Final comprehensive assignment

EEE 410-ETE 411: Semiconductor Devices and Technology

Section 1

Spring 2020 semester

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Full Marks: 110

Notice to all students: Please submit with your full name, student ID, Course Name, Course code and Section (Top sheet with university logo just like regular assignment case). Do not plagiarize. Consult textbook and my notes to solve the numerical and analytical with short descriptive problems. A word or pdf version of submission is preferred. Check for viruses while you save the file and return to me in on-line google classroom.

1 (a) Briefly describe incomplete ionization at lower temperature than T = 300 K. [5]

(b) Suppose no is the electron density in the conduction band and nd is the unionized electron density in the donor states. Find the fraction of electrons in percentage still on the donor states for T = 150 K and T = 420 K for ND = 3.2 × 1016 cm-3. Value of Ec-Ed = 0.038 eV (fixed at all temperatures). Nc at T = 300 K is 2.8 × 1019 cm-3. ( Hint: You need to find Nc any T from the 300 K reference value. Consult relevant part of the textbooks for the equations). [10]

2 (a) Of the two parameters, scattering time and effective mass, at much lower temperature in the vicinity of 100 K or less, which of these two parameters will change more (increase or decrease)? As a result, comment on the value of bulk mobility at this reduced temperature (increase or decrease). [5]

(b) A silicon sample has Nc at T = 300 K 2.8 × 1019 cm-3. Donor type dopant is added to the material with ND = 3.5 × 1015 cm-3. Assume 100% ionization of donors. Find the value of Ec-EF in eV. Show it in a band diagram assuming Ev = 0 eV and EG = 1.12 eV. Also find EF-EFi in eV.

[10]

(c) Now consider acceptor dopants NA = 3.3 × 1015 cm-3 is added to part 3(b) at T = 300 K. After compensation, comment whether the silicon sample is still n-type or p-type. Find the new value of Ec-Ev. Assume 100% ionization for acceptors. Show it in a band diagram. If ni for silicon is 1.5 × 1010/cm3, what is the minority carrier concentration? [10]

Consult the textbook for relevant equations to solve the above problem.

3. A silicon semiconductor resistor in the shape of a rectangular bar with a cross sectional area of A = 2.25 × 10-2 cm2. The bar has a length of 2.7 cm and doped with a concentration of ND = 4.3 × 1015 cm-3 donor atoms at T = 300 K. If the bias voltage is 7.2 V across the length of the bar and the values of μn and μp are 1310 cm2/V-s and 520 cm2/V-s respectively, then using ni = 1.5 × 1010 /cm3 for silicon at T = 300 K, compute

(i) drift field E in V/cm

(ii) electron and hole drift current density

(iii) drift current flowing through the slab

(iv) resistivity of the slab. [2.5 ×4=10]

Use relevant equations from the textbook to solve this problem.

FINAL

4 (a) When high doping is used for both p and n-side substrate of a p-n junction diode, show that Vbi at T = 300 K is a higher value. Will the reverse saturation current Is increase or decrease as Vbi is increased? State all the parameters through which Vbi is impacted. What parameter affects Vbi through a change in band gap? [5]

(b) A silicon p-n junction diode at T = 300 K has doping concentrations of NA = 3.8 × 1016 **/** cm3 and ND = 7.3 × 1017 **/** cm3. Value of ni at T = 300 K is 1.5 × 1010 **/** cm3 . Calculate

(i) built in potential Vbi

(ii) total depletion width W in μm

(iii) the depletion capacitance in F/cm2 [10]

For the equations, look for relevant equations from the textbook.

5 (a) Draw the induced electrostatic potential across the depletion width in μm ( -xp to xn) of a p-n junction diode at zero bias for which (i) p and n-side doping are low and (ii) p and n-side doping are high. [5]

(b) A silicon p-n junction at T = 300 K has the following parameters NA = 5.2 × 1015 **/** cm3 and ND = 6.2 × 1016 **/** cm3, Dn = 22 cm2/s , Dp = 14 cm2/s, τno = 7.2 × 10-7 s and τpo = 3.4 × 10-7 s. The cross sectional area is A = 2.8 × 10-3 cm2 and the forward bias voltage is Va = 0.618 V. Calculate the total current Idiode in ampere for this p-n junction diode. Value of ni at T = 300 K is 1.5 × 1010 **/** cm3.

[10]

For the equations, look for relevant equations from the textbook.

6. For a p-substrate silicon MOS capacitor at T = 300 K, the substrate doping is NA = 3.3 × 1016 **/** cm3. Value of ni at T = 300 K is 1.5 × 1010 **/** cm3.

(i) what is bulk potential φB ?

(ii) When the surface is inverted, what is the total surface band bending φs ?

(iii) For ϕm = 4.26 eV and χ = 4.01 eV, what is the flat band voltage VFB?

(iv) Find the maximum depletion width xDT (μm) when the surface is inverted.

(v) How does bulk doping affects the VFB? For a particular semiconductor if doping is fixed, how can you make VFB less negative?

For relevant equations other than the ones provided with question 6, consult the textbook.

(vi) Find the threshold voltage of this device VT in V if the oxide thickness tox = 8.8 nm. Consider NA = 3.3 × 1016 **/** cm3. All other parameters are as given in question 6. [6 ×2.5 =15]

For relevant equation in question 6 (vi) consult the textbook and for VFB, use the equation provided above.

7 (a) Suppose for an n-channel enhancement mode MOSFET, VT = 0.4 V. Draw the Ids as a function of Vds for Vgs = 0.5 V, 1.2 V and 2.5 V in a single plot. Make sure the sketch is pictorial and numerical accuracy is not warranted here. Focus on Ids (sat) shift with different Vgs levels as you plot. Point the position of Vds(sat) on all these curves. [5]

(b) An ideal n-channel silicon MOSFET has the following parameters VT = 0.38 V, μn = 780 cm2/V-s, tox = 9.2 nm, W = 11.8 μm and L = 1.28 μm. Find the drain current Ids for this MOSFET when

(i) Vgs = 0.2 V and Vds = 0.11 V,

(ii) Vgs = 1.85 V and Vds = 0.65 V,

(iii) Vgs = 2.15 V and Vds = 2.4 V.

(iv) For which of the above bias case, the channel is pinched off? Is the channel pinched off just at the drain junction or away from the drain junction? Explain with comments. [4 ×2.5=10]

Useful equation: