**Electronics (I) 1st Mid-term Examination** 班級__________ 學號________________ 姓名________________

**(closed book, using calculator is ok)** 10:15 ~ ………… 2019/10/30

1. (a) (10%) For silicon (Si), the number per unit volume of effectively available states $(B)$ for silicon is $7.3\times10^{15}$ $cm^{-3}K^{-3/2}$ and the bandgap voltage $E_g$ = 1.12 eV. As it is doped with phosphorus, what must $N_D$ be if at T=300 K the hole concentration drops below the intrinsic level $n_i$ by a factor of $10^7$? Note : Boltzmann's constant $k$ is $8.62\times10^{-5}$ eV/K

+2

① $n_i = BT^{\frac{3}{2}} e^{\frac{-E_g}{2kT}} = 7.3\times10^{15}\times 300^{\frac{3}{2}} \times e^{\frac{-1.12}{2\times300\times8.62\times10^{-5}}}$
$= 1.494\times10^{10}$ holes/$cm^3$ +1

② $P_n = \frac{1.5\times10^{10}}{10^7} = 1.5\times10^{3}\ cm^{-3}$ +2 +1

③ $n_n \simeq N_D$, $P_n n_n = n_i^2 \rightarrow n_n = \frac{n_i^2}{P_n} = \frac{(1.5\times10^{10})^2}{1.5\times10^{3}} = 1.5\times10^{17}\ cm^{-3}$ +2 # +3 +1

(b) (10%) Contrast the electron and hole drift velocities through a 10-μm layer of intrinsic silicon across which a voltage of 3 V is imposed. Let $\mu_n$ = 1350 $cm^2/V\bullet s$ and $\mu_p$ = 480 cm2/$V\bullet$ s.

① $E = \frac{V}{cm} = \frac{3}{10\times10^{-6}\times10^{2}} = 3000$ +2 +1

② $V_{p\,drift} = \mu_p E = 480\times3000 = 1.44\times10^{6}$ cm/s +2 +1

$V_{n\,drift} = \mu_n E = 1350\times3000 = 4.05\times10^{6}$ cm/s +2 +1

$\frac{V_n}{V_p} = \frac{4.05\times10^{6}}{1.44\times10^{6}} = 2.8125$ # +1

2. Calculate the built-in voltage of a PN junction in which the p and $n$ regions are doped equally with 5 × $10^{16}$ atoms/$cm^3$. Assume $n_i$ = 1.5 × $10^{10}$/$cm^3$.

(a) (5%) With the terminals left open, what is the width of the depletion region?

$N_A = N_D = 5\times10^{10}$ atoms/$cm^3$ . $n_i = 1.5\times10^{10}/cm^3$

① $V_o = V_T \ln\left(\frac{N_A N_D}{\ldots}\right)$ +2 … $1.5\times10^{16}\times5\times10^{16}$ … +1

(d) $v_{GS}$ =2.5V and $v_{DS}$ =2.5 $V$ +1

$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$ +1 $I_D = \frac{1}{2}k_n V_{ov}^2 = 5.3$ mA # +1

$k_n = \mu_n C_{ox}\frac{W}{L}$ +1 $V_{ov} = V_{GS} - V_t = 2V$ +1

4. (20%) For a particular NMOS technology with the minimum channel length is 0.5 μm, the associated value of λ is 0.03 $V^{-1}$.

(a) If the gate length $L_G$ becomes 1.5 μm and operates in saturation at $v_{DS}$ = 1 V with 100 μA drain current, what does the drain current become if $v_{DS}$ is raised to 5 V?

+2 $L = 1.5\ \mu m = 3\times 0.5\ \mu m$

+2 $\lambda = \frac{0.03\,V^{-1}}{3} = 0.01\,V^{-1}$

$I_D = 100\ \mu A = I_D'(1+\lambda\times1) = 1.01 I_D'$

+3 $I_D + \Delta I_D = I_D'(1+\lambda\times5) = 1.05 I_D'$

+2 $I_D' = \frac{100}{1.01} \Rightarrow 1.05\times\frac{100}{1.01} = 104\ \mu A$ # +1

or

+2 $k_n V_{ov}^2 = \frac{20000}{101}$

+3 $I_D = \frac{1}{2}k_n V_{ov}^2(1+\lambda V_{DS})$

$V_{DS} = 5$ ⇓ +1

$I_D = 103.96\ \mu A$ #

(b) What can be done over the channel length $L_G$ to reduce the percentage by a factor of 2?

($L_G$)

Doubling channel length to 3 μm #

+10

5. (20%) A signal attenuator as shown in below with the attenuation factor controlled by the value of the dc current $I$, and $v_S$ is a sinusoidal signal. Capacitors $C_1$