Birla Institute of Technology and Science, Pilani
MEL G611 IC Fabrication Technology
COMPREHENSIVE EXAMINATION

Time 3 hrs **13.12.2016** **MM 120**

You may need: $N_A = 6.02 \times 10^{23}$, $K_B = 1.38 \times 10^{-23}$ J/K, R = 8.31 J/mol.K

Paper contains three parts.

- For part A (Quiz/short answer, 35 marks) there is no partial marking and precise answers expected.
- Part B (closed book-40 marks) and C (open book-45 marks) are descriptive.
- Part A and B should be done in answer sheet I. Part C in sheet II.
- After submission of I (max 1 h 40 min), part C answer sheet will be given.

Part A (35 marks)

Write only answers in a box from the first page of answer sheet I in sequence. You may use last few pages if sheet I for rough work.

1. Consider Si|SiO_2 interface. Prior to oxidation silicon was doped with Boron. Plot concentration profiles of B distrobution across the interface after oxide is grown. (It is known that B has higher equilibrium concentration in SiO_2 than in Si. Further its diffusion in oxide is slow) **[2]**

2. What do you understand by "clean room of class 10" **[2]**

3. In an experiment, 2 micron of silicon oxide is being etched on the top of silicon substrate. Etch rate for SiO_2 is 0.5 µm/min. Etch selectivity is 50:1. If etch is done for 5 mins, how much underlying silicon will be etched? **[4]**

4. A Silicon crystal is etched in a KOH solution through a 2 µm x 2 µm window defined in SiO_2. The etch rate normal to (100) and $(\bar{1}10)$ planes is 0.6 and 0.1 µm/min, respectively. In each case, find the width of the bottom surface after 40 seconds. **[2+2]**

5. What is the total planar density (atoms/nm^2) of (100) plane of GaAs? (atomic radius of Ga and As are 0.122 nm and 0.205 nm, respectively) **[2]**

6. A 100 keV Boron implants on 200 mm diameter silicon wafer with a dose of 5×10^{14} /cm^2 for 1 min of implantation. What should be required ion beam current? **[2]**

7. Schematically draw positive photoresist contrast curves to compare two photo resists with $\gamma = 2$ and 4. Which of them should be preferred? **[2+1]**

8. Write down an expression for temperature dependence of parabolic growth rate constant. Plot its temperature dependence. **[2]**

9. In an optical non-contact lithography technique wavelength of light used is λ. The mask has a slit of width ***a***. Plot, comparatively, the diffraction pattern likely on the substrate for (i) $a = \lambda$ (ii) $a = 5\lambda$ **[2]**

10. In the vapour phase epitaxy, write down one usefulness and one drawbacks of SiH_4 method. Write the chemical reaction. **[2+1]**

11. Assume a situation where diffusion constant is proportional to cube of the concentration. If the diffusio constant at the surface is 2x 10^{-12} m^2/s and concentration at the surface is maintained at 0.8 wt%, what will be the concentration (in wt %) beneath the surface where the value of diffusion constant is 3.125 x 10^{-14} m^2/s. [3]

12. In a vapour phase epitaxy experiment, without changing the geometry of the setup, mention two ways to reduce the stagnant layer thickness. **[2]**

13. In an experiment of X-ray diffraction, what information you get if (i) peaks are broadened and (ii) peaks are shifted **[1+1]**

14. In an in situ experiment of RHEED in MBE (reflection high energy electron diffraction) electron beam wavelength used is 4 A. What should be smallest possible inter planar spacing that will produce diffraction? [2]

PART B (40 marks) (closed book)

1. Assuming that 20 kg pure silicon charge is used, find the amount of phosphorous that must be added to get phosphorous-doped silicon to have a $10^{17}/cm^3$ concentration of P atoms if one fifth of the ingot is grown? (Given: effective segregation coefficient for P in Si = 0.35; density of Si = 2.33 g/cm^3density of liquid Si = 2.53 g/cm^3atomic weight of P = 30.97 g/mol, Atomic weight of Si = 28.9 g/mol) **[6]**

2. Explain the mechanism of etching of Silicon. You are given chemicals: HF, HNO_3 and H_2O composition. Discuss chemical reactions involved in different steps. **[8].**

3. Mean time of failure (MTF) of aluminum is found to be 'T_{pc}' when deposition is in polycrystalline form. The activation energy for MTF for this polycryalline system is 0.5 eV. However, when deposition of aluminum is single crystalline the MTF is found to be 'T_{sc}' with activation of MTF as 1.4 eV. What should be relationship between T_{sc} and T_{pc} under same electrical conditions at 300K? Which of the MTFs will be higher and why? **[5+3]**

4. Taking example of DQ (Diazo Neptha Quinone) explain the mechanism of positive photoresist removal after UV exposure. (detailed chemical reactions are not expected but conceptually adequate information should be provided). **[8]**

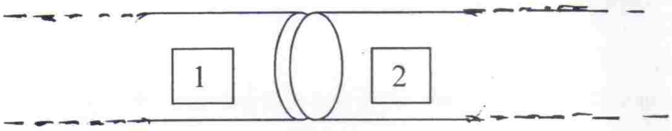
5. Design a vertical reactor for a vapour phase epitaxy setup with facilities to (i) seven samples preparation at a time (ii) create and measure vacuum of the order of 10^{-8} Torr (iii) sample Heating arrangement (iv) phosphorous doping facility (v) in situ surface crystal structure characterization facility. **[10]**

PART C (OPEN BOOK) (45 marks) 80 mins

1. Two cylindrical semi-infinite rods of silicon are taken. A constant uniform concentration of Boron is found to be C_1 and C_2 in rods 1 and 2, respectively. Now the two pieces are connected and a smooth junction is ensured. The diffusion const. is assumed to be independent of the concentration. $x = 0$ is a position taken at the interface of the diffusion couple. If a general solution for such a situation is given by,

$$C(x,t) = A - B\, erf\left(\frac{x}{2\sqrt{Dt}}\right)$$

Where A and B are constants.



(i) find the values of A and B **[5]**

(ii) If rod 1 contains 1 wt% Al and rod 2 contains 4 wt% of Al before the junction is made, determine the time this diffusion couple must be heated at 1000 C in order for the composition to be 2.8 wt% Al at 10 micron position in the rod 2 after formation of the junction. Given: $D_0 = 1.3 \times 10^{-5}$ m^2/s and activation energy for diffusion is 252 kJ/mol. **[10]**

2. If boron is implanted into the silicon substrate, calculate the damage density and the percentage damage for two cases of average nuclear energy loss of (i) 40 eV/nm and (ii) 120 eV/nm, for projected range of 300 nm. The silicon displacement energy is 15 eV/atom and the range is 2.5 nm. The spacing between the silicon lattice planes is 0.25 nm. Atomic radius of Si = 0.118 nm. **[15]**

3. A Silicon sample is oxidized in wet-dry-wet step of oxidation at 1200 ^{0}C.

(i) In **step I** wet oxidation is performed for 3 hrs. What is the thickness of the oxide grown?

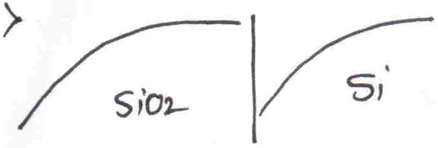
(ii) In the **step II**, dry oxidation is performed so that the total grown thickness reaches to 2 micron. Calculate the additional time required.

(iii) In the **step III** again wet oxidation is performed for 15 hrs. Calculate the total thickness at the end of the complete wet-dry-wet process. **[15]**

Model Solutions
MEL G 611
2016-17 I SEM

QUIZ part

1>



B diffusion profile. [2]

2> clean room of class '10'
⇒ in 1 ft³ volume no. of particles of size 0.5 μm is ≥ 10 [2]

Q3> etch rate selectivity

$$S = \frac{r_{SiO_2}}{r_{Si}} = \frac{50}{1}$$

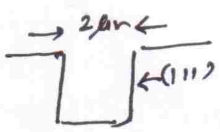
$$\Rightarrow r_{Si} = 0.01 \ \mu m/min$$

Total 2 μm SiO_2 etching will take 4 min whereas total etching is done for 5 min so 1 min for Si etch.

$$\text{Si etch} = 0.01 \frac{\mu m}{min} \times 1 = 0.01 \ \mu m$$

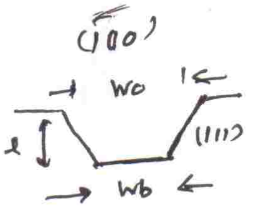
Ans = 0.01 μm [4]

Q4> $\bar{1}10$



rat → 0.1 μm/min

At any depth same straight wall groove [2]



$$W_b = W_0 - \sqrt{2}\, l$$

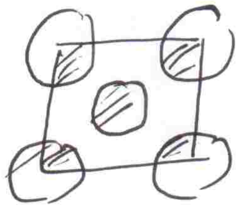
0.6 μm/min

$$l = 0.6 \times \frac{40}{60} = 0.4 \ \mu m$$

$$W_b = 2 - 0.4 \times \sqrt{2} = 1.43 \ \mu m$$ [2]

$(\bar{1}10)$	→	2 μm
(100)	→	1.43 μm

Q5>



Atoms = 2

area = a^2

$$r_{Ga} + r_{As} = \frac{\sqrt{3}}{4} a$$

$$a = \frac{4}{\sqrt{3}}(0.122 + 0.205) = 0.755 \ nm$$

$$PD = \frac{2}{(0.755)^2} = 3.50/nm^2$$ [2]

Q6>

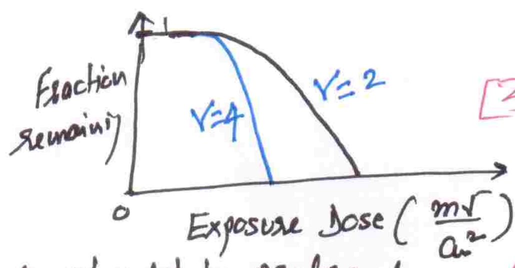
$$I = \frac{qA\phi}{t}$$

dia = 20 cm
r = 10 cm

$$= \frac{1.6\times10^{-19} \times \pi \times 10^2 \times 5\times10^{14}}{60}$$

**I = 0.419 mA or 419×10^{-6} A
419 μA** [2]

Q7>



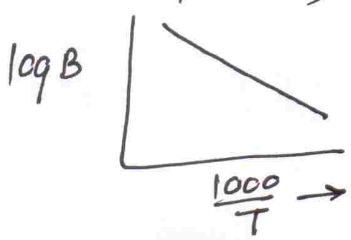
[2]

γ=4 should be preferred → [1]

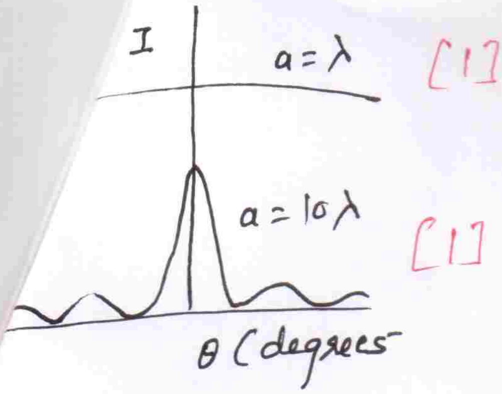
Q8>

$$B = B_0 e^{-E/KT}$$ [1]

It increases exponentially with T



[1]



Q 10>

reaction

$SiH_4 \xrightarrow{500°C} Si + H_2$ [1]

Advantage :
- i> No HCl
- ii> Reaction at low T
- iii> non reversible

[2]

flip side → soot of sample spreads in chamber

Q 11>

$$D = D_s \left(\frac{C}{C_s}\right)^3$$

$$C = C_s \left(\frac{D}{D_s}\right)^{1/3}$$

$$= 0.8 \left(\frac{2\times10^{-14}}{3.125\times10^{-14}}\right)^{-1/3}$$

C = 2 wt % [3]

Q 12>
- i> increase velocity of
- ii> increase N_R Raynold no
- iii> Decrease viscocity.

[2]

Q 13>

i> γ peaks get broadened ⟹ particle size reduces [2]

ii> peaks shifted ⟹ lattice strains

Q 14> For diffraction

$$\lambda \leq 2d$$

if $\lambda = 4 A$

$$d \geq 2A$$ [2]

any separation more than 2A can only be detected.

Q 1 Part B

$M_0 = 20 Kg$, $K_0 = 0.35$, $C_s = 10^{17}/cm^3$

$$C_s = K_0 C_0 \left(1 - \frac{M}{M_0}\right)^{K_0 - 1}$$

Substitution gives

$$C_0 = 2.47\times10^{17}/cm^3$$ [2]

This is Con. in 20 Kg liquid Si volume.

Thus no. of P atoms

$$= 2.47\times10^{17}\times\left(\frac{20\times10^3}{2.53}\right)$$

$$= 2.47\times10^{17}\times$$

No of P atoms = 1.95×10^{21} [2]

$$M = \frac{A N}{N_A} = \frac{30.97\times1.95\times10^{21}}{6.02\times10^{23}}$$

$$= 0.100 \text{ gms}$$ [2]

~~Mechanism~~ of etching of Si

$$MTF \approx \frac{1}{J^2} e^{\frac{Q}{KT}}$$

There may be other constants but we are not interested.

polycrystalline Si

$\phi = 0.50 eV$

$$T_{pc} \approx \frac{1}{J^2} e^{\frac{0.50}{KT}}$$ [2]

$$T_{sc} \approx \frac{1}{J^2} e^{\frac{1.40}{KT}}$$

if J is same, as given

$$\frac{T_{pc}}{T_{sc}} = e^{\frac{1}{KT}(0.50-1.40)}$$

$$T_{sc} = e^{\frac{(1.4-0.50)}{KT}} T_{pc}$$

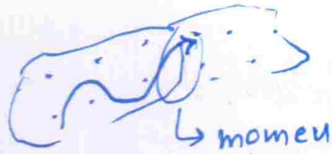
$$T_{sc} = T_{pc} e^{\left(\frac{0.9 \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23} \times 300}\right)}$$

$$T_{sc} = T_{pc} e^{34.78}$$

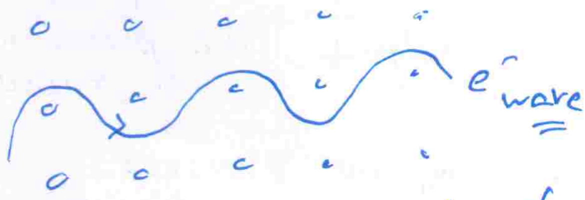
$$\boxed{T_{sc} = 1.27 \times 10^{15} T_{pc}}$$ [3]

Justification

In a polycrystalline system physical scattering is predominant at the interface of grain boundaries. That leads to momentum transfer.



On the other hand, in single crystal such physical scattering is unlikely.



Thus single crystal geometry of metal line is useful. [3]

Q2 Etching of Si

Step 1 : Si to SiO_2 Conversion

HNO_3 is used here which has HNO_2 existence.

$$HNO_3 + HNO_2 \rightarrow N_2O_4 + H_2O$$
$$\downarrow$$
$$NO_2$$
$$\downarrow$$

holes or e⁻ difficient sites creation $\rightarrow 2h^{++} + (2NO_2)^-$

$$Si + 2h^{++} \rightarrow Si^{++}$$

$$Si + 2OH^- \rightarrow Si(OH)_2$$ [5]

$$Si(OH)_2 \xrightarrow{\Delta} SiO_2 + H_2\uparrow$$

Finally in step II

$$SiO_2 + 6HF \rightarrow H_2SiF_6 + 2H_2O$$ [3]

Total Composition: $HNO_3 + H_2O + HF$

Q4 positive photoresist removal

- DQ is hydrophobic and non ionizable compound
- Mixed with hydrophilic polymer like phenolic resin. [2]
- on UV exposure

DQ leaves N_2 [2]

↓

Converts to Ketene through a rearrangement

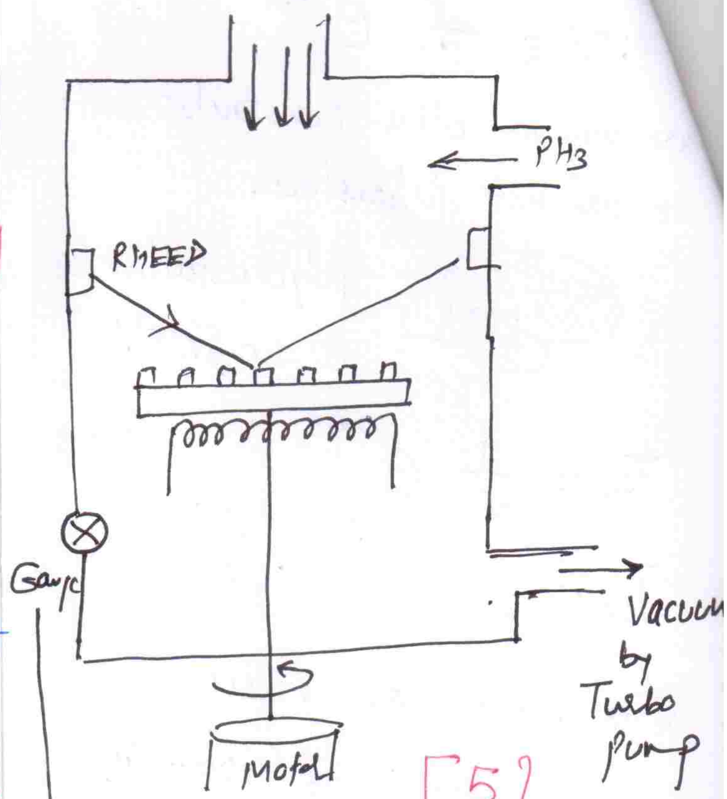
↓ on H_2O addition

Carboxilic acid [2]

↓

This compound dissolves in H_2O [2]

Q5



ionization Gauge to measure 10^{-8} T

[5] imp to show different facilities at right place.

justification

i> surface crystal str : RHEED

ii> vacuum : Ion/Turbo

iii> Heater : beneath substrate

iv> phosphorus doping : Through PH_3 or any other P containing gas supply

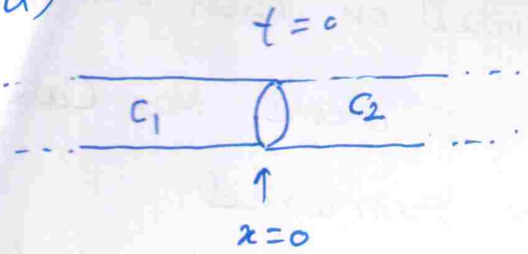
v> seven sample stage with rotation facility is imp

[5] one mark each

Open book Solutions

Q.1

(a)



$C(x,t) = A - B \operatorname{erf} z$

$z = \frac{x}{2\sqrt{Dt}}$

at $t = 0$ $x < 0$ $c = c_1$

$x = -\infty$ $c = c_1$

$\operatorname{erf}(-\infty) = -1$

$c_1 = A + B$ — (1)

$t = 0$ $x > 0$ $c = c_2$

$c_2 = A - B$ — (2)

From (1) & (2)

$A = \frac{c_1 + c_2}{2}$; $B = \frac{c_1 - c_2}{2}$ [3]

Thus,

$c(x,t) = \left(\frac{c_1 + c_2}{2}\right) - \left(\frac{c_1 - c_2}{2}\right) \operatorname{erf} z$ — (1) [2]

using Eq (1)

Need to find t for $x = 10\,\mu m$, $c(x,t) = 2.8$ wt%.

$2.8 = C(x,t) = \frac{5}{2} - \left(\frac{-3}{2}\right) \operatorname{erf} z$

$\Rightarrow z = 0.179$ [4]

$\frac{x}{2\sqrt{Dt}} = 0.179$

$t = 344$ hrs [3]

A little different answer may also be awarded provided close!

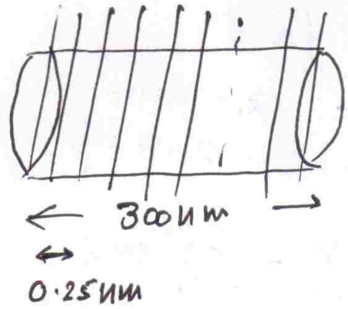
(b) $D \Rightarrow$ at 1273 K

$D = 1.3 \times 10^{-5}\, e^{-\left(\frac{258 \times 10^3}{8.31 \times 1273}\right)}$

$= 3.31 \times 10^{-16}\ m^2/s$ [3]

Q2

B to implant in Si Substrate



Total planes = $\frac{300}{.25}$ = 1200 [2] ①

Case (i) 40 $\frac{eV}{nm}$

1 nm → 40 eV

0.25 nm → ?

loss = 10 eV/plane

on one plane 10eV is delivered.

To remove one Si from its position, as given, 15eV is required.

Therefor with such a loss no damage will take place [3]

damage density = 0

Case (ii) 120 eV/nm

Now 30 eV will be delivered on each plane.

⟹ 2 atoms max can be removed.

$$\text{Damage density} = \frac{\text{atoms displaced}}{\text{Damage Vol.}}$$

atoms displaced = 2400 [3]

$V_D = \pi \times (2.5)^2 \times 300 \ nm^3$

$= 5.8875 \times 10^3 \ nm^3$ [2]

$$\text{Damage density} = \frac{2400}{5.8875 \times 10^3} / nm^3$$

$= 407.64 \times 10^{-3} / nm^3$

$S_{D} = 4.07 \times 10^{20} / cm^3$ [3]

Total atom density = $\frac{8}{a^3}$

$2r = \frac{\sqrt{3}}{4} a$

a for Si = $\frac{8 r_{Si}}{\sqrt{3}}$

= 0.5450 nm

$S_{Si} = 4.94 \times 10^{22} / cm^3$

% Damage = 0.8235 %

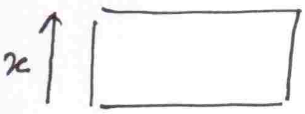
For $\frac{S_D}{S_{Si}} \times 100$ [3]

CB

Q3

wet - Dry - wet

(i)



$x^2 + Ax = B(t + \tau)$

$\tau = 0$

$A = 0.05$ mm

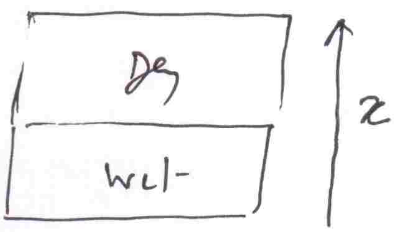
$B = 0.72$ mm²/h

$x^2 + 0.05x - 0.72 \times 3 = 0$

$x^2 + 0.05x - 2.16 = 0$

$x = 1.45$ mm [5]

ii)



$\tau = \tau_{dry} + \left(\frac{x_i^2 + Ax_i}{B}\right)$

A & B of Dry to be taken

$\tau = 0.027$, $A = 0.040$, $B = 0.045$ (in own units)

$\tau = 0.027 + \left[\frac{(1.45)^2 + 0.04 \times 1.45}{0.045}\right]$

$= 48.038$ h

$x^2 + Ax = B(t + \tau)$

t ↑ to calculate; τ ↓ 48.038

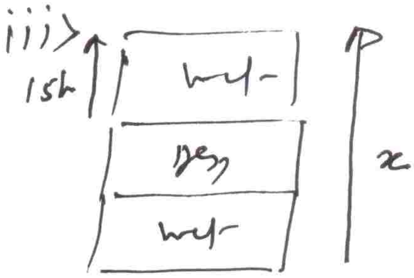
$t = \frac{x^2 + Ax}{B} - \tau$

$= \left[\frac{(2)^2 + .04 \times 2}{0.045}\right] - 48.038$

$t = 42.63$ h [5]

No partial marks for formula for CB

iii)



$t = 15$ h $\quad \tau = \left(\frac{x_i^2 + Ax_i}{B}\right)$

$x_i = 2$ for A & B wet

$\tau = \frac{2^2 + (0.05) \times 2}{0.72} = 5.69$ h

$x^2 + 0.05x - 0.72(15 + 5.69) = 0$

$x^2 + 0.05x - 14.897 = 0$

$x = 3.83$ mm [5]