1. Crystallography (20%)

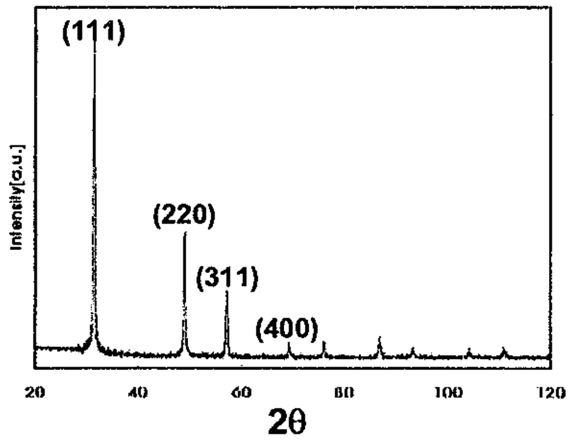

Fig. 1

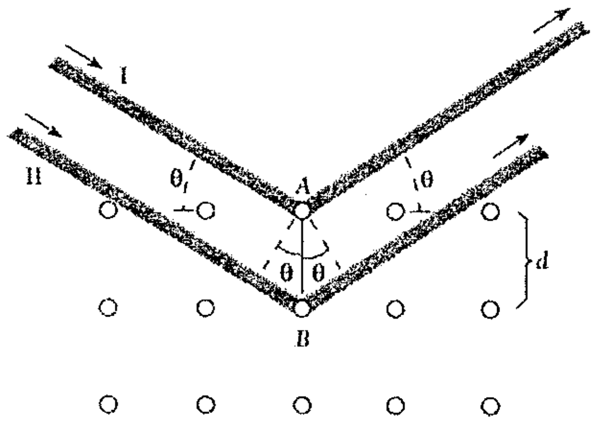

Fig. 2

In a group-IV material lab, researchers work on C (a = 3.57 Å), Si (a = 5.43 Å), or Ge (a = 5.66 Å), where a is the lattice constant. Now we have an x-ray diffraction (XRD) spectrum (Fig. 1), but we are not sure what that material is. Assume the material is crystalline (i.e. atoms are orderly placed in the bulk). Let's work it out.

(a) **(4%)** XRD is a common tool to determine the material type. Principles of XRD are schematically shown in Fig. 2 and assume parallel incident x-rays (I and II) are scattered from a cubic crystal. Please derive the relationship between d, θ, λ, and n, where d is the plane distance, θ is the angle between the incident direction of X-ray and the plane, λ is the wavelength of incident wave and n is a positive integer.

(b) **(6%)** In Fig. 1, the fourth peak ($2\theta \sim 70^o$) corresponds to a crystal plane (400), if the wavelength (λ) of the incident x-ray is 1.5406 Å, please calculate the lattice constant a. (Hint: you need to figure out the relationship between d for plane (400) and a for the plane).

(c) **(10%)** In Fig. 1, the third peak ($2\theta \sim 48^o$) corresponds to a crystal plane (220). Repeat (b) for (220) plane. Based on the lattice constants obtained, what is the material? C, Si, or Ge?

2. Quantum Physics (40%)

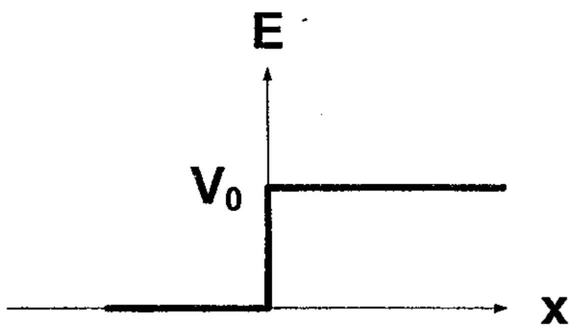

Fig. 3

(a) **(6%)** For a wave function which is a solution to Schrödinger's equation, its first derivative and itself must be continuous over the space. Please explain (Hint: from the conservation point of view).

(b)(8%) Consider a step potential in Fig. 3. For $E < V_0$, show that R (reflectance)=0 and T (transmittance)=1. You need to solve Schrödinger's equation to get credits.

(c) **(12%)** Following (b), if $E > V_0$, please derive R and T in terms of E and V_0 and show that R + T = 1.

(d) **(6%)** Draw R and T vs. E. Please label V_0 in E-axis

(e) **(8%)** Assume in a closed system at thermal equilibrium, the smallest energy partition is ΔE. There exist four particles with a total energy of 3ΔE. Please calculate the probable (expected) numbers of each energy state (i.e. four energy states: E = 0, ΔE, 2ΔE, and 3ΔE).

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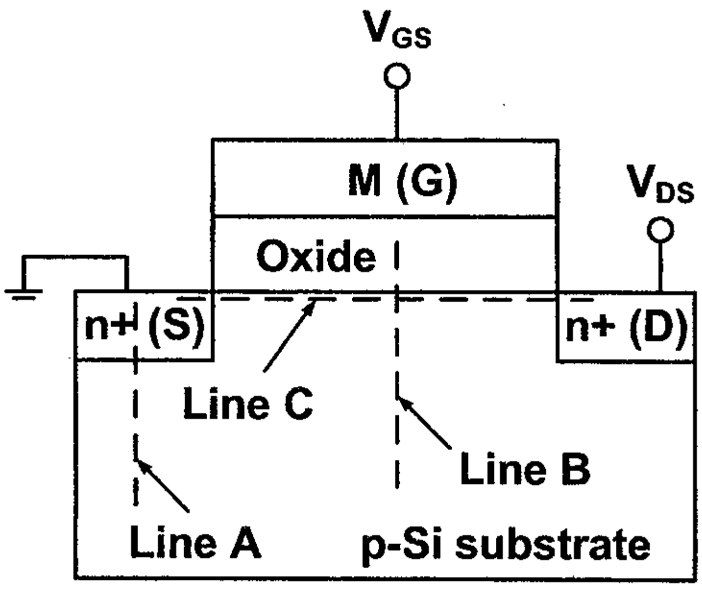
3. Semiconductor Devices (40%)



Consider a Si MOSFET and answer the following questions. Ignore the body effect. N_D in source/drain regions is 5×10^{19} cm^{-3}, N_A in the substrate is 10^{17} cm^{-3}. $V_{FB} = -0.6$ V. L = 10 μm. The oxide is HfO_2 with a dielectric constant of 32 and its thickness (t_{ox}) is 8 nm.

(a) **(4%)** Please calculate the depletion width of source/substrate junction (along line A).

(b) **(4%)** Please calculate the depletion width in the semiconductor region under the oxide/semiconductor interface (along line B).

(c) **(8%)** Calculate V_{th} ($n_i = 1.5 \times 10^{10}$ cm^{-3}).

(d) **(12%)** Please draw the band diagrams along the line A, B, and C. Assume $V_{DS} = 0.5$ V, $V_{GS} = V_{th}$, and $V_{SB} = 0$. For line C, you can think it is located in the semiconductor region and extremely close to the oxide/semiconductor interface.

(e) **(12%)** Please explain what the subthreshold conduction means. Express the subthreshold slope in terms of kT, q, C_{Si} and C_{ox}. Is a smaller or larger subthreshold slope better for a MOSFET? If the oxide is thinner, does the slope increase or decrease?

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