ENSC 495/851 mid Term (Mar. 8, 2016)

This test is OPEN BOOK:
any book, notes and calculator may be used, but not a computer.
Time: 90 minutes

NOTE: **Do 2 questions in part I 25 marks each for a total of 50 marks**
Do 1 question in part II for 50 marks.
Test Total is 100 marks.

Section 1: Do 2 of these 3 questions: 25 marks each

(1a) Gallium Arsenide is another semiconductor that chips is made of. Name at least 3 advantages Silicon has that means it continued to dominate the integrated circuit field? (7 marks)
(b) In a clean room the two utilities which must be carefully controlled are air and water. What is the factor measured for each utility which determines the if the purity level is sufficient? How are these typically specified? Give typical levels for each in good clean room operation. Give the name of the major filters used in the systems used to obtain this purity. (8 marks)
(c) Why does a salt shaker placed in a microfab facility cause the fab engineers to get very excited? (2 marks)
(d) Why is the light in the photolith room yellow? (2 marks)
(e) Why can you not take resist coated wafers from the photolith into the regular furnace area of the clean room?(2 marks)
(f) What colour is photoresist? (2 marks)

1(a) Silicon has the following advantages over GaAs
(i) Silicon forms a stable oxide in furnace which has a high dielectric constant and good breakdown voltage
(ii) Si is much cheaper than GaAs (low cost to buy)
(iii) Si is one of the most common materials in earth crust - will not run out of it
(iv) Si wafers are much larger than GaAs - easier to grow crystals.
(v) Si has had huge process development + experience + very costly to change over
(vi) Si is a mono element i.e. more stable than GaAs

(b) 2 major utilities are air & water measured by following
air – 0.5 μm or larger particle count per cubic ft of air
- gives class of clean room (at least a class 1000 for semi fab)
particle size distribution important (smaller geometry of critical dimension small particles that become critical
- Use HEPA filters to remove particles
- Positive pressure in clean room air (keeps dirt out)

Water – measure water resistivity
best < 15 MΩ cm
also biometrical count
highly mobile ions (eg salt)

Created by using particle filters, + reverse osmosis + UV exposure

(c) Salt contains sodium – highly mobile ion that is deadly to transistor operation

(d) Yellow light in photolith because it does ~~not~~ not expose photoresist

(e) Flouresent lamp produce UV in the furnace area which would expose photoresist

(f) photoresist is red (dark red) in colour when liquid.

(2) Assume a oxide film is grown on a wafer. Positive photoresist is then spun on the wafer and properly exposed to a mask. What type of structures will result from the following conditions:

(a) What type of structures will predominate for the following mask types. (ie type of patterns are generally created by this mask type)

(i) Dark Field (2 marks)

(ii) Light Field (3 marks)

(b) The following defects appear in the photoresist or on the mask. For each of these 4 problems what type of defect structures will they generate after etching the layer. Again for each of these 4 types consider both light and dark field mask types and state whether this defect almost always causes a problem or has little effect? Give only 1 or 2 sentence answers:

(i) Dust particles on the mask. (4 marks)

(ii) Thermal expansion of the mask causes it to expand in by 2 microns along each edge. (4 marks)

(iii) Missing resist area (a fish eye). (4 marks)

(iv) Dust particle trapped in the resist. (4 marks)

(v) A fiber, where resist has piled up thickly along its length. (4 marks)

1(a) Structures created by the mask types

(i) Dark field - vias or contact cuts (holes); corner glass opens

2

5

(II) Light field - lines, islands

3

1(b) Defect structures created

(i) Dust on mask - creates areas left where they should not be

4

- Blocked or partially blocked holes in dark field - seldom dark field problem because most areas already blocked

- light field unwanted islands or shorted lines - nearly always a problem

(II) Thermal expansion by 2um
get remotest - aligned a center
but displaces ±1 um by edges in
all directions
repeats on all prints of mask
same for either mask type

(III) Missing resist (fish eye)
- dark field - unwanted openings
- mostly a problem (buy opens wanted)
Q - lightfield - broken lines,
- seldom problem because most
areas open

(IV) Dust in resist
Q - darkfield - blocked vias/cuts
- seldom problem (mostly dark)
- lightfield - extra islands, shorted
lines - mostly a problem
General - will dust go when resist stripped

V) Lifes in resist with resist pileup
- Darkfield — blocked vias/cuts
mostly not a problem (few vias/cuts)
- lightfield — large area shorts of lines
and islands —
usually very bad problem

4

- general — resist pile up means
difficulty in stripping resist
& problem for next area.

(3) Detail the steps necessary to create a patterned p diffusion layer of 5x5 micron squares on an n substrate wafer. Assume you start with a bare wafer. Just summarize each step, with its name and the important process step and way it is done. State what needs to be done starting from bare silicon wafer to have the final structure. (25 marks).

Start with bare wafer <100> N type

(1) RCA Clean wafer
SC-1 (H_2O_2 + DI + NH_4OH) remove organics
DI water rinse
HF dip — remove surface layer
DI water rinse
SC-2 (H_2O_2 + DI + HCl) metals
DI rinse
Spin dry

(2) Grow Oxide in furnace (steam 1100°C 40 min)

(3) Prebake
Spin on Photoresist,
Soft Bake
Pattern 10 x 10 um square
Develop pattern → inspect
Hard bake

(4) Etch square (BOE) until clear
inspect
Strip resist

(5) RCA clean (as 1) but 100:1 HF

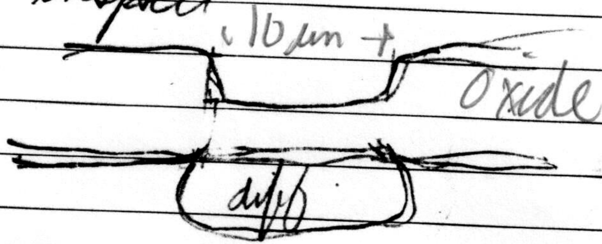
(6) Boron diffusion 1000°C 30 min

(7) strip oxide (borosilicate)

(8) RCA clean if delay

1½ mark 1 step

8 Diff drive in by oxide growth
(~~Steam~~ Ox, 30 min 1000 °C)
inspect



(5) The structure below consists of a field wet oxide 450 nm layer, which has two openings etched in it down to the <100> silicon. Some other process steps were then performed which do not affect the growth of silicon dioxide.

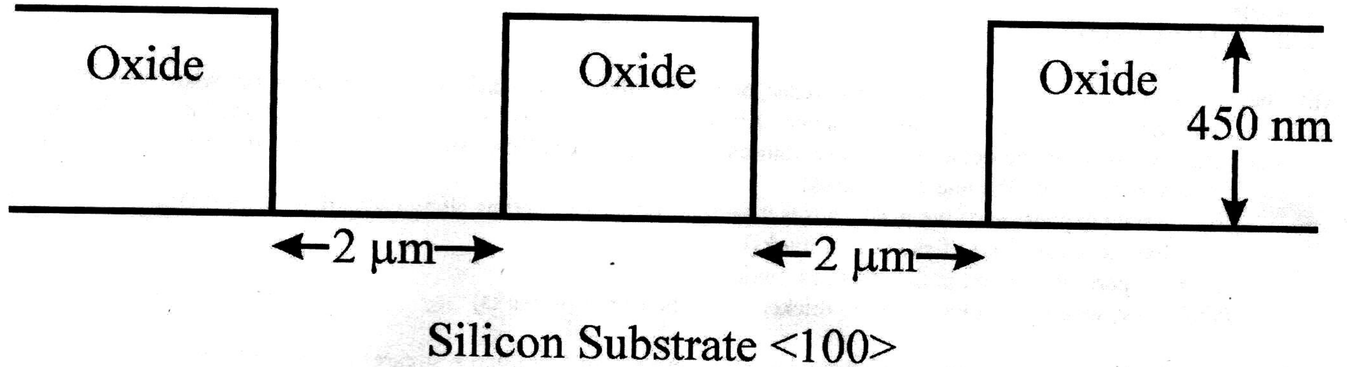
(5a) Choose a time, temperature combination that will grow 400 nm of wet oxide in the etched away area in under 120 minutes. Use the chart from the notes for this. (5 marks)

(5b) What is the resulting oxide thickness of the field area (outside the etched area). Show how you calculate that using both A & B coefficients from the notes and from the chart. (10 marks)

(5c) Sketch the resulting structure, showing the oxide/Si interface position at each point. Note thickness and positions of one layer relative to the other. Show the original Si surface position on the same drawing. (15 marks)

(5d) What is the colour appearance of the wafer pattern under the microscope (assume it shows the same as under fluorescent light sources). (5 marks)

(5e) If the same structure had instead been exposed to 3 hours of dry oxidation at 1100°C what would be the oxide thicknesses in the field and opened areas. Sketch the resulting structure as in part (c). Assume the continued growth of an oxide is not affected by whether the original oxide was wet or dry. Compare the estimates from the A & B coefficients from the notes to that from the from the charts. Now what is the colour appearance of the wafer. (15 marks)



Silicon Substrate <100>

5(a) for 400 nm of wet oxide from charts
1100°C for 0.45±0.9 hrs = 27 min
1000°C for 1.25 hrs = 75 min

(b) Thickness in field starts at 450 nm
at 1100°C would take 0.55 hrs = 33 min = τ
this becomes the τ

Combine $t + \tau = 0.45 + 0.55 = 1.00$ hrs
= 60 min

resulting thickness from chart 0.60 μm
or 0.15 μm growth

and
at 1000°C 450 nm takes 1.45 hrs = τ
$t + \tau = 1.25 + 1.45 = 2.75$ hrs
From chart = 0.695 μm
or gain of 0.145 μm

(2) From equations

	1100°C	1000°C
A	0.11 um	0.226
B	0.510 um²/hr	0.286

$\tau = 0$

$$x^2 + Ax - B(t+\tau) = 0$$

For original 450nm

$$\tau = \frac{x_i^2 + Ax_i}{B} = \frac{(0.45)^2 + (0.11 * 0.45)}{0.510}$$

$$= 0.494 \text{ hrs}$$

Using the 0.45 hr growth at 1100°C
∴ the field oxide becomes

$$t = t_0 + \tau = 0.45 + 0.494$$
$$= 0.944 \text{ hrs}$$

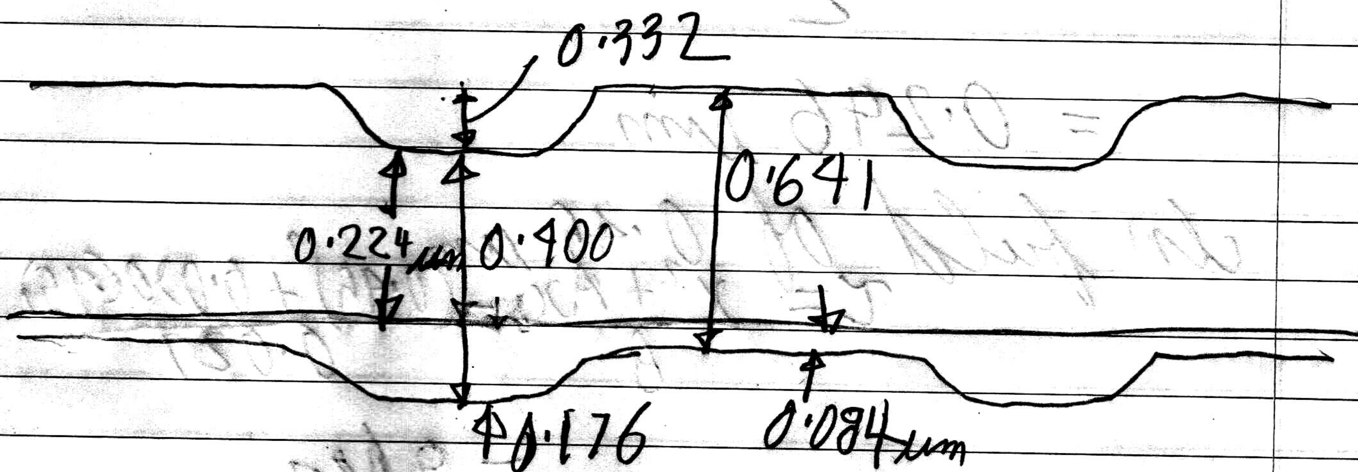
$$x_{field} = \frac{-A + \sqrt{A^2 + 4B(t+\tau)}}{2}$$

$$= \frac{-0.11 + \sqrt{(0.11)^2 + 4 * 0.510 (0.944)}}{2}$$

$$= 0.641 \text{ um}$$

(If used A, B for 0.400 time
$t = 0.4$ hrs)

(c) cross section



Recall 0.44 of oxide goes in Si
In field 0.641 µm adds 0.641 − 0.450 = 0.191 µm
Thickness into Si = 0.191 × 0.44 = 0.084 µm

(d) Colour in field from colour chart
In growth (cuts) = yellow to light orange
In field = violet red to bluish

(e) If instead had 3 hrs of dry oxid at 1100°C

In the cuts
dry ox
A = 0.090
B = 0.027
τ = 0.067

$$\frac{-A + \sqrt{A^2 + 4B(3+0.067)}}{2}$$

$= 0.246\ \mu m$

In field of $0.45\ \mu m$

$$\tau = \frac{x^2 + Ax_0}{B} = \frac{(0.45)^2 + 0.090(.45)}{0.027}$$

$= 9\ hrs$

$t + \tau = 9 + 3 = 12\ hrs$

$$\therefore \frac{-0.090 + \sqrt{(0.09)^2 + 4(0.027)(12)}}{2}$$

$= 0.526\ \mu m$