1. Quantum theory of atoms (22%)

(a) **(4%)** What is the electron configuration of Ge? (for example $1s^2 2s^2 2p^5$ for F atoms).

(b) **(4%)** For an electron in the valence band (outmost shell) of Ge crystals, what are the possible sets of quantum numbers? Neglect the hybridization of s and p orbitals. Treat them as discrete orbitals. Note that for each set, you MUST write down its four quantum numbers (n, l, m_l, m_s).

(c) **(14%)** Considering spin-orbit coupling for an electron of the outmost shell in Ge by treating a Ge atom like hydrogen atom, please calculate the following parameters: radius ($r = n^2 a_0$, $a_0 = 0.529$ Å), electron velocity ($m = 0.1m_0$), frequency, magnetic field ($B = \frac{\mu_0 f e}{2r}$, $\mu_0 = 4\pi \times 10^{-7}$), and the energy difference ($\Delta E = \frac{e\hbar B}{m}$) of the splitting states in terms of eV and its equivalent temperature.

2. Quantum Mechanics (28%)

A particle of mass *m* is in a delta potential quantum well of

$$U(x) = -A\delta(x)$$

(a) **(14%)** If $E < 0$, it is called "bound states" case. Wave function can be expressed as $\sqrt{B}e^{-Bx}$. Find *B* and the associated energy level. (Hint: 1. $\psi(x)$ is continuous and 2. $\frac{d\psi(x)}{dx}$ is continuous except at x = 0).

(b) **(14%)** If $E > 0$, it is called "scattering states" case. See Fig. 1 for scattering details. Assume an incident electron from the left (i.e. G = 0), what are the reflection coefficient ($R = \frac{|B|^2}{|A|^2}$), transmission coefficient ($T = \frac{|F|^2}{|A|^2}$)? Please show that $R + T = 1$. Express *R* and *T* in terms of *m*, *A*, *ħ*, *E*,

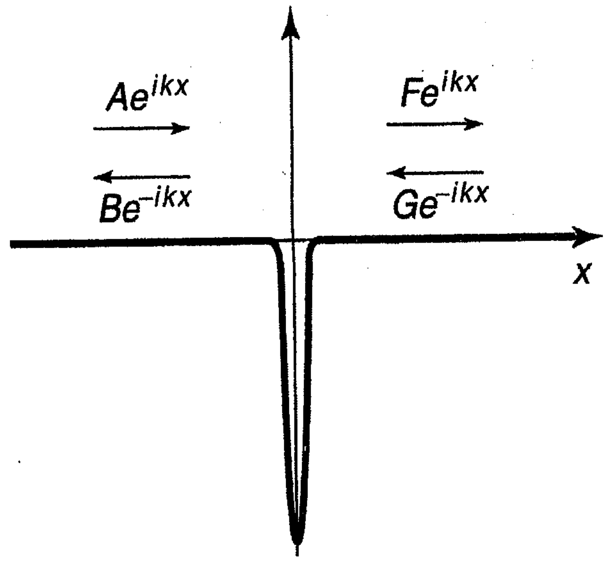

Fig. 1 An electron incident on a delta potential.

3. Semiconductor physics and devices (50%)

For a n-MOSFET (Fig. 2), if N_D in the n-type source/drain region is 5×10^{19} cm^{-3} and N_A in the p-type substrate is 10^{17} cm^{-3}. $N_C = 2.8 \times 10^{19}$ cm^{-3} and $N_V = 1 \times 10^{19}$ cm^{-3}.

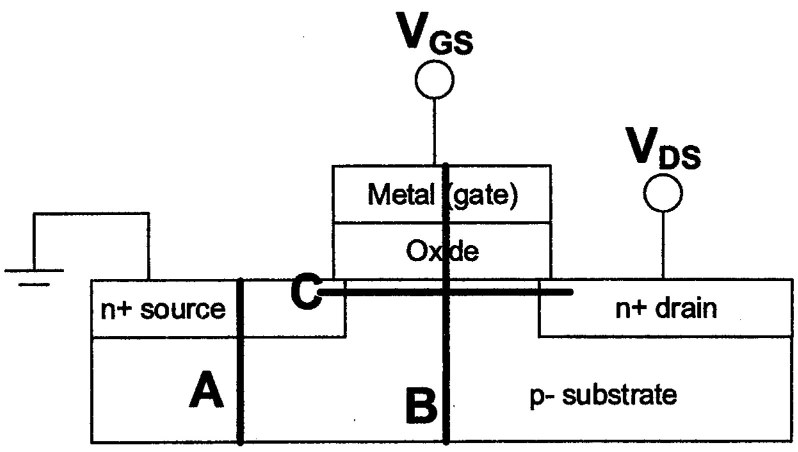

Fig. 2 A n-type Si MOSFET device

見背面

(a) **(4%)** Calculate $E_F - E_V$ in the p-type Si substrate.

(b) **(6%)** Please draw the band diagram along line A by labeling all energy levels (and its relative positions in the source and substrate regions. You can assume $E_F \sim E_C$ in the n+ source region.

(c) **(10%)** Please qualitatively draw the band diagram along line B. Assume $V_{GS} = 2$ V, $V_{FB} = 0$ V, and the system is in strong inversion. Label the energy levels of E_{FM} (Fermi level in metal), E_C, E_i, E_{FS} (Fermi level in semiconductor), and E_V. Note that you also need to mark the energy differences between (i) E_{FS} and E_{FM}, (ii) E_{FS} and E_V in the bulk p-Si, and (iii) E_{FS} and E_C at the oxide/p-Si interface.

(d) **(10%)** Please qualitatively draw the band diagram along line C (in the Si region and right at the oxide/Si interface). Following (c) by assuming the system is in strong inversion and $V_{DS} = 2$ V. Label the energy levels of E_C, and E_V, and Fermi levels in the source (E_{FS}), drain (E_{FD}), and channel (E_{FC}),. You need to mark the energy differences between (i) E_{FS} and E_{FD}, (ii) E_{FC} and E_C at the oxide/p-Si interface.

(e) **(10%)** Considering the following parameters: work function of metal gate, substrate doping level, and oxide thickness. Please describe how we could vary the above three parameters to reduce the threshold voltage.

(f) **(10%)** Considering the following parameters: gate length, oxide capacitance, and mobility. Please describe how we could adjust the above three parameters to enhance the device performance in MOSFETs (i.e. higher current density).

試題隨卷繳回