ECE609 Spring06

MID-TERM EXAM- SOLUTIONS

1 Review of Modern Physics

- $\lambda = h/(mv)$ so (i) $6.63 * 10^{-35} m$, (ii) $7.2 * 10^{-10} m$. The de Broglie wavelength for the bullet is immensurably small. A bullet is a classical particle and therefore, does not need to be treated as wavelike (unlike the electron).
- the density of probability to find an electron in the second energy state is $|A \sin(2\pi x/L)|^2$, which is maximum at two locations: $x = L/4$ and $x = 3L/4$.
- Solutions are given in Fig.1. In the case of $0 < E < U$ there is a probability to find an electron in the region $x > 0$ (evanescent waves - origin of the tunneling effect). Two examples of potential barriers are given by: (i) the work-function W_0 involved in the photo-electric effect, (ii) Built-in potential for the P-N junction.

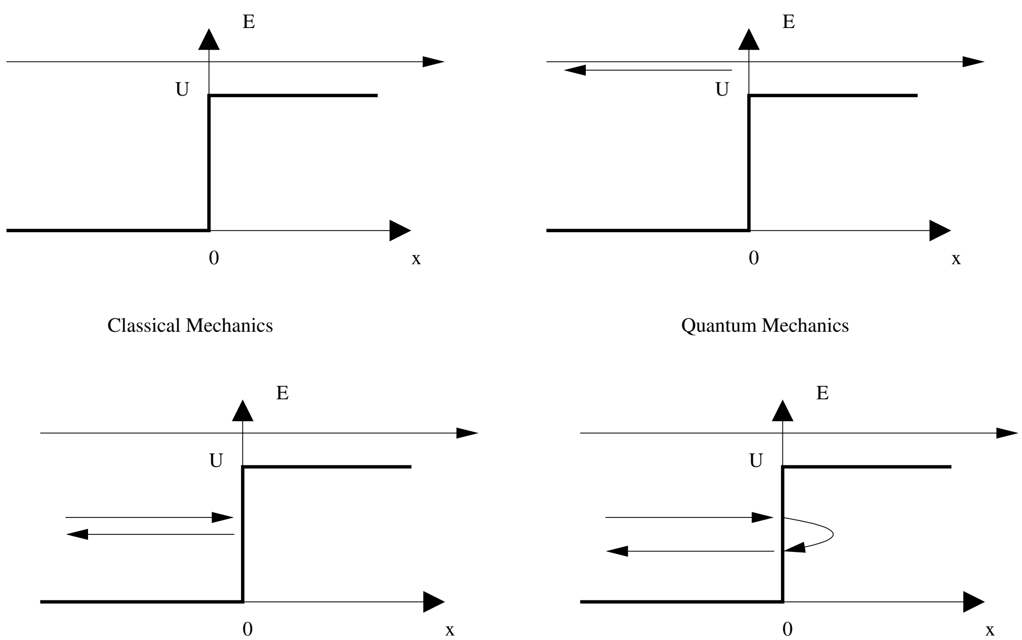

Figure 1: Potential barrier- Different configurations

- $E - E_F = 2.94 k_B T$

2 Energy Band Theory

- (ii) to (i): $\Psi_k(r+R) = e^{ikR} e^{ikr} u_k(r+R) = e^{ikR} e^{ikr} u_k(r) = e^{ikR} \Psi_k(r)$

  (i) to (ii): we set $u_k(r) = e^{-ikr} \Psi_k(r)$, then $u_k(r+R) = e^{-ikr} e^{-ikR} \Psi_k(r+R) = u_k(r)$, since $e^{-ikR} \Psi_k(r+R) = \Psi_k(r)$.

- $$\nabla(e^{ikr}u_k(r)) = ike^{ikr}u_k(r) + e^{ikr}\nabla u_k(r)$$
  $$\Delta(e^{ikr}u_k(r)) = -k^2e^{ikr}u_k(r) + ike^{ikr}u_k(r) + ike^{ikr}u_k(r) + e^{ikr}\Delta u_k(r) = e^{ikr}(-k^2 + 2ik\nabla + \Delta)u_k(r)$$
  Finally, we obtain the expression we saw in class.

3 Semiconductor Fundamentals

- Jeopardy: These are the questions:
  1. What is an intrinsic semiconductor ?
  2. What is $1 - f_{FD}$ (where F_{FD} is the Fermi-Dirac distribution)?
  3. What is happenning if the temperature increases in a semiconductor?
  4. What is an extrinsic semiconductor ?
  5. What is a semiconductor ?
  6. What is a semiconductor ?
  7. Why do we want to introduce donor atoms in a semiconductor ?
  8. Why do we want to introduce acceptor atoms in a semiconductor ?
  9. What is happenning in a semiconductor if the doping concentration becomes very large ?
- $1 - f_{FD}(E) = 0.01$, so $T = 756K$
- 10%, 5% and 1%.

4 Theory of Electrical Conduction

1. - $$\frac{\partial p(x)}{\partial t} = D_p\frac{\partial^2 p(x)}{\partial x^2} - p(x)\mu_p\frac{\partial E}{\partial x} - \mu_p E\frac{\partial p(x)}{\partial x} + G - \frac{p - p_0}{\tau_p}$$
   - (i) steady state condition $\frac{\partial p(x)}{\partial t} = 0$, (ii) no electric field $E = 0$, (iii) no generation due to an external source of energy $G = 0$. We get:
     $$0 = D_p\frac{\partial^2 p(x)}{\partial x^2} - (p(x) - p_0)/L_p^2$$
   - $$A = \frac{(p(0) - p_0)e^{W/L_p}}{2\sinh(W/L_p)}$$
     $$B = \frac{(p_0 - p(0))e^{-W/L_p}}{2\sinh(W/L_p)}$$
     we get finally:
     $$p(x) - p_0 = (p(0) - p_0)\frac{\sinh{(W - x)/L_p}}{\sinh(W/L_p)}$$
     if $W << L_p$, $p(x) - p_0 = (p(0) - p_0)(1 - x/W)$, the density of carriers decreases linearly in function of x.
     if $W >> L_p$, $p(x) - p_0 = (p(0) - p_0)\exp(-x/L_p)$, the density of carriers decreases exponentially in function of x.

- $$J_{diff}(W) = \frac{qD_p}{L_p}(p(0) - p_0)\frac{1}{\sinh(W/L_p)}$$

  if $W << L_p$, $J_{diff}(W) = \frac{qD_p}{L_p}(p(0) - p_0)$, the current is independant of x.
  if $W >> L_p$, $J_{diff}(W) = 0$, the current is equal to zero far from the injection x.

2. by neutrality $n = p$, also $n = p = N_0 \left(\frac{m_e m_h}{m^2}\right)^{3/4} \exp(-\beta(Ec - Ev)/2) = 3.7 * 10^12m^{-3}$, we then get $\rho = (nq(\mu_e + \mu_h))^{-1} \simeq 1.8 * 10^6 \Omega.m$

5 P-N junctions

- ....
- $N_a l_p = N_d l_n$ so $l_n = 0.103nm$, see also p103 of textbook; $l_n << l_p$ since the N-side is heavily doped.