NAME [ ] UCID [ ]

1. Answer all four questions. Maximum mark is 18.

3. Show your work as much as possible, within time and space constraints.

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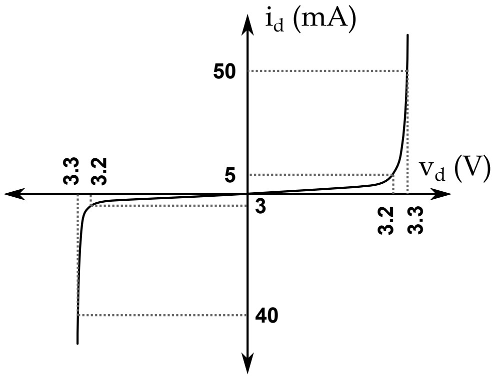
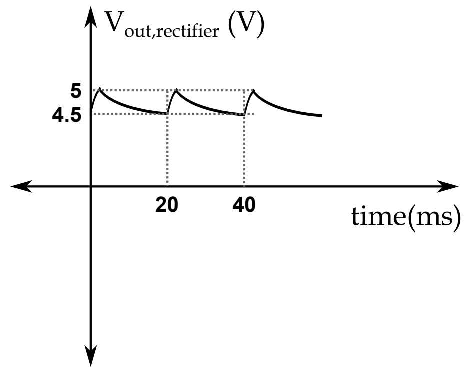
1. *(2 marks)* The figures below show the iv characterstics of a 1 W Zener diode and the output of a rectifier whose input is 11 V peak-to-peak at 50 Hz. The diode and rectifier are used to create a regulator whose output is supposed to be between 3.2-3.3 V. Answer the three questions below the figures.





(a) The absolute maximum Zener current magnitude is _____

(b) The minimum Zener current magnitude during proper regulator operation is _____

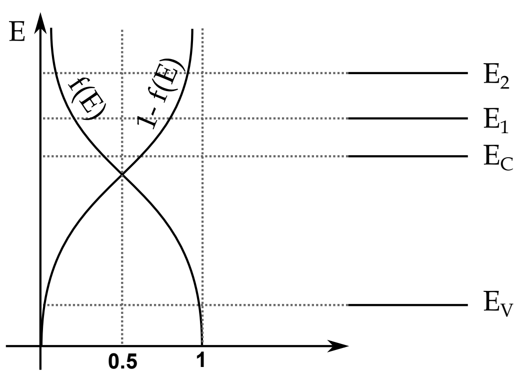
(c) What kind of rectifier (half or full-wave) is it? You need to give a reason for any credit for this part.

2. *(2 marks)* Mark true or false

(a) Pure silicon has free electrons.

(b) Acceptor-doped silicon has free electrons.

3. *(2 marks)* Consider the Fermi function and the energy band diagram shown below and answer the two questions to the right of the figure. Explanation is needed for any credit.



(a) What kind is the semiconductor (intrinsic, n or p)?

(b) Fill in the blank with $<$, $>$ or $=$

p(hole @E_1) _____ p(hole @E_2)

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

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

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

Germanium@300K

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

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4. *(12 marks)* Si at 300 K is doped with an unknown concentration of two acceptor and donor impurities X and Y in the ratio of 1:10 that is 10 atoms of Y are added for each atom of X that is added. As a result, the Fermi level is 606 meV above E_V.

(a) Identify the impurities X and Y as donors or acceptors (ie which impurity is which type)

(b) Find the free electron and hole concentrations

(c) Find the doping concentrations

(d) $1\times10^{16}/\text{cm}^3$ acceptor atoms are added to the already doped silicon. What is the new location of the Fermi level?

(e) After the doping of part (d) is the material n type or p type?

(f) After the doping of part (d), find the minority carrier concentration.

NAME

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