Reg. No.										

MANIPAL INSTITUTE OF TECHNOLOGY
Manipal University

SECOND SEMESTER M. TECH (DEAC & ME) DEGREE END SEMESTER EXAMINATION

SUBJECT: INTRODUCTION TO MEMS TECHNOLOGY (ECE - 555)

TIME: 3 HOURS **MAX. MARKS: 50**

Instructions to candidates
- Answer any **FIVE** full questions.
- Missing data may be suitably assumed and assumptions should be clearly mentioned.

1A. A silicon circular plate with fixed edges has a radius of 500μm and thickness of 20μm. It is loaded with uniform pressure load of 20MPa. (i)Determine the maximum stress developed at the edges. (ii) Does the stress induced exceed the Yield strength (7GPa)? If so what is the upper limit on pressure that can be applied so that induced stress is below Yield strength? (iii) With given radius and pressure, what should be the membrane thickness to keep the stress within Yield strength? (iii) Determine the size of square plate which has area same as that of 500μm radius circular plate. If this plate has a thickness of 20μm and is loaded with uniform pressure load of 20MPa repeat part (i) and (ii).

1B. Calculate the packing density for a FCC lattice.

1C. (a) An n-type silicon is ___ conductive when compared to p-type silicon when is doped with same dose of dopant.
(i) Less ii) more iii) equally

(b) Plasma is a gas that ____ carry electric charges
(i) Does ii) does not iii) may

(c) The term LIGA refers to ____
(i) A process for micro-manufacturing ii) a micro-fabrication process iii) a material treatment process

(d) As the gap between the electrodes reduces, the electrostatic forces _____
i) Increases ii) reduces iii) do not change

(5+3+2)

2A. Figure Q2(a) is parallel plate tunable capacitor. (i) Assuming Young's modulus to be 160GPa, determine the spring constant of the system. (ii) Assuming gap between the plate and substrate to be 1μm, determine the tunable range of the capacitance. Neglect the capacitance due to beams and the fringe fields. (iii) Etch holes are to be placed such that during the sacrificial layer etching, the etch time is fixed by the beam width and the reduction in capacitance is less than 10%. Determine the spacing between etch holes, number of etch holes and the size of the etch holes. Assume square shape etch holes. (iv)Determine the new tuning ranging for the capacitance. If this capacitance is part of a tank circuit with an inductor value of 10nH, determine the tunable range of resonance frequency (a) before (b) after the etch holes are placed.

2B. A p-type piezoresistor realized using a resistivity of 7.8Ωcm has $\pi_{11}=6.6\times10^{-11}Pa^{-1}$, $\pi_{12}=-1.1\times10^{-11}Pa^{-1}$, and $\pi_{44}=138.1\times10^{-11}Pa^{-1}$. This resistor is exposed to a stress of σ = 20MPa in longitudinal direction and $\nu\sigma$ in transverse direction. If ν = 0.2, determine the percentage change in the resistance value.

2C. (a) From mechanics point of view most preferred diaphragm geometry in micro pressure sensors is ____.
(i) Circular (ii) square (iii) rectangular

(b) The natural frequency of a micro device is determined by its ____.
(i) Mass (ii) stiffness (iii) both mass and stiffness

(c) Material that has a change in electrical properties on being exposed to particular gas can be used as a ___.
(i) Chemical sensor (ii) biosensor (iii) thermal sensor

(d) Acoustic sensors are used to detect ____.
(i) Sound (ii) temperature (iii) chemical compositions

(5+3+2)

3A. A d_{31} type piezoelectric cantilever beam has 300μm length, 20μm width and 2μm thickness. The beam tip is loaded with a point load of F(t)=5N+5Nsin(2π50t). With respect to F(t), (i) Plot the resulting stress value at the anchor. (ii) Plot the tip deflection (iii) If d_{31}=2.3pC/N, plot the developed open circuit voltage (iv) If the gap between the beam and the substrate is 1μm, does your answer to part (i) to (iii) remain the same or is it different? If it is different, sketch the new plots.

3B. With necessary mathematical analysis, explain how a change in resonance frequency of a cantilever beam on loading it with a small mass Δm, can be used in measuring Δm.

3C. (i) Miller indices are used to designate a ____.
(ii) The 110 plane in silicon crystal consists of ___ atoms.
(iii) The toughest plane to process in single crystal silicon is ____.
(iv) The photo resist that, after exposer to light, dissolves on development is known as ____.

(5+3+2)

4A. Figure Q4(a) is a valve less micro pump. (i) If the inlet and outlet ports are realized using KOH etching of 100 silicon wafer with a square window with sides aligned along 110 direction, determine the hole dimension 'a' (ii) The top membrane is a square membrane. Determine the value of 't' such that chamber volume is 40pL (iii) If the membrane moves down by 3μm (assume the movement to be parallel), what is the amount of liquid pushed out from the chamber? (iv) With the condition of part (iii), if 12nL of liquid has to be pushed out per minute, at what rate the membrane should vibrate? (v) If the membrane area, 't' and vibration rate are doubled, what is the amount of liquid pushed in a minute?

4B. Following measurement values on a set of cantilever beams realized on a wafer are available. Gap between the beam and the substrate is 1μm. Density of the beam material is 3.44g/cm^3. By manipulating the resonance frequency and pull-in voltage equations,

i) Calculate the length of the second beam. ii) Calculate the beam thickness iii) Calculate the Young's modulus of the beam material.

Length (μm)	Pull-in Voltage (V)	Resonance frequency (kHz)
200	6.9	75.2
L	3.0	33.42

4C. i) In a bi-metallic cantilever structure, top layer has higher TCE than bottom layer. On heating, the beam bends ___.
ii) Pull-in voltage is always ____ than pull-out voltage.
iii) HNA is a ____ etchant.
iv) For a same area and thickness, with a uniform pressure load, the circular membrane has ___ stress when compared to square type.

(5+3+2)

5A. In Fig. Q5(a), $\frac{V_{out}(s)}{V_{in}(s)} = \frac{1}{4\times10^{-24}s^2+1}$ (i) If the capacitance value is 2pF, determine the 'L' value. (ii) The inductor is a circular type MEMS inductor. If d_{in}=10μm, d_{out}=70μm, determine the number of turns to result in inductance value obtained in part (i). (iii) Sketch the inductor layout assuming inductor width to be 5μm.

5B. With necessary diagram and equations explain how a series of laterally deflecting fixed-fixed beams can be used in measuring the residual stress in the material.

5C. With necessary diagram and process steps, explain the SMART Cut technique of getting SOI wafers.

(5+3+2)

6A. KOH etching is performed on a 100 silicon wafer using the mask pattern of Fig. Q6(a). Draw the final etch patterns when the etching stops automatically when the slow etching 111 planes are encountered. How many free hanging structures are present?

6B. Figure Q6(b) is a thermally actuated switch. Explain how this switch works.

6C. Match the following.

ELTRAN	Dry etching
RIE	Piezo electricity
ZnO	Strain gauge
Gauge factor	SOI

(5+3+2)

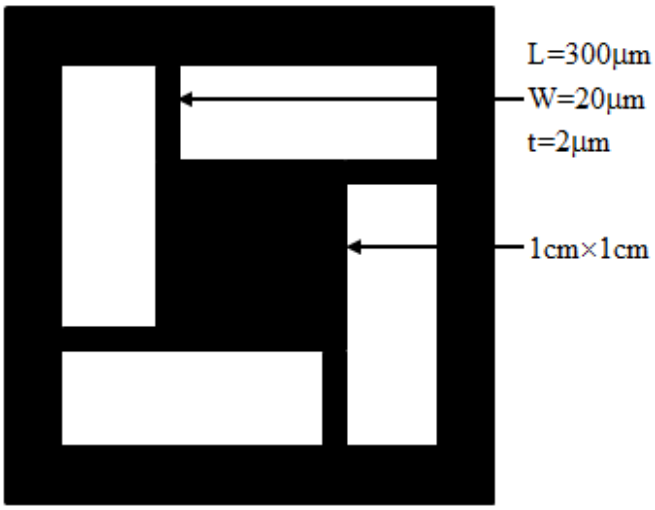

Fig. Q2(a)

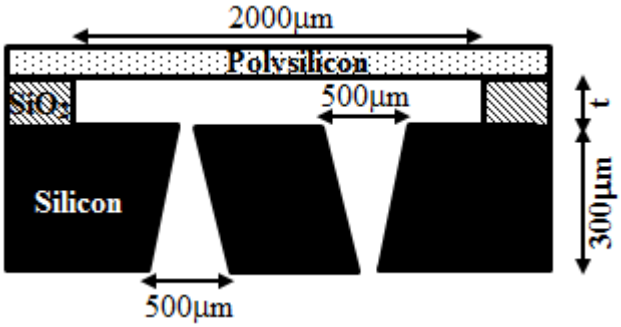

Fig. Q4(a)

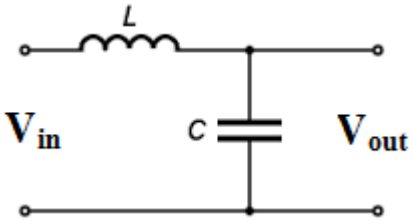

Fig. Q5(a)

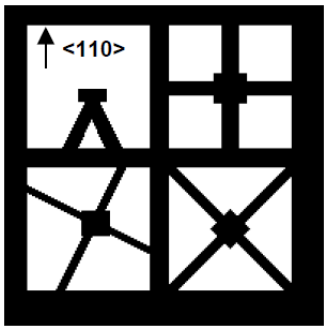

Fig. Q6(a)

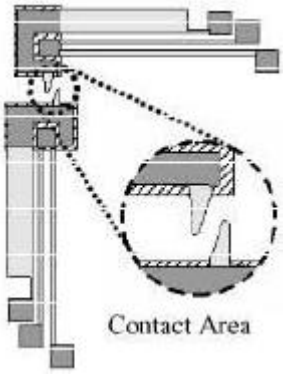

Fig. Q6(b)

****

$$(\sigma_{rr})_{max} = \frac{3W}{4\pi h^2} \qquad (\sigma_{\theta\theta})_{max} = \frac{3\nu W}{4\pi h^2} \qquad \sigma_{max} = \frac{0.308Pa^2}{h^2} \qquad k - \frac{Ewt^3}{4L^3}$$

$$\pi_t = \frac{1}{2}(\pi_{11} + \pi_{12} - \pi_{44}) \qquad \pi_l = \frac{1}{2}(\pi_{11} + \pi_{12} + \pi_{44}) \qquad \sigma(x) = \frac{6F}{h^2 w}(L - x) \qquad f = 0.16\frac{t}{L^2}\sqrt{\frac{E}{\rho}}$$

$$V_{PI} = \sqrt{\frac{0.28Et^3g^3}{\varepsilon L^4}} \qquad V = \sigma_{xx} d_{31} t_{pzt} \qquad w_{max} = \frac{4FL^3}{Ewh^3} \qquad L = \frac{394a^2n^2}{8a + 11c}$$

$a = (d_0 + d_i)/4$ $\qquad$ $c = (d_0 - d_i)/2$