NE 205: Semiconductor Devices and IC Technology
Indian Institute of Science, Bangalore.
Autumn Semester 2019, Digbijoy N. Nath
Homework IV Total points: 40

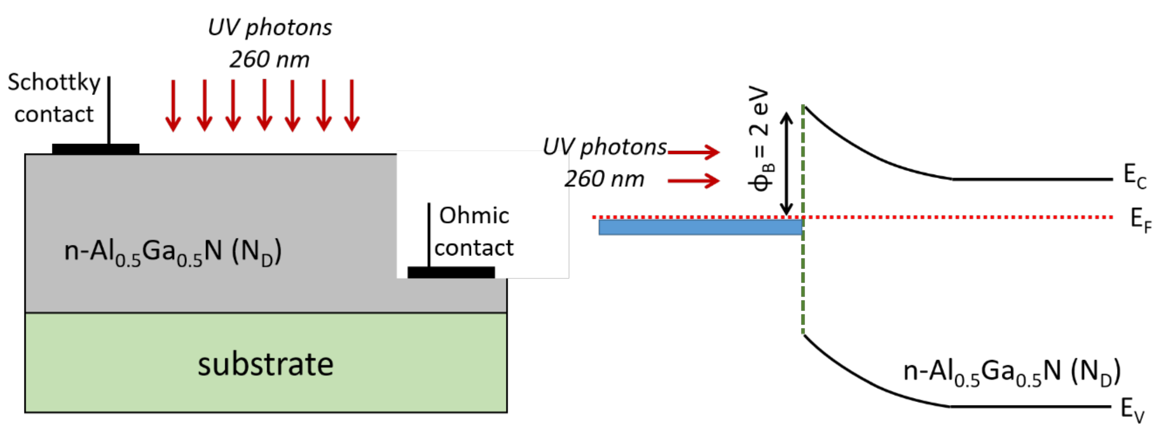
1. Consider a GaAs p^+-i-n^+ photodetector with an active area of 100 μm^2 which is biased at a high enough reverse bias for carriers to attain saturation velocity in the i-layer. Assume the total series resistance to be R = 20 Ω, electron velocity to be 3×10^7 cm/s while the hole velocity is 7×10^6 cm/s.

   a) Plot the 3-dB cut-off frequency of this detector as a function of the i-layer thickness from 30 nm to 3 µm. What is the optimum thickness of i-layer for maximum f_{3dB}?

   b) What would be the best f_{3dB} if the device area was 1 mm^2? Take ε= 13

   8 + 4 = 12

2. You need to design a high-speed $Al_{0.5}Ga_{0.50}N$-based deep-UV Schottky photodetector for tactical missile plume detection (λ = 260 nm). **Your goal is to estimate the doping range possible for the n-$Al_{0.5}Ga_{0.50}N$layer**. The band diagram and the schematic are shown in the figure below.



As shown in the figure, the Schottky detector consists of a thick n-doped $Al_{0.5}Ga_{0.50}N$ layer grown on some substrate. Schottky contact is formed on the top with Nickel (ϕ_B = 2 eV), while Ohmic contact is formed by using Ti/Au metal contact on etched $Al_{0.5}Ga_{0.50}N$as shown. The equilibrium band diagram (below the Schottky contact) is also shown. Take $N_C = 4 \times 10^{18}$ cm^{-3}. The following assumptions are to be made:

- Only those UV photons which are absorbed within the depletion region of n-$Al_{0.5}Ga_{0.50}N$ will contribute to photo-current and hence to efficiency. And note that the depletion region thickness depends on the reverse bias applied on the Schottky contact.

- Photons are absorbed uniformly within the depletion region.
- Extraction and transmission efficiencies are 100%. There is no reflection of photons. Thus EQE = IQE.

You need to meet the following three specifications for the detector:

a) The detector needs to be operated under zero bias, i.e. no voltage is applied on the Schottky contact.

b) The EQE should be at least 60% under operation. The absorption coefficient of $Al_{0.5}Ga_{0.50}N$at 260 nm is $\alpha = 2x10^5$ cm^{-1}.

c) The 3-dB cut-off frequency should be at least 10 GHz or more For simplicity, ignore RC delay. Assume that the transit delay depends on electrons traveling the depletion thickness only. Electron saturation velocity for $Al_{0.5}Ga_{0.50}N$ = $2x10^7$ cm/s. Assume that all carriers travel at v_{sat} in the depletion region.

Make sure that the maximum electric field is lower than the breakdown field of 5 MV/cm. (The dielectric constant for $Al_{0.5}Ga_{0.50}N$is $\varepsilon = 9$).

What is the range of doping (N_D) you can use for n-$Al_{0.5}Ga_{0.50}N$and still meet the above conditions? What is the maximum EQE this detector can exhibit under these conditions with the doping range you obtain? 14

3. Consider a silicon n-p-n BJT with the following parameters -

$$D_n = 30\ cm^2/s$$
$$D_e = 10\ cm^2/s$$
$$L_n = 15\ \mu m$$
$$L_e = 5\mu m$$

Consider $N_{A,Base} = 2x10^{17}$ cm^{-3}, $N_{D,Collector} = 10^{16}$ cm^{-3}. Base-collector junction is reverse biased at 5 V. Ignore the depletion in the forward biased E-B junction, and that the base current is predominantly the current due to injected holes from the base to the emitter.

Plot the gain β as a function of emitter doping for the range $N_{D,Emitter} = 10^{18}$ cm^{-3} to $6x10^{19}$ cm^{-3}, for W_{base} (metallurgical) = 1 µm and 0.5 µm [i.e. there will be two graphs in the same β vs. $N_{D,E}$ plot: one corresponding to W_B = 1 µm, and another for W_B = 0.5 µm].

Please note that beyond a doping of $5x10^{18}$ cm^{-3}, the emitter band gap will undergo a band gap shrinkage given by $|\Delta E_G| = 22.5[N_D*300/(10^{18}*T)]$ meV.

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