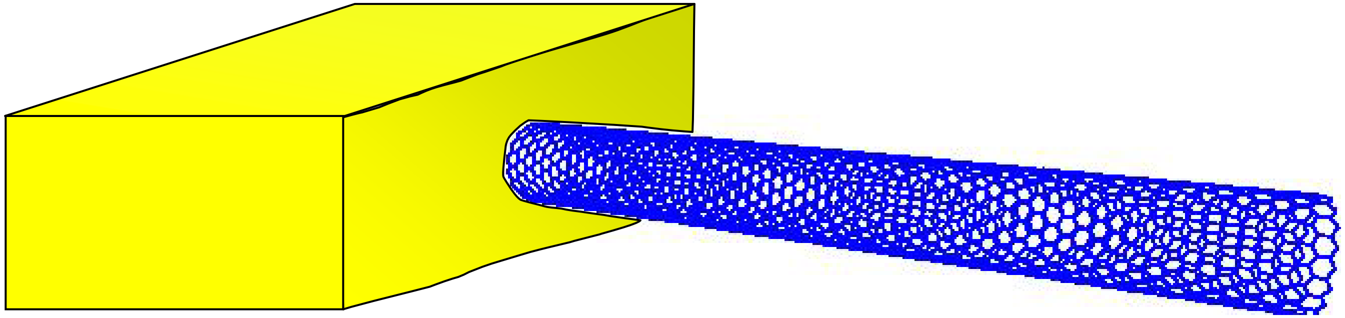
SAND2006-6488P

Electrical contacts to nanotubes and nanowires: why size matters



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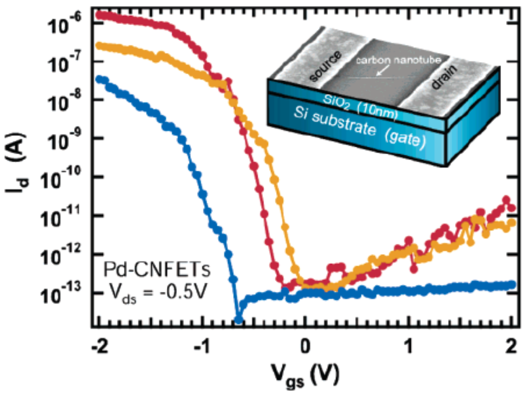
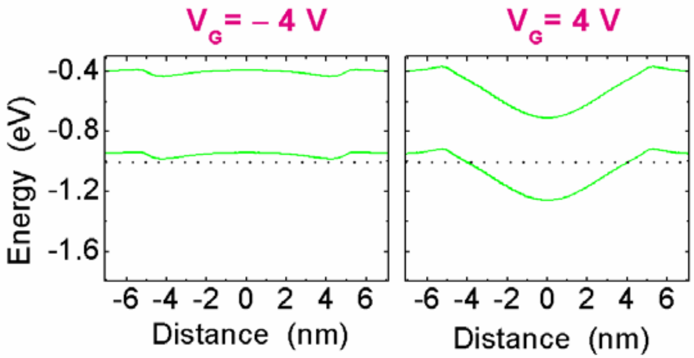
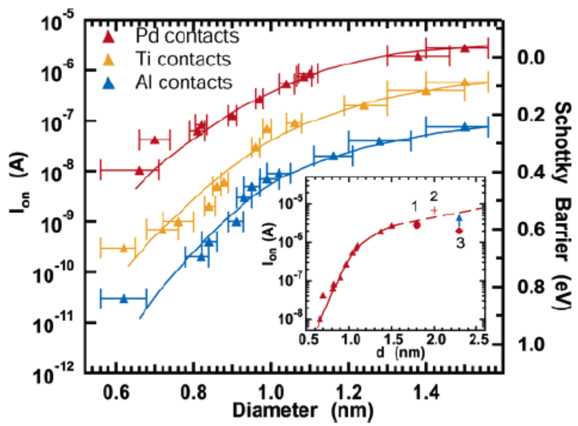
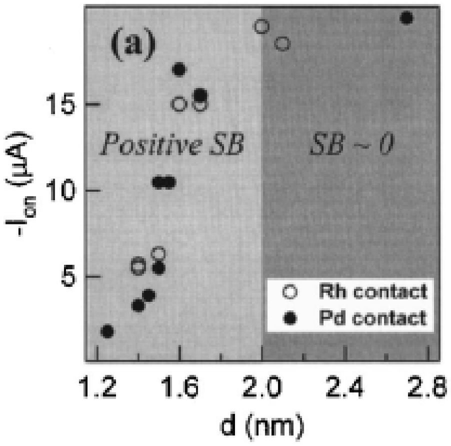
F. Léonard and A. A. Talin, *Physical Review Letters* **97**, 026804 (2006).

Experimental Observations for Contacts to Carbon Nanotubes





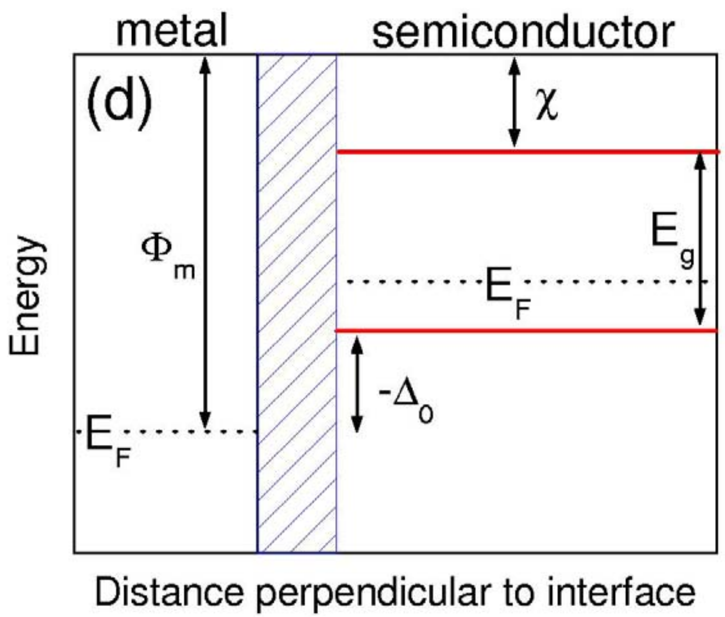


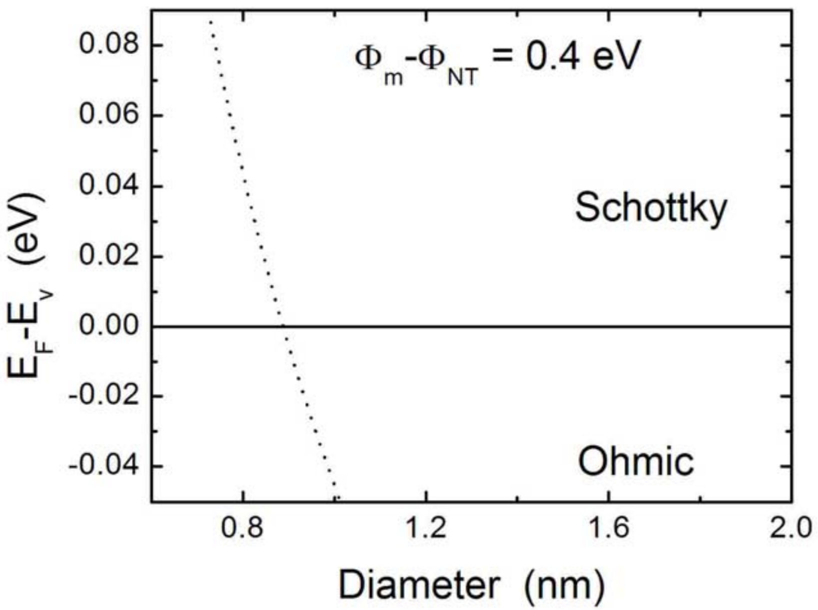


Chen et al, *NL* (2005).

Kim et al, *APL* (2005).

Simplest Picture: Direct Band Alignment

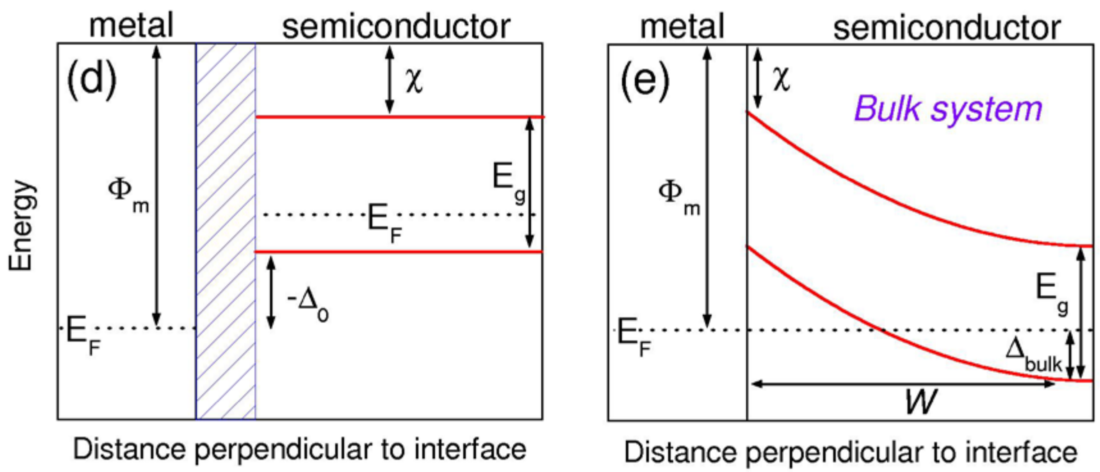




$$\Delta_0 = E_g + \chi - \Phi_m$$

For CNTs: $$E_g = \frac{2a\gamma}{d}$$

Charge Transfer

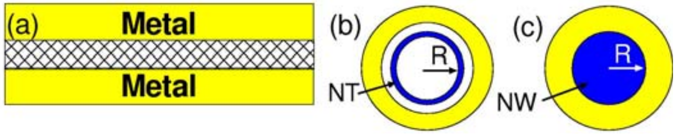


$$\Delta_{bulk} = E_g + \chi - \Phi_s$$

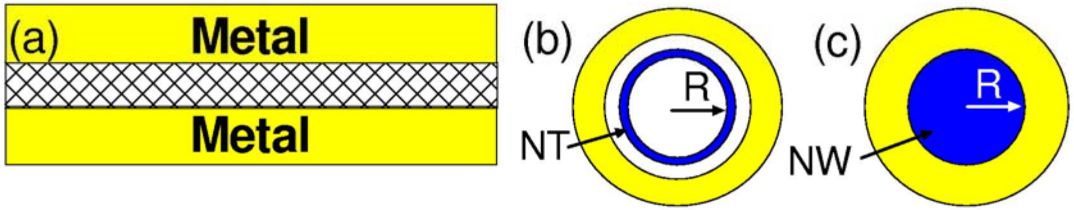
For undoped NT:

$$\Delta_{bulk} = \frac{E_g}{2}$$

Key nanoscale physics: $d << W$



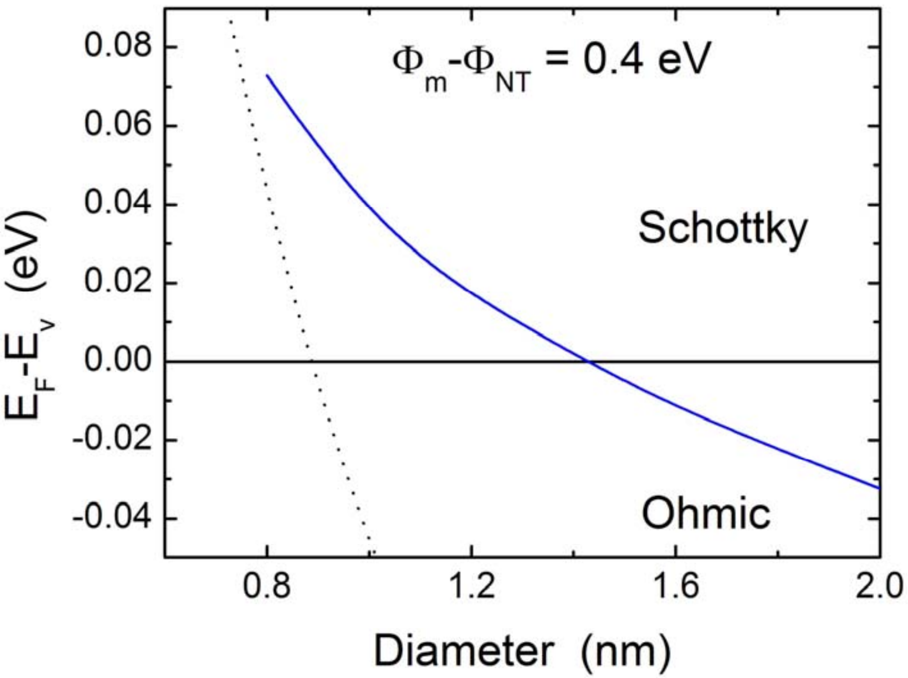
Model



$$\sigma = eN\int D\left(E + eV_{NT}\right)f\,(E - E_F)\,dE$$

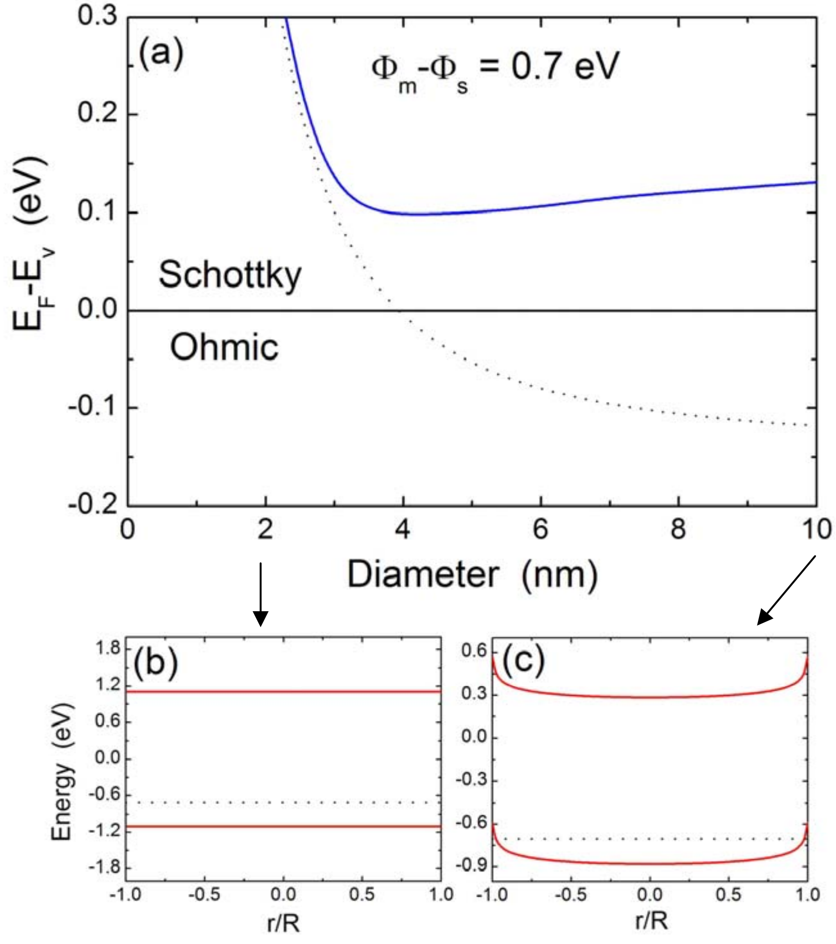
$$eV_{NT} = -\sigma\frac{eR}{\varepsilon_0}\ln\frac{R+s}{R} = -\frac{e^2}{C}\sigma$$

Carbon Nanotubes



$$d^* = d_0\left(1 + \frac{\alpha}{C}\sqrt{\frac{kT}{\Phi_m - \Phi_{NT}}}\right)$$

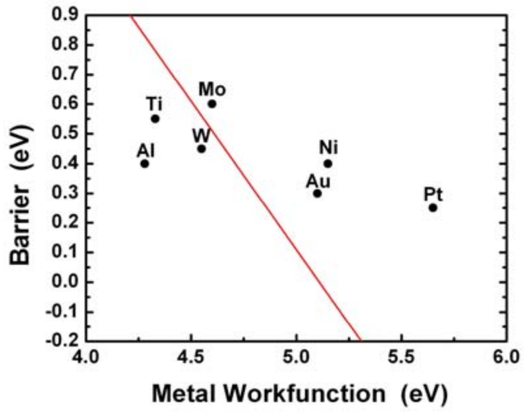
Nanowires

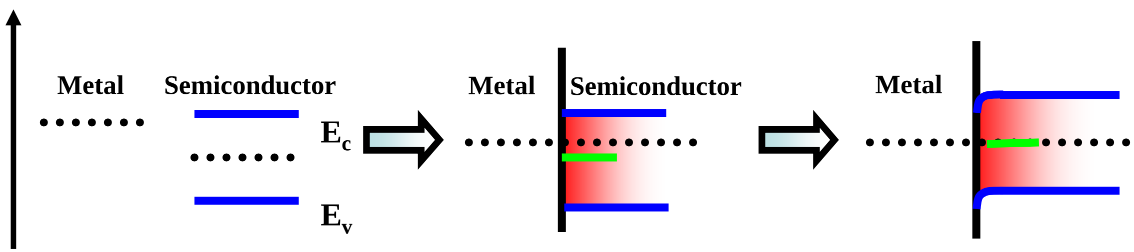


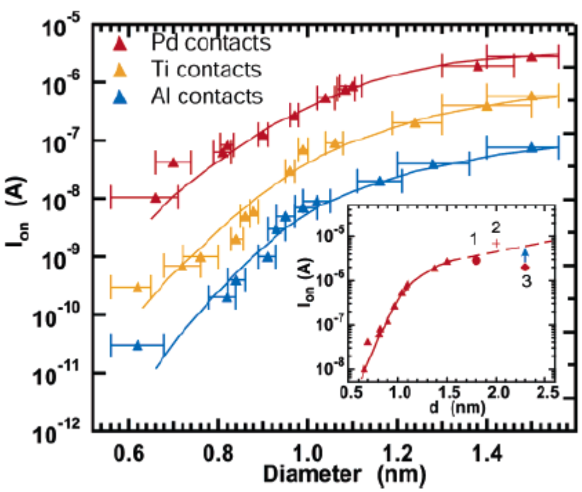
(a)
Φm-Φs = 0.7 eV
Schottky
Ohmic
EF-Ev (eV)
Diameter (nm)
0.3
0.2
0.1
0.0
-0.1
-0.2
0
2
4
6
8
10
(b)
(c)
Energy (eV)
r/R
1.8
1.2
0.6
0.0
-0.6
-1.2
-1.8
0.3
-0.3
-0.9
-1.0
-0.5
0.0
0.5
1.0

Fermi Level Pinning

Bulk Silicon







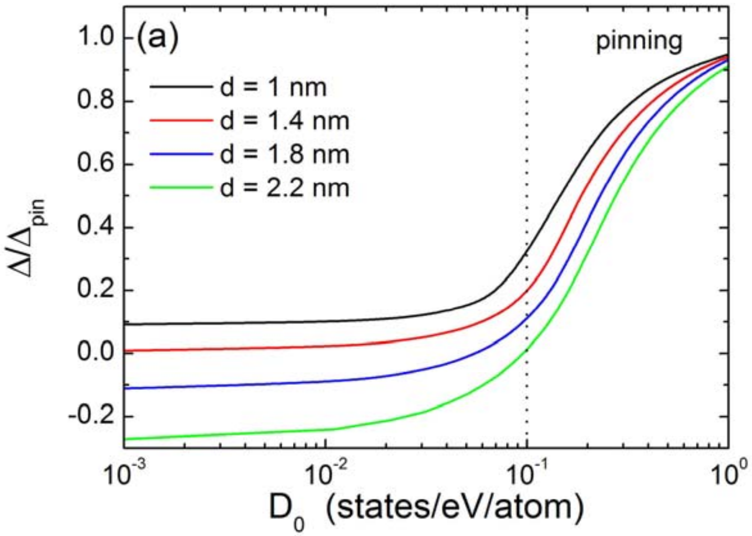
$$\sigma(r) = eN\int D\big(E + eV(r)\big) f(E - E_F)\,dE + \sigma_{pin}$$

$$\sigma_{pin}(r) = D_0 N_A\big[E_F - E_N(r)\big]h(r)$$

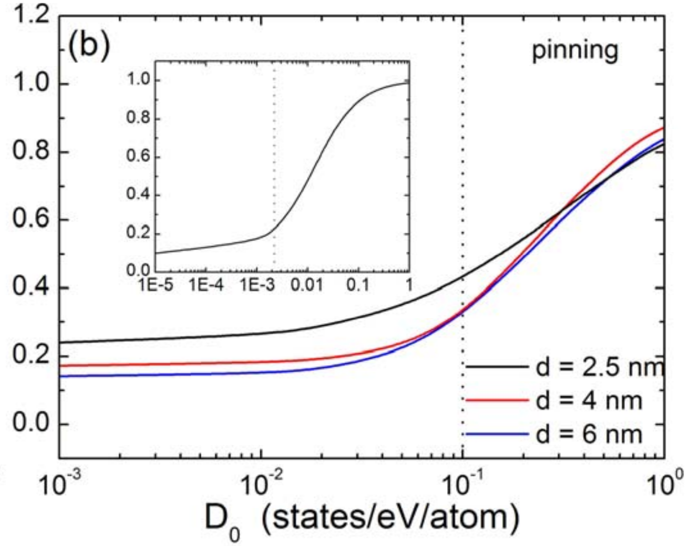
$$h(r) = \begin{cases} \delta_{r,R} & \text{NTs} \\ e^{-(R-r)/l} & \text{Nanowires} \end{cases}$$

Weak Fermi Level Pinning in Q1D systems

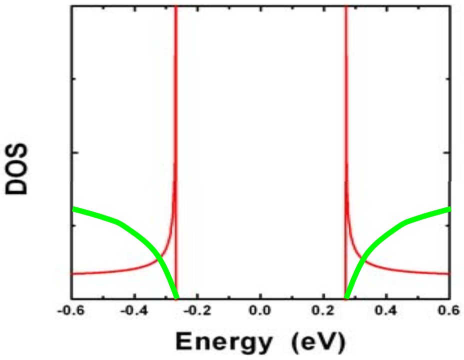
Nanotubes



Nanowires

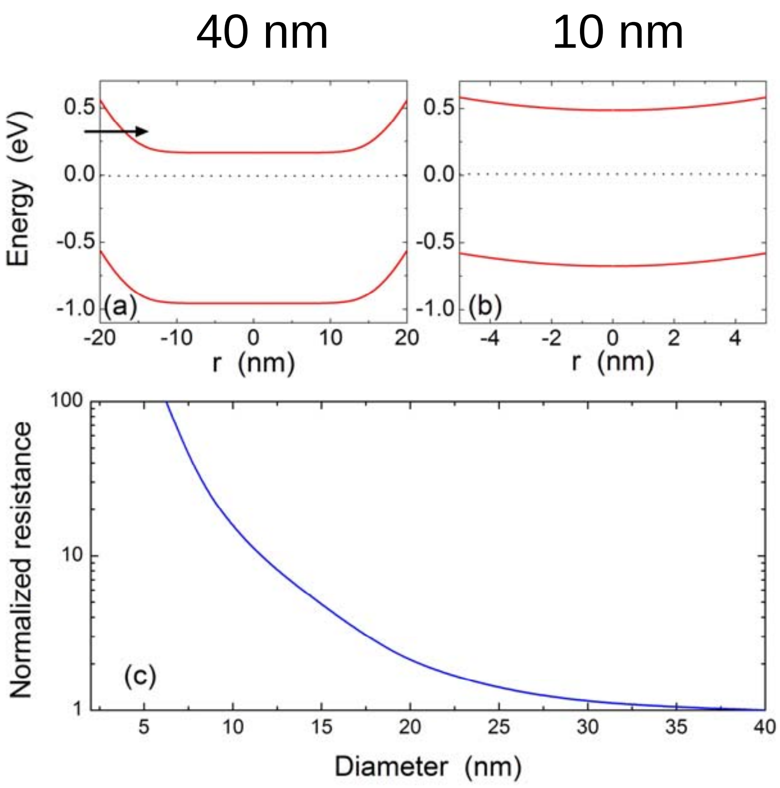


Key nanoscale physics:



$$\frac{\sigma_{NW}}{\sigma_{bulk}} \approx 100$$

Breakdown of Doping Approach



Conclusions

- Band re-alignment due to charge transfer is weak, in contrast to bulk contacts

- Schottky barriers are smaller than would be expected from the bulk limit

- Fermi level pinning is weaker for Q1D structures

- As nanowire diameters are reduced, larger doping levels are required to obtain ohmic contacts