
EE566 Solid State Devices

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Assignment 2

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Reading

Chapters 3 & 4 of textbook (MS).

Problem 1[1]

We learnt that the electron density in a bulk (3D) semiconductor in the most general case is given by $n_{3d} = N_C^{3d} F_{1/2}(\eta)$, where N_C^{3d} is the conduction band effective density of states, $F_{1/2}(...)$ is the Fermi-Dirac integral of order $1/2$, and $\eta = (E_F - E_C)/kT$. Similar results exist for electrons free to move in 2D and 1D.

a) Show that if electrons are confined to move in *two dimensions*, the sheet density (in /cm^2) is given by

$$n_{2d} = N_C^{2d} F_0(\eta) = N_C^{2d} \ln(1+e^{\eta}),$$

where $N_C^{2d} = m^* kT/\pi\hbar^2$. Use the 2D DOS $g_{2d}(E) = m^*/\pi\hbar^2 \cdot \theta(E-E_c)$, where $\theta(E-E_c)$ is the unit-step function. Plot $E_F - E_C$ as a function of the 2DEG density (typical values are $10^{11}/cm^2 < n_{2d} < 10^{12}/cm^2$) for $T = 0, 77,$ & $300\ K$ for a 2DEG located in a GaAs quantum well. Show that at low temperatures, n_{2d} becomes *independent* of temperature. Give examples of devices where electron motion is 2-dimensional.

b) Show that if electrons are confined to move in one dimension, linear density (in /cm) is given by

$$n_{1d} = N_C^{1d} F_{-1/2}(\eta),$$

Where $N_C^{1d} = \sqrt{2m^* kT/\pi\hbar^2}$. Use the 1D DOS $g_{1d}(E) = \sqrt{2m^*/\pi^2\hbar^2(E-E_c)}$. Show that under non-degenerate conditions, the Boltzmann approximation $n_{1d} \approx N_C^{1d} e^{(E_F - E_C)/kT}$ still holds. Give examples of 1D devices.

Problem 2

Concentration gradients in a semiconductor lead to diffusion currents. However, the flow of charges causes electric fields, which limit the flow of a net current through equal and opposite flow of drift current. To show this, you are given a piece of semiconductor that has an *arbitrary* doping profile $N_D(x)$ along the *x*-axis.

a) Find the *internal* electric field profile $E(x)$ that develops inside the semiconductor at a temperature *T*. Explain all your steps at arriving at this result.

b) What happens to the electric field as the temperature changes?

c) Verify from your result that $E(x) = 0$ for a constant doping profile.

d) Plot the field for a silicon sample at room temperature and mobility $\mu = 400 cm^2/V.s$ where the doping profile from the surface ($x = 0$) is given by $N_D(x) = N_0 e^{-x/\lambda}$ ($N_0 = 10^{18}/cm^3$, λ=100nm).

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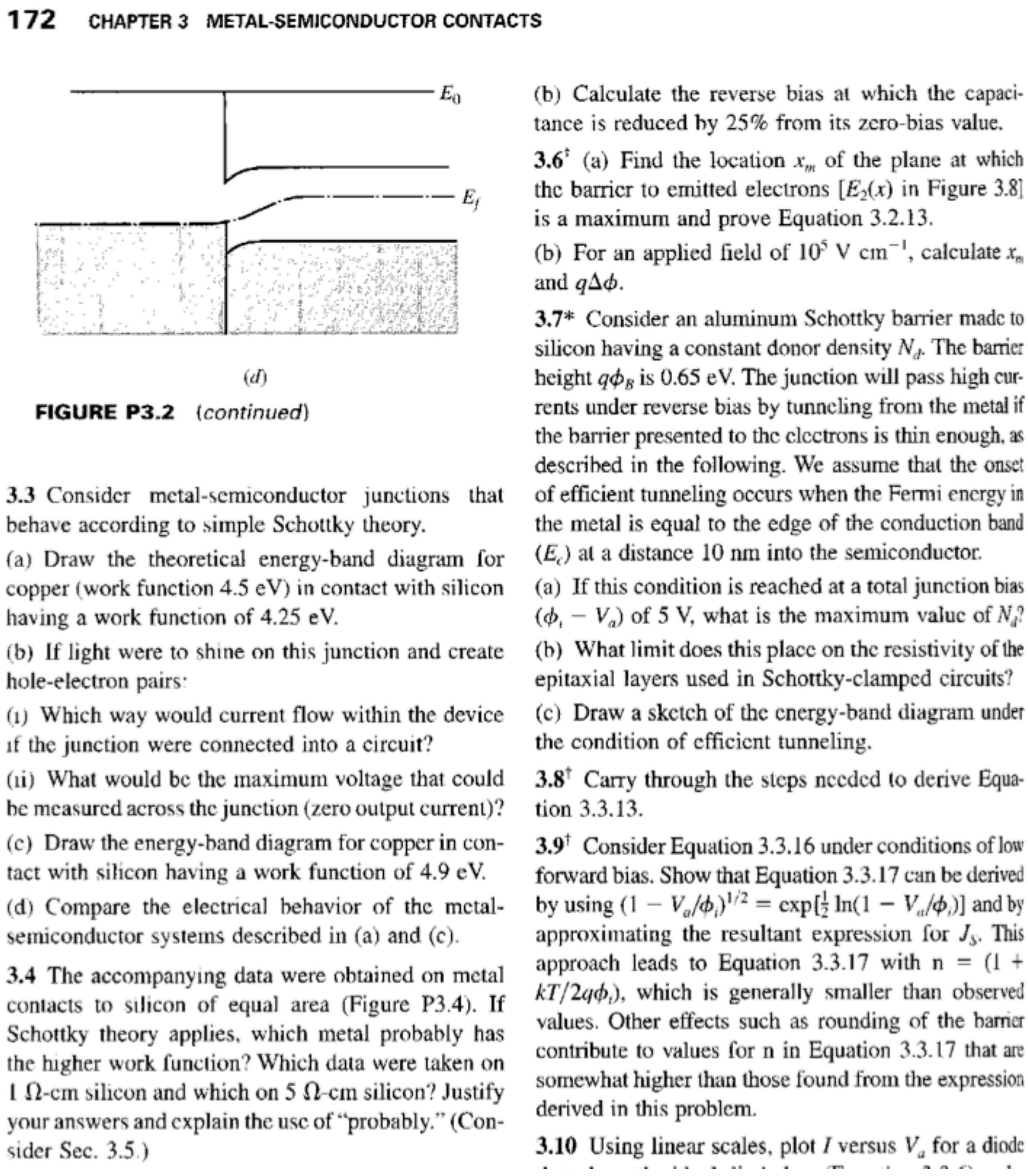
[1] Remember to use proper <u>units</u> and <u>label</u> every figure/plot. Turn in your answers worked out neatly. Please attach this question sheet to your solution when you turn it in.

Problem 3 (from Ref. MKC): Problem 3.3 below.

Problem 4 (from Ref. MKC): Problem 3.7 below.



(*d*)

FIGURE P3.2 (*continued*)

3.3 Consider metal-semiconductor junctions that behave according to simple Schottky theory.

(a) Draw the theoretical energy-band diagram for copper (work function 4.5 eV) in contact with silicon having a work function of 4.25 eV.

(b) If light were to shine on this junction and create hole-electron pairs:

(i) Which way would current flow within the device if the junction were connected into a circuit?

(ii) What would be the maximum voltage that could be measured across the junction (zero output current)?

(c) Draw the energy-band diagram for copper in contact with silicon having a work function of 4.9 eV.

(d) Compare the electrical behavior of the metal-semiconductor systems described in (a) and (c).

3.4 The accompanying data were obtained on metal contacts to silicon of equal area (Figure P3.4). If Schottky theory applies, which metal probably has the higher work function? Which data were taken on 1 Ω-cm silicon and which on 5 Ω-cm silicon? Justify your answers and explain the use of "probably." (Consider Sec. 3.5.)

(b) Calculate the reverse bias at which the capacitance is reduced by 25% from its zero-bias value.

3.6† (a) Find the location x_m of the plane at which the barrier to emitted electrons [$E_2(x)$ in Figure 3.8] is a maximum and prove Equation 3.2.13.

(b) For an applied field of 10^5 V cm^{-1}, calculate x_m and $q\Delta\phi$.

3.7* Consider an aluminum Schottky barrier made to silicon having a constant donor density N_d. The barrier height $q\phi_B$ is 0.65 eV. The junction will pass high currents under reverse bias by tunneling from the metal if the barrier presented to the electrons is thin enough, as described in the following. We assume that the onset of efficient tunneling occurs when the Fermi energy in the metal is equal to the edge of the conduction band (E_c) at a distance 10 nm into the semiconductor.

(a) If this condition is reached at a total junction bias ($\phi_i - V_a$) of 5 V, what is the maximum value of N_d?

(b) What limit does this place on the resistivity of the epitaxial layers used in Schottky-clamped circuits?

(c) Draw a sketch of the energy-band diagram under the condition of efficient tunneling.

3.8† Carry through the steps needed to derive Equation 3.3.13.

3.9† Consider Equation 3.3.16 under conditions of low forward bias. Show that Equation 3.3.17 can be derived by using $(1 - V_a/\phi_i)^{1/2} = \exp[\frac{1}{2}\ln(1 - V_a/\phi_i)]$ and by approximating the resultant expression for J_S. This approach leads to Equation 3.3.17 with n = $(1 + kT/2q\phi_i)$, which is generally smaller than observed values. Other effects such as rounding of the barrier contribute to values for n in Equation 3.3.17 that are somewhat higher than those found from the expression derived in this problem.

3.10 Using linear scales, plot I versus V_a for a diode