Name KEY SID

EE147/247A Midterm, Fall 2014

NO CALCULATORS, CELL PHONES, or other electronics allowed. Show your work, and put final answers in the boxes provided. Use proper units in all answers. Wrong formula −5 Bad math −1 wrong or missing term −2

1. [35pts, 5 each] You are characterizing a new process and a new material, a thin film. You have made a variety of test structures, and want to find the material properties of the thin film. The film is 1μm thick. You have made a several beams that are 10μm wide and 1000μm=1mm long.

   a. You apply 1V across the ends of the beam, and measure a current of 1mA. What is the resistivity of the material?

   $\rho = 10^{-5}\ \Omega m$

   $R = 10^3 = \rho \frac{L}{A} = \rho \frac{10^{-3}m}{(10^{-5}m)(10^{-6}m)} = \rho 10^{8}\frac{1}{m} \quad \rho = \frac{10^3 \Omega}{10^{8}\frac{1}{m}}$

   b. You flow 1μW of power along the length of the beam, and measure a temperature difference of ΔT =10 Kelvin. What is the thermal conductivity of the material?

   $K = 10 \frac{W}{mK}$

   $10^{-6}W = \dot{Q} = K\frac{A}{L}\Delta T = K\frac{10^{-11}m^2}{10^{-3}m} 10K = K 10^{-7}[mK] \quad K = \frac{10^{-6}W}{10^{-7}mK}$

   c. When you heat the beam uniformly by 10 Kelvin, the resistance changes by 5 percent. What is the temperature coefficient of resistance?

   $TCR = 5\times10^{-3}\frac{1}{K}$

   $5\times10^{-2} = \frac{\Delta R}{R} = \alpha \Delta T = \alpha\, 10K \quad \alpha = 5\times10^{-3}\frac{1}{K}$

   d. When you pull on the beam with a force of 1mN, you measure a change in length of 1μm. What is the modulus of elasticity?

   $E = 10^{11}\frac{N}{m^2}$

   $\frac{10^{-3}N}{10^{-6}m} = \frac{F}{x} = K = E\frac{A}{L} = E\,10^{-8}m = 10^3\frac{N}{m} \quad E = 10^{11}\frac{N}{m^2}$

   e. When you pull on the beam with a force of 1mN, you measure a resistance change of 1 percent. What is the piezoresistive gauge factor?

   $G = 10$

   $\epsilon = \frac{10^{-6}}{10^{-3}} = 10^{-3} \quad \frac{\Delta R}{R} = 10^{-2} = G\epsilon = G\,10^{-3} \quad G = \frac{10^{-2}}{10^{-3}} = 10$

   f. You pull on the end of the beam and slowly stretch it. At the point when it is 20μm longer, it breaks. What is the strain limit?

   $\varepsilon_{max} = 2\%$

   $\varepsilon = \frac{\Delta L}{L} = \frac{2\times10^{-5}m}{10^{-3}m} = 2\times10^{-2}\ m$

   g. If one end of the beam is attached to the substrate, you notice that the rest of the beam curls slightly out of plane, with the tip displacement equal to 10μm. What is the unreleased surface strain gradient parameter σ_1 divided by the elastic modulus?

   $\sigma_1/E = 10^{-5}$

   $y = \frac{\sigma_1}{E}\frac{L^2}{a} \quad \frac{\sigma_1}{E} = \frac{ya}{L^2} = \frac{(10^{-5}m)(10^{-6}m)}{(10^{-3}m)^2} = 10^{-5}$

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2. [10] In the polyMUMPS process, if you draw three large concentric circles in your layout on layers ANCHOR2, POLY2, and METAL what is the list of materials in the center of the circle just before the HF release etch? Start at the silicon substrate and work up, in order.

~~oxide~~, nitride, poly 2, gold

extra layer: −1 each
missing layer: −3 each

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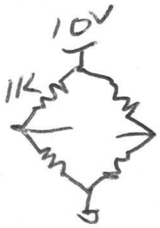

3. [20] You have made a Wheatstone bridge with four identical silicon resistors. The nominal resistance of each is 1kΩ. They have a gauge factor of G=100, and a temperature coefficient of resistance of α=0.1%/K. The bridge excitation voltage is V_X=10V.

   a. If all of the resistors heat up by ΔT=10K, what is the output voltage of the bridge.

   V_{out}= 0 V

   b. If three of the resistors heat up by 10K, and one heats up by 20K, what is the output voltage of the bridge?

   $\frac{\Delta R}{R} = (10^{-3} \frac{1}{K})(10 K) = 10^{-2}$

   $V_{out} = \frac{1}{4} V_x 10^{-2}$

   V_{out}= 25mV

   c. Assume that all resistors are the same temperature, and one of them experiences a strain of $\varepsilon=10^{-6}$=1ppm. What is the output voltage of the bridge?

   $\frac{\Delta R}{R} = G\varepsilon = 10^{-4}$ $V_{out} = \frac{V_x}{4} 10^{-4}$

   V_{out}= 250μV

   d. If your sense electronics has a noise floor of V_{noise}=100nV, what is the noise-equivalent (minimum detectable) strain?

   $V_{out} = \frac{V_x}{4} G\epsilon = 250V\epsilon = V_{noise} = 100nV$

   $\epsilon = \frac{100nV}{250V} = 0.4 \times 10^{-9}$

   ε_{neq}= 4×10^{-10}

4. [24] You have made a classic "Tang, Nguyen, Howe" comb drive resonator in an SOI process . You apply pure force $f(t)=F_0\sin(\omega t)$ and measure a resonant frequency of ω_n=1,000rad/s and a Q of 1,000 in vacuum. The DC response to F_0 is a 10nm displacement. You sweep the force over a range of frequencies.

   a. [6] What is the displacement at the resonant frequency (should be a sinusoid, show magnitude in meters, and phase)

   $x_n(t)$= 10μm sin(1000t − 90°)

   b. [6] What is the displacement at ω=1 rad/s? (again, w/ magnitude and phase)

   $x_1(t)$= 10nm sin(t)

   c. [6] What is the displacement at ω=10,000 rad/s? (again, w/magnitude and phase)

   $\omega = 10\omega_n \Rightarrow |x| = \frac{10nm}{10^2} = 0.1nm$

   phase is −180

   $x_{10k}(t)$= 0.1nm sin(10^4t − 180)

   d. [6] You apply a force $F(t) = F_0\sin(\omega_n t) + F_0\sin(t) + F_0\sin(10{,}000t)$. What is the resulting displacement in terms of $x_n(t)$, $x_1(t)$, and $x_{10k}(t)$ and possibly other things? (box your answer)

   $x(t) = x_n(t) + x_1(t) + x_{10k}(t)$