二下

2015 Spring CS 210001 Circuits and Electronics (I) Midterm I

Class: ____________

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Part One: Calculation (80%)

$E_g = 1.1$ eV for Si, $B = 5.23 \times 10^{15}$ cm^{-3} K$^{-3/2}$ for Si, $k = 86 \times 10^{-6}$eVK^{-1},

$u_n = 1350 cm^2V^{-1}S^{-1}$, $u_p = 480 cm^2V^{-1}S^{-1}$, $ni(T) = BT^{\frac{3}{2}}e^{(-Eg/2kT)}$

1. (11%) The electron concentration in silicon at $T = 300$ K is $n_0 = 2\times10^4$ cm^{-3}. (a)(4%) Determine the hole concentration. (b)(2%) Is the material n-type or p-type? (c)(2%) What might be the impurity? (d)(3%) What is the conductivity σ of this material?

2. (10%) Ohm's Law can be expressed as $J = \sigma \times E$. Prove that this is held for a semiconductor where $\sigma = qnu_n + qpu_p$, q is charge, n is electron concentration, p is hole concentration, u_n is the electron mobility, u_p is the hole mobility, J is current density, and E is electrical field.

3. (6%) Prove that the Vp $=\sqrt{2}$ Vrms for a sine wave V= Vp×sinθ where Vp is peak value and Vrms is the effective value of signal V.

4. (8%) Given a diode circuit as shown in Fig. 1. Assume the diode is modeled as V_γ in series with a forward diode resistance rf when the diode is forward biased. Show that the V_D can be expressed as $\dfrac{V_s \times rf + V_\gamma \times R}{rf + R}$ when the diode is forward biased.

Vγ+rf

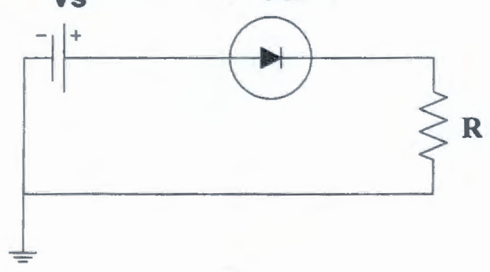


Fig. 1

$V_D = V_r + rf \cdot I = V_s - IR$

$I = \dfrac{V_s - V_D}{R}$

$V_r + rf \cdot \left(\dfrac{V_s - V_D}{R}\right)$

$V_D \quad \dfrac{V_rR + V_s \cdot rf - V_D - rf}{R}$

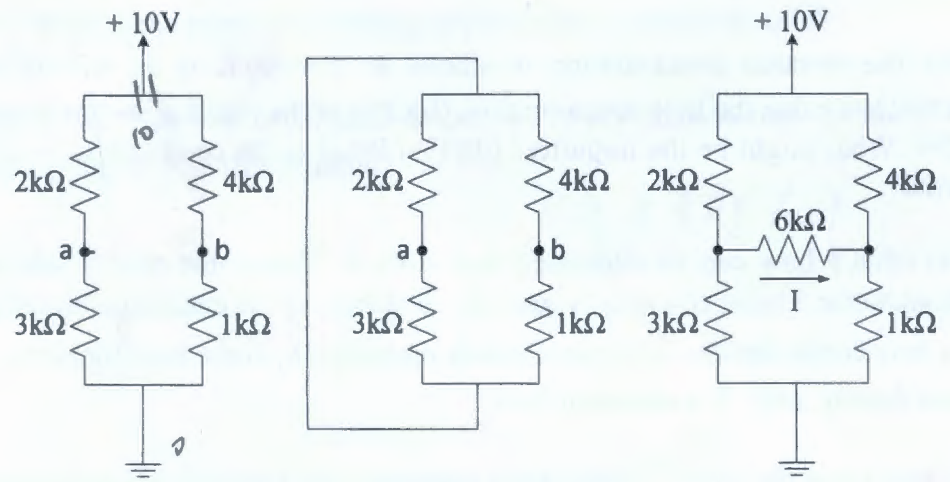
5. (4%) Prove that the equivalent resistance of two parallel resistors is $(R1 \times R2) \big/ (R1 + R2)$.

$\frac{V'}{R} = \frac{V}{R_1} + \frac{V}{R_2}$

$R_1 — R_2 —$

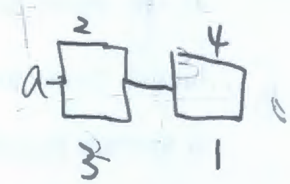
$IR = IR_1 + IR_2$

6. (10%)(a)(3%) For the circuit in Fig. 2(a), find the voltage of node a and voltage of node b. What is the voltage Vab between node a and b? (b)(3%) Find the terminal resistance between node a and node b of Fig. 2(b), that is, Rab=? (c)(4%) Determine the current I in Fig. 2(c) by using Thevenin's Theorem.



(a) (b) (c)

Fig. 2



7. (6%) Using the superposition theorem, solve for the current I in Fig. 3.

$8-4-4+6=0$

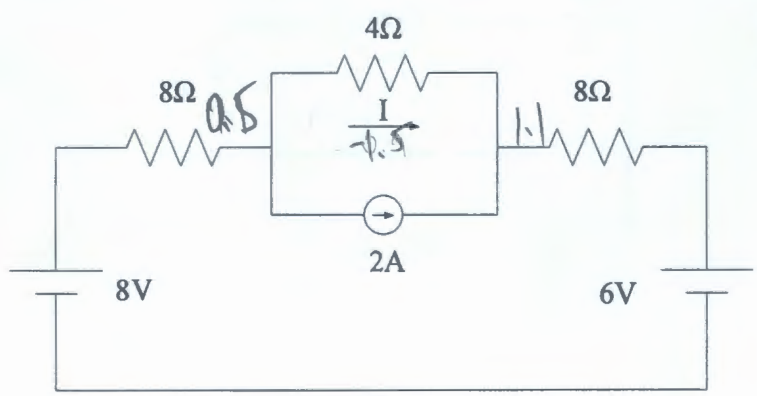


Fig. 3

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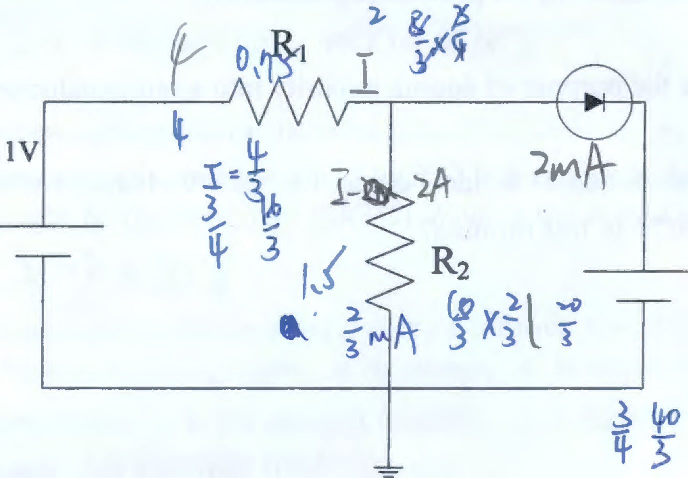
8. (6%) Consider a silicon pn junction at 300K. n-type is doped to $N_d = 10^{17}$ cm^{-3}. If the built-in potential barrier V_{bi} =0.712V, determine the p-type doping concentration.

$V_t \ln \frac{N_a N_d}{n_i}$

9. (10%) For the circuit in Fig. 4, assume V_γ=0.7V, rf =0 for the diode. The diode is to remain "on" for a power supply voltage in the range 5 <= V_{PS} <= 11. The minimum diode current is 2mA and the maximum power dissipated in the diode is to be no more than 7mW. Determine the values of R1 and R2.

$R_1 = 0.75$
$R_2 = 0.3$



$\frac{8}{3} - 2 = \frac{1}{R_2}$

$\frac{2}{3}$

$R_3 = 1.5\,k\Omega$

$4 \times \frac{4}{3} - \frac{1}{R_2} - 2 = 0$

$\frac{1}{R_2} = \frac{10}{3}$

Fig. 4

10. (9%) Use the mesh analysis method to solve for the currents I_1, I_2 and I_3 in Fig. 5. You just list the equations only. Do not solve the currents explicitly.

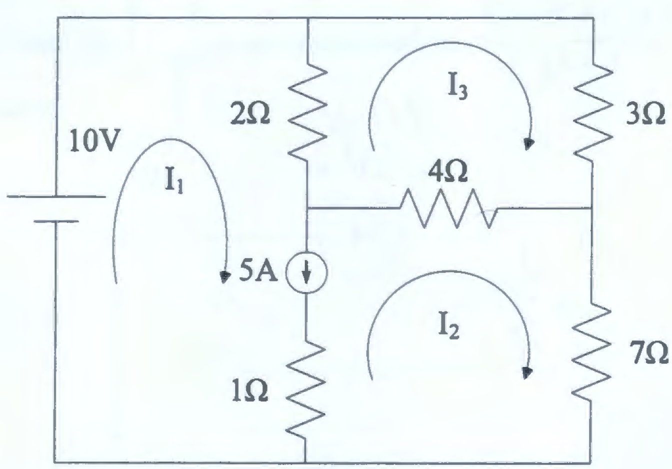


Fig. 5

Part Two: Answer the following question as clear as you can (20%)

1. (4%) Explain the mechanism of Zener breakdown.

2. (4%) Explain why the iteration method is useful in solving the current and voltage of a diode circuit.

3. (4%) Why is the breakdown voltage of a diode positive-temperature-coefficient under the mechanism of the avalanche breakdown?

4. (4%) What is the purpose of doping impurity into a semiconductor?

5. (4%) In the modeling of an ideal diode, i.e., its I-V characteristic formula, what's the purpose of -1 in this formula?

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1、(a) $n_i(300) = 5.23\times10^{15}(300)^{\frac{3}{2}} e^{\left(-\frac{1.1}{2\cdot 8.6\times10^{-6}\cdot 300}\right)}$

$= 5.23\times10^{15} \times 5196.152423 \times 5.518\times10^{-10}$

$\fallingdotseq 1.5\times10^{10}$

$p_0 = \dfrac{(1.5\times10^{10})^2}{2\times10^4} = 1.125\times10^{16}$ #

A: $1.125\times10^{16}\ cm^{-3}$

~~(b)~~

-2

$n_0 > p_0$ $p_0 > n_0$

∴ n-type # p-type

~~(c)~~

-2

5價 ex: P、As 3價 B

~~(d)~~

-3

$\sigma = q n_0 u_n + q p u_p \fallingdotseq q n_0 u_n$; A: $2.43\ 1/cm\Omega$

$= 1.6\times10^{-19} \cdot 1.125\times10^{16} \cdot \overset{480}{1350}$

2、

Assume know $V_d = u\cdot E$ 設 N 為全电子數

$V_d = \frac{L}{t}$ $n = \frac{N}{AL}$ 設 L 為長度

for 電子 $J_n = \dfrac{I_n}{A} = \dfrac{\frac{qN}{t}}{A} = -\dfrac{q n L}{t} = -q n V_d = -q n(-u\cdot E)$

$= q n u_n E$

for 電洞 $J_p = \dfrac{\frac{qP}{t}}{A} = q n V_d = q n u_p E$

電子、電洞都會產生J且方向相同 故 $J = q n u_n E + q p u_p E$

$= (q n u_n + q p u_p) E$

$= \sigma \times E$ #

3、 -1

$V = V_p \sin\theta$

平方 $V^2 = V_p^2 \sin^2\theta$

平均 $V_{avg}^2 = \frac{1}{\pi}\int_0^{\pi} V_p^2 \sin^2\theta\, d\theta = \frac{V_p^2}{\pi}\int_0^{\pi} \frac{1-\cos 2\theta}{2} d\theta = \frac{V_p^2}{2\pi}\left[\theta - \frac{\sin 2\theta}{2}\Big|_0^{\pi}\right] = \frac{V_p^2}{2\pi}(\pi - 0 - 0 + 0)$

$= \frac{V_p^2}{2}$

開根 $\sqrt{V_{avg}^2} = \frac{V_p}{\sqrt{2}}$

$V_{rms} = \frac{V_p}{\sqrt{2}} \Rightarrow V_p = \sqrt{2}\, V_{rms}$ #

4. $V_D = V_r + r_f \cdot I = V_S - IR$

$$I = \frac{V_S - V_D}{R}$$

$$V_D = V_r + r_f\left(\frac{V_S - V_D}{R}\right)$$

$$V_D + \frac{r_f}{R}V_D = V_r + \frac{r_f V_S}{R}$$

$$V_D\left(1 + \frac{r_f}{R}\right) = \frac{V_r R + r_f V_S}{R}$$

$$V_D = \frac{V_r R + r_f V_S}{\cancel{R}} \times \frac{\cancel{R}}{R + r_f} = \frac{V_S \times r_f + V_r \times R}{R + r_f} \#$$

5. 電阻並聯時 V 相同

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2}$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 + R_2}{R_1 \times R_2}$$

$$R = \frac{R_1 \times R_2}{R_1 + R_2} \#$$

6.

(a)

$$10 \times \frac{3}{5} = 6 = V_a$$

$$10 \times \frac{1}{5} = 2 = V_b$$

$$V_{ab} = 6 - 2 = 4V$$

(b)

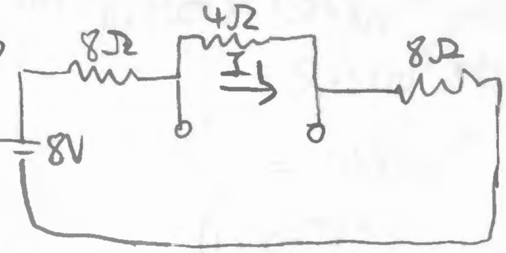
$$R_{ab} = \frac{2 \times 3}{5} + \frac{4 \times 1}{5} = \frac{10}{5} = 2\ k\Omega$$

(c)

$$I = \frac{4}{2+6} = 0.5mA$$

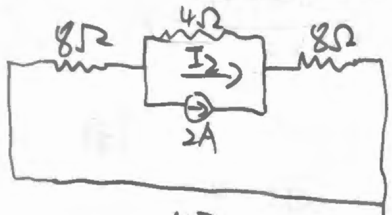
7.

①



$I_1 = \frac{8}{8+8+4} = \frac{8}{20} = \frac{2}{5} = 0.4A$

②

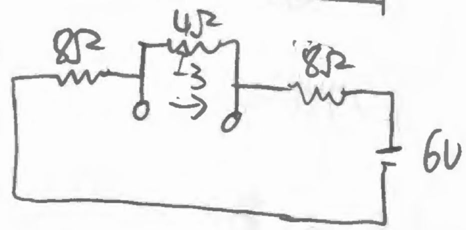


$8(2+I_2) + 4\cdot I_2 + 8(2+I_2) = 0$

$32 + 20 I_2 = 0$

$I_2 = -\frac{32}{20} = -1.6A$

③



$I_3 = \frac{-6}{8+8+4} = \frac{-6}{20} = -0.3A$

$-1.6 + 0.4 - 0.3 = -1.5$

A: -1.5 A

8.

$V_{bi} = V_t \ln \frac{N_a N_d}{n_i}$

$V_t(300) = \frac{300}{11600} \doteq 0.026$

$n_i(300) \doteq 1.5\times10^{10}$

$0.712 = 0.026 \ln \frac{N_a \times 10^{17}}{(1.5\times10^{10})^2}$

$\frac{N_a\times10^{17}}{(1.5\times10^{10})^2} = e^{\frac{712}{26}}$

$N_a = (1.5\times10^{10})^2 \times 10^{-17} \times \underset{7.816\times10^{11}}{e^{\frac{712}{26}}} = 1.7586\times10^{15}\ cm^{-3}$

A: $1.7586\times10^{-15}\ cm^{-3}$

9. min: $V_{PS} = 5V$

$I_D = 2mA$

$V_r = 0.7V$

max $V_{PS} = 11V$

$I_D = \frac{7m}{0.7} = 10mA$

$V_r = 0.7$

① $\frac{4}{R_1} - \frac{1}{R_2} = 2mA$

② $\frac{10}{R_1} - \frac{1}{R_2} = 10\ mA$

①−② ⇒ $\frac{6}{R_1} = 8mA$

$R_1 = 0.75k\Omega$

$R_2 = 0.3k\Omega$ #

A: $R_1 = 0.75k\Omega$, $R_2 = 0.3k\Omega$

10. ① $I_1 - I_2 = 5$

$10 = (I_1 - I_3)2 + 5 \cdot 1$

③

$3I_3 + (I_3 - I_2)4 + (I_3 - I_1)2 = 0$

④ $(I_2 - I_3)4 + I_2 7 + (-5)1$

1. 因電場過大，e^-、h^+ 獲得足夠能量脫離產生電流

2. iteration method 是用逼近法一步一步向答案靠近，誤差較小能得到較精準的答案

3. 因溫度上升熱擾動增加，碰撞共價鍵機率下降，e^-、h^+ 產生變少，故所需 breakdown voltage 上升

4. 因 semiconductor 原本只會生成 10^{10} 個自由電子，doping impurity 後可增加自由電子的數目，以增加導電性

5. 因可能會有逆偏的情況發生

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