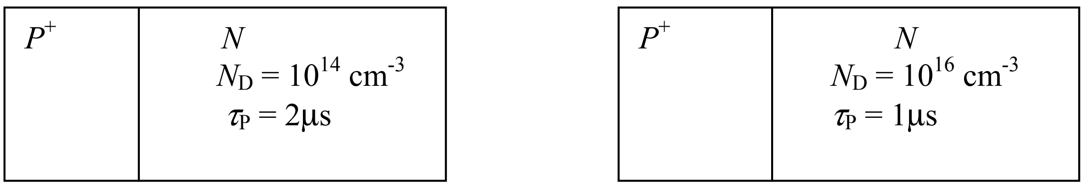
ECSE-2210 Microelectronics Technology
Class Activity 14 – Solution

1. Two silicon p^+-n step junction diodes are physically identical except for the n-side doping and the lifetimes. Compare the operation of the two diodes by answering the questions below. Try to explain by using physical reasoning, rather than using formula (One or two sentences are enough).

Diode #1 Diode #2



(a) Which diode will exhibit the larger built-in voltage, V_{bi} (also called the contact potential)?
Diode #2. From the doping concentrations we know that the $E_F - E_i$ in the n-side is larger for the second diode. Hence in equilibrium the bands have to bend more. As a result the V_{bi} is greater for the Diode #2.

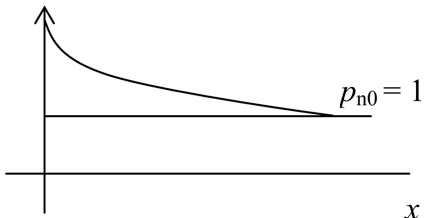
(b) Which diode will have a larger depletion layer width, W, for a given reverse bias?
Diode #1. For a given reverse voltage, the $\mathcal{E}$-vs.-x curve should occupy the same area since voltage is $\int \mathcal{E}\, dx$. Since $d\mathcal{E}/dx$ (compare the values of N_D !) is smaller for diode #1, the depletion region in diode #1 extends a longer distance away from the metallurgical junction.

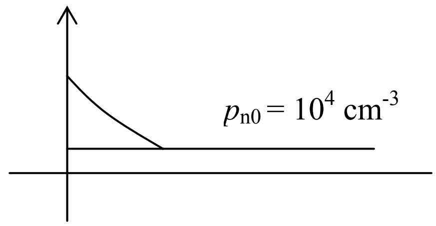
(c) Which diode will have a larger reverse saturation current, I_o ?
Diode #1. The reverse saturation current depends on the minority carrier concentrations p_{n0} and n_{p0} present in either side of the diode (se equation below):

I_o = hole current + electron current = $q\,A\,D_p/L_p \times p_{n0} + q\,A\,D_n/L_n \times n_{p0}$

In a p^+n junction you will always have $p_p >> n_n$.
(Majority hole concentration is much larger than majority electron concentration)
This results in (using the law of mass-action): $n_{p0} << p_{n0}$
You can therefore make the approximation: $I_o \approx q\,A\,D_p/L_p \times p_{n0}$
Since $L = (D\,\tau)^{1/2}$ we can also write $I_o = q\,A\,(D_p/\tau_p)^{1/2} \times p_{n0}$
In diode #1 the minority hole concentration p_{n0} is larger by a factor 100, and the lifetime τ_p is larger by a factor 2. So, I_o will be larger by a factor of $100/\sqrt{2}$ for diode #1.

(d) If the diodes are forward biased, qualitatively plot the minority carrier profiles in the n-region of each diode (Your plot should show the differences between these two diodes).





As the lifetime of the minority carriers in the Diode 1 is larger than in Diode 2, the injected carriers will travel a larger distance before they can recombine in Diode1. Therefore, the profiles are as shown above.

2. An abrupt Si p-n junction has the following properties at 300 K. Assume a junction area $A = 1\text{cm}^2$.

P-side	N-side
$N_A = 2 \times 10^{17}\text{cm}^{-3}$	$N_D = 3 \times 10^{15}$
$N_D = 10^{17}$ cm^{-3}	$N_A = 2 \times 10^{15}$
$\tau_n = 0.1$ µs	$\tau_p = 10$ µs
$\mu_P = 200$ cm^2/Vs	$\mu_n = 1300$ cm^2/Vs
$\mu_n = 700$ cm^2/Vs	$\mu_P = 450$ cm^2/Vs

$$\frac{D}{\mu} = \frac{kT}{q}$$

$$L = \sqrt{D\tau}$$

a. Calculate the built-in voltage, V_{bi}.
On the p-side
$N_A^{eff} = N_A - N_D = (2X10^{17} - 1017) = 1 \text{ x } 10^{17}\text{cm}^{-3}$
On the n-side
$N_D^{eff} = N_D - N_A = (3 \times 10^{15} - 2 \times 10^{15}) = 1 \text{ x } 10^{15}$ cm^{-3}

$V_{bi} = kT / q \times \ln [(N_A^{eff})_{p\text{-side}} \times (N_D^{eff})_{n\text{-side}} / n_i^2]$
$= 0.0259$ V x
$= 0.715$ V

b. Calculate the reverse saturation hole current.
First find D_p, L_p for n-side and D_n and L_n for p-side.

$D_p = 0.0259 \text{ V} \times 450 \text{ cm}^2/\text{Vs} = 11.6 \text{ cm}^2/\text{s}$;
$L_p = (11.6 \text{ cm}^2/\text{s} \times 10^{-5} \text{ s})^{1/2} = 0.0107 \text{ cm} = 107$ µm

$D_n = 0.0259\text{x}700 = 18.1 \text{ cm}^2/\text{s}$;
$L_n = 18.1\text{x}0.1\text{x } 10^{-6} = 13.4$ µm

I_o = hole current + electron current
$= q\, A\, D_p / L_p \times p_{n0} + q\, A\, D_n / L_n \times n_{p0}$;

$p_{n0} = n_i^2 / (N_D^{eff}) = 10^5$ cm^{-3}
$n_{po} = n_i^2 / (N_A^{eff}) = 10^3$ cm^{-3}

$I_o = 1.73 \times 10^{-11}$ A + 2.15×10^{-12} A = 1.945×10^{-11} A..........................(1)
So, reverse saturation hole current is 1.73×10^{-11} A.

c. Calculate the reverse saturation electron current.
From (1) reverse saturation electron current is 2.15×10^{-12} A

d. Find the total current under reverse bias.
From (1) total reverse saturation current is summation of the above two, i.e.,
Io = 1.945×10^{-11} A.

e. Find the current *I* at a forward bias of 0.5 V.
$I = I_o\,[\exp\,(qV / kT) - 1]$
$= 1.945\text{x}10^{-11}[\exp\,(0.5/0.0259) - 1]$
= 4.7 mA.