UCONN ENGR-ECE4243/6243 **Solution** HW# 3 09/26/16 F. Jain

HW3 Conductivity Quantization in Nanowires and CNTs

Q.1(a). Calculate the minimum value of resistance in a nanowire.

Q. 1. Minimum value of resistance is

$$1/(2e^2/h) = \frac{h}{2e^2} = \frac{6.65\times10^{-34}\ \text{J-s}}{2(1.6\times10^{-19})^2} = \frac{6.65\times10^{-34}}{2\times2.56}\times10^{38} = \frac{6.65}{2\times2.56}\times10^{4}\ \Omega = 1.2988\times10^{4}\ \Omega$$

Q.1(b) Point out the difference between elastic and inelastic scattering of electrons in a semiconductor.

Q.2. why is the phonon scattering is phase breaking or coherence breaking and results in non-ballistic transport?

Q.2. Phonon scattering involves energy exchange with electrons or holes. The final energy after phonon scattering is

$$E_{final} = E_{initial} \pm E_{phonon}$$

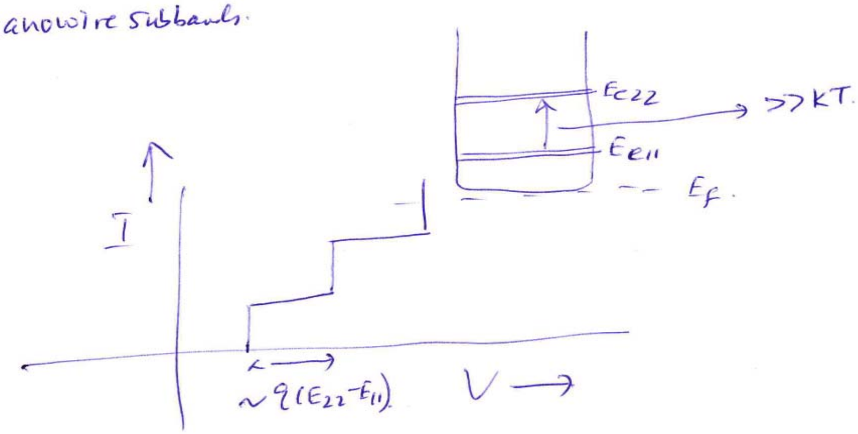
+ for phonon absorption
− for phonon emission.

Once the energy of electron (or hole) is changes its frequency ν or angular frequency ω change as $E = h\nu$.

Once ν changes, one cannot keep track of the phase of electron wave (Plain wave $e^{j(\omega t - kx)}$)

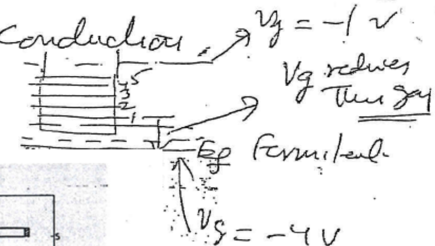
Q.3 If we have discrete energy levels with some energy width in a nanowire, how the current will flow. Will this cause conductivity quantization in nanowires and nanotubes as we increase the value of current?

Q. 3. The current will flow in steps provided kT is much smaller than energy difference between (2) nanowire subbands.



Q.4. Explain the resistance plots of Wharam et al paper (page 99-102A).

Q.4 Higher gate voltage means more sub-bands are permitted to participate in conduction. This is due to the fact that



Fermi level moves closer to levels in the conduction band

$V_g = -1$ V means about 10 subbands participate.

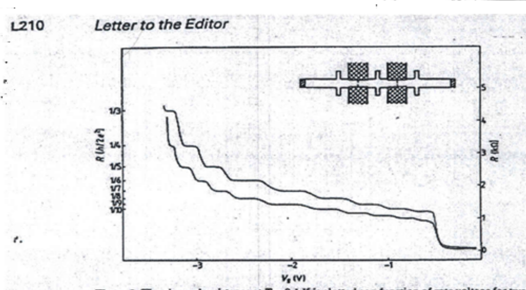


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Figure 1. The channel resistance at $T \sim 0.1$ K is plotted as a function of gate voltage for two different carrier concentrations induced by illumination. The existence of a resistance quantised in units of $h/2ie^2$, where i is the number of occupied sub-bands, is illustrated. The inset shows a schematic diagram of the device used in this work. The split gate itself is 0.5 μm wide and 0.4 μm long. Two split gates are illustrated, one of which is selected for the experiment.

Q.5. What is the ballistic or quasi-ballistic current transport also called global transport.

That is, electron wave mode (like fundamental) converts to another one.

This causes conductivity fluctuation.

The scattering centers are not distributed at same locations. So conductivity changes from nanowire sample to other.

Q.6. What is the primary cause of universal conductivity fluctuation in nanowires and nanotubes.

In Ballistic or quasi-ballistic transport electrons propagate as waves.

The scattering due to walls of samples and due to scattering centers do not change their energy.

Only the direction is changes.

Direction change is equivalent to mode conversion of a wave having multiple modes.

That is, electron wave mode (like fundamental) converts to another one.

This causes conductivity fluctuation.

The scattering centers are not distributed at same locations. So conductivity changes from nanowire sample to other.

Global Transport: Electron waves propagate like transmission line or microwave waveguides.

Any change at any location affects the whole (or global) system.