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Theory of Semiconductor Devices
Final exam

June 11, 2018

Note
Closed Book.
Show all work on these pages. When backside page is used, make a note on the front page.
Don't forget to **write down your name and ID on each answer sheet.**

- Useful data and formulae

$n_i = 1.5\times10^{10}\text{cm}^{-3}$ in silicon at 300 K
$k_B T(300\text{K}) = 0.0259$ eV
$q = 1.602\times10^{-19}\text{C}$
$h = 6.63\times10^{-34}$ J · sec $= 4.14\times10^{-15}$ eV · sec
$c = 3\times10^{8} m/s$
$1\ W = 6.24\times10^{18} eV/s$

$$f(E) = \frac{1}{1+\exp(\frac{E-E_f}{k_B T})}$$

$$n_0 = n_i\exp[(E_f - E_i)/k_B T] = N_c\exp[-(E_c - E_f)/k_B T] \qquad N_c = 2(\frac{2\pi m_n^* k_B T}{h^2})^{3/2}$$

$$p_0 = n_i\exp[(E_i - E_f)/k_B T] = N_v\exp[-(E_f - E_v)/k_B T] \qquad N_v = 2(\frac{2\pi m_p^* k_B T}{h^2})^{3/2}$$

$$n_0 p_0 = n_i^2 \qquad p_0 + N_d^+ = n_0 + N_a^-$$

$$J_n = qn\mu_n\mathcal{E} \qquad J_p = qp\mu_p\mathcal{E} \qquad \frac{1}{\mu} = \frac{1}{\mu_1} + \frac{1}{\mu_2} + \ldots.$$

$$\sigma = q(n\mu_n + p\mu_p) = 1/\rho \qquad R = \rho L/A$$

$$I(x) = I_0 e^{-\alpha x}$$

$$\delta n = \delta p = g_0\tau_n \qquad \tau_n = 1/\alpha_r(n_0 + p_0)$$

$$n = n_i e^{(F_n - E_i)/k_B T} \qquad p = n_i e^{(E_i - F_p)/k_B T}$$

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#1. (20 pts) The linear PN junction is the extreme approximation that is opposite to the abrupt-junction approximation: the charge concentration changes from the most positive value (the donors on the N-type side) to the most negative value (the acceptors on the P-type side) in the smoothest possible way. The linear PN junction is the one where the charge concentration in the depletion layer changes linearly,

$$\rho_{charge} = -ax$$

where a is the slope of the linear dependence. Solve the Poisson equation for this case to determine the dependence of the depletion layer width and the depletion layer capacitance on reverse-bias voltage.

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#2. (20 pts) A junction is formed between a metal and an n-type Si doped with $N_d = 3 \times 10^{16}$ / cm^3 at 300 K. The metal has a work function of 4.5 eV. Knowing that the electron affinity of Si is 4 eV at 300 K, answer the following questions.

(a) Assuming that the junction is ideal and that there is no Fermi level pinning, indicate if the M-S junction will be Ohmic or rectifying. Justify your answer.

(b) Draw a detailed equilibrium band diagram of the M-S junction including the correct location of the Fermi level and the correct values of the contact potential V_0 and the barrier height Φ_B. You should label the transition region width as W, but it is not necessary to explicitly calculate its value.

(c) Determine the profile of the semiconductor conduction band, $E_c(x)$ near the M-S interface. Assume that the interface is at x=0 and the unbiased device is at thermal equilibrium.

Hint: Solve Gauss's equation and make use of the fact that $E(x) = -dV(x)/dx$ and in the quasi neutral region the electric field is zero.

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#3. (20 pts) Draw Energy levels in a MOS system with p-type silicon before and after contact. Assume that the work function of metal is lower than that of semiconductor. From the band diagram, determine the metal-semiconductor work function difference. Drive the flat band voltage and threshold voltage in ideal case (i.e. no oxide charge).

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#4. (20 pts) Let's consider n-P heterojunction. Assume that the narrow gap semiconductor is doped n-type and the wide gap semiconductor is doped p-type. When the heterojunction is formed, a space charge region will exist due to the diffusion or redistribution of free carriers at thermal equilibrium. Draw energy band diagrams before and after contact. Drive the equations for 1) charge density, 2) electric field, and 3) electrostatic potential as a function of x.

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#5. (a) (5 pts) Explain the Schottky Barrier diodes and their advantages and drawbacks compared to conventional pn junction diodes.

(b) (5 pts) Explain Ohmic contact and transparent conducting oxides.

(c) (5 pts) Draw/explain C-V curves in MOS capacitor at low frequency.

(d) (5 pts) Explain ‘escape cone’ in light emitting diodes.

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