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.*/9

/11

/24

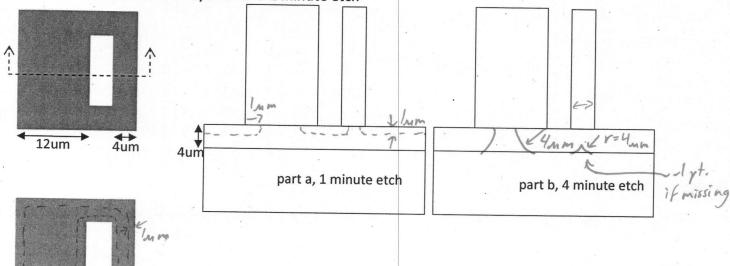
/44

1. [6] In the figure below, the structure on the left is the pattern on a mask. The mask is used for a Deep Reactive Ion Etch (DRIE) into a Silicon-on-insulator (SOI) wafer with a top-layer thickness of 20μm, and an oxide thickness of 4μm. Two copies of a cross-section of the device are shown after the DRIE etch and subsequent photoresist removal. The device is then dropped into a hydrofluoric (HF) acid solution with an SiO<sub>2</sub> etch rate of 1um/minute.

a. Carefully draw the process cross-section after 1 minute in HF. Isotropic, distance

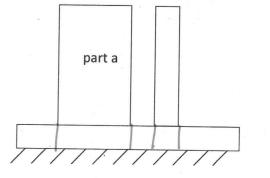
2 b. Carefully draw the cross-section after 4 minutes in HF. Isotropis distance

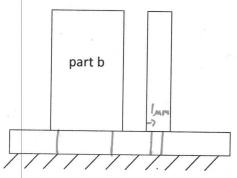
2c. On a top-down view of the structures, carefully sketch where there would still be oxide in contact with the SOI layer after a 1 minute etch

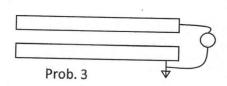


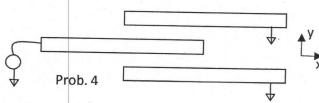
part c, 1 minute etch

- 2. [3] With the mask above, you run two different variants of the oxide etch process on two different wafers:
  - a. reactive ion etch (RIE) with vertical sidewalls
  - b. reactive ion etch (RIE) with vertical sidewalls, followed by 49% HF etch with 1um etch distance Draw the cross section after each etch.









- 3. [6] You have two conductive parallel plates that are 10um square (10x10um2) separated by a gap of 1um. One plate is grounded, the other is biased at 15V. A cross-section is shown above.
  - a. What is the approximate magnitude of the force between them? You may ignore fringing fields.

F= 1280 V 2 A = (INN) (100)

b. If the potential on the biased plate is switched from 15V to -15V, how does the force change? (increase by ..., decrease by ..., change sign, stay the same, ...)

+lp+

c. If the potential on the biased plate is switched from 15V to 150 V, how does the force change?

100

d. At 15V, if the gap between the plates is decreased to 0.1um, how does the force change?

- 4. [5] You have three conductive parallel plates that are 10um square (10x10um2) separated by gaps of 1um. The middle plate is offset from the other two by 5um. The middle plate is biased at 15V. A cross-section is shown above.
  - What is the approximate vertical force (y axis) on the middle plate?

b. What is the approximate horizontal force (x axis) on the middle plate? pt. # pt. vnit  $F_x = 20nN$ 

If the middle plate is offset further, to a total of 9um offset (1um overlap), how does the horizontal force change? (increase by ..., decrease by ..., change sign, stay the same, ...)

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5. [8] In the polyMUMPS process, you draw a 2um wide, 200um	long ca	ntilevered beam (and	charad an annual
free on the other) on layer POLY1. Assume E=150 GPa	iong ca	nthevered beam (and	chored on one end,
a. If you apply an axial force of 1uN at the tip, ignoring stres			
i. What is the stress near the base of the boam?	s concer	itrations	
$G = \frac{1}{A} = \frac{106N}{4 \times 10^{12}}$ what is the stress near the base of the beam?			
ii. what is the strain near the base of the beam?	200		0= 250KPa
what is the strain flear the base of the beam?	11-11		
$E = \frac{6}{E} = \frac{2.5 \times 10^5}{1.5 \times 10^{11}} = \frac{5}{3} \times 10^6 = 1.7 \text{m}$			ε= <u>5</u> μ
<ul> <li>If you apply a transverse force of 1uN at the tip</li> </ul>			
i. What is the moment near the base of the beam?			
(10-6N)(2x104n)			M=2x1610
ii. What is the maximum strain near the base of the base	m 2	-6 14	-10 Mm
ii. What is the maximum strain near the base of the bea $E = \frac{2}{C} = \lim_{n \to \infty} \frac{M}{EI} = \frac{(10^6 \text{m})(2 \times 10^{10} \text{ Nm})}{(1.5 \times 10^{11} \text{ Nm})} = \frac{10^{-6-10+13}}{(1.5 \times 10^{11} \text{ Nm})} = $	I=(	2×10 m)	, -3
EI (I = 1/2) (H = 24 4)	,	12	E= /6
= 10 6-10+13 (1-5 X/0 m)	= 4	2 X/0 T	
	- //	, -24	
test in a rang style resolutor, you have set up your biases so t	hat ther	e is 1uN at DC, 0.1ul	I at the AC supply
frequency $\omega$ , and 0.01uN at twice the AC supply frequency. The	ne spring	constant in your de	vice is 1 N/m, and
the resonant frequency $\omega_n$ is approximately 10 kHz. The Q of t	he resor	nator is roughly 50	
a. When $\omega$ =1 Hz, what is the amplitude of the displacement a	t DC, ω,	and 2 ω?	
			T
$x_{DC} = \mu_{m}$		xo= Oolum	x <sub>20</sub> = 0 20/μh
			- mh
b. When $\omega = \omega_n/2$ , what is the amplitude of the displacement a			Jan
b. When $\omega = \omega_n/2$ , what is the amplitude of the displacement a	at ω, and	Ι 2ω?	
	at ω, and		
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<ul> <li>b. When ω=ω<sub>n</sub>/2, what is the amplitude of the displacement at ω = 50 (0.0 μ)</li> <li>c. When ω=ω<sub>n</sub>, what is the amplitude of the displacement at ω 50 (0.0 μ)</li> <li>d. If the resonator is driven as in part c, how does the displacement</li> </ul>	w?	$x_{\omega} = O_{\omega} / 3 \mu m$	$x_{2\omega} = 0.5 \text{ m}^{3}$ $x_{\omega} = 5$
b. When $\omega = \omega_n/2$ , what is the amplitude of the displacement at $\omega = \frac{\omega_n}{5}(0.1 \mu m)$ $\omega_n = \frac{50(0.01 m)}{50(0.01 m)}$ c. When $\omega = \omega_n$ , what is the amplitude of the displacement at $\omega = \frac{50(0.01 m)}{50(0.01 m)}$	w?	$x_{\omega} = O_{\omega} / 3 \mu m$	$x_{2\omega} = 0.5 \text{ m}^{2\omega}$ $x_{\omega} = 5$ pressure drops
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EE147/247A Midterm Fall 2016

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