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Transport through carbon nanotube wires

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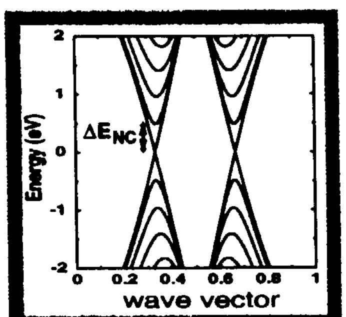
Outline

- Motivation
- Model & Assumptions
- Results
- Bragg reflection & Zener tunneling
- Defects

Motivation

- What is the current carrying capacity of nanotube wires?
- Georgia Tech group: Small increase in dI/dV with bias
- Delft group: Decrease in dI/dV with applied bias



Relevant bias at which electrons are injected into non crossing subbands is ΔE_{NC}

size	(5,5)	(10,10)	(20,20)	(40,40)
ΔE_{NC} (eV)	1.9	0.96	0.5	0.25

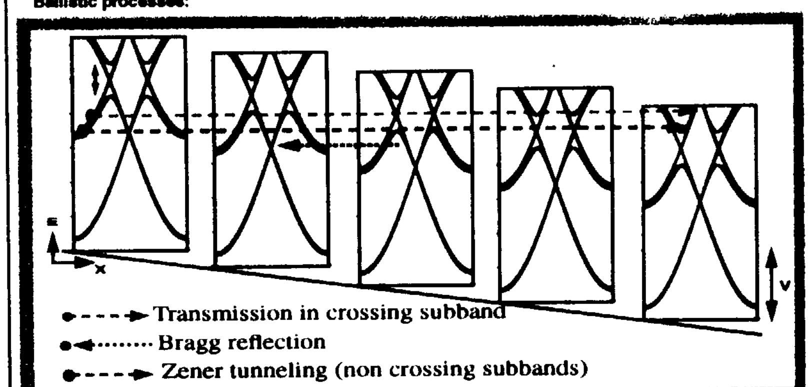
For example, in a (20,20) nanotube electrons are injected into over 20 subbands at an energy of2.5eV.

The maximum conductance if the Fermi energy is at 2.5 eV is ~ $40e^2/h$

Conductance as a function of applied bias rather than as a function of gate bias?

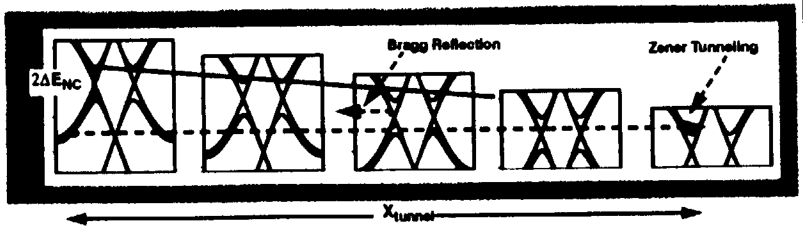
Semiclassical picture at an applied bias

Ballistic processes:



The relative importance of these processes in determining the current depends on:

- nanotube diameter
- length scale over which the potential drops
  - Lin et. al, Phys. Rev. B, 56, 4996 (1997): large screening length
  - Screening length is usually larger away from equilibrium

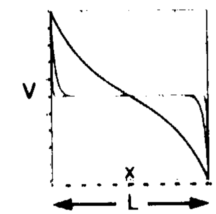


- A unique feature of the nanotube band structure: electron incident in the non crossing subband has to pass through a region where *only* the crossing subbands are present:
  - Bragg reflected at band edges
  - Transmitted by inter subband Zener tunneling.
- The strength of the two processes are determined by:
  - Tunneling distance (X_{tunnel})
  - Barrier height, $2\Delta E_{NC}$
  - Scattering and Defects
- ΔE_{NC} α 1/Diameter. So, the importance of Zener tunneling increases with increase in nanotube diameter.

Model

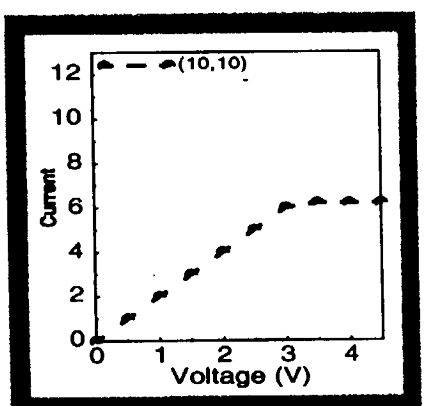
- Phys. Rev. B 58, 4882 (1998)
- pi-orbital based tight binding method
- Ideal contacts
- Potential Drop
  - Linear
  - Exponential (Screening length, L_{sc})

$$V(x) = \frac{V_a}{2}\{1 + \frac{1+e^{\frac{L}{L_{sc}}}}{e^{\frac{L}{L_{sc}}} - e^{-\frac{L}{L_{sc}}}} e^{-\frac{x}{L_{sc}}} - \frac{1+e^{-\frac{L}{L_{sc}}}}{e^{\frac{L}{L_{sc}}} - e^{-\frac{L}{L_{sc}}}} e^{\frac{x}{L_{sc}}}\}$$



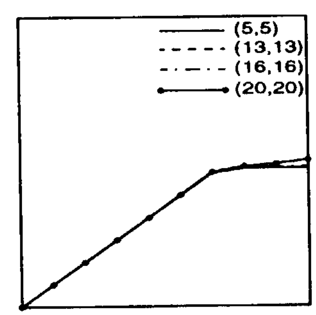
  - L=2400 Å, L_{sc}=10, 50, 500 Å

I-V

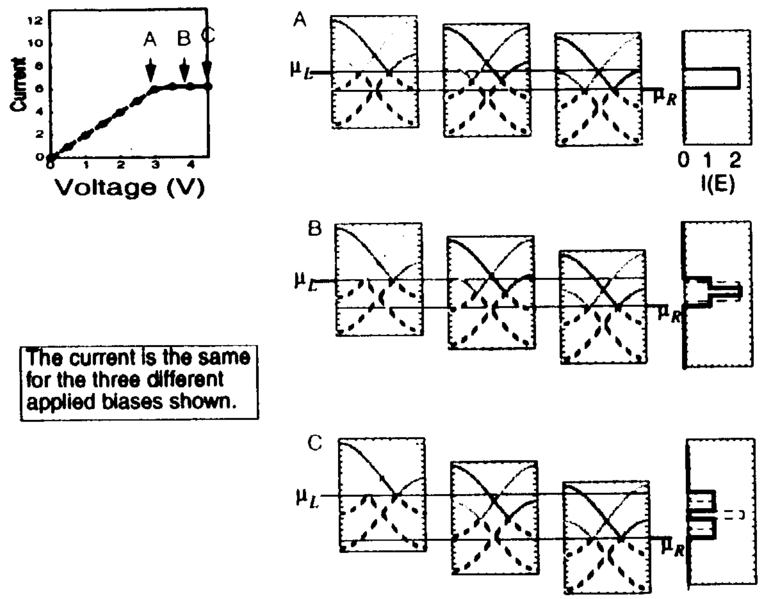


- L=60 Å
- dI/dV ≈ $4e^2/h$ for $V_a < 3.1$ V
- dI/dV ≈ 0 for $V_a > 3.1$ V

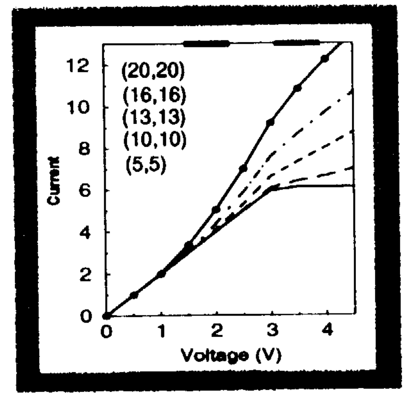
- ΔE_{NC} = 0.98eV;
- $V_a < \Delta E_{NC}$, injection only into crossing subbands - $4e^2/h$
- $V_a > \Delta E_{NC}$ - Electrons are injected into non crossing subbands, and they are Bragg reflected - $4e^2/h$



- ΔE_{NC} = 1.9eV; 0.5eV



The current is the same for the three different applied biases shown.



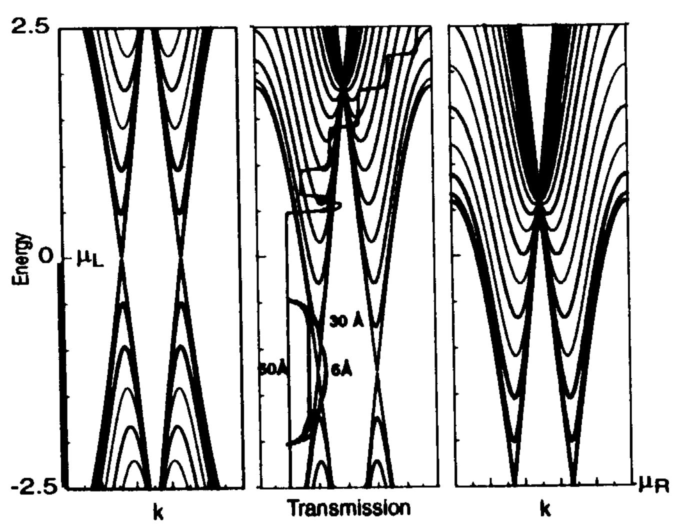
- L=10 Å
- dI/dV ≈ $4e^2/h$ for $V_a < 2\Delta E_{NC}$
- Threshold changes with diameter
- Barrier height (ΔE_{NC}) decreases with increase in diameter
- Total Current increases with increase in diameter
- dI/dV > 0 for $V_a > 3.1$ V, except for the (5,5) nanotube
- (5,5) nanotube $\Delta E_{NC} \approx 1.9$eV

The differential conductance is NOT comparable to the increase in the number of subbands.

For a (20,20) nanotube, there are 35 subbands at E = ± 3.5V.

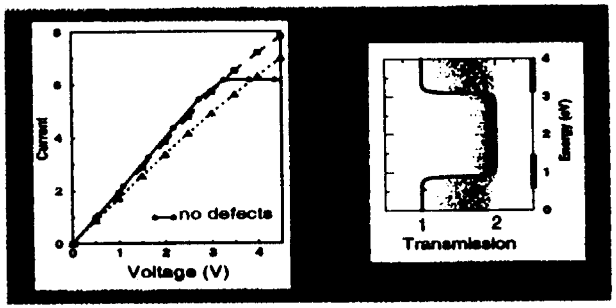
Transmission versus Energy (V_a = 2.5V)

- L = 60, 30, 6 Å

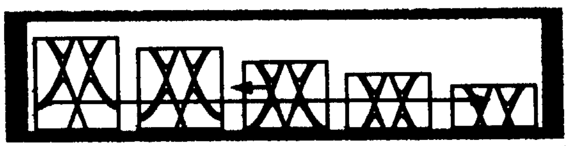


Influence of Defects

- New transmission paths involving inter subband scattering
- Gradual drop in potential - Zener tunneling

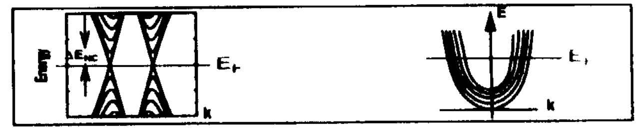


- Enhanced dI/dV for $V_a > 3.1V$
- In spite of inter subband scattering, $dI/dV < 4e^2/h$

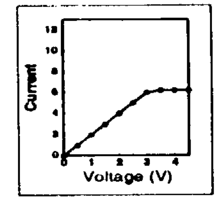


Conclusions

- dI/dV versus V does not increase in a manner commensurate with the increase in number of subbands.



- Small diameter nanotubes [(5,5) ΔE_{NC} ≈1.9eV]: Zener tunneling is ineffective.
- $dI/dV \approx 4e^2/h$



- Barrier height, $\Delta E_{NC} \propto 1/\text{Diameter}$

  As a result, Zener tunneling contributes to current with increase in nanotube diameter.
- The increase in dI/dV with bias is much smaller than the increase in the number of subbands