題號： 433
科目：電子學(E)
節次： 7

國立臺灣大學 104 學年度碩士班招生考試試題

1. Please choose the correct statement(s). (5 %)
   (A) In thermal equilibrium, extrinsic silicon semiconductor has a smaller electrical conductivity than intrinsic silicon semiconductor does due to the effect of impurities at 300 K.
   (B) In thermal equilibrium, p-type silicon semiconductor is positively-charged and n-type silicon semiconductor is negatively-charged at 300 K.
   (C) A silicon diode has low radiative emission efficiency due to the effect of scattering at 300 K.
   (D) The intrinsic carrier concentration of a large-bandgap semiconductor material is smaller than a small-bandgap semiconductor material at 300 K.
   (E) GaAs has a larger electron drift velocity than Silicon does under the same moderate electrical field application due to the effect of smaller electron effective mass at 300 K.

2. Please choose the correct statement(s). (5 %)
   (A) The excess concentration of minority carriers in the *pn* junction under forward bias will decay with distance linearly due to the recombination process with majority carriers.
   (B) The charge-storage effects in the *pn* junction can be modeled by junction capacitance in reverse bias and diffusion capacitance in forward bias.
   (C) The depletion region in the p-side will be smaller than that in the n-side if the n-type doping is smaller than the p-type doping in the *pn* junction diode.
   (D) When a diode is forward-biased, the forward conducting current can be formed by holes drifting from p-side to n-side and electrons drifting from n-side to p-side, depending on the values of applied voltage and electrical field.
   (E) The turn-on voltage of a diode is smaller if the ambient temperature is increased.

3. Consider a Si *npn* bipolar junction transistor (BJT). The doping level are 10^{18}, 10^{17}, 10^{16} cm^{-3} for emitter, base, and collector, respectively. The thickness of emitter, base, and collector are all 1 μm. Assume $n_i = 1.5 \times 10^{10}$ cm^{-3}, $\epsilon_s = 11.7$, $\epsilon_0 = 8.85 \times 10^{-14}$ F/cm.
   (a) Draw the schematic band diagram in thermal equilibrium (assume in 300 K). Label E_C, E_V, and E_F in your plot. Identify the range of depletion region at BE and BC junction correctly. (7 %)
   (b) Draw the distribution of "minority carrier concentration" in the emitter, base and collector region under forward-active operation. (3 %)
   (c) What are the two main components of base current? (2 %)
   (d) If we can change the emitter material only to another kind of semiconductor that has larger bandgap than silicon, how will that affect current gain $\beta(\equiv I_C/I_B)$ of the transistor and why? (3 %)

4. Consider a Si enhancement-mode metal-oxide-semiconductor field-effect transistor (MOSFET).
   (a) Draw and label correctly the cross section and all terminals of an NMOS. Indicate the induced channel shape under (1) no V_{DS}; (2) small V_{DS}, (3) $V_{DS}>V_{GS}$. (3 %)
   (b) Derive the relationship $i_D - v_{DS}$ in triode region. (5 %)
   (c) Explain the channel-length modulation and its effect on drain current. (3 %)
   (d) If we can shrink the gate length extremely, say below 100 nm, how will that affect the transistor performance in terms of channel-length modulation in (c) and why? (4 %)

5. The circuit in the Figure 1 is a non-inverting amplifier and the circuit parameters of the OP amp are given as: low-frequency gain (A_0) = 80 dB, unity-gain bandwidth (f_t) = 1 MHz, rated output voltage = ±15 V,

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maximum output current = ±5 mA, slew rate = 1 V/μs.

(a) Assume $R_1 = 1\ \text{k}\Omega$ and $R_L = \infty$. For an amplifier bandwidth ≥ 10 kHz, find the maximum voltage gain in dB and the value of R_2. (5 %)

(b) A low-frequency sine wave is applied to the input of the amplifier with $R_1 = 1\ \text{k}\Omega$, $R_2 = 9\ \text{k}\Omega$, and $R_L = 2\ \text{k}\Omega$. Find the maximum input amplitude of the amplifier such that the output waveform is not distorted. (3 %)

(c) For an amplifier with $R_1 = \infty$ and $R_L = \infty$, find the maximum input amplitude of a sine-wave at 50 kHz. (2 %)

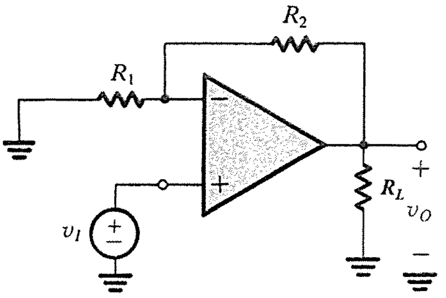

Figure 1

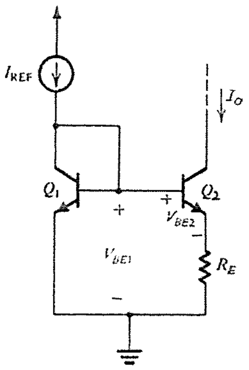

Figure 2

6. For the BJT circuit in Figure 2, assume that Q_1 and Q_2 are matched, and $I_O = 10 \times I_{REF}$.
   (a) Find the expression of the current I_O. (10 %)
   (b) If the temperature of the circuit rises from 27 °C to 57 °C, how will I_O change? Express the change in percentage. (5 %)

7. For the MOSFET cascode amplifier in Figure 3,
   (a) Draw its equivalent small-signal equivalent circuit. The output resistance of the transistor needs to be included. (5 %)
   (b) Derive the overall transconductance gain $G_m = i_O/v_i$. (5 %)
   (c) Derive the amplifier's output resistance R_O. (5 %)

8. For the circuit in Figure 4,
   (a) Derive the expression for input capacitance C_{in}. (10 %)
   (b) Use open-circuit time constant approximation to derive the expression of the upper 3-dB frequency ω_H. (10 %)

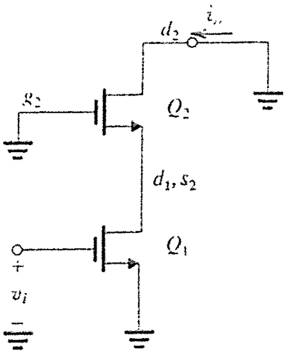

Figure 3

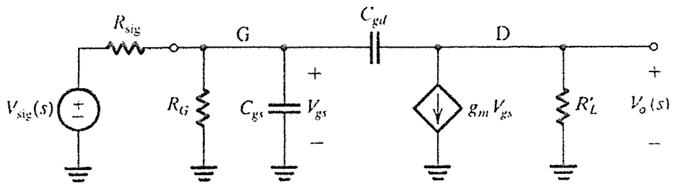

Figure 4

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