Data Provided: You may need to use the following physical constants:

Charge on electron:	-1.602×10^{-19} C
Free electron rest mass:	$m_0 = 9.110 \times 10^{-31}$ kg
Speed of light in vacuum	$c = 2.998 \times 10^{8}$ m s^{-1}
Planck's constant:	$h = 6.626 \times 10^{-34}$ Js
Boltzmann's constant:	$k = 1.381 \times 10^{-23}$ JK^{-1}
Melting point of ice:	0^{o}C = 273.2 K
Permittivity of free space:	$\varepsilon_0 = 8.854 \times 10^{-12}\,\mathrm{Fm}^{-1}$
Permeability of free space:	$\mu_0 = 4\pi \times 10^{-7}\,\mathrm{Hm}^{-1}$

The University of Sheffield

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Semiconductors for Electronics and Devices

Answer **ALL** questions.

Part A: State whether each of the following statements is TRUE or FALSE and justify your answer with a brief (2 lines maximum) justification.

1) For conduction to occur in silicon at room temperature, you must have the presence of donors and acceptors.

   False: A completely undoped semiconductor will conduct as there will always be intrinsic carriers.

2) High doping in semiconductors can enable higher temperature device operation.

   True: Higher doping means that the semiconductor can go to higher temperatures before it starts to act like an intrinsic semiconductor.

3) The built-in voltage (or contact potential) in a p-n junction is approximately $0.6E_g$, where E_g is the band-gap of the semiconductor.

   False: The true value is close to the actual band-gap.

4) In a metal-semiconductor schottky junction, the reverse leakage current is determined primarily by the band-gap of the semiconductor.

   False: The reverse barrier depends on the relative work functions and thermionic emission over the metal-semiconductor barrier height.

5) If a semiconductor material can be used to make a good LED, it can potentially be used to make a laser.

True: A good LED implies a direct band-gap semiconductor and in theory, this could be used to make a good laser.

6) Any semiconductor material that can be used to make a solar-cell can also be used to make a LED.

False: Indirect semiconductors like Silicon make good solar cells but are poor as acting as light emitters.

7) In an enhancement mode MOST, the conducting channel under the gate first forms near the drain.

False: The mobile charge first forms under the source end of the gate as that is where the vertical electric field across the gate oxide is greatest.

8) When you have good compensation doping, the concentration of acceptors and donors in a semiconductor falls to below the intrinsic carrier concentration.

False: It is the net electron and hole concentration that decrease in compensation doping – the acceptor and donor concentrations do not change.

9) Most fibre based telecommunication systems use the semiconductor material InGaAs to make lasers and photodiodes.

True: The direct band-gap means that it can make good lasers and photodiodes and it can transmit well in 1550nm minima in optical fibres.

10) In an enhancement mode MOST, the drain current saturates as long as the gate voltage is equal to or larger than the drain voltage.

False: The gate voltage has to be larger than the drain voltage by at least the turn on voltage (V_T), for the drain current to saturate.

Part B:

1. a. **(i)** A semiconductor is known to contain both acceptors and donors. If you knew their concentrations, how would you determine if it is extrinsically doped or if it is effectively intrinsically doped?

(ii) What is the normal relationship between the acceptor concentration and hole concentration in a semiconductor at room temperature?

b. An intrinsic layer of GaAs is uniformly doped n-type such that the original intrinsic resistivity changes by a factor of $5\text{x}10^5$.

(i) What level of doping do you need to use?

You wish to make a light emitting diode (LED) from this material so need to further dope the top part of this semiconductor layer. You have a choice of doing this with donor or acceptor atoms.

(i) Which dopant type would you chose and why?

The intrinsic carrier concentration of GaAs at room temperature is 2×10^{12} cm^{-3}, and μ_e=0.85m^2 V^{-1} s^{-1}, μ_h=0.04m^2 V^{-1} s^{-1} and E_g=1.42eV. (Note: all the symbols have their usual meaning.

c. Draw and identify clearly the conduction band, valence band and Fermi-level of this LED when it has no external bias and is in equilibrium.

d. Sketch the shape of the output spectral response of this LED as a function of the wavelength. Indicate the expected peak position and the typical width of the spectral output in nanometers.

END OF PAPER

EEE 225 Part B Solution : 2014/2015

1(a) (i) If $|N_A - N_D| \gg n_i$, it is extrinsically doped

(ii) If $|N_A - N_D| \ll n_i$, it is intrinsically doped

(b)(i) We first work out the conductivity of the original intrinsic semiconductor using:

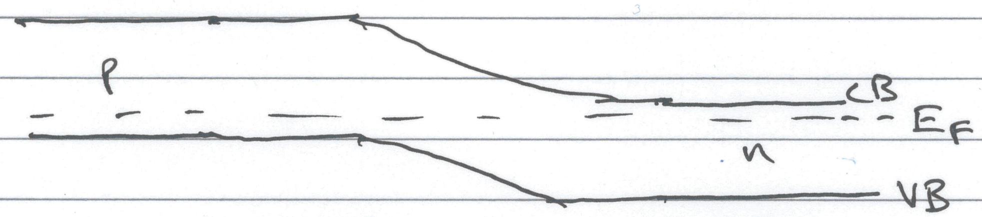
$$\sigma_i = e(n_i \mu_e + n_i)\mu_h$$

Any doping will increase σ_i, or decrease ρ_i (the resistivity.

$\therefore$ after n-doping, $\sigma_n = 5 \times 10^5 \sigma_i = e n \mu_e$ (ignore holes as it is n-doped). From this, you can get the n-type doping level.

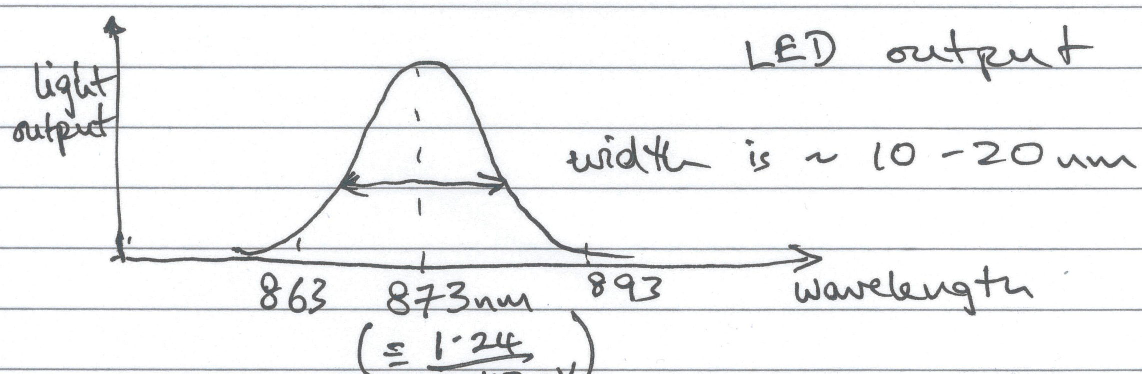
(ii) You have a n-type semiconductor. You need a p-n junction to make a LED, so you need to dope the top part with acceptors.

(c)



p-n junction in equilibrium.

(d)



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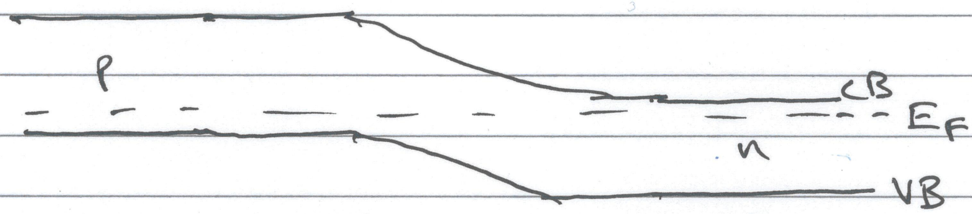

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