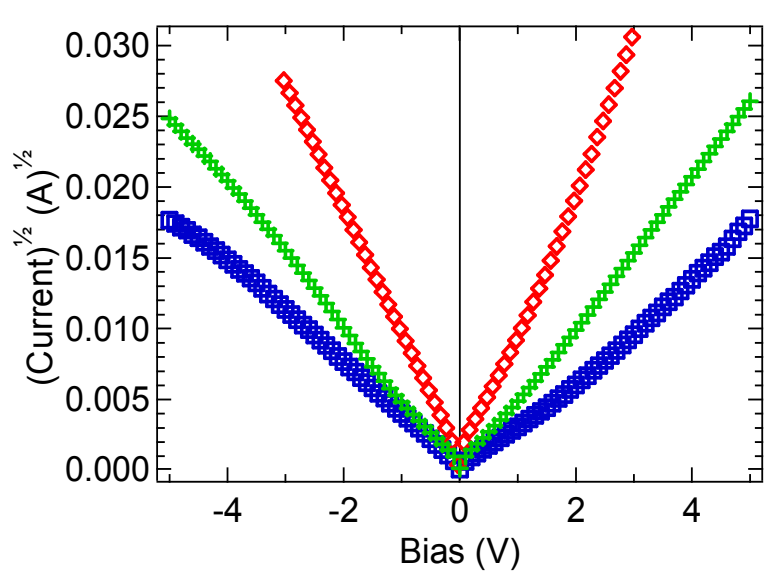
4 point probe measurements yield resistivity, contact resistance for nanowires >10 µm)

In many cases, I-V for nanowires is not linear (i.e not ohmic); contacts are usually blamed

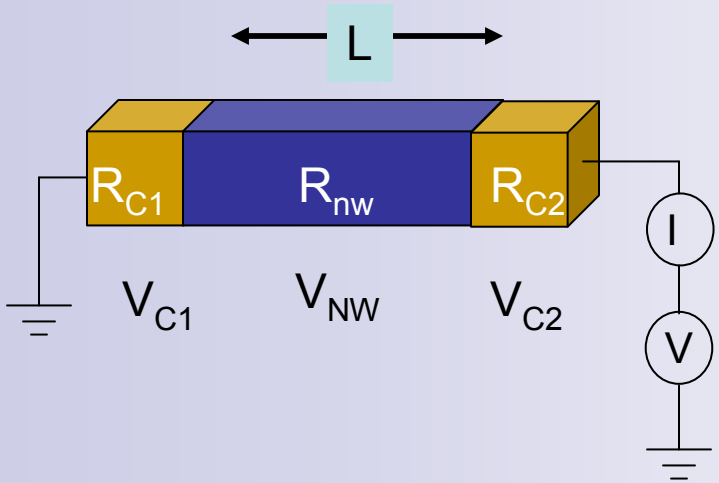






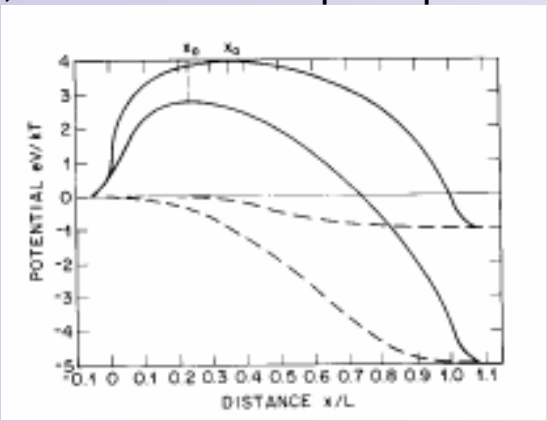


In some cases, $R_c << R_{nw}$:



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

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



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

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

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

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

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

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

Can we ‘control’ contact transport?

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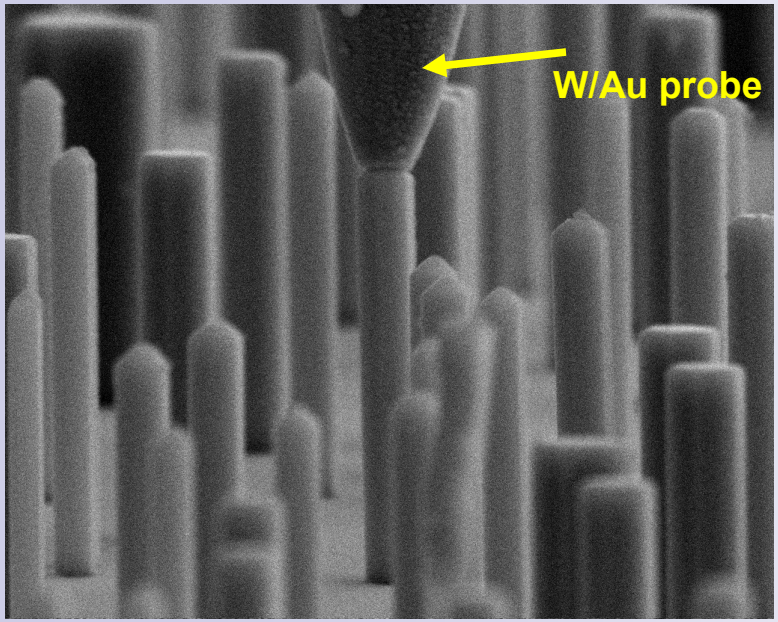
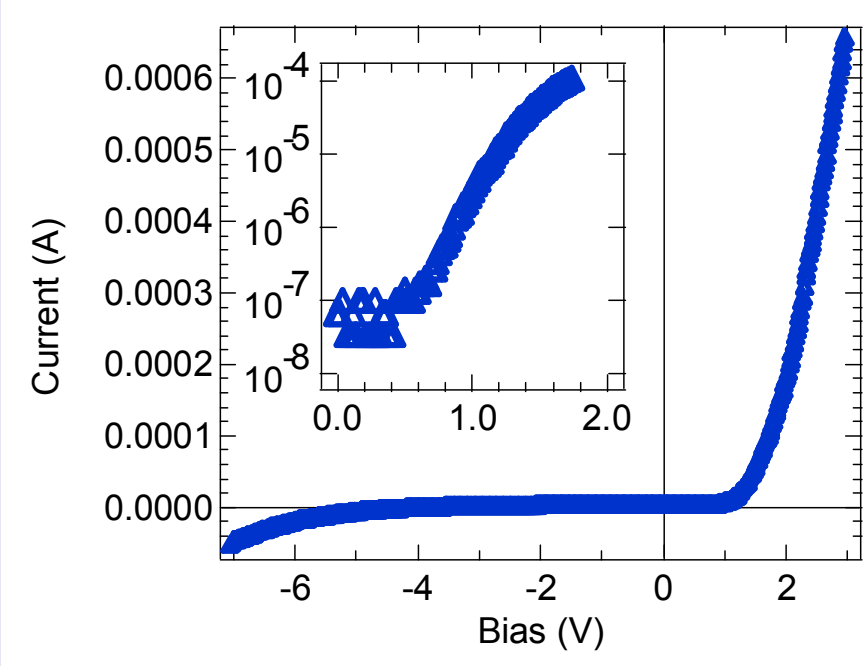
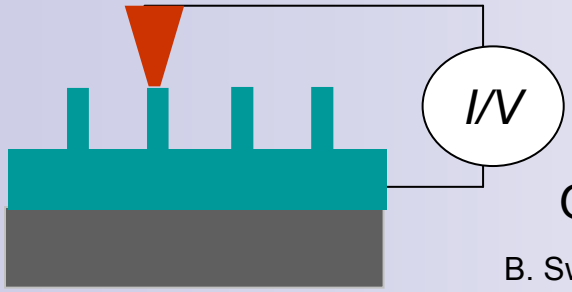
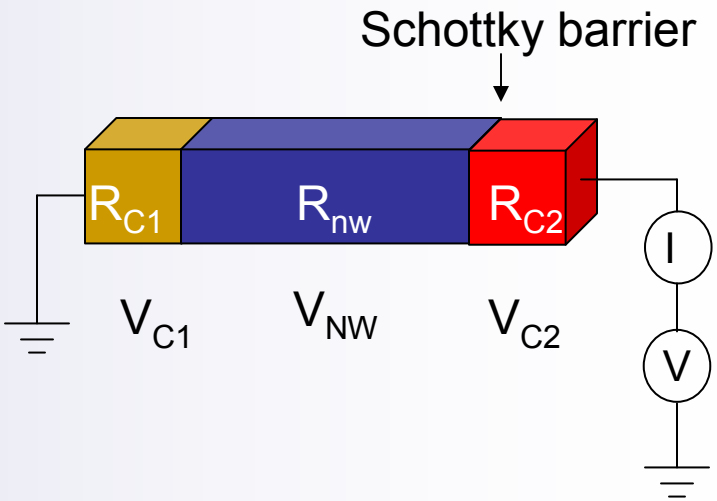




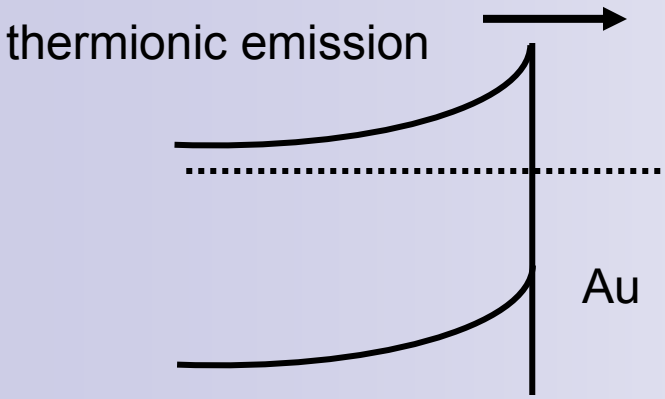


GaN

B. Swarttzentruber



I~exp(V), rectification indicate Schottky barrier, thermionic emission transport (approx.)



$$I \approx AJ_o \exp(\frac{qV}{nkT})$$

$$J_o = A^* T^2 \exp(-\frac{q\varphi_b}{kT})$$

For I-V curves from previous slide, fit of ln(I) vs. V yields IC of -21, slope of 8, resulting in ϕ_b~0.4 eV, and ideality factor of ~4; *this is a lousy diode!*
Tunneling is likely to contribute significantly to the current because of contact geometry

Pressing probe onto nanorod ‘breaks’ Schottky barrier, transport becomes space-charge limited

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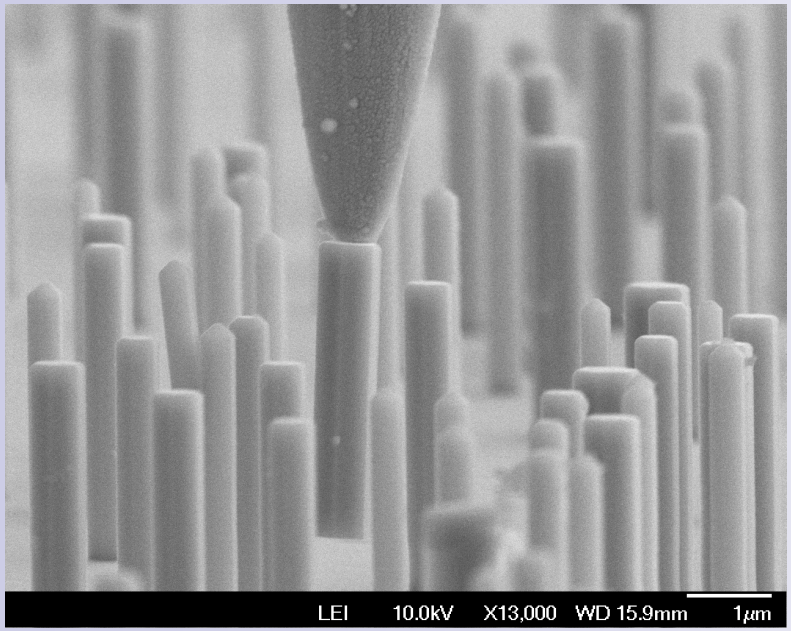
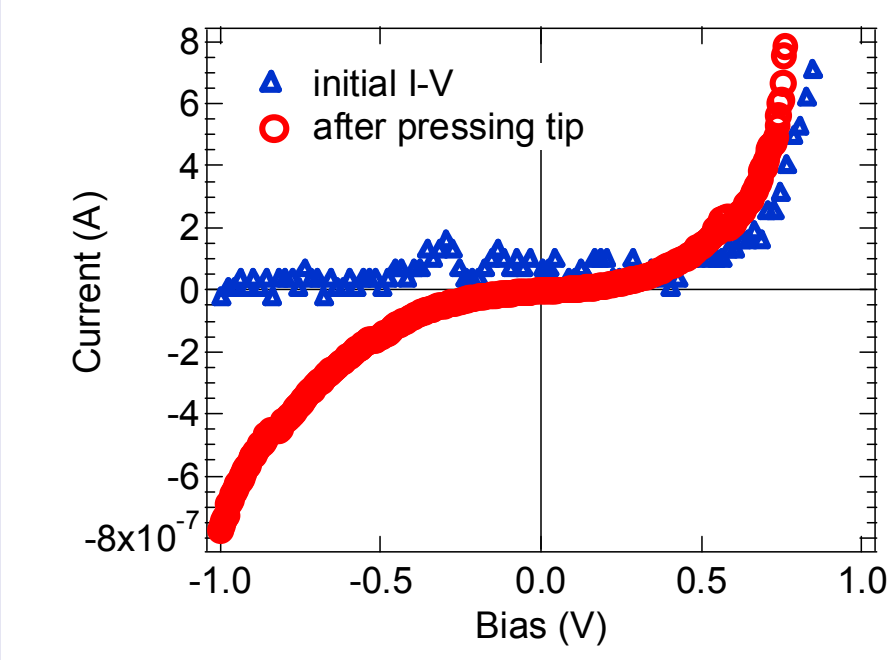
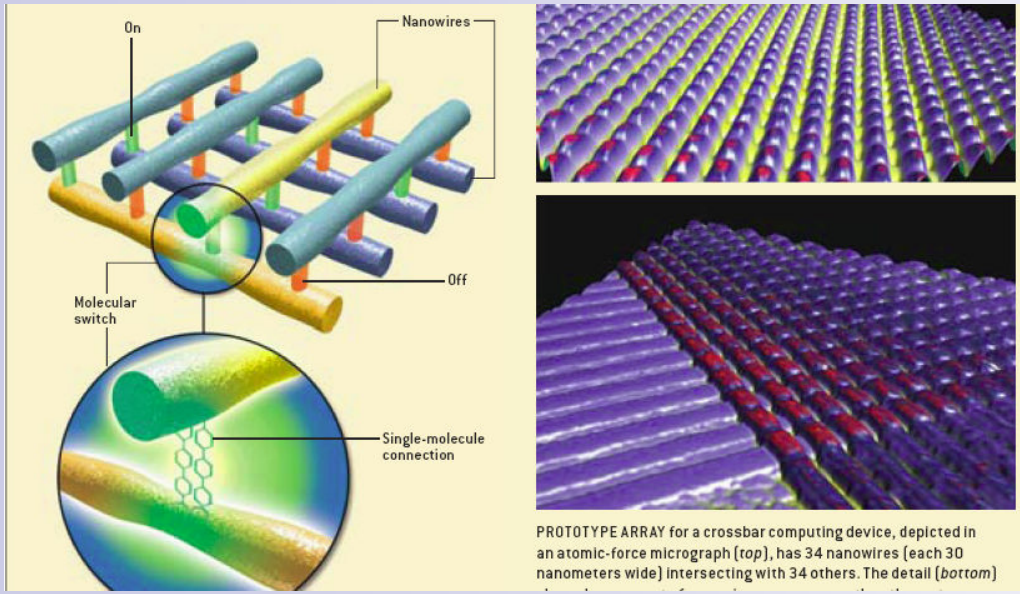


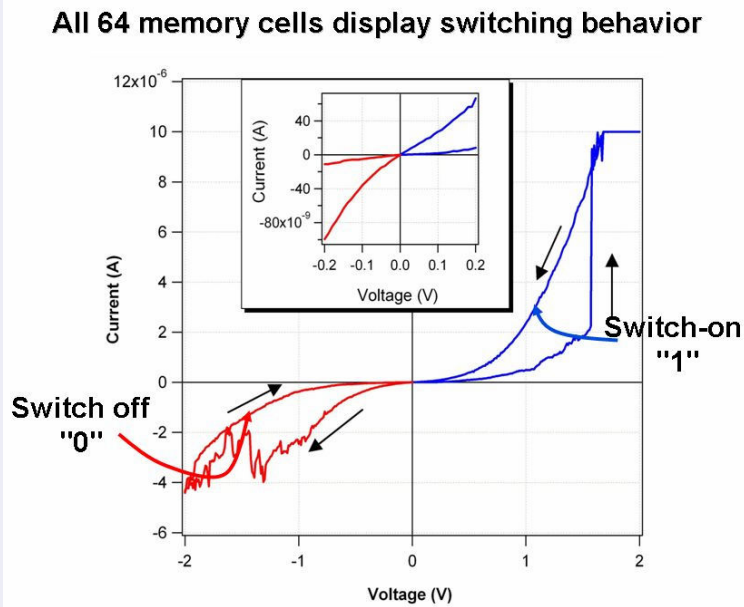


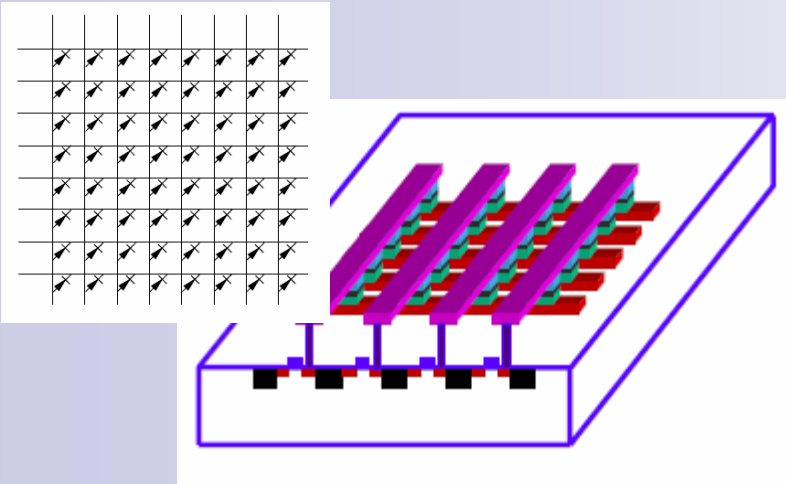
Switching materials for memory and logic

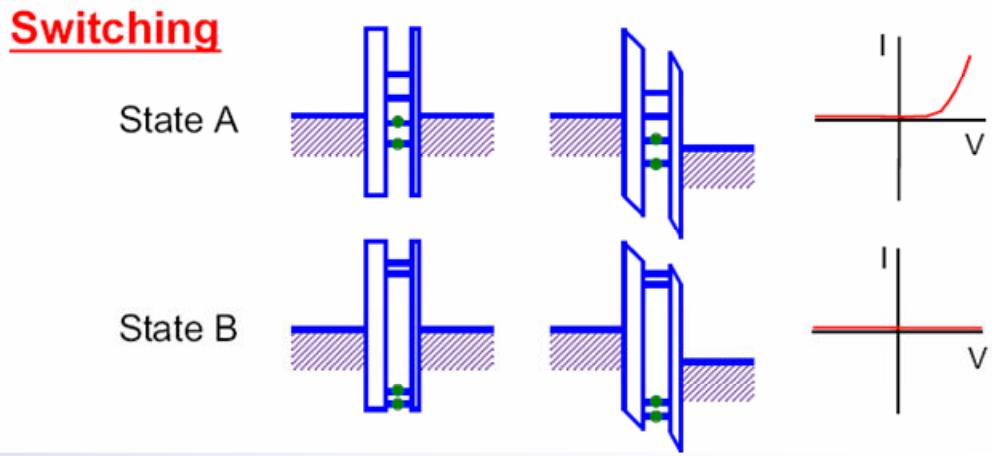
Resistive switches for memory and logic (S. Williams, T. Kamins, W. Tong HP)



PROTOTYPE ARRAY for a crossbar computing device, depicted in an atomic-force micrograph (*top*), has 34 nanowires (each 30 nanometers wide) intersecting with 34 others. The detail (*bottom*)

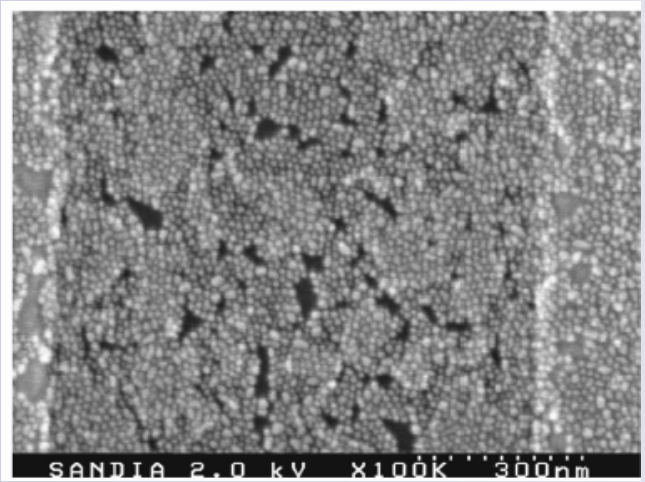


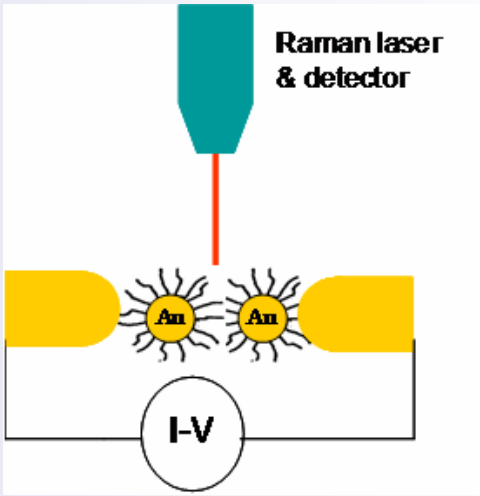


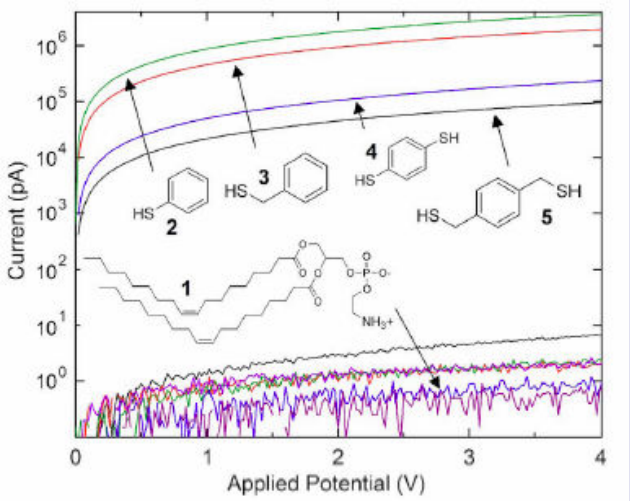


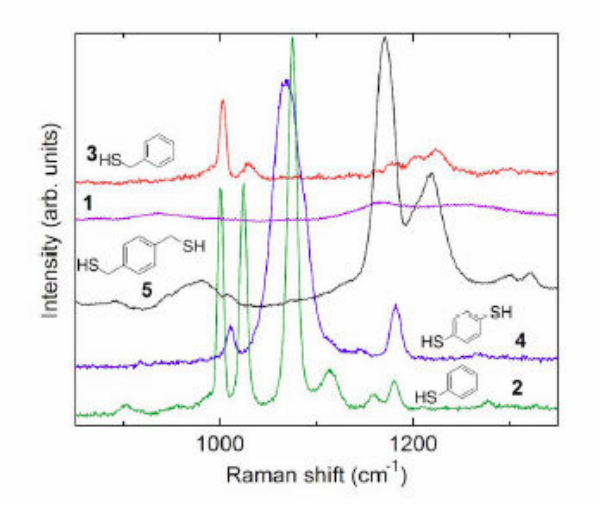
Switching materials for memory and logic

We combine I-V measurements with vibrational molecular spectroscopy (Surface Enhanced Raman)









AC dielectrophoretic assembly is a quick, convenient way to assembly variety of nanodevices

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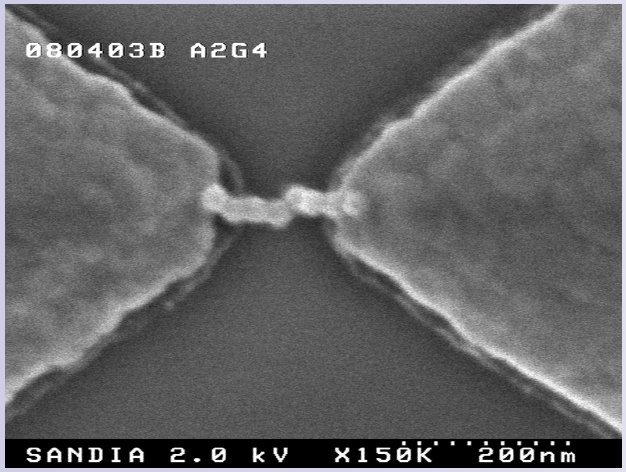

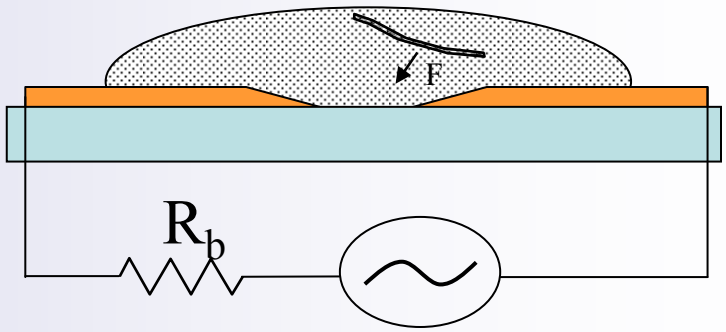

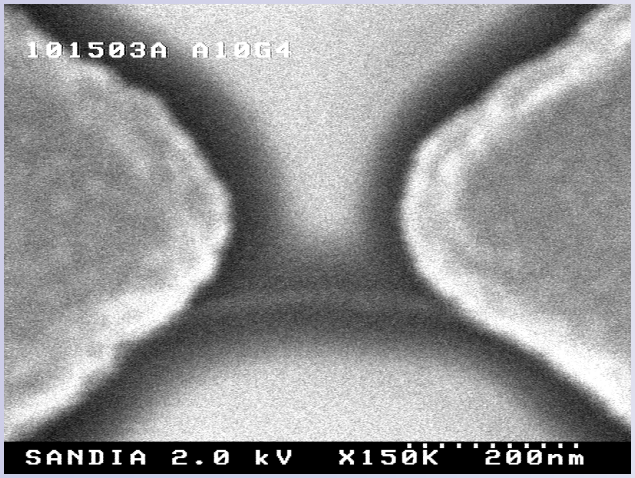

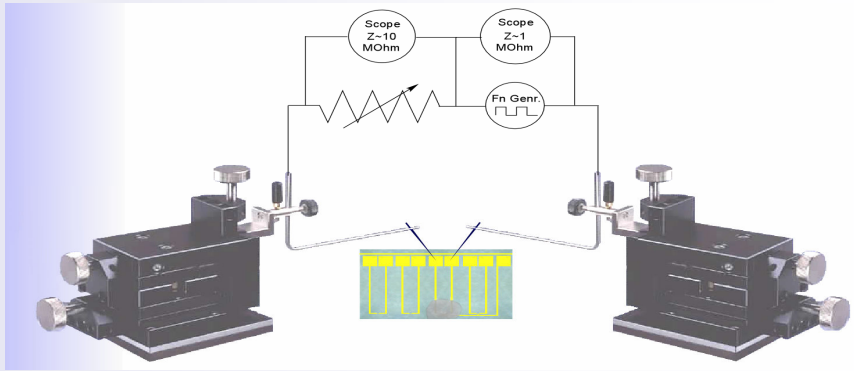

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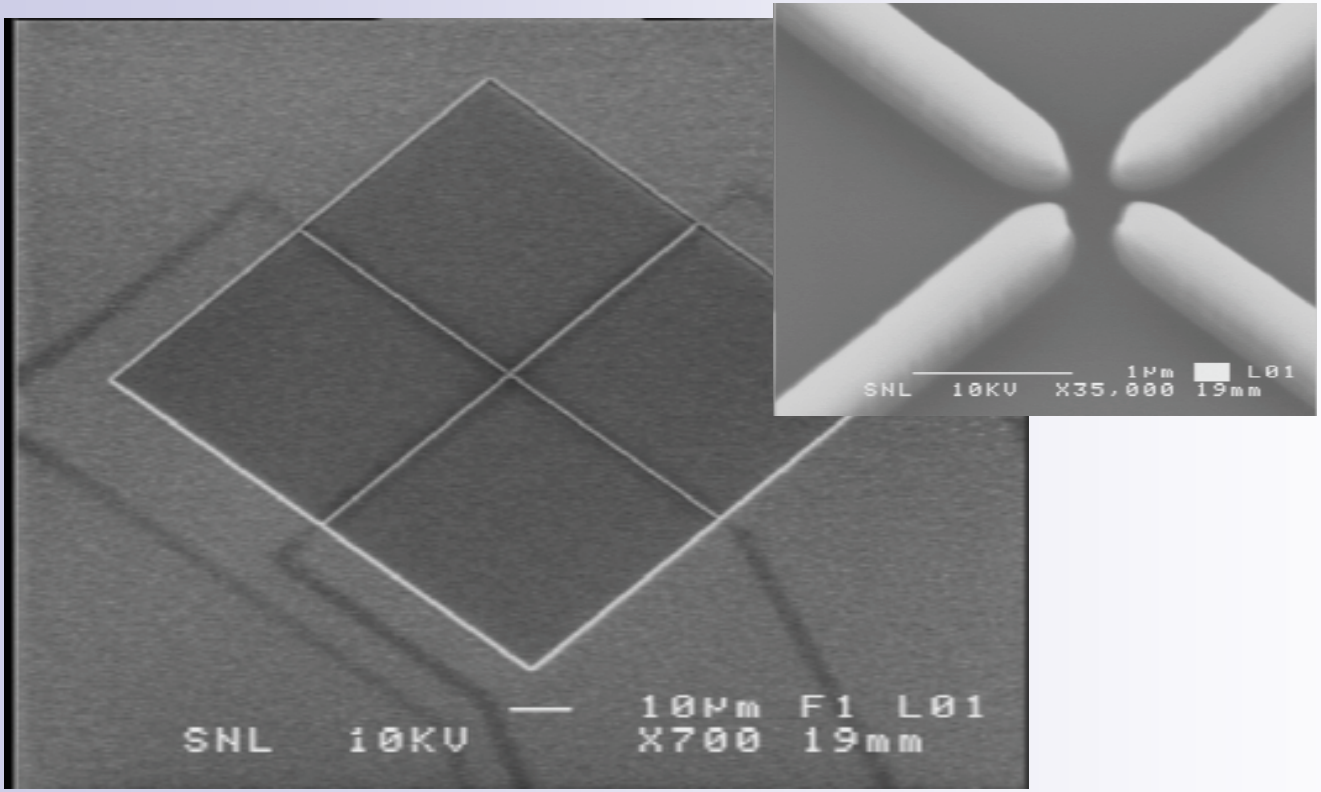
The CINT Transport Discovery Platform™ provide small gap electrodes which can be used for nanodevice assembly



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References

1. G. T. Wang et al., *Highly aligned, template-free growth and characterization of vertical GaN nanowires on sapphire by metal–organic chemical vapour deposition,* Nanotechnology **17**, 5773 (2006).
2. F. Jones et al., *Electrical conduction and photoluminescence properties of solution grown ZnO nanowires*, J. Appl. Phys., ASAP
3. F. Jones et al, *Effect of Electrode Material on Transport and Chemical Sensing Characteristics of Metal/Carbon Nanotube Contacts*, J. Elect. Materials, 38, (2006).
4. D. B. Robinson et al., *Spectroscopic observation of chemical change during molecular electronic experiments*, Appl. Phys. Lett. 90, 083119 (2007)
5. F. Leonard and A. A. Talin, *Size-dependent effects on electrical contacts to nanotubes and nanowires*, Phys. Rev. Lett. 97, 026804 (2006).

Acknowledgements

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G. Wang
R. Anderson
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F. Jones

NNEDC/NINE/CINT funding

Photoluminescence provides additional insight

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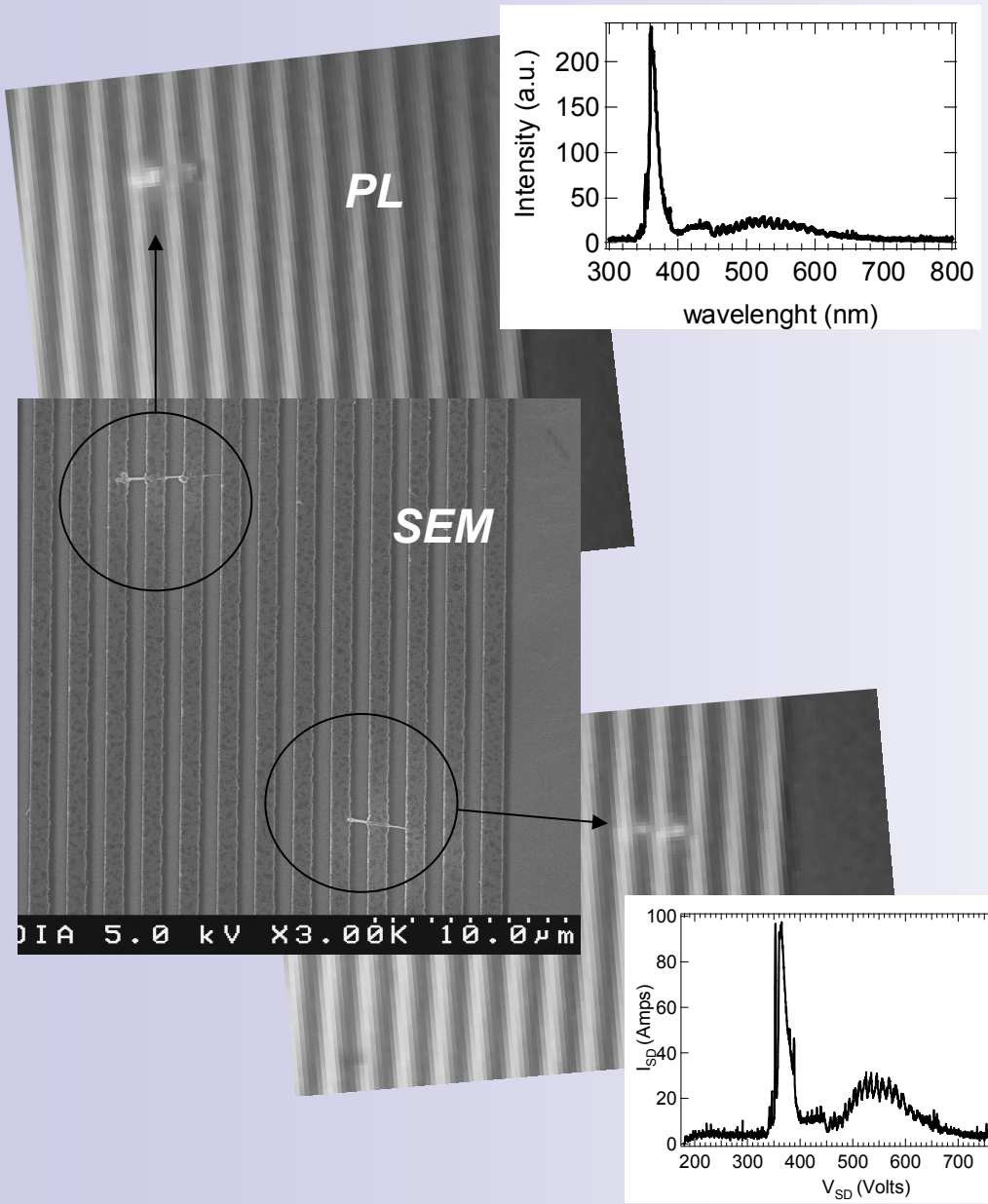
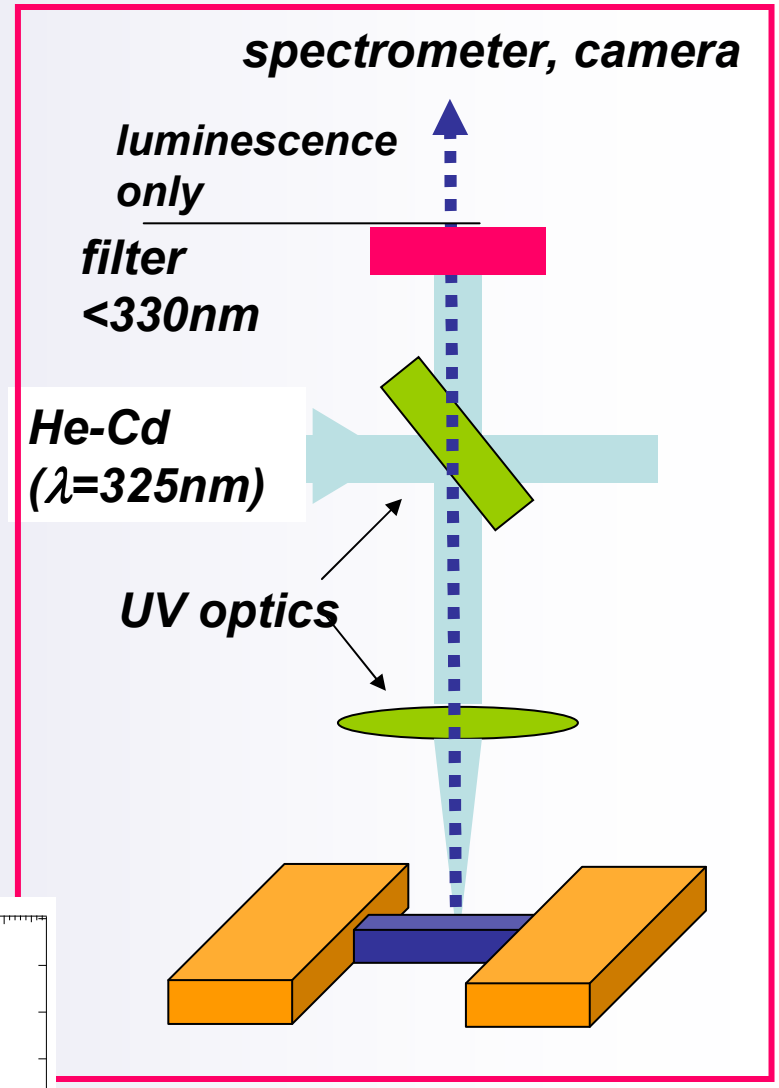
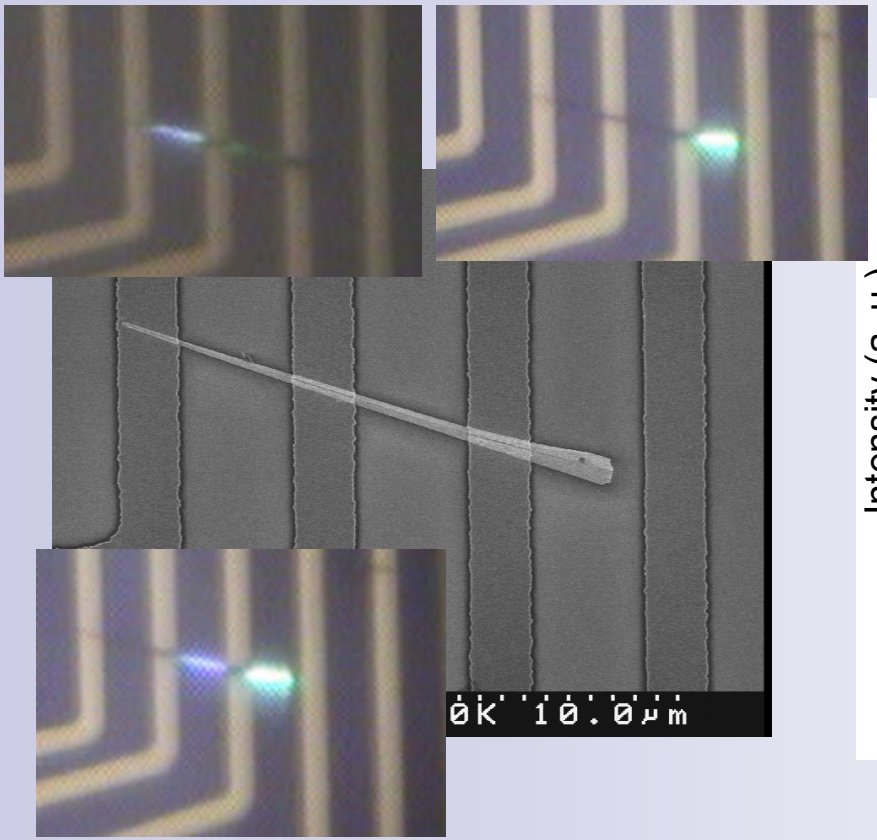
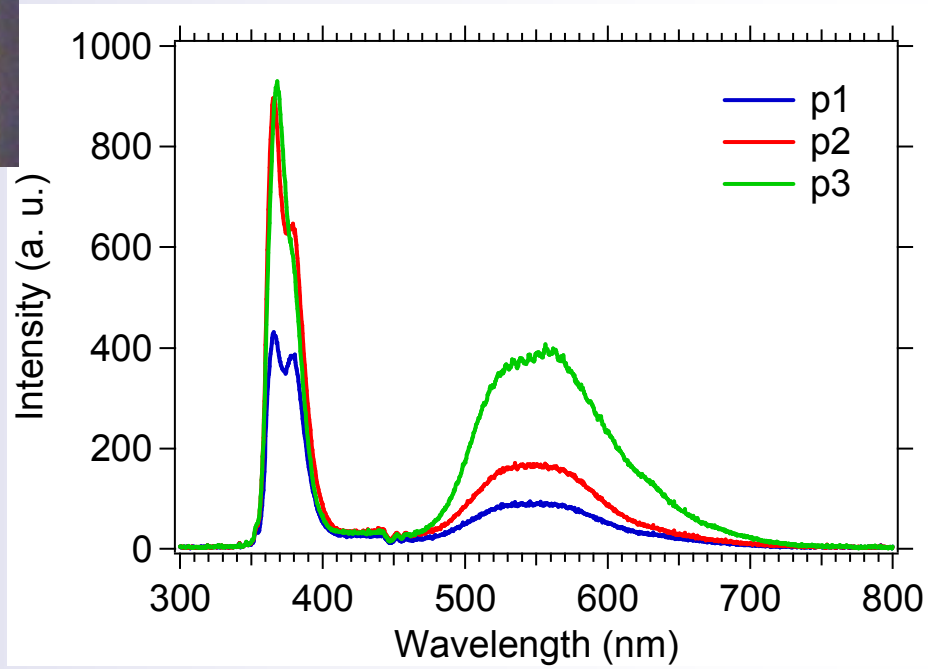




Spatially resolved PL imaging, spectra, I/V





Effect of growth T on PL, I/V: 900°C-> BEL dominates, R~$10^5\Omega$

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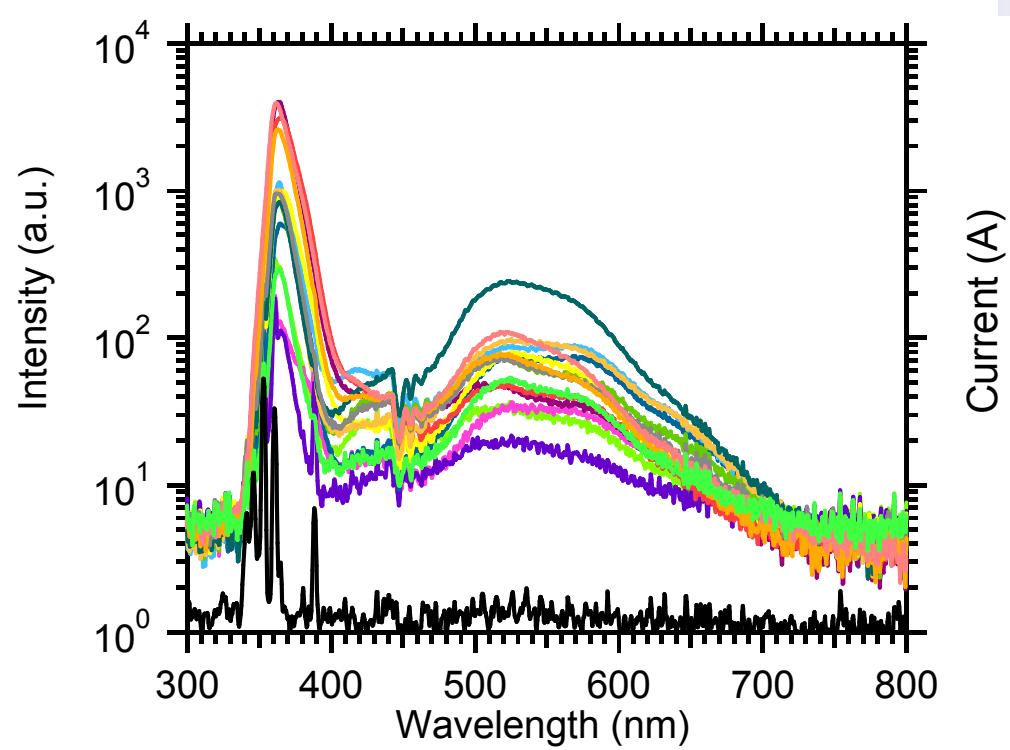
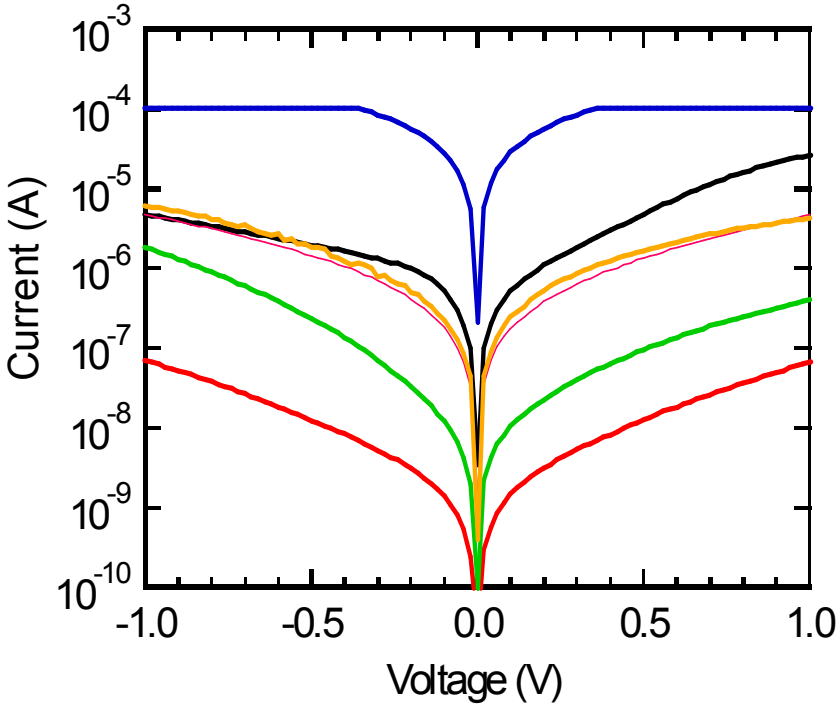
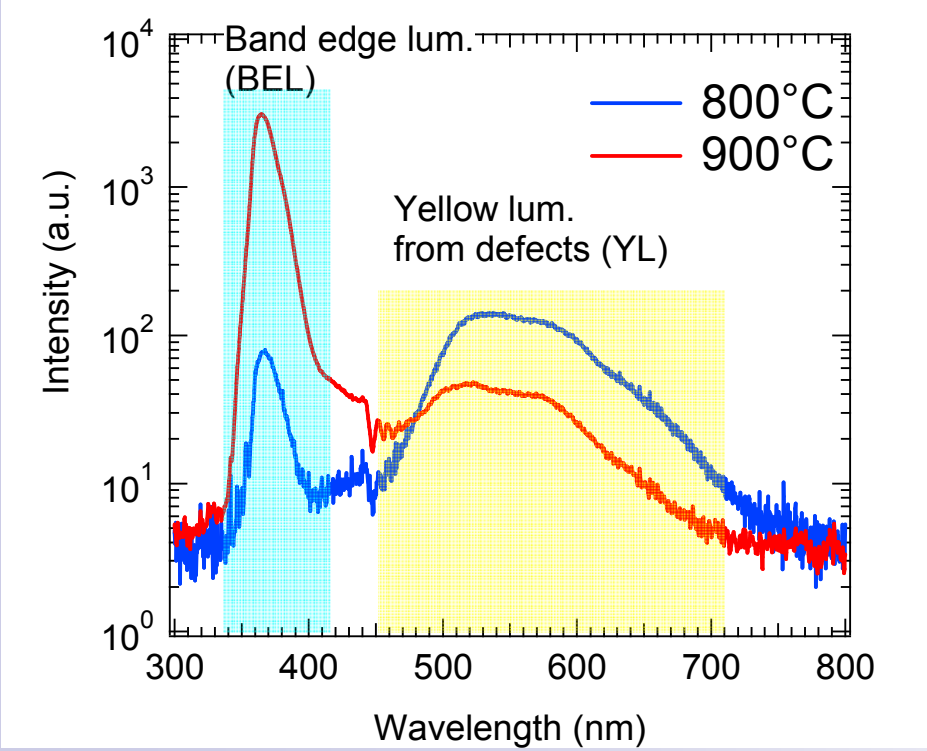
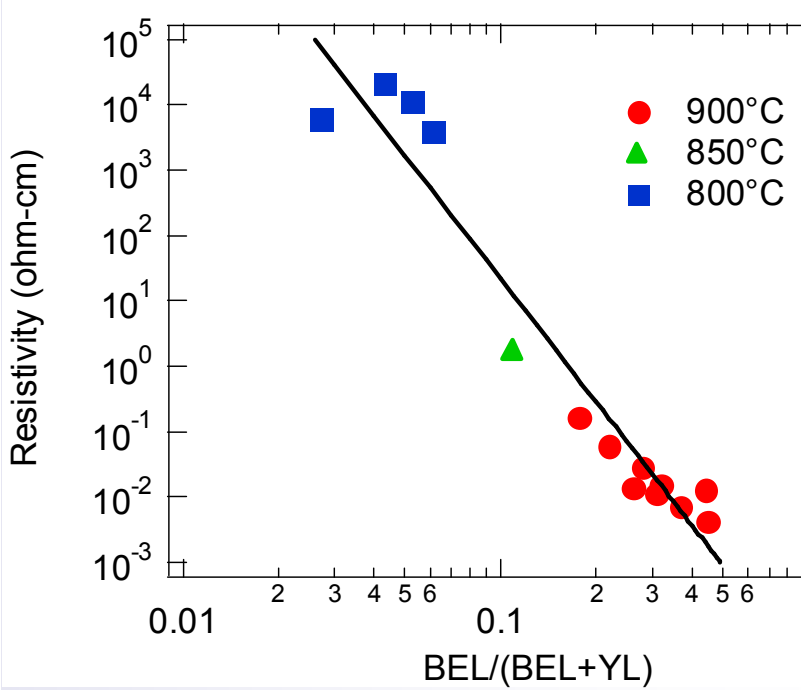




Substrate temp. and electrical/optical properties are strongly related

As substrate T increases from 800°C to 900°C, yellow lum., resistance decreases





Wang,Talin, Werder, Creighton, Lai, Anderson, Arslan, Nanotechnology 17, 5773, 2006

Nanowires grown at 800°C: strong YL, high R

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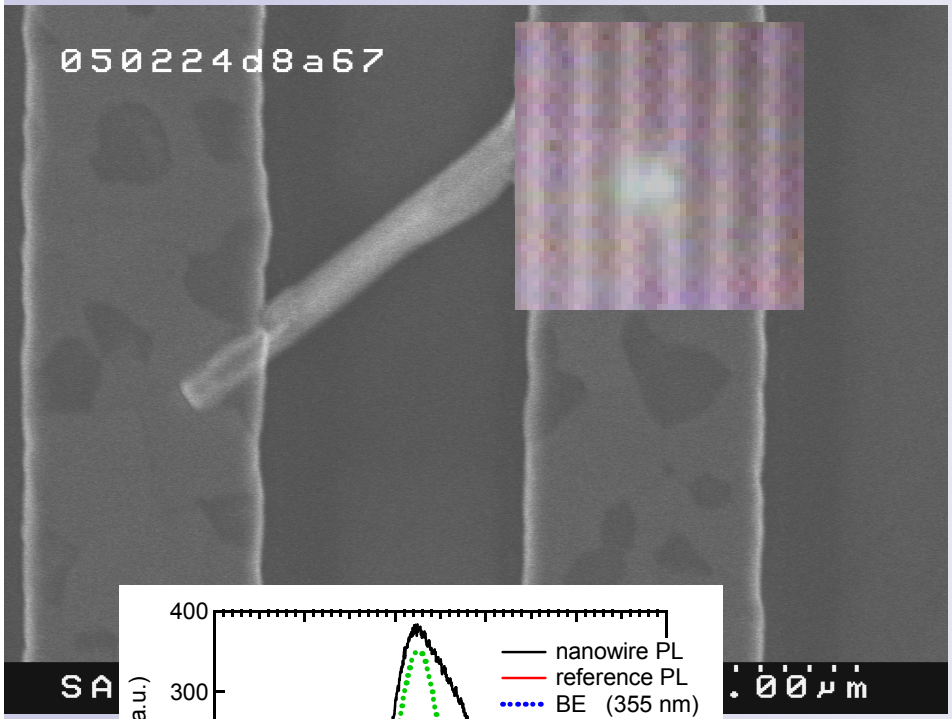
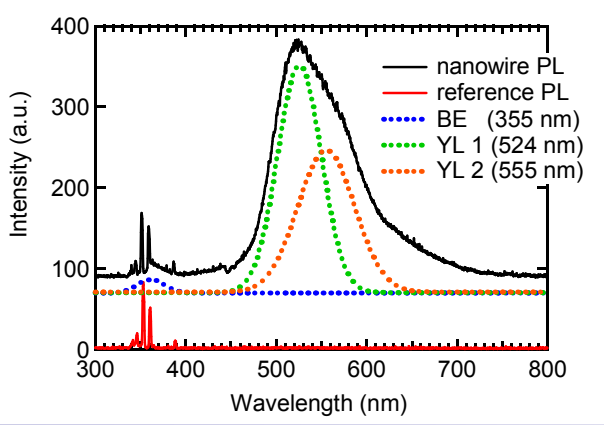
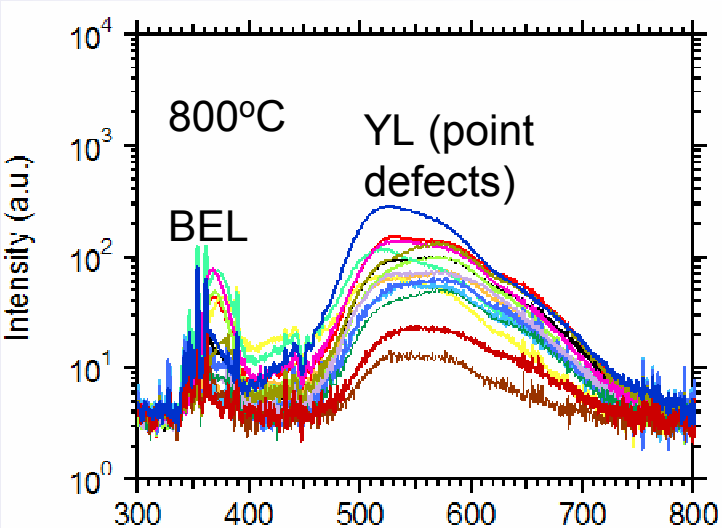
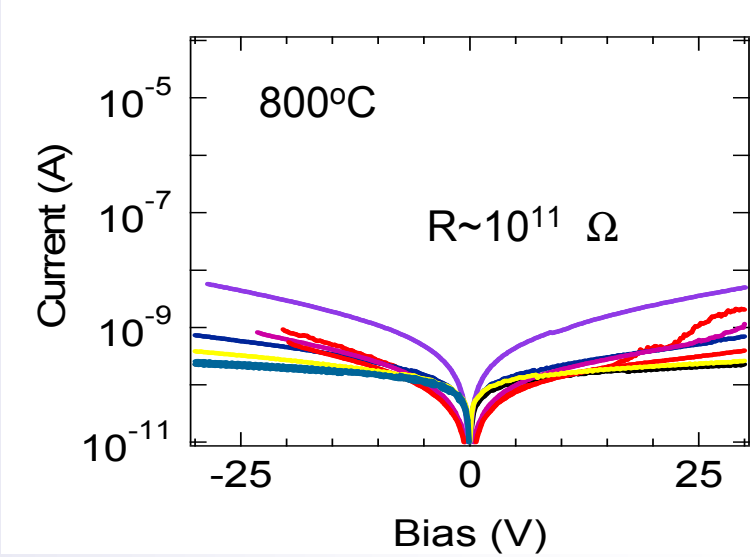


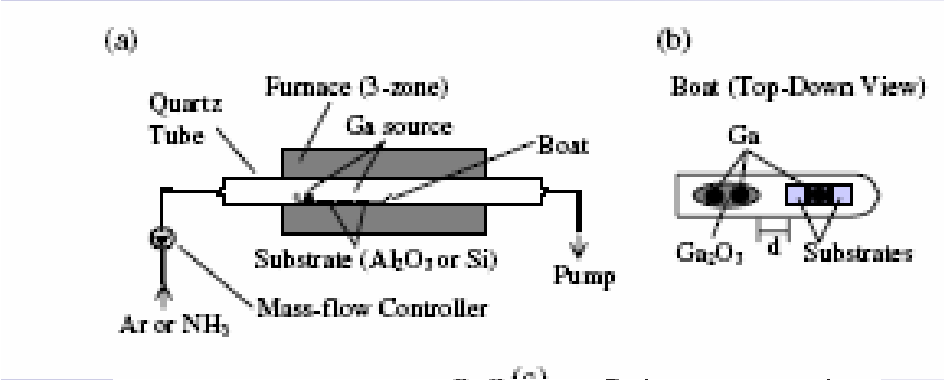


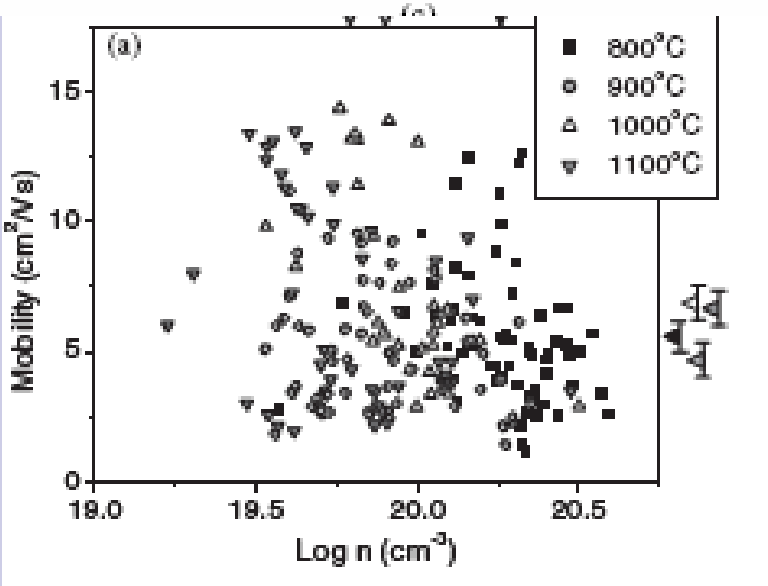




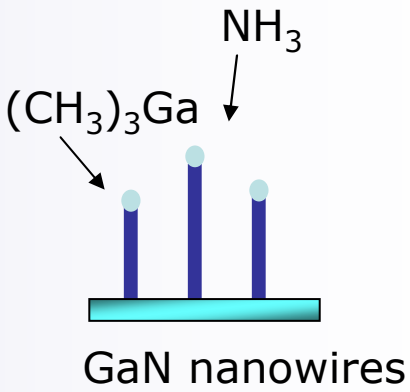
Carbon from TMGa may lead to carrier compensation

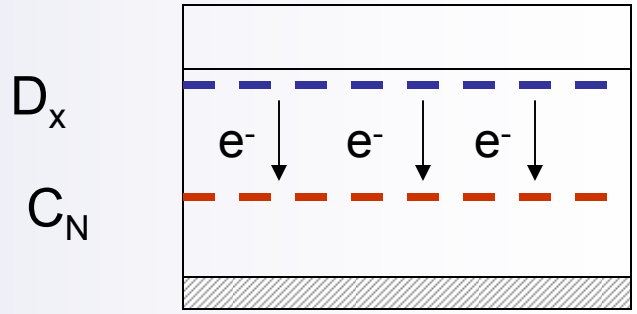
No effect of T_{sub} on [e^-] for elemental Ga or Ga_2O_3 source

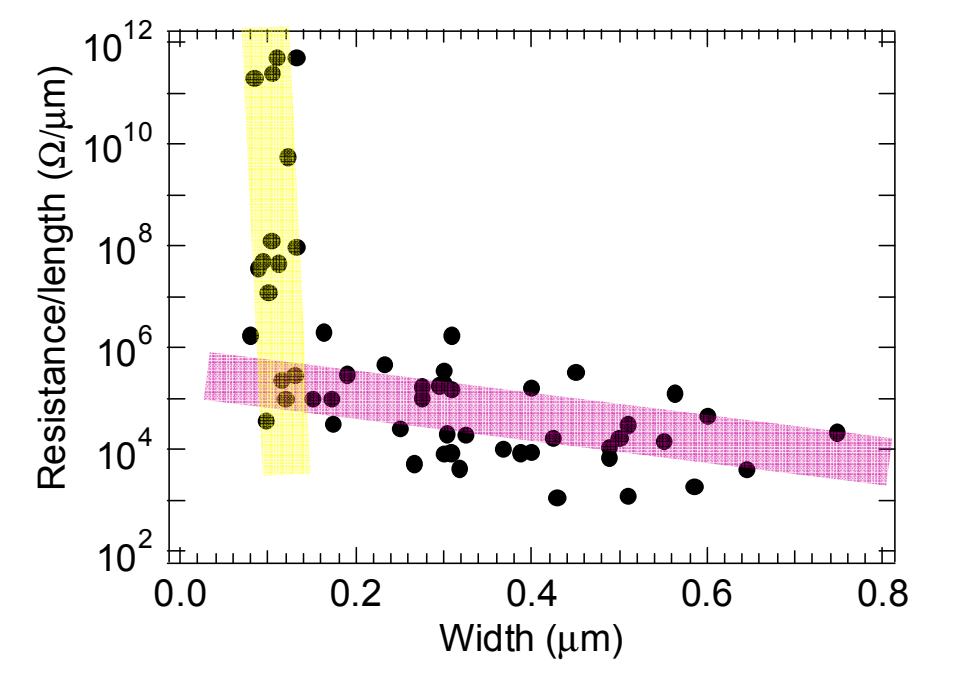
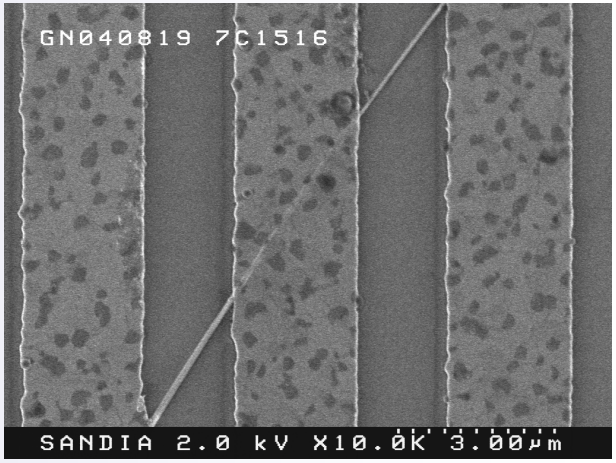
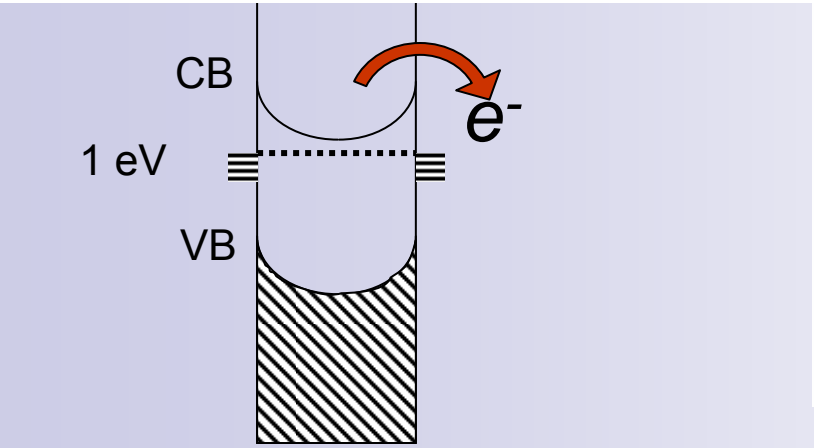
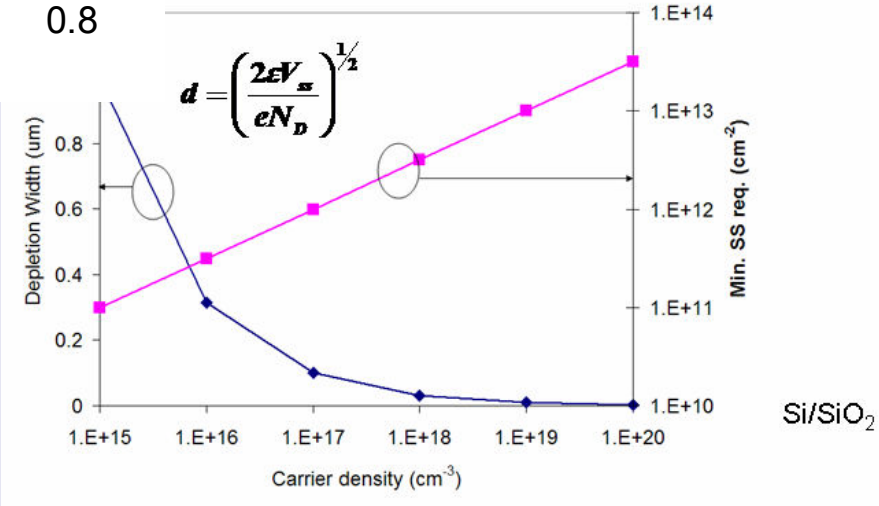




Stern et al., Nanotechnology, 2006





Bellow ~100 nm, GaN nanowires grown at 900°C are insulating!

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