Solution # 6

1. a) No, the nanowire shall be doped. The dominant carriers shall be holes because from the gate voltage dependence we can see that the positive gate voltage decreases the nanowire conductance which is consistent with p-type materials. The slight suppression of the conductance at low source-drain bias is due to the slight nonohmic property of the contacts.

b) The reason why the mobility is very low is following: (i) poor contacts between single-crystal nanowire and source-drain metals and (ii) additional scattering from the boundary of the nanowire.

To improve the performance, we can increase the doping level or improve the contacts.

c) They improved the device performance by making good contacts between the SiNW and source-drain metal with thermal annealing at 300-600°C for 3 minutes and passivation of oxide defects. In undoped bulk Si material, the mobility is about 3000 cm²/Vs at room temperature. But due to contact problem and additional boundary scattering in the nanowire, the mobility in 1D wire is much lower than that of bulk Si. As the authors can reach mobility with peak value of 1350 cm²/Vs, which has same order of that of bulk Si, we shall say this is very big improvement.

2. a) \[ \Delta E = 2 \times \frac{\hbar^2 k^2}{2m^*} = \frac{\hbar^2}{m^*} \left( \frac{\pi}{t_{Si}} \right)^2. \]

b) \[ J_0(kr) = 0 \Rightarrow kr \geq 2.4 \Rightarrow \Delta E = \frac{\hbar^2 k^2}{2m^*} = \frac{\hbar^2}{m^*} \left( \frac{2.4}{d_{Si}/2} \right)^2 = \frac{2\hbar^2}{m^*} \left( \frac{2.4}{d_{Si}} \right)^2. \]

c) From the above results, we can see that the cylindrical case has the larger confinement effect. The reason for this is that the area of cross section of cylindrical rod is smaller than that of square rod, less cross section area, larger confinement effect.

For \( t_{Si} = 5nm, m^* = 0.31m_0 \), we get \( \Delta E \cong 112meV \) which will increase the threshold voltage by 0.11V. This increase is very significant. At room temperature, the thermal energy is \( 26meV \), when \( t_{Si} \cong 10nm \), then confinement energy will be equal to the thermal energy, so we shall worry about the quantum voltage shift if \( t_{Si} \) is smaller than 10nm.