NAME UCID

1. Answer all four questions. Maximum mark is 18.
2. For multiple-choice questions, circle the correct answer. There may be more than one correct answer, in which case circle all correct answers.
3. Show your work as much as possible, within time and space constraints.

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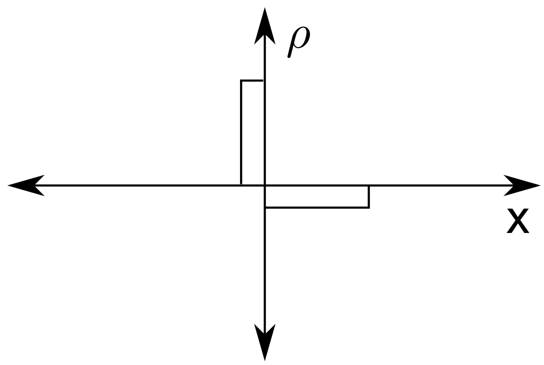
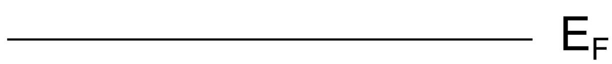
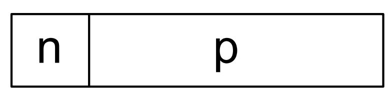
1. *(2 marks)* The figure below shows the charge density (ρ) measured in a pn junction with the junction located at x=0. In the space below it (using the already drawn Fermi level), draw an energy band diagram for the junction. No bias is applied.





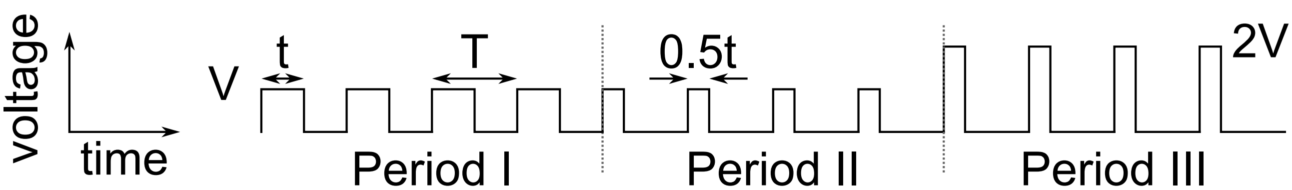
2. *(2 marks)* You are given the junction shown to the right. $N_A > N_D$. A reverse bias is applied. Which region will get completely depleted first (*i.e.* depletion region will reach the end of the junction)



(a) The n region (b) The p region

(c) Insufficient information (d) Both together

3. *(2 marks)* An LED is powered using a square wave of constant frequency shown below. The amplitude and on-time change from (V, t) in period I to $(V, t/2)$ in period II to $(2V, t/2)$ in period III. If the frequency is much higher than what your eyes can resolve, how are the apparent intensities seen by you in the three periods (denoted by $I_{PI}, I_{PII}, I_{PIII}$) related?



(a) $I_{PI} > I_{PII}$ (b) $I_{PIII} > I_{PII}$

(c) $I_{PI} = I_{PIII}$ (d) $I_{PIII} = 2 \times I_{PII}$

General

$$
\begin{aligned}
n &= \frac{N_D - N_A}{2} + \sqrt{\left(\frac{N_D - N_A}{2}\right)^2 + n_i^2} \\
&= N_D - N_A \text{ if } N_D - N_A > 10n_i \\
p &= \frac{N_A - N_D}{2} + \sqrt{\left(\frac{N_A - N_D}{2}\right)^2 + n_i^2} \\
&= N_A - N_D \text{ if } N_A - N_D > 10n_i \\
np &= n_i^2 \text{ at equilrium} \\
n &= N_C e^{-(E_C - E_F)/kT} \\
p &= N_V e^{-(E_F - E_V)/kT} \\
f(E) &= \frac{1}{1 + e^{(E - E_F)/kT}} \\
|v| &= \mu E \\
v_{th} &= \sqrt{3kT/m} \\
D &= (kT/q)\mu \\
\mu &= q\tau_m/m \\
R &= \rho l/A \\
E &= \frac{1}{q}\frac{dE_C}{dx} = \frac{1}{q}\frac{dE_V}{dx} \\
dE/dx &= \rho/\epsilon \\
|E| &= \nabla V
\end{aligned}
$$

Junction

$$
\begin{aligned}
V_{bi} &= (kT/q)\log(N_A N_D/n_i^2) \\
W_{dep} &= \sqrt{\frac{2\epsilon(V_{bi} - v)}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)} \\
x_N N_D &= x_P N_A \\
C &= \epsilon A/d
\end{aligned}
$$

Universal constants

$$
\begin{aligned}
k &= 1.38 \times 10^{-23}\ J/K \\
h &= 6.63 \times 10^{-34}\ Js \\
q &= 1.60 \times 10^{-19}\ C \\
m_0 &= 9.1 \times 10^{-32}\ kg \\
\epsilon_o &= 8.85 \times 10^{-12}\ F/m
\end{aligned}
$$

@300K

$$
\begin{aligned}
kT &= 26\ meV \\
v_T = kT/q &= 26\ mV
\end{aligned}
$$

Silicon@300K

$$
\begin{aligned}
N_C &= 2.8 \times 10^{19}/cm^3 \\
N_V &= 1.0 \times 10^{19}/cm^3 \\
n_i &= 1.0 \times 10^{10}/cm^3 \\
E_g &= 1.1\ eV \\
\epsilon_r &= 12 \\
\mu_n &= 1400\ cm^2/Vs \\
\mu_p &= 470\ cm^2/Vs
\end{aligned}
$$

Germanium@300K

$$
\begin{aligned}
N_C &= 1.0 \times 10^{19}/cm^3 \\
N_V &= 6.0 \times 10^{18}/cm^3 \\
n_i &= 2.0 \times 10^{13}/cm^3 \\
E_g &= 0.67\ eV \\
\epsilon_r &= 16 \\
\mu_n &= 3900\ cm^2/Vs \\
\mu_p &= 1900\ cm^2/Vs
\end{aligned}
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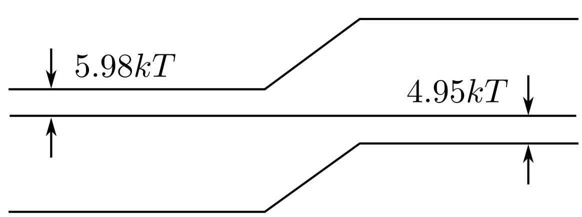
4. *(12 marks)* A silicon junction has the energy band diagram as below (not drawn to scale). Doping concentration on both sides of the junction are almost equal (you can assume that they are).



(a) Find the built in potential
(b) Calculate the depletion width at zero bias.
(c) What percentage of the depletion width is on p side of the junction?
(d) At what bias will the depletion capacitance be 4 times the zero-bias capacitance? Indicate whether this is a forward or reverse bias.
(e) Under the bias you found in (d), what percentage of the depletion width is on the n side of the junction?

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