BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE, PILANI
FIRST SEMESTER 2022-23
BITS F415: Introduction to MEMS
Comprehensive examination (Open book) Part B

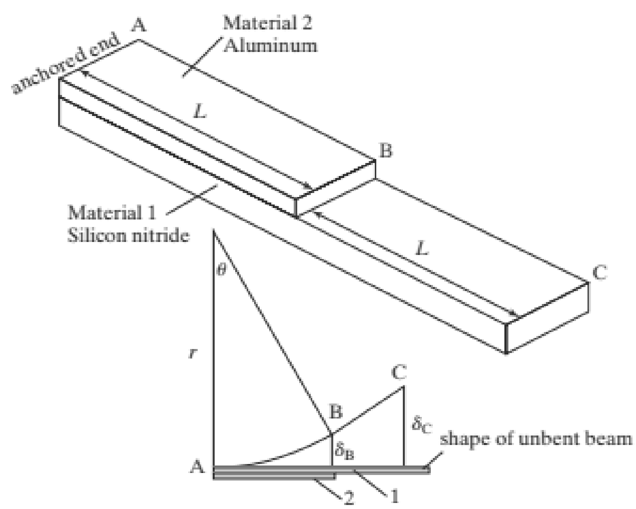
DATE: 20/12/2022 (Tuesday) **Duration: 120 min** **Maximum Marks: 30**

Name: Id:

Q.1. Thermal deposition is carried out on 305 mm diameter wafer from a point source. In which θk = 45˚, the evaporation rate is 1×10^{-3} gm sec^{-1}, the distance from the source to the closest end of the wafer is 5 cm (which is used for the calculation of θk), and the density of the material being deposited equal 5 gm cm^{-3}. The deposition is carried out for 1 min. What is the percentage change in the thickness of the deposition from the closest to the farthest end of the wafer from the source? [7M]

Q.2. A boule of silicon is pulled from a melt that contains 0.01% phosphorus (P) in the melt.
(a) What concentration of phosphorus (P) would you expect at the top of the boule (x=0)?
(b) If the boule is 1m long and it has a uniform cross-section, at what position (or x value) would you expect the concentration of phosphorus to be twice as large as it is at the top?
(c) Now consider the melt to contain gallium as well. (Gallium is a p-type dopant for silicon, but it is not commonly used.) The concentration of gallium is such that at the top of the boule (x=0), the concentration of gallium and phosphorus are exactly equal. What is the concentration of gallium halfway down the boule (x=0.5) that of the phosphorus? if the segregation coefficient (k) for gallium is 8×10^{-3} and the segregation coefficient (k) for phosphorus (P) is 0.35. Assume the Carbon unit cell volume as 1.6×10^{-22} cm^3. [7M]

Q.3. A bimetallic cantilever beam is made of two layers of different lengths. The layer on top is made of aluminum (Material 2), whereas the layer on the bottom is made of silicon nitride (Material 1). The width of both layers is 20 μm. The length of the segment between point A and B is 100 μm, so is the length of the segment from point B to C. The Young's modulus of aluminum and silicon nitride are E_2=70 GPa and E_1=250 GPa, respectively. The thickness of aluminum and silicon nitride sections is t_2=0.5 μm and t_1=1 μm respectively. The thermal expansion coefficients of aluminum and silicon nitride are $\alpha_2 = 25 \times 10^{-6}/^oC$ and $\alpha_1 = 3 \times 10^{-6}/^oC$ respectively. At room temperature, the cantilever is straight.



Find the radius of curvature (r) of the cantilever beam when the beam is uniformly heated to 20°C (ΔT) above the room temperature. Determine the amount of vertical displacement at the free end of the beam under this condition.[7M]

Q.4. A uniform oxide layer of 0.4µm thickness is selectively etched to expose the silicon surface in some locations on a wafer surface. A second oxidation at 1000˚C in H_2O grows 0.2µm on the bare silicon. Sketch a cross-section of the SiO_2 in all locations on the wafer and the position of the Si/SiO_2 interface. (Use the chart given at the end of the paper. Assume (100) plane). [5M]

Q.5. Give the process model for fabrication of out-of-plane array of pointed micro-needles shown in Figure well supported with pictorial models and masking schemes. [4M]

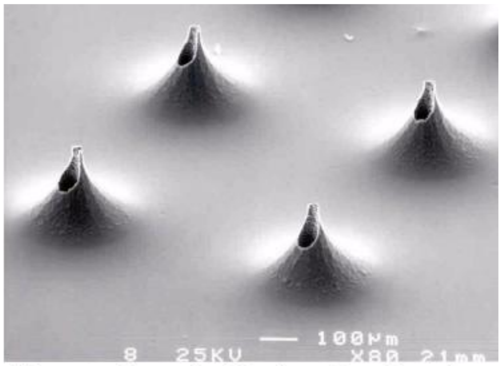


Figure Array of pointed needles; channel diameter $\delta = 40\mu m$, height $h = 200\mu m$, distance between needles: $750\mu m$, dislocation $\delta = 20\mu m$.

Rate constant describing (111) silicon oxidation kinetics at 1 atmospheric total pressure. For the corresponding values for(100) silicon, all C_2 values should be divided by 1.68		
Ambient	$B = C_1 \exp\left(-E_1/kT\right)$	$B/A = C_2 \exp\left(-E_2/kT\right)$
Dry O_2	$C_1=7.72\times10^2$ µm² hr⁻¹	$C_2=6.23\times10^6$ µm² hr⁻¹
	$E=1.23$ eV	$E_2=2.0$ eV
Wet O_2	$C_1=2.14\times10^2$ µm² hr⁻¹	$C_2=8.95\times10^7$ µm² hr⁻¹
	$E_1=0.71$ eV	$E_2=2.05$ eV
H_2O	$C_1=3.86\times10^2$ µm² hr⁻¹	$C_2=1.63\times10^8$ µm² hr⁻¹
	$E_1=0.78$ eV	$E_2=2.05$ eV

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DATE: 20/12/2022 (Tuesday) **Part A** **Maximum Marks: 10**

Data: $k=8.6173324 X 10^{-5}$ eV/K ; $N_A=6.023 x 10^{23}$ mole^{-1}

Name:____ID___________________________

1.	A Czochralski crystal is pulled from a melt containing $2x10^{14}$ cm^{-3} phosphorus. What will be the concentration of phosphorus at 50% of the boule length. Assuming k_O = 0.32 for phosphorus.
2.	Time required for growing 2 µm of oxide on a bare silicon wafer at 900^{0}C under both dry (A_{DG} =0.235 µm and B_{DG} =0.0049 µm^2/hr) and wet (A_{DG} =0.5 µm and B_{DG} =0.203 µm^2/hr) conditions are (assume long time deposition)
3.	For 900^{0}C CVD deposition of a film, it is found that the mass transfer coefficient h_G = 10.0 cm sec $^{-1}$ and the surface reaction rate coefficient k_S = $1x10^7$exp(-1.9eV/kT) cm sec-1. What is the regime in which CVD occurs?
4.	SiO_2 is deposited by LPCVD on a flat surface. If the sticking coefficient is equal to 0.3, the maximum unobstructed flux is equal to 3 $x10^{15}$ molecules/cm^2/sec and the density of deposited oxide film is 2.3 $x10^{22}$ molecules/cm^3. What will be the rate of deposition?
5.	Metal bimorph actuator works on ______________________________________ principle.

6.	Calculate the mean free path of a particle in the gas phase of a deposition system and estimate the number of collisions it experiences in traveling from the source to the substrate in the following case. Assume that the molecular collisional diameter is 0.4 nm, the source-to-substrate distance is 5 cm, and that the number of collisions is approximately equal to the source-to-substrate distance divided by the mean free path. **Case:** An evaporation system in which the pressure is 10^{-5} torr and the temperature is 25˚C.
7.	Calculate the deposition rate for a small planar surface evaporation source in which $\theta i = 30˚$, $\theta k = 45˚$, the evaporation rate is 1 x 10^{-3} gm sec^{-1}, the distance from the source to the wafer is 5 cm, and the density of the material being deposited equal 5 gm cm^{-3}.
8.	If the anisotropy (A) of an etch process is 0.45 [A=1-(lateral etching/vertical etching)]. What percentage of the etch rate in the vertical direction is due to the chemical component and what percentage is ionic/physical component?
9.	What will be the perimeter of sole if a 80 kg person wants to walk on water? [Surface tension of the liquid is water (γ=0.072 N/m) and g=9.8 ms^{-2}].
10.	{100} p-type silicon wafer has a secondary flat cut at -------------------------to primary flat.