EE566 Solid State Devices

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Dept of Electrical Engineering
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Assignment 3

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Reading: Chapter 5 of the Textbook (MS).

Problem 1[*]

We saw in class that the I-V characteristics of rectifying Schottky junctions can be calculated in 2 ways – one by heuristic arguments, and the second by Schottky's drift-diffusion theory. The third method is based on thermionic emission theory, and was first used by the celebrated physicist Hans Bethe in 1943. His result for a Schottky-diode of barrier height $q\Phi_B$ is $J = J_0[\exp(qV_a / kT) - 1]$ (the same as by other methods!), where $J_0 = A^* T^2 \exp(-q\Phi_B / kT)$, and

$$A^* = \frac{4\pi q m^* k_B{}^2}{h^3} \approx 120 \left(\frac{m^*}{m_0} \right) \frac{A}{cm^2 K}$$

is the effective Richardson's constant and m^* is the el. effective mass. You will now verify this result.

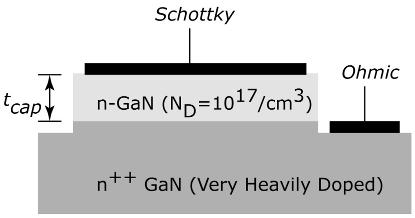
a) Derive this result assuming that the current is ENTIRELY due to thermionic-emission. You might need to read up the corresponding section in the textbook (MS) for help.

Answer the following *qualitatively* with help of sketches -

b) The derivation holds for *both* a Schottky and a Mott-diode – why?

c) What would happen to the current-voltage characteristic of the Schottky diodes if I shine light with photon energy larger than semiconductor bandgap?

Problem 2



The GaN structure shown was grown epitaxially, but due to the carelessness of the grower, the thickness of the cap layer t_{cap} was not recorded. After growth, a Schottky-diode was formed by etching and metal evaporation steps, by depositing Nickel ($q\Phi_B$=1eV) on the cap layer, and an ohmic contact on the heavily doped layer under it. From your knowledge of device physics, you will find the thickness of the cap layer, t_{cap}. You have to figure out where to draw charge-field-band diagrams in the way.

a) What is the depletion thickness x_{depl} with *no applied bias* for a Nickel- (very long n-GaN) Schottky diode with doping $N_D=10^{17}/cm^3$? What is the electric field at the surface of the semiconductor of the long Schottky diode? Is it larger or smaller than the critical breakdown field for GaN $F_{BR} \sim 5$ MV/cm?

b) The careless grower had performed a capacitance-voltage measurement on the structure shown above. He tells you that the capacitance *did not change appreciably* as he increased the reverse bias on the Schottky diode. However, he forgot to note down the *value* of the (constant) capacitance! Using his information, what can be inferred about t_{cap} in relation to x_{depl} calculated in part (a)? If he had recorded the capacitance, could you have found t_{cap}?

c) You take matters into your own hands, and measure the current-voltage characteristic of the Schottky diode. You observe that the diode has a sharp and well-defined breakdown at a reverse bias of $|V_R|$=38.4 Volts. Find t_{cap}. (***NEXT PAGE…***)

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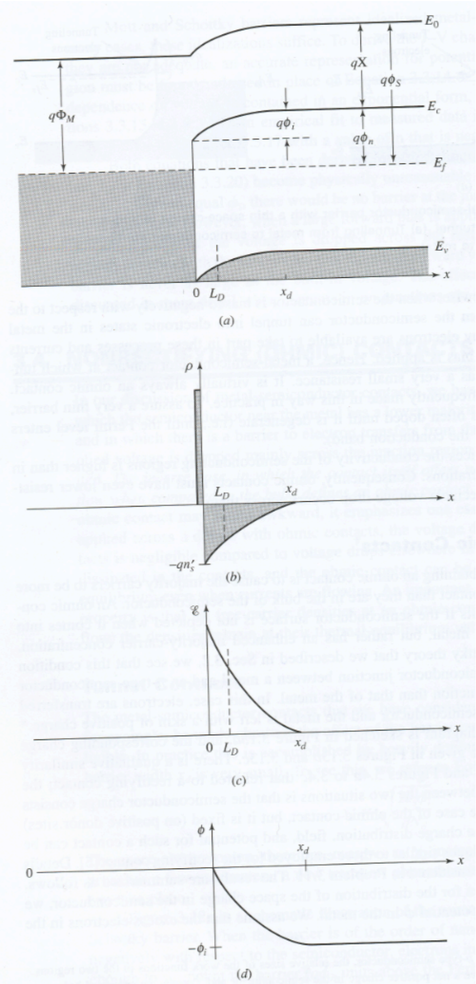
[*] Remember to use proper units and label every figure/plot. Turn in your answers worked out neatly. Please attach this question sheet to your solution when you turn it in.

Problem 3

In class, we discussed about the case of a metal-semiconductor Schottky Ohmic contact by suitable choice of work functions. The figure below shows the charge-field-band diagram for such a contact. Show the following –



a) Explain why if we have an <u>accumulation</u> region at the surface of the semiconductor, the I-V characteristics are not rectifying, but Ohmic.

b) What is the built-in voltage ϕ_i if the other parameters are as shown in Fig (a)?

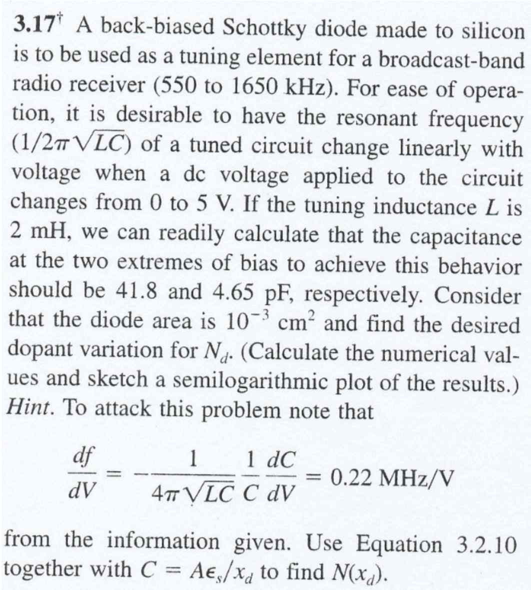
c) Set up the Poisson equation in the space-charge region of the semiconductor. Solve the equation to show that the electric field varies as $F(x) = \sqrt{2}\frac{V_T}{L_D}\left(1+\frac{x}{\sqrt{2}L_D}\right)^{-1}$ (Fig c), and the accumulation charge varies as $n(x) = n(x=0)/\left(1+\frac{x}{\sqrt{2}L_D}\right)^{2}$ (Fig b). Here $V_T = kT/q$ is the thermal voltage, and $L_D = \sqrt{\varepsilon_S kT/q^2 n(x=0)}$ is the 'Debye-length' at the surface.

d) Show that the space-charge accumulation layer extends out to roughly $x_d \sim \sqrt{2}L_D(\exp[\frac{\phi_i}{V_T}]-1)$ into the semiconductor.

e) Choose a suitable metal and semiconductor combination that will give you such a contact. Identify the doping in the semiconductor. Find the surface Debye length and built-in potential for the contact from the results derived above.

Problem 4 (**MKC** Problem 3.17) – An application for a Schottky diode.

(Use the relation between capacitance and doping we derived in the class – Eq. 3.2.10 is that same equation.)



3.17[†] A back-biased Schottky diode made to silicon is to be used as a tuning element for a broadcast-band radio receiver (550 to 1650 kHz). For ease of operation, it is desirable to have the resonant frequency ($1/2\pi\sqrt{LC}$) of a tuned circuit change linearly with voltage when a dc voltage applied to the circuit changes from 0 to 5 V. If the tuning inductance L is 2 mH, we can readily calculate that the capacitance at the two extremes of bias to achieve this behavior should be 41.8 and 4.65 pF, respectively. Consider that the diode area is 10^{-3} cm^2 and find the desired dopant variation for N_d. (Calculate the numerical values and sketch a semilogarithmic plot of the results.) *Hint*. To attack this problem note that

$$\frac{df}{dV} = -\frac{1}{4\pi\sqrt{LC}}\frac{1}{C}\frac{dC}{dV} = 0.22 \text{ MHz/V}$$

from the information given. Use Equation 3.2.10 together with $C = A\epsilon_s/x_d$ to find $N(x_d)$.