NAME ____________ UCID ____________

1. Answer all four questions. Maximum mark is 18.
2. Show your work as much as possible, within time and space constraints.

$$\begin{aligned}
n &= \frac{N_D - N_A}{2} + \sqrt{\left(\frac{N_D - N_A}{2}\right)^2 + n_i^2} \\
&= N_D - N_A \text{ if } N_D - N_A > 10n_i \\
p &= \frac{N_A - N_D}{2} + \sqrt{\left(\frac{N_A - N_D}{2}\right)^2 + n_i^2} \\
&= N_A - N_D \text{ if } N_A - N_D > 10n_i \\
np &= n_i^2 \\
n &= N_C e^{-(E_C - E_F)/kT} \\
p &= N_V e^{-(E_F - E_V)/kT} \\
N_C &= 2\left(\frac{2\pi m_n kT}{h^2}\right)^{3/2} \\
N_V &= 2\left(\frac{2\pi m_p kT}{h^2}\right)^{3/2}
\end{aligned}$$

Silicon@300K

$$\begin{aligned}
N_C &= 2.8 \times 10^{19}/cm^3 \\
N_V &= 1.0 \times 10^{19}/cm^3 \\
n_i &= 1.0 \times 10^{10}/cm^3 \\
E_g &= 1.1\ eV
\end{aligned}$$

$$\begin{aligned}
D_C(E) &= \frac{8\pi m_n \sqrt{2m_n(E - E_C)}}{h^3} \\
D_V(E) &= \frac{8\pi m_p \sqrt{2m_p(E_V - E)}}{h^3} \\
f(E) &= \frac{1}{1 + e^{(E - E_F)/kT}}
\end{aligned}$$

Constants

$$\begin{aligned}
k &= 1.38 \times 10^{-23}\ J/K \\
h &= 6.63 \times 10^{-34}\ Js \\
q &= 1.60 \times 10^{-19}\ C
\end{aligned}$$

@300K

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

Germanium@300K

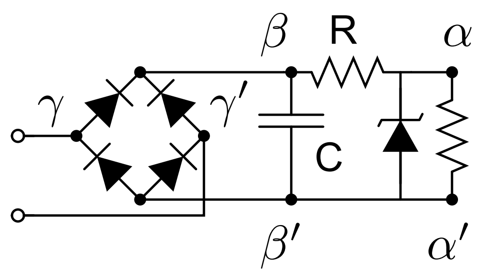
$$\begin{aligned}
N_C &= 1.0 \times 10^{19}/cm^3 \\
N_V &= 6.0 \times 10^{18}/cm^3 \\
n_i &= 2.0 \times 10^{13}/cm^3 \\
E_g &= 0.67\ eV
\end{aligned}$$

1. *(2 marks)* State true or false. Make no assumptions beyond what is stated.

(i) Carrier concentrations always increase with increased doping concentration.

(ii) In intrinsic semiconductors, there are no free electrons in the valence band.

2. *(2 marks)* Consider the regulator shown below. Answer the two questions to the right.



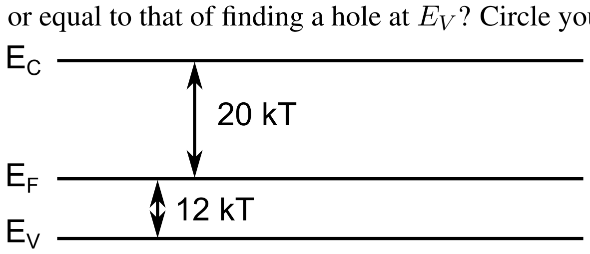
(i) Choosing R effects the ripple voltage measured between

(a) $\alpha\alpha'$ (b) $\beta\beta'$ (c) $\gamma\gamma'$

(ii) Choosing C effects the ripple voltage measured between

(a) $\alpha\alpha'$ (b) $\beta\beta'$ (c) $\gamma\gamma'$

3. *(2 marks)* Consider the energy band diagram below. Is the probability of finding an electron at E_C higher, lower or equal to that of finding a hole at E_V? Circle your answer in the options below the diagram and justify it.



(a) Higher (b) Lower (c) Equal

4. *(12 marks)* (a) What doping (acceptor/donor and concentration) is required to create p-Si with majority concentration 10^4 times the minority concentration?
(b) How would you dope (acceptor/donor and concentration) germanium to create a hole concentration equal to the doped silicon hole concentration in part (a)?
(c) Where is the Fermi level located in germanium after doping as in part (b)?
(d) After doping, is the germanium n or p type? Why?
(e) After doping, what is the minority carrier concentration in the germanium?

NAME | UCID

1. Answer all four questions. Maximum mark is 18.
2. Show your work as much as possible, within time and space constraints.

$$\begin{aligned}
n &= \frac{N_D - N_A}{2} + \sqrt{\left(\frac{N_D - N_A}{2}\right)^2 + n_i^2} \\
&= N_D - N_A \text{ if } N_D - N_A > 10n_i \\
p &= \frac{N_A - N_D}{2} + \sqrt{\left(\frac{N_A - N_D}{2}\right)^2 + n_i^2} \\
&= N_A - N_D \text{ if } N_A - N_D > 10n_i \\
np &= n_i^2 \\
n &= N_C e^{-(E_C - E_F)/kT} \\
p &= N_V e^{-(E_F - E_V)/kT} \\
N_C &= 2\left(\frac{2\pi m_n kT}{h^2}\right)^{3/2} \\
N_V &= 2\left(\frac{2\pi m_p kT}{h^2}\right)^{3/2}
\end{aligned}$$

Silicon@300K

$$\begin{aligned}
N_C &= 2.8 \times 10^{19}/cm^3 \\
N_V &= 1.0 \times 10^{19}/cm^3 \\
n_i &= 1.0 \times 10^{10}/cm^3 \\
E_g &= 1.1\, eV
\end{aligned}$$

$$\begin{aligned}
D_C(E) &= \frac{8\pi m_n \sqrt{2m_n(E - E_C)}}{h^3} \\
D_V(E) &= \frac{8\pi m_p \sqrt{2m_p(E_V - E)}}{h^3} \\
f(E) &= \frac{1}{1 + e^{(E - E_F)/kT}}
\end{aligned}$$

Constants

$$\begin{aligned}
k &= 1.38 \times 10^{-23}\, J/K \\
h &= 6.63 \times 10^{-34}\, Js \\
q &= 1.60 \times 10^{-19}\, C
\end{aligned}$$

@300K

$$\begin{aligned}
kT &= 26\, meV \\
\frac{kT}{q} &= 26\, mV
\end{aligned}$$

Germanium@300K

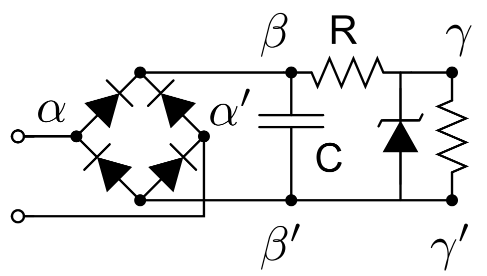
$$\begin{aligned}
N_C &= 1.0 \times 10^{19}/cm^3 \\
N_V &= 6.0 \times 10^{18}/cm^3 \\
n_i &= 2.0 \times 10^{13}/cm^3 \\
E_g &= 0.67\, eV
\end{aligned}$$

1. *(2 marks)* State true or false. Make no assumptions beyond what is stated.

(i) Carrier concentrations always increase with increased doping concentration.

(ii) In intrinsic semiconductors, there are no free electrons in the valence band.

2. *(2 marks)* Consider the regulator shown below. Answer the two questions to the right.



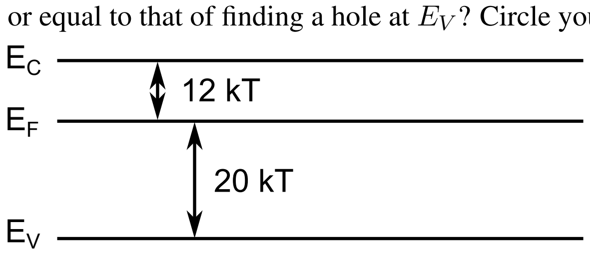
(i) Choosing R effects the ripple voltage measured between

(a) $\alpha\alpha'$ (b) $\beta\beta'$ (c) $\gamma\gamma'$

(ii) Choosing C effects the ripple voltage measured between

(a) $\alpha\alpha'$ (b) $\beta\beta'$ (c) $\gamma\gamma'$

3. *(2 marks)* Consider the energy band diagram below. Is the probability of finding an electron at E_C higher, lower or equal to that of finding a hole at E_V? Circle your answer in the options below the diagram and justify it.



(a) Higher (b) Lower (c) Equal

4. *(12 marks)* (a) What doping (acceptor/donor and concentration) is required to create n-Si with majority concentration 10^4 times the minority concentration?
(b) How would you dope (acceptor/donor and concentration) germanium to create an electron concentration equal to the doped silicon electron concentration in part (a).
(c) Where is the Fermi level located in germanium after doping as in part (b)?
(d) After doping, is the germanium n or p type? Why?
(e) After doping, what is the minority carrier concentration in the germanium?