

**BITS PILANI DUBAI CAMPUS**  
**EA C415 – INTRODUCTION TO MEMS**

SEM II 2012-2013

**COMPREHENSIVE EXAMINATION**    **CLOSED BOOK**

Total Marks : 80    Weightage: 40%    Time Allowed: 3 hours    Date: 5 June 2013

**INSTRUCTIONS**

1. This paper contains **NINE (9)** questions and comprises **FOUR (4)** pages. Answer **ALL** questions. Unless specifically stated, all symbols have their usual meanings.

- Q1. What are the advantages and disadvantages of using (a) piezoresistors and (b) capacitors as signal transducers. (5 marks)
- Q2. Why are electrostatic forces used to run micromotors and the same technique is not used in macrodevices and machines? (5 marks)
- Q3. Two identical and parallel metal plates of length L and width W are separated by a gap d. The gap is filled with a material of dielectric constant  $\epsilon_r$ . The plates are misaligned in the length and width directions by 20 %. Show that an applied potential V across the plates results in electrostatic forces exerted in the direction of misalignment as well as in the direction normal to the plates. Derive expressions for these forces. If  $L = 1000 \mu\text{m}$ ,  $W = 1200 \mu\text{m}$ ,  $d = 2 \mu\text{m}$ ,  $V = 70$  volts and a solid pyrex is used as the dielectric, calculate the forces. If the potential is continued to be applied, what happens to the plates eventually? (10 marks)
- Q4. State Fick's laws of diffusion. Define diffusion coefficient. Explain the significance of the negative sign in the expression for the flux due to diffusion. Phosphorus is diffused into silicon. The length and width of the opening through which diffusion takes place is  $20 \mu\text{m}$  and  $2 \mu\text{m}$  respectively. The diffusion cycle consists of a 10-minute constant source phosphorus predeposition at  $1000^\circ\text{C}$  followed by a 30-minute drive-in at  $1100^\circ\text{C}$ . Determine the phosphorus concentration at a depth of  $1 \mu\text{m}$  after drive-in. In what MEMS application is the diffused layer used? (12 marks)
- Q5. Explain capillary effect in microfluidic flow and state why conventional mechanical pumping cannot move fluids in microfluidic channels. (4 marks)
- Q6. (a) In surface micromachining,  $\text{SiO}_2$  is often used as a sacrificial layer for MEMS microstructures. Distinguish between wet and dry thermal oxidation methods of growing oxide on silicon. Show that the growth rate is rapid in the early stages of oxide growth but slows down as the oxide growth progresses. (5 marks)
- (b) Show that a layer of silicon of thickness approximately equal to  $0.44t_0$  is consumed when a  $\text{SiO}_2$  layer of thickness  $t_0$  is formed during thermal oxidation. Given: density of  $\text{Si} = 2.33 \text{ g.cm}^{-3}$  and density of  $\text{SiO}_2 = 2.27 \text{ g.cm}^{-3}$ , Atomic Wt of:  $\text{Si} = 28$ ,  $\text{O} = 16$  (5 marks)

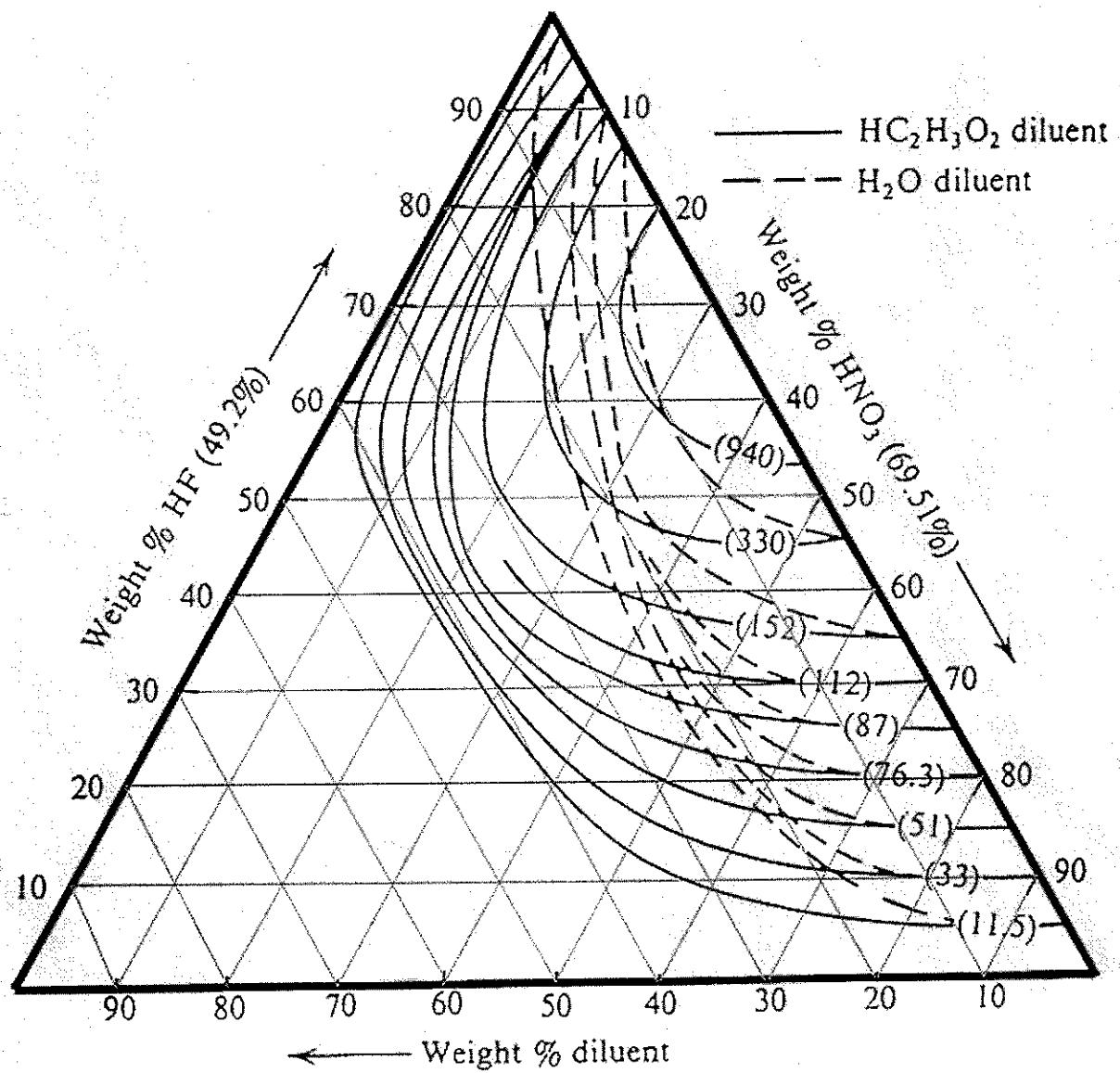
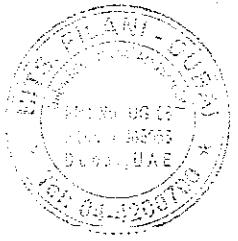


Figure 2

## EAC 415 Introduction to MEMS

Sem 2, 2012-13, Comprehensive Exam  
Answering Scheme



Q 1

Piezoresistors : Advantages: High sensitivity, small size

Disadvantages: Sensitive to temp,  
Need to use foreign substance to  
dope Si substrates

Capacitors : Advantages : Simple in structure  
less expensive  
Not sensitive to temp  
Suitable for high temp.

Disadvantages : Nonlinear I/O relationship,  
Careful calibration reqd.  
Much bulkier than piezoresistors  
uses more floor space in the IC.  
microfabrication

— (5)

Q 2

The assembly of minute overlapped electrodes like combdrive can produce electrostatic forces (separation being very small & the mass also very small) Scaling laws show that electrostatic force actuation scale down two orders of magnitude better than electromagnetic force. In macro devices hence electrostatic force become more powerful & the technique is used for actuation while micro ~~motors~~ depend on electrostatic forces. Drawback for microactuation is that the forces are low in magnitude.

— (5)

Page-1

Q3

When the plates are misaligned, the overlap length  $L' = 0.8L$

Overlap width =  $W' = 0.8W$ .

gap =  $d$ .

When a potential  $V$  is applied, energy associated with the potential  $U = -\frac{1}{2}C \cdot V^2$

$$\text{where } C = \frac{\epsilon A}{d} = \frac{\epsilon_0 \epsilon_r \cdot L' W'}{d}$$

$$U = -\frac{\epsilon_0 \epsilon_r W' L' V^2}{2d}$$

Force on the plates normal to the plane of plates is

$$F_d = -\frac{\partial U}{\partial d} = -\frac{1}{2} \cdot \frac{\epsilon_0 \epsilon_r W' L' \cdot V^2}{d^2}$$

-ve sign indicates decreasing  $d$  means increasing  $F_d$ .

For lateral forces due to misalignment will be

$$F_W = -\frac{\partial U}{\partial W} = \frac{1}{2} \cdot \frac{\epsilon_r \epsilon_0 L' V^2}{d}$$

$$F_L = -\frac{\partial U}{\partial L} = \frac{1}{2} \cdot \frac{\epsilon_r \epsilon_0 W' V^2}{d}$$

— (7)

Using values:

$$F_d = 0.0195 N,$$

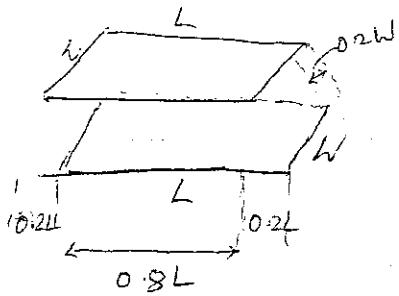
$$F_W = 4.07 \times 10^{-5} N$$

$$F_L = 4.89 \times 10^{-5} N$$

If potential is continued to be applied, the plates become aligned & the lateral forces reduce to zero.

— (1)

Page-2



Q4. Stating Fick's 2 laws —

(2)

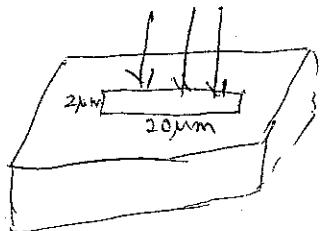
$$J = -D \frac{\partial C}{\partial x}$$

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2}$$

Define  $D$  — (1)

Negative sign indicates that the direction of flux is opposite to the direction of increasing concentration (1)

(a) 10 minute constant source P diffusion at  $1000^\circ\text{C}$  (predeposition)



$$Q = 2N_0 \sqrt{\frac{Dt_1}{\pi}}$$

$N_0$  = solid solubility at  $1000^\circ\text{C}$

$$= 10^{21} \text{ cm}^{-3}$$

$$D_1 = 3 \times 10^{-14} \text{ cm}^2/\text{s}$$

$$t_1 = 10 \times 60 \text{ s} \quad Q = 2.39 \times 10^{15} \text{ cm}^{-2}$$

— (4)

This is the limited source available for the next cycle,

(b) drive in  
drive in  $\Rightarrow$  30 mins, at  $1000^\circ\text{C}$ ,  $D_2 = 3.1 \times 10^{-13} \text{ cm}^2/\text{s}$ ,  $t_2 = 30 \times 60$

$$C(x, t_2) = \frac{Q}{\sqrt{\pi D_2 t_2}} e^{-\frac{x^2}{4D_2 t_2}}$$

At a depth of  $x = 2 \mu\text{m} = 2 \times 10^{-4} \text{ cm}$ ,

$$C(x, t_2) = \frac{2.708 \times 10^{13}}{\sqrt{\pi D_2 t_2}} = 6.46 \times 10^{17} \text{ cm}^{-3}$$

The diffused layer in MEMS application is used as a micro resistor — (1)

Page 3

Q5

Explanation of capillary effect — (2)

due to surface tension effects & Van der Waals forces  
in micro channels, conventional volumetric  
mechanical pumping cannot be used effectively.

Explain

— (2)

Q6

a) Dry oxidation : slow process, uniformity in  
the oxide structure. Interface  
is smooth between Oxide + Si

Wet oxidation : rapid process steam can  
corrode the interface which  
is therefore prone to defects  
when growth rate becomes very  
large in the initial stages.

Both dry & wet oxidation are pure thermal processes. — (2)

Based on the Deal-Grove model for pure thermal oxidation

$$\text{of Si, } A t_{\text{ox}}^2 + At_{\text{ox}} = B(t)$$

$$t_{\text{ox}}^2 + At_{\text{ox}} = B \cdot t.$$

To understand the growth rate -

$$2t_{\text{ox}} \cdot \left( \frac{dt_{\text{ox}}}{dt} \right) + A \left( \frac{dt_{\text{ox}}}{dt} \right) = B$$

$$\boxed{\frac{dt_{\text{ox}}}{dt} = \frac{B}{A + 2t_{\text{ox}}}}$$

(2)

In the early stages of oxide growth  $t_{\text{ox}} = 0$  or small  
 $\frac{dt_{\text{ox}}}{dt} = \text{large}$

When sizeable oxide grows, growth rate drops. — (1)

Page 4

6 (b)



28 g of Si gives 60 g of  $\text{SiO}_2$

For a thickness 't' of Si consumed,  
we have  $(t \times A \times 2.33)$  g of Si used.

Amount of  $\text{SiO}_2$  produced should be

$$\left( \frac{60}{28} \times t \times A \times 2.33 \right) \text{ g}$$

If a thickness  $t_0$  of  $\text{SiO}_2$  is formed,

$$\text{then } \frac{60}{28} \times t \times A \times 2.33 = t_0 \times A \times 2.27$$

$$\text{This gives } \frac{t}{t_0} = 0.44 \quad \boxed{t = 0.44 t_0}$$

— (5)

6 (c)

From growth chart, select wet oxidation,  $90^\circ\text{C}$  and 1 hour, the thickness produced is

approx.  $0.16 \mu\text{m}$ . — (2)

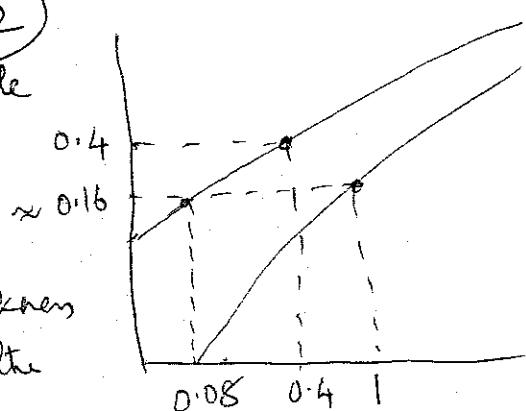
The same thickness is available when oxidation is performed at  $110^\circ\text{C}$  for 0.08 h.

When extended for a further period of 0.32 hr, the thickness corresponding to 0.4 h on the  $110^\circ\text{C}$  graph is to be noted.

This is  $0.4 \mu\text{m}$ .

The overall thickness of oxide formed =  $0.4 \mu\text{m}$ .

— (3)  
Page 5



Q7. In bulk micromachining substrate material is removed in the bulk by physical or chemical means to produce the desired structure.

In surface micromaching, thin layers are deposited and patterned to produce the microstructure. Layers are added in this process. — 2

Surface Micromaching process steps for a cantilever.

①



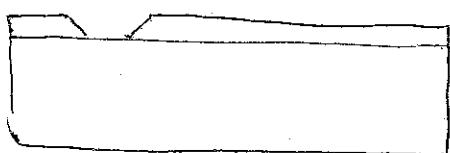
Si base

②



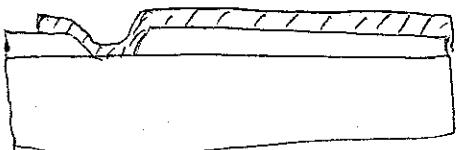
Grow Sacrificial  
PSG

③



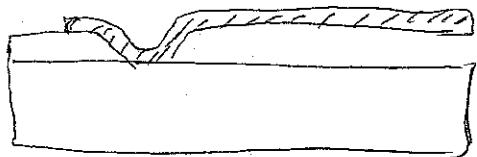
use appropriate mask  
& pattern the PSG.  
(use Photolithography).

④



deposit polysilicon

⑤



remove the PSG by  
etching

⑤

microcantilever

Limitation of photo Details of Photolithography — 2

Limitations: Resolution

①

Role of sacrificial layer to create a shape for the layer deposited on its top.

①

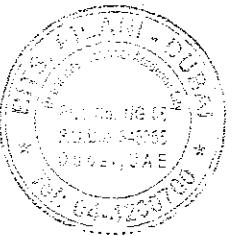
Advantage of SMM: Minimum wastage of material • fine definitions possible

①

D. - advantages • friction, Interfacial stress, adhesion

Q 8.

Describe DRIE — (4)



Virtually perfect vertical walls are due to continuous ~~sticking~~ coating of side walls as material is etched deeper & deeper. The polymeric sidewall protection results in preventing undercutting. If this is not done, it would decrease the stability of structure and the walls will require more floor space. Furthermore each device will require more floor space if sidewall protection is not done. — (4)

Advantage of DRIE: high aspect ratio.

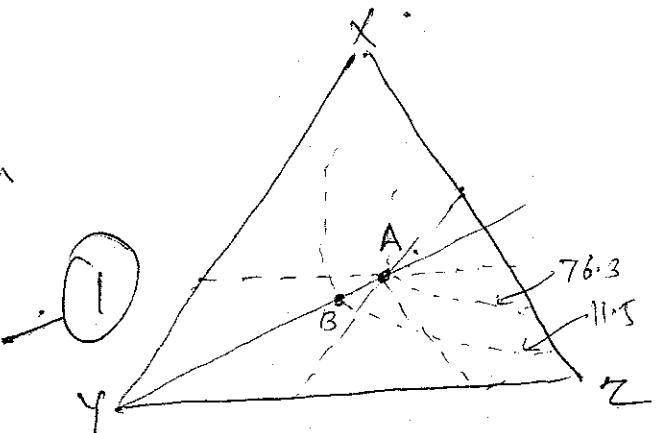
Q 9

From iso-etch conc.

$\text{HF : HNO}_3 : \text{H}_2\text{O} = 29 \text{ gm : } 50 \text{ gm : } 21 \text{ gm}$

in wt% corresponds to

$29\% : 50\% : 21\%$



From Iso-etch graph,

the etch rate corresponding to point A is  $76.3 \mu\text{m/min}$  (double sided)

So  $100 \mu\text{m}$  will be etched in [1.31 mins] — (4)

Let  $x \text{ g. of water is added. The ratio of HF : HNO}_3$  remains unaffected. If the etch rate is decreased to  $11.5 \mu\text{m/min}$ , then the new composition must lie at the point of intersection of line YA and the  $11.5 \mu\text{m/min}$  etch line. (Point B)

line YA and the  $11.5 \mu\text{m/min}$  etch line. (Point B)

Composition of point B =  $27\% \text{ HF, } 48\% \text{ HNO}_3, 25\% \text{ H}_2\text{O}$ .

In the new composition  $\text{HF\%} = \frac{29}{100+x} \times 100 = 27$

Solving  $x = 7.4 \text{ gm of water added}$  — (4)

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**INSTRUCTIONS**

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(c) A bare (100) silicon wafer is subjected to 1 hr of wet oxidation at 900 °C followed by another wet oxidation cycle for 0.32 hr at 1100°C. What is the overall thickness of the oxide formed? Use the growth chart for wet oxidation in Si shown in Figure 1.

- Q7. Distinguish between bulk micromachining and surface micromachining. It is desired to fabricate a microcantilever using surface micromachining technique. Describe the sequence of process steps for the fabrication and explain in detail the role of photolithography in the process. What are the limitations of photolithography? Describe the role of sacrificial layer in surface micromachining. Give one advantage and one disadvantage of using surface micromachining

(12 marks)

- Q8. Describe a DRIE process. How does a DRIE achieve a virtually perfect vertical etching? Why it is necessary to have a vertical etch? State one major advantage of DRIE.

(8 marks)

- Q9. A wet etchant for Si is prepared by mixing 29 grams of HF, 50 grams of HNO<sub>3</sub> and 21 grams of diluent (water). How much time would this etchant take to remove 100 µm of silicon. Some more water is added to the etching mixture and the etch rate drops to 11.5 µm/min. How much water has been added? Show your answers using the isoetch curves of Figure 2

(9 marks)

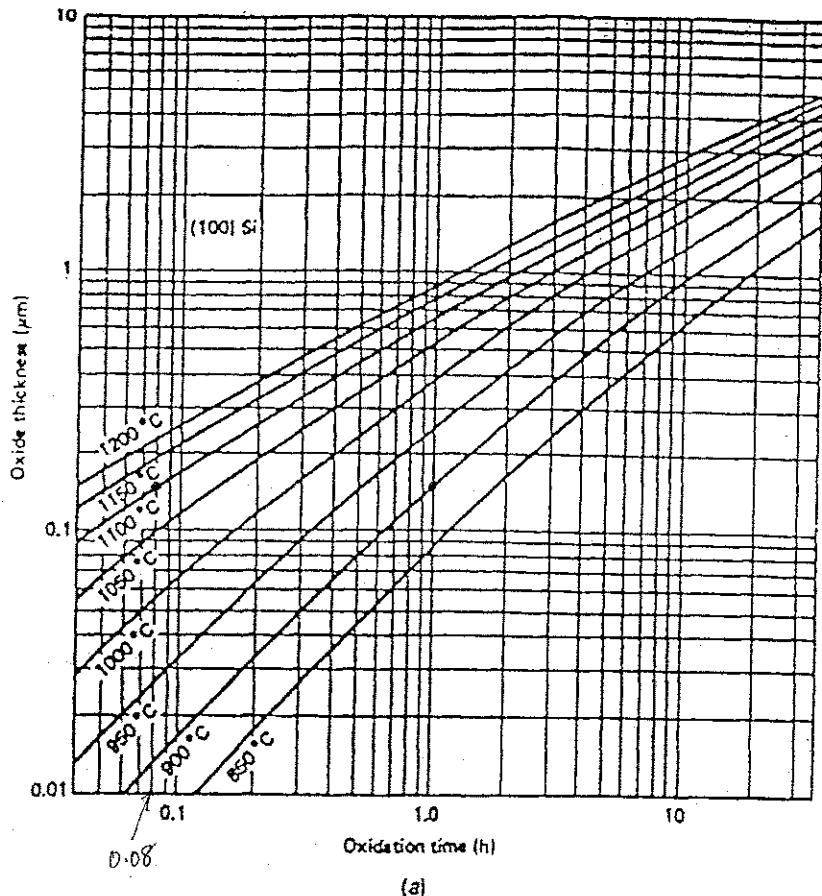


Figure 1: Wet Oxide Growth chart for (100) Silicon

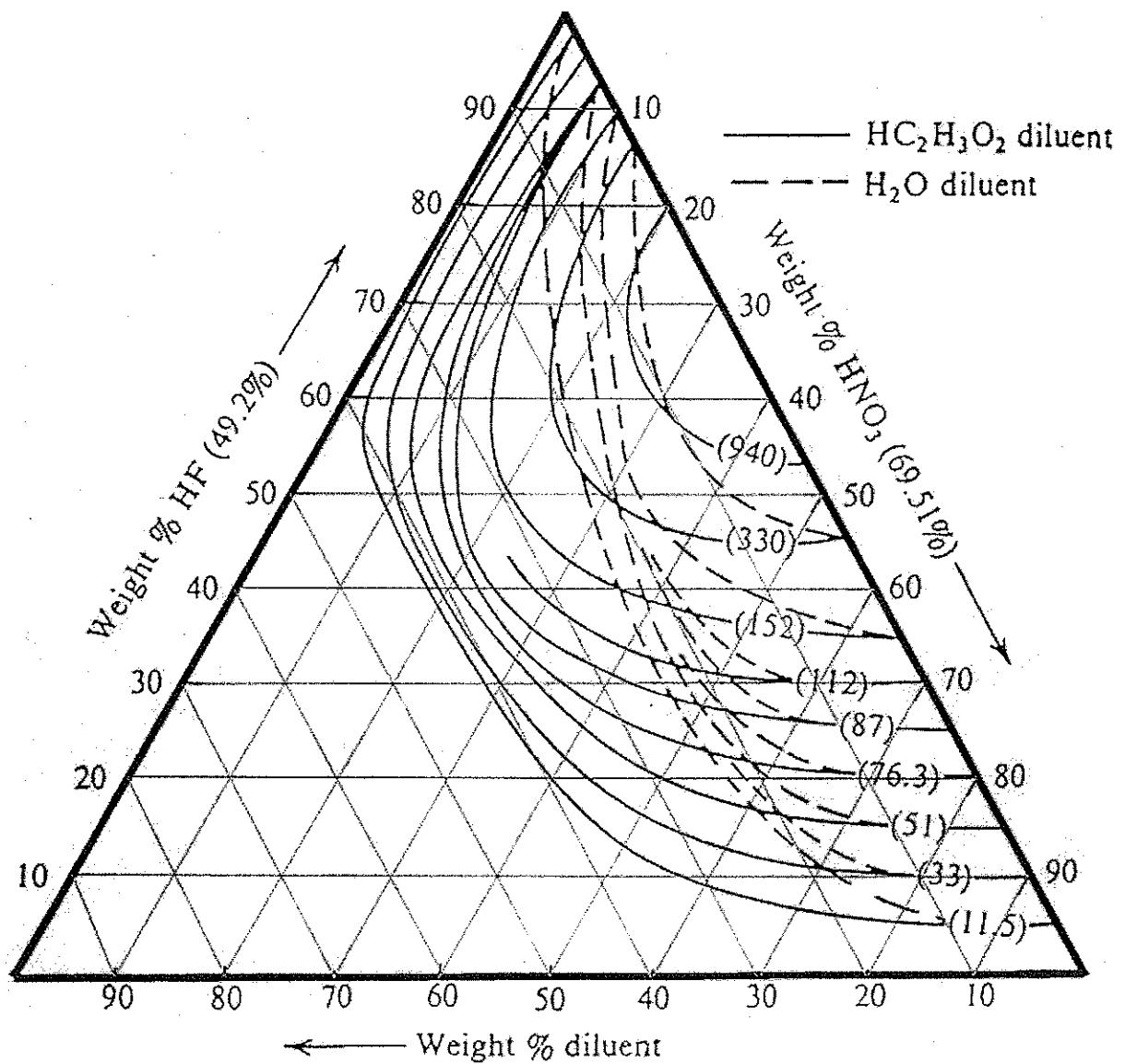


Figure 2

## Appendix

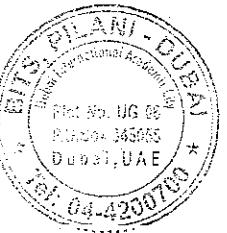
Table of Physical Constants and selected properties of microelectronic materials

	<b>Symbol</b>	<b>Value</b>	<b>Units</b>
Boltzmann's constant	$k_B$ (or $k$ )	$1.38 \times 10^{-23}$	J/K
Electronic charge	$q$	$1.6 \times 10^{-19}$	C
Electron-volt	1 eV	$1.6 \times 10^{-19}$	J
Free electron rest mass	$m_0$	$9.1 \times 10^{-31}$	kg
Permittivity of free space	$\epsilon_0$	$8.85 \times 10^{-12}$	F/m
Planck's constant	$h$	$6.626 \times 10^{-34}$	J·s
Speed of light	$c$	$3.0 \times 10^8$	m/s
Thermal voltage ( $T = 300$ K)	$kT/q$	0.0259	V
Dielectric constant of Si	$\epsilon_{Si}$	11.8	
Atomic density of Si	$C_a$	$5 \times 10^{22}$	cm <sup>-3</sup>
Dielectric constant of SiO <sub>2</sub>	$\epsilon_{ox}$	3.9	
Dielectric constant of TiO <sub>2</sub>	$\epsilon_{iox}$	80	
Dielectric constant of pyrex	$\epsilon_r$	4.7	
Intrinsic carrier concentration in Si at 300 K	$n_i$	$10^{10}$	cm <sup>-3</sup>
Diffusion Coefficient of boron or phosphorus in Si	$D_B$ or $D_P$	$3 \times 10^{-14}$ at 1000°C $3.1 \times 10^{-13}$ at 1100°C	cm <sup>2</sup> /s
Solid-solubility limit of phosphorus in Si	$C_{oP}$	$1 \times 10^{21}$ at 1000°C $1.2 \times 10^{21}$ at 1100°C	cm <sup>-3</sup>
Solid-solubility limit of boron in Si	$C_{oB}$	$1.7 \times 10^{20}$ at 1000°C $2.2 \times 10^{20}$ at 1100°C	cm <sup>-3</sup>
Mobility of electrons in Si	$\mu_n$	1350	cm <sup>2</sup> V <sup>-1</sup> s <sup>-1</sup>
Mobility of holes in Si	$\mu_p$	450	cm <sup>2</sup> V <sup>-1</sup> s <sup>-1</sup>

End of Paper

## EAC415 Introduction to MEMS

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Peizoresistors : Advantages: High sensitivity, small size  
Disadvantage: Sensitive to temp;  
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The assembly of minute overlapped electrodes like combdrive can produce electrostatic forces (separation being very small & the mass also very small) Scaling laws show that electrostatic force actuation scale down two orders of magnitude better than electromagnetic force. In macro devices hence electrostatic force become more powerful & the technique is used for actuation while micro ~~motors~~ depend on electrostatic forces. Drawback for micro actuation is that the forces are low in magnitude.

— (5)

Page-1

Q3

When the plates are misaligned, the overlap length  $L' = 0.8L$

Overlap width  $= W' = 0.8W$ .

gap  $= d$ .

When a potential  $V$  is applied, energy associated with the potential  $U = -\frac{1}{2}C \cdot V^2$

$$\text{where } C = \frac{\epsilon A}{d} = \frac{\epsilon_0 \epsilon_r \cdot L' W'}{d}$$

$$U = -\frac{\epsilon_0 \epsilon_r W' L' V^2}{2d}$$

Force on the plates normal to the plane of plates is

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-ve sign indicates decreasing  $d$  means increasing  $F_d$ .

For lateral forces due to misalignment will be

$$F_W = -\frac{\partial U}{\partial W} = \frac{1}{2} \cdot \frac{\epsilon_r \epsilon_0 L' V^2}{d}$$

$$F_L = -\frac{\partial U}{\partial L} = \frac{1}{2} \cdot \frac{\epsilon_r \epsilon_0 W' V^2}{d}$$

— ⑦

Using values:

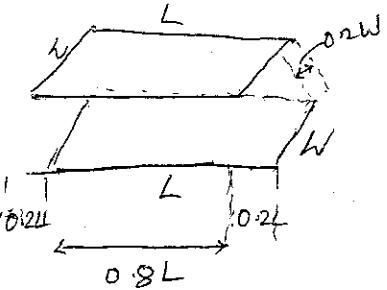
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If potential is continued to be applied, the plates become aligned + the lateral forces reduce to zero. — ①

Page 2





Q4. Stating Fick's laws. — (2)

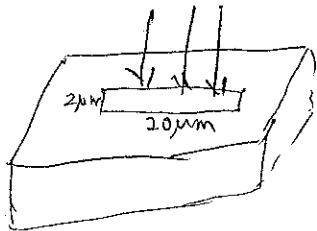
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Define  $D$  — (1)

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$N_0$  = solid solubility at  $1000^\circ\text{C}$

$$= 10^{21} \text{ cm}^{-3}$$

$$D_i = 3 \times 10^{-14} \text{ cm}^2/\text{s}$$

$$t_i = 10 \times 60 \text{ s}$$

$$Q = 4.87 \times 10^{15} \text{ cm}^{-2}$$

— (4)

This is the limited source available for the next cycle,

(b) drive in  
drive in  $\Rightarrow$  30 mins, at  $1100^\circ\text{C}$ ,  $D_2 = 3.1 \times 10^{-13} \text{ cm}^2/\text{s}$   
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At a depth of  $x = 7 \mu\text{m} = 7 \times 10^{-4} \text{ cm}$ ,

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The diffused layer in MEMS application is used as a micro resistor

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Explanation of capillary effect — (2)

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Based on the Deal-Grove model for oxide thermal oxidation

$$\text{of Si, } \frac{dt_{ox}^2}{dt_{ox}} + At_{ox} = B(t_{ox})$$

$$t_{ox}^2 + At_{ox} = B \cdot t$$

To understand the growth rate,

$$2t_{ox} \cdot \left( \frac{dt_{ox}}{dt} \right) + A \left( \frac{dt_{ox}}{dt} \right) = B$$

$$\boxed{\frac{dt_{ox}}{dt} = \frac{B}{A + 2t_{ox}}} \quad — (2)$$

In the early stages of oxide growth  $t_{ox} = 0$  or small  
 $\frac{dt_{ox}}{dt} = \text{large}$

When sizeable oxide grows, growth rate drops. — (1)

6 (b)



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Amount of  $\text{SiO}_2$  produced should be

$$\left( \frac{60}{28} \times t \times A \times 2.33 \right) \text{ g}$$

If a thickness  $t_0$  g of  $\text{SiO}_2$  is formed,

$$\text{then } \frac{60}{28} \times t \times A \times 2.33 = t_0 \times A \times 2.27$$

$$\text{This gives } \frac{t}{t_0} = 0.44$$

$$t = 0.44 t_0$$

— (5)

6 (c).

From growth chart, select wet oxidation,  $90^\circ\text{C}$  and 1 hour, the thickness produced is

approx.  $0.16 \mu\text{m}$ . — (2)

The same thickness is available when oxidation is performed at  $110^\circ\text{C}$  for 0.08 h.

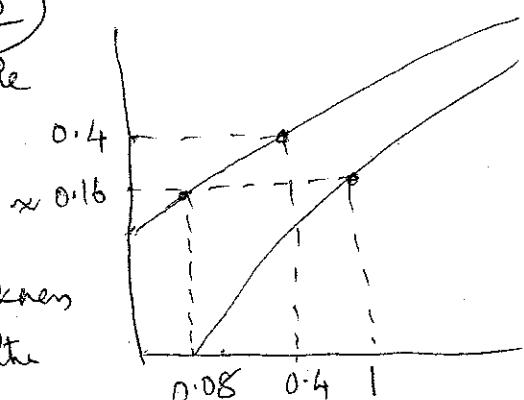
When extended for a further period of 0.32 hr, the thickness corresponds to 0.4 h on the

$110^\circ\text{C}$  graph is to be noted.

This is  $0.4 \mu\text{m}$ .

The overall thickness of oxide formed =  $0.4 \mu\text{m}$ .

— (3)  
Page 5



Q7. In bulk micromachining substrate material is removed in the bulk by physical or chemical means to produce the desired structure.

In surface micromaching, thin layers are deposited and patterned to produce the microstructure. Layers are added in thin process. — 2

Surface Micromaching process steps for cantilever.

①



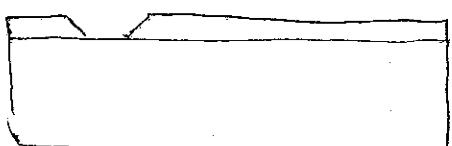
Si base

②



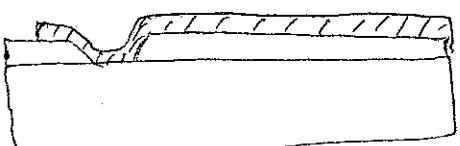
Grow sacrificial  
PSG

③



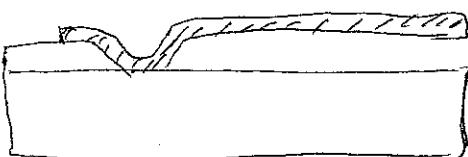
use appropriate mask  
& pattern the PSG.  
(use Photolithography).

④



deposit polysilicon

⑤



remove the PSG by  
etching

⑤

microcantilever

Limitation of photolithography — 2

Limitations: Resolution

①

Role of sacrificial layer to create a shape for the layer deposited on its top.

Advantage of SMM: Minimum wastage of material, fine definitions possible.

①

Disadvantages: Stiction, Interfacial stress, adhesion

Q 8.

Describe DRIE — (4)

Virtually perfect vertical walls are due to continuous ~~etching~~ coating of side walls as material is etched deeper & deeper. The polymeric sidewall protection results in preventing undercutting. If this is not done, it would decrease the stability of structure and also would require more floor space. Furthermore each device will require more floor space if sidewall protection is not done — (4)

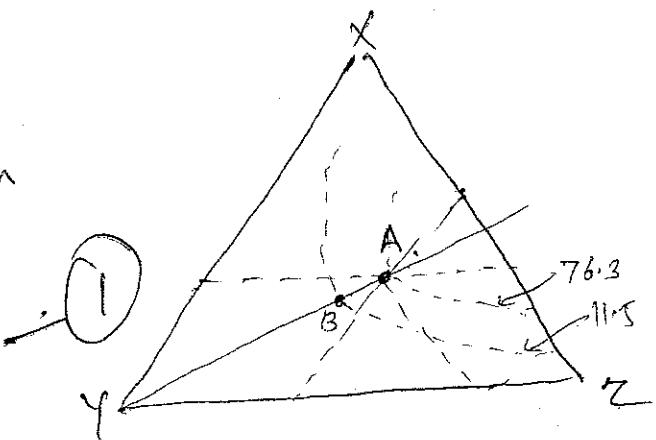
Advantage of DRIE : high aspect ratio

Q 9

From iso etch coo  
 $29 \text{ gm} : 50 \text{ gm} : 21 \text{ gm}$   
 HF HNO<sub>3</sub> H<sub>2</sub>O

in wt% corresponds to

~~29~~%, 50%, ~~21~~%



From Iso-etch graph,

the etch rate corresponding to point A is  $76.3 \mu\text{m/min}$  (double sides)

So  $100 \mu\text{m}$  will be etched in  $1.31 \text{ mins}$  — (4)

Let  $x \text{ g.}$  water is added. The ratio of HF : HNO<sub>3</sub> remains unaffected. If the etch rate is decreased to  $11.5 \mu\text{m/min}$ , then the new composition must lie at the point of intersection of the line YA and the  $11.5 \mu\text{m/min}$  etch line. (Point B)

line YA and the  $11.5 \mu\text{m/min}$  etch line. (Point B)

Composition of point B =  $27\% \text{ HF}, 48\% \text{ HNO}_3, 25\% \text{ H}_2\text{O}$ .

In the new composition  $\text{HF\%} = \frac{29}{100+x} \times 100 = 27$

Solving  $x = 7.4 \text{ gm}$  of water added — (4)

**BITS PILANI DUBAI CAMPUS**  
**EA C415 –INTRODUCTION TO MEMS- Test2**

Sem2, 2012-13  
 Total Marks : 20

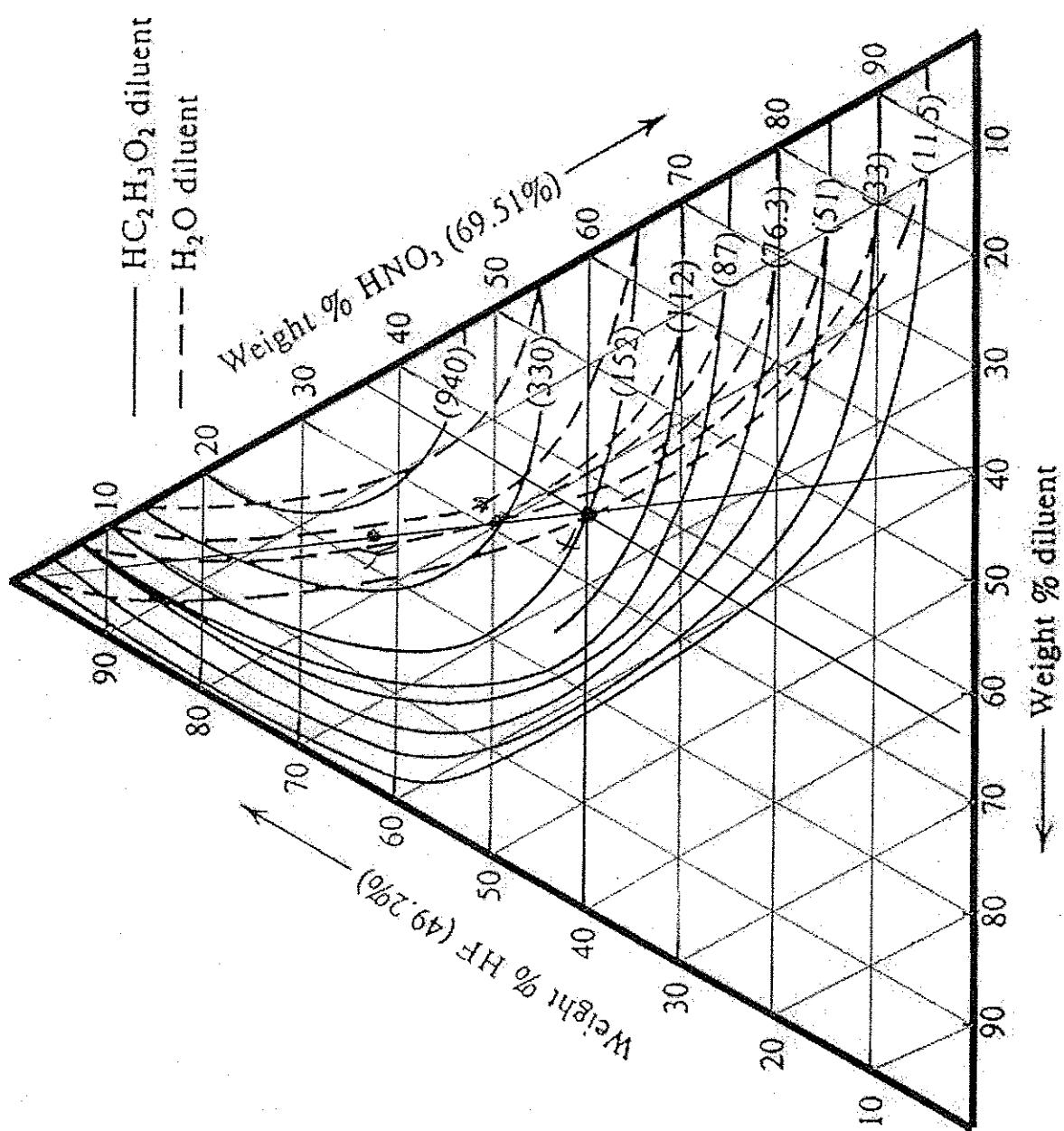
OPEN BOOK

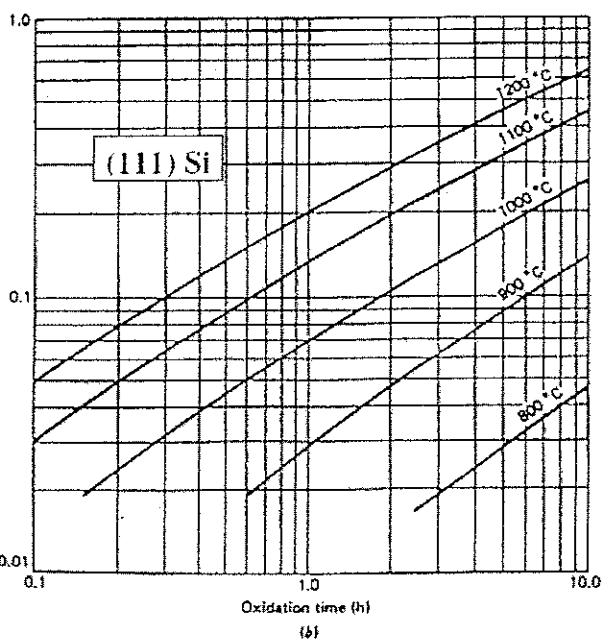
Time Allowed: 50 mins  
 Weightage: 20%

**INSTRUCTIONS**

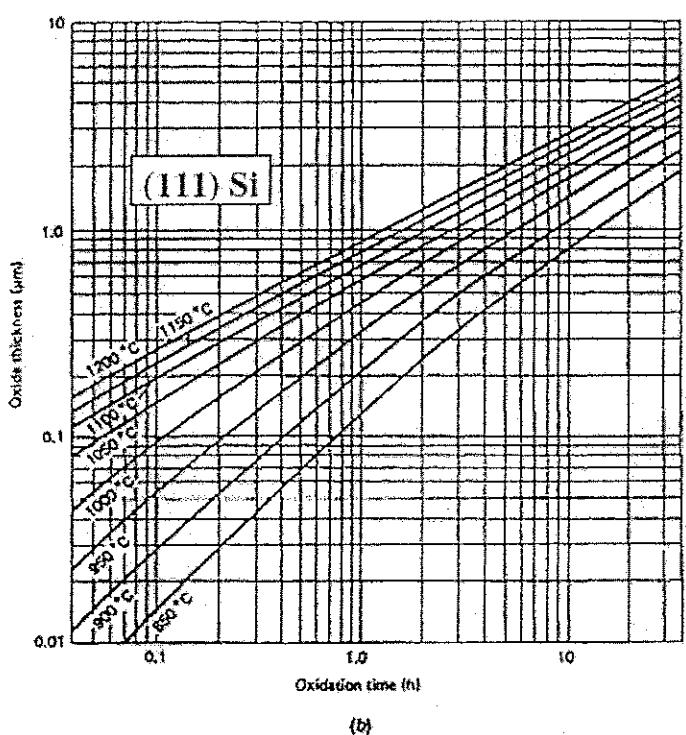
1. Answer ALL questions. Unless specifically stated, all symbols have their usual meanings.
  1. (a) Briefly discuss the advantages and disadvantages of electron beam lithography as compared to optical lithography.
  - (b) The de Broglie wavelength,  $\lambda = \frac{h}{mv}$ , where  $h$  is Plank's constant, and  $m$  and  $v$  are the mass and the velocity of the particle, respectively, can be shown using the relationship between the momentums of photon and particle. For an electron accelerated between two electrodes with a potential difference  $V$ , show that the de Broglie wavelength of an electron is
- $$\lambda = \frac{h}{\sqrt{2meV}}. \quad (4 \text{ marks})$$
2. List the process steps involved in a typical photolithography process. It is required to form a metal pattern shape of  on a silicon surface.  
 Explain how this can be achieved using through any method that you know. (4 marks)
  3. Three cans consisting of 49.2% HF (component A), 69.51% HNO<sub>3</sub> (component B) and distilled water (component C), are available in a laboratory. One side of a silicon substrate is etched in an etching mixture consisting of 40 grams of A, 36 grams of B and 24 grams of C. Determine time  $t_1$  taken to etch a thickness of 23  $\mu\text{m}$  of Si. By adding an amount  $x$  grams of one of the components (A, B or C) to the existing mixture, it is found that the mixture so formed has the same ratio of HF : HNO<sub>3</sub> as before, but the time taken to etch the same thickness of silicon is reduced to  $t_1/ 13.22$ . Determine the component added and the amount added ( $x$ ) in grams. Use the isoetch graph for Si provided. (4 marks)
  4. Show that a layer of silicon of thickness approximately equal to 0.44 $t_0$  is consumed when a SiO<sub>2</sub> layer of thickness  $t_0$  is formed during thermal oxidation. Given: density of Si=2.33g.cm<sup>-3</sup> and density of SiO<sub>2</sub>=2.27g.cm<sup>-3</sup>, Atomic Wt of: Si=28, O=16 (4marks)
  5. Calculate the oxide thickness for a slice of (111) silicon subjected to:  
 a) 10 minutes of wet oxidation at 1100°C followed by  
 b) 3 hr. dry oxidation at 1100°C. (4 marks)

The End





Oxide Growth rate in (111) Silicon for dry Oxygen



Oxide Growth rate in (111) Silicon for wet Oxygen



## Supplementary Answer Sheet

EAC 415

Test II

ID No. \_\_\_\_\_

Name \_\_\_\_\_

Start writing from here

Test - 2 EAC-415

Sem 2 2012-13

Answering Scheme

① a) <sup>+ high resolution</sup> The wavelength for electron beam can be continuously adjusted to very low values giving very sharp features for lithography. Optical beam is limited to optical wavelength, low resolution. E-beam equipment very complex, optical beam lithography equipment very simple & cheaper. (2)

b)  $\lambda = \frac{h}{mv} \cdot \frac{1}{2}mv^2 = eV$  (Kinetic energy of electron gained from field). (2)

Combining  $\lambda = \frac{h}{\sqrt{2meV}}$

- ② ① clean wafer ② Grow a thin layer (500 nm) of  $\text{SiO}_2$  by thermal oxidation ③ Coat wafer with 1  $\mu\text{m}$  of PR ④ Use an appropriate mask & back resist with UV (Expose) ⑤ Develop the image (remove softened PR) & bake the resist to get the image (remove softened PR) ⑥ Put wafer in plasma etcher to remove  $\text{SiO}_2$  rid of solvents ⑦ Put wafer in plasma stripper - from exposed regions PR + leave  $\text{SiO}_2$  untouched oxygen ion remove oxygen ion remove A pattern of  $\text{SiO}_2$  is now formed on Si. (3)

To make a pattern of L.

wafer, then use a mask



with +ve PR, expose and develop, then use a metal etch followed by PR stripper. (1)

first grow metal layer on

with +ve PR, expose and

develop, then use a metal etch followed by PR stripper.

③ composition HF : HNO<sub>3</sub> : H<sub>2</sub>O = 40% : 36% : 24%.

The etch rate for one-sided Si corresponds to point X on the iso etch curve (which is 5.75 μm/min)

To etch 23 μm of Si, time taken  $t_1 = \frac{23}{5.75} = \underline{\underline{4 \text{ min}}}$

If water is added etch rate will only decrease. So not possible

Required etch rate is 76 μm/min (one sided)  
equivalent to 152 μm/min (double sided).

If HF is added, this is possible  
so the corresponding point is Y (63% HF, 23% HNO<sub>3</sub>,  
24% H<sub>2</sub>O)

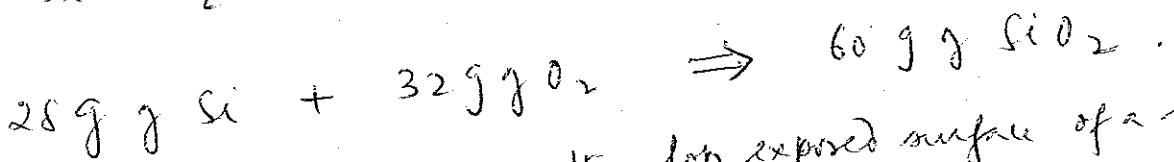
By adding x gms of HF, we have

$$(40+x) : 36 : 24$$

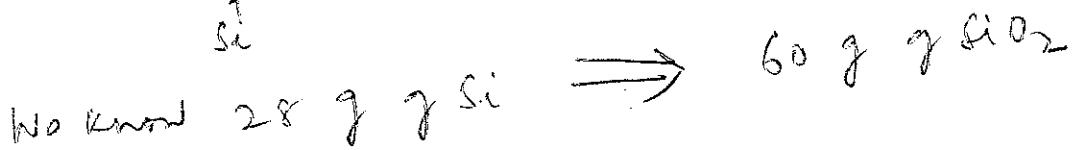
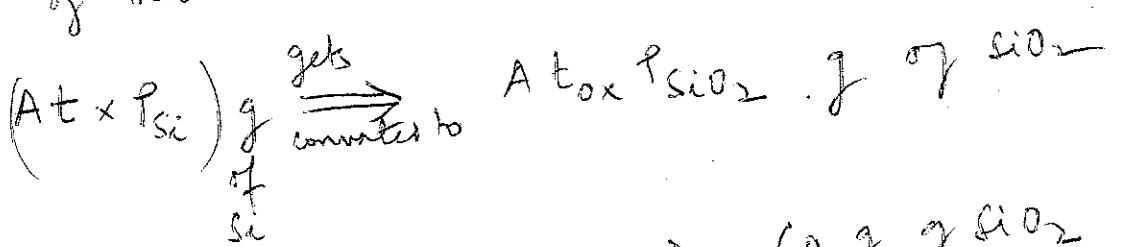
$$\% \text{ of HNO}_3 \text{ in the mixture is } \frac{36}{100+x} \times 100\% = 23$$

$$\boxed{x = 56.5 \text{ g.}}$$

Q4



Assume oxide grows on the top exposed surface of a slab of Si of area A and thickness t to form a  $\text{SiO}_2$  layer of thickness  $t_{\text{ox}}$  and Area A.



$$\text{Therefore } \frac{60}{28} \times At \times p_{\text{Si}} = A t_{\text{ox}} p_{\text{SiO}_2}$$

$$t = \frac{28}{60} \times \frac{2.27}{2.33} t_{\text{ox}} = 0.44 t_{\text{ox}}$$

(4)

(5)

(0.166 h)

a) 10 min/g wet oxidation of (111) Si at 1100°C  
from chart gives approx  $0.25 \mu\text{m}$  of oxide

①

b) When this is followed by 3 h. of dry oxidation  
at 1100°C.,  $0.25 \mu\text{m}$  under thin condition  
is equivalent to 3 hours. Thin is extended by 3 hr  
so total time = 6 hours and total oxide thickness  
is  $0.36 \mu\text{m}$ . Additional thickness grown during 2nd phase  
is  $0.11 \mu\text{m}$ . Total thickness after (a) + (b) is  $0.36 \mu\text{m}$

③

**BITS PILANI DUBAI CAMPUS**  
**EA C415 –INTRODUCTION TO MEMS- Test1**

Sem2, 2012-13  
 Total Marks : 25

CLOSED BOOK

Time Allowed: 50 mins  
 Weightage: 25%

**INSTRUCTIONS**

1. Answer **ALL** questions. Unless specifically stated, all symbols have their usual meanings.
1. Distinguish between biomedical and biosensors. What are the major technical issues involved in the application of MEMS in biomedicine? Describe the working principle of a biomedical sensor for measuring blood glucose concentration (4 marks)
2. A micro pressure sensor based on changes in capacitance due to applied pressure on a diaphragm is constructed using a rigid plate and a diaphragm, both having dimensions  $L = W = 1000 \mu\text{m}$  and separated by an air gap  $d = 2 \mu\text{m}$ . An applied pressure on the diaphragm is expected to reduce the air gap. Plot the change in capacitance (in pF) with change in air gap (in  $\mu\text{m}$ ) due to changes in applied pressure on the diaphragm. A Wheatstone bridge is constructed with this capacitive pressure sensor as one arm while identical standard capacitors form the other three arms. The bridge is driven by an input  $V_{\text{in}}$  while the output  $V_o$  is measured. Plot the ratio  $V_o/V_{\text{in}}$  as a function of air gap (in  $\mu\text{m}$ ) when the applied pressure on the diaphragm is progressively increased. Permittivity of free space is  $8.85 \text{ pF/m}$  (8 marks)
3. Distinguish between diffusion and ion implantation. (2 marks)  
 A *n*-type Si substrate with a background concentration of  $5 \times 10^{16} \text{ cm}^{-3}$  forms the collector of an *n-p-n* transistor. The base diffusion cycle consists of a 15-minute constant source boron predeposition at  $1000^\circ\text{C}$  followed by a 60-minute drive-in at  $1100^\circ\text{C}$ . Use the data given in Table 1.
 

Temp. ( $^\circ\text{C}$ )	Diffusion Coefficient of boron or phosphorus in Si ( $\text{cm}^2/\text{s}$ )	Solid-solubility of boron in Si ( $\text{cm}^{-3}$ )	Solid-solubility of phosphorus in Si ( $\text{cm}^{-3}$ )
1000	$3 \times 10^{-14}$	$1.7 \times 10^{20}$	$1 \times 10^{21}$
1100	$3.1 \times 10^{-13}$	$2.2 \times 10^{20}$	$1.2 \times 10^{21}$

 (a) Calculate the base-collector junction depth that results from the above process. (5 marks)
   
 (b) Is the base diffusion profile likely to be affected by an emitter diffusion? If so, how? (2 marks)
4. A sample of Si is doped simultaneously with donors ( $N_D = 5 \times 10^{10} \text{ cm}^{-3}$ ) and acceptors ( $N_A = 4.5 \times 10^{10} \text{ cm}^{-3}$ ). Determine the thermal equilibrium electron and hole concentrations at 300 K. Intrinsic carrier concentration  $n_i$  for Si at 300 K =  $10^{10} \text{ cm}^{-3}$ . (4 marks)

The End

### Supplementary Answer Sheet

ID No. EAC - 415

Name Semester 2, 2012-13

Start writing from here

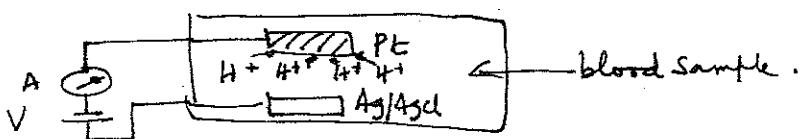
### INTRODUCTION TO MEMS Test - 1

#### Marking Scheme :

**Q1.** Bio sensors work on the principle of interaction of analytes that need to be detected with biologically derived bio molecules such as enzymes, antibody, proteins etc which when attached to sensing elements interact with analytes to alter the output signal. Biomedical Sensors can be classified as biomedical instruments to detect biological substances for medical diagnosis purposes (1M)

Major Technical Issues: 1) Functionality 2) Adaptivity (1M)  
3) Compatibility & 4) Controllability + 5) Fabrication

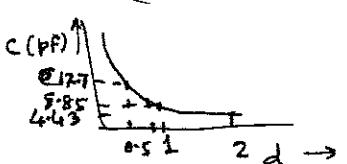
#### Biomedical Sensor for glucose measurement

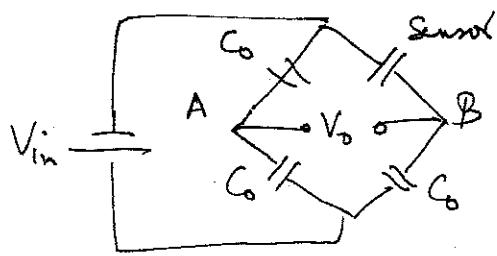


Blood sample in polyvinyl alcohol solution introduced in chamber. O<sub>2</sub> in blood solution reacts with Glucose in blood to produce H<sub>2</sub>O<sub>2</sub>. This is electrolysed with 2 electrodes. The current flow indicates the amount of glucose in blood. (2M)

**Q2**  $C = \frac{\epsilon_0 A}{d}$   $A = 1000 \times 1000 \mu\text{m}^2$ .  
 $\epsilon_0 = 8.85 \text{ pF/m}$ ,  $d = 2 \mu\text{m}$   
 $\epsilon_r = 1$  Default capacitance  $C_0 = 4.43 \text{ pF}$ .

There will be change in  $C_0$  with change in  $d$  (rectangular hyperbola)

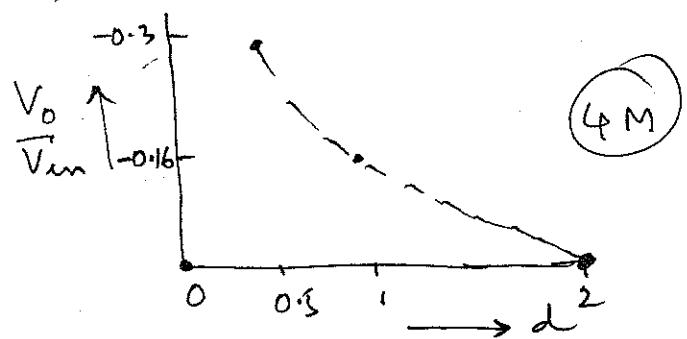




$$V_A = \frac{V_{in}}{2}$$

$$V_B = \frac{V_{in}}{\frac{1}{C_s} + \frac{1}{C_0}} \cdot V_{in} \quad \text{where } C_s = \frac{\epsilon_0 A}{d} \quad \text{and } d \text{ changes from } 2\mu\text{m towards zero}$$

$$\frac{V_0}{V_{in}} = \frac{V_A - V_B}{V_{in}} = \frac{1}{2} - \frac{1}{1 + (C_0/C_s)} = \frac{1}{2} - \frac{1}{(1 + \frac{d}{2})}$$



Q3 Scattering diffusion works on the basis of conc. gradient, slow, to temp, implantation is due to highly energetic bombardment of ions, forced by dose depends on implantation energy, temp., scattering, fast. (2M)

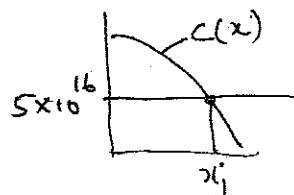
a) Predose: dose  $Q = 2 \times 1.7 \times 10^{20} \cdot \sqrt{\frac{3 \times 10^{-14} \times 15 \times 60}{\pi}} \text{ cm}^{-2}$  (2M)  
 $= 9.96 \times 10^{14} \text{ cm}^{-2}$

Drive-in profile:  $C(x) = \frac{9.96 \times 10^{14}}{\sqrt{\pi \times 3.1 \times 10^{-13} \times 60 \times 60}} \times e^{-\frac{x^2}{4 \times 3.1 \times 10^{-13} \times 60 \times 60}}$   
 $= 1.68 \times 10^{19} e^{-\frac{x^2}{4.464 \times 10^{-9}}}$  (2M)

At the base-collector junction  $x_j$ ,

$$5 \times 10^{16} = 1.68 \times 10^{19} e^{-\frac{x_j^2}{4.464 \times 10^{-9}}}$$

Solving,  $x_j = 1.61 \mu\text{m}$  (1M)



(b) An emitter diffusion in another high temp. cycle hence the previously diffused p-type dopants for the base region will be re-distributing during the emitter diffusion cycle and their profile will be affected. The base diffusion profile will be shallower and deeper into the silicon. (2 M)

Q 4.



$$n \cdot p = n_i^2 \Rightarrow p = \frac{n_i^2}{n} = \frac{10^{20}}{n}.$$

$$\frac{10^{20}}{n} - n + 0.5 \times 10^{10} = 0 \quad \text{---} (2m)$$

$$n^2 - 5 \times 10^9 n - 10^{20} = 0$$

$$n = \frac{5 \times 10^9 \pm \sqrt{25 \times 10^{18} + 4 \times 10^{20}}}{2} = \frac{5 \times 10^9 \pm 2.06 \times 10^{10}}{2}$$

-ve sign not allowed

$$\boxed{n = 1.28 \times 10^{10} \text{ cm}^{-3}}$$

$$\boxed{p = 7.81 \times 10^9 \text{ cm}^{-3}}$$

--- (2m)

**BITS PILANI DUBAI CAMPUS**  
**EA C415 -INTRODUCTION TO MEMS- Quiz 1**

Sem2, 2012-13  
Total Marks : 15

CLOSED BOOK

Time Allowed: 20 mins  
Weightage: 5%

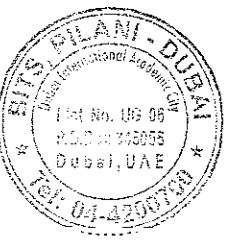
**INSTRUCTIONS**

1. Answer **ALL** questions. Unless specifically stated, all symbols have their usual meanings.
1. Use scaling laws to estimate the variations of volumetric flow and pressure drop in a circular tube if the radius of the tube is reduced by a factor of 10. What happens if the radius is at the microscale? (3 marks)
2. Four piezo resistors are connected in a Wheatstone Bridge arrangement to form a micro pressure sensor. Draw the typical sensor assembly and the equivalent Wheatstone Bridge circuit. Under what condition does the bridge exhibit highest sensitivity? Explain. (4 marks)
3. Two plates have identical dimensions of  $L = W = 200 \mu\text{m}$  with a gap  $d = 2 \mu\text{m}$ . The plates are initially misaligned by 25% in both length and width directions. Pyrex glass is used to fill the gap between the plates. Dielectric constant of pyrex is 4.7. If the voltage across the plates is 50 V DC, how much is the electrostatic force on the electrodes, along its length and width directions? (4 marks)
4. Explain the action of a micro motor actuated by electrostatic forces. (4 marks)

The End

EAC-415 Introduction to NEMS

Quiz 1 Sem 2 2012-13  
Marking Scheme.



Q1.

$$Q = \frac{\pi r^2 h}{\ell} \quad Q \propto L^3$$

$$2\pi R \Rightarrow \frac{R}{10}, \quad Q \Rightarrow \frac{Q}{100}$$

All fluid flow at microscale is in laminar regime

We use Hagen-Poiseuille Law

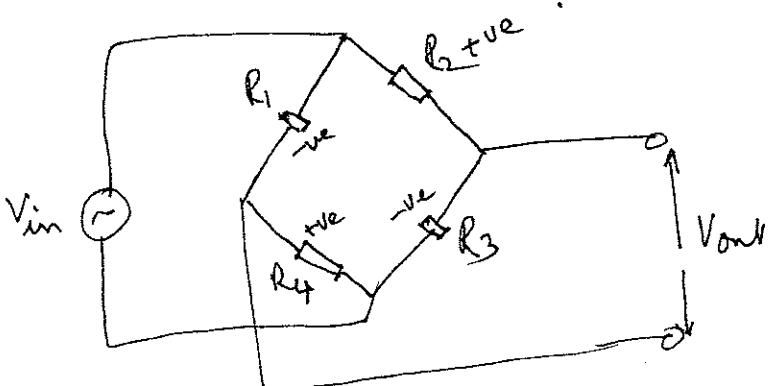
$$Q = \frac{\pi a^4 \Delta P}{8 \mu L}$$

If  $\Delta P$  is reduced by 10,  $Q$  reduces by  $10^{-4}$

— (2)

— (1)

Q2.



— (1)

$$V_{out} = \left[ \frac{R_3}{R_2 + R_3} - \frac{R_4}{R_2 + R_4} \right] \cdot V_{in} \quad — (1)$$

When the piezo resistors are placed such that the applied pressure develops +ve strain to  $R_2, R_4$  and -ve strain to  $R_3 + R_4$ , the sensitivity is maximum.

— (2)

Q3

$$F_e = \frac{1}{2} \cdot \frac{\epsilon_r \epsilon_0 W' V^2}{d}$$

$$F_w = \frac{1}{2} \cdot \frac{\epsilon_r \epsilon_0 L' V^2}{d}$$

$$L' = W' = 150 \mu\text{m}$$

Find  $F_e, F_w$  with  $\epsilon_r = 4.7, \epsilon_0 = 8.85 \times 10^{-12}, W' = L' = 150 \times 10^{-6}$ ,  $V = 50, d = 2 \times 10^{-6} \text{ m}$ . (2)

Since gap is filled with solid pyrex, there will not be any displacement in the d direction. The displacement in the L and W directions above to the force  $F_e$  and  $F_w$  will be such that the plates align with each other eventually.

(2)

Q4.

Micromotor - explanation -

(2)

Diagram with labeling —

(2)