4M6 - MATERIALS & PROCESSES FOR MICROSYSTEMS

EXAM CRIB 2004

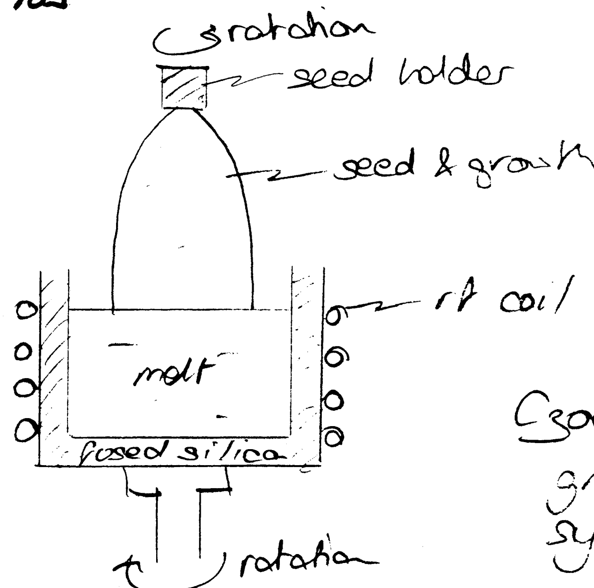
QUESTION 1

a. The two most common methods for producing c-Si are:

- Czochralski growth [5%]
- Float zone growth [5%]

In both cases, quartzite is the raw material, which is a pure form of SiO_2, and is first reduced by coke or coal in a furnace [5%] to produce metallurgical grade silicon. This is reacted with HCl to form liquid trichlorosilane [5%] which can be fractionally distilled ~~and reduced~~ for purification before being reduced in a hydrogen environment to give high purity electronic grade polycrystalline silicon [5%].

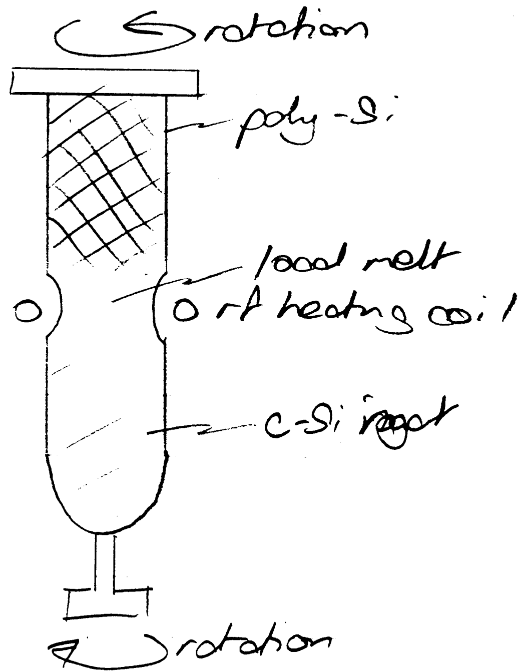
In the Czochralski process, the poly-Si is melted in a fused silica crucible, and a seed crystal introduced, which is slowly rotated and drawn out of the melt, allowing the melt to solidify around the seed in the same orientation. [5%]



[5%]

Czochralski growth system

a. In the float zone growth technique, the poly-Si ingot is counter rotated over a c-Si seed. The poly-Si is locally melted by an rf heating element and crystallises on the seed. [5%] In this way, impurities are reduced compared with Czochralski growth as the silicon melt is not in contact with a crucible [5%]



[5%]

b i. From figure 2, a boron concentration of ~~2×10^{23}~~ $10^{26}\ m^{-3}$ is required to reduce the etch rate to 1% [5%] In order to implant to 1 μm depth, an ion energy of 500 keV is required from figure 1 [5%]

From eqn. 2.9 of the data book,

$$N_i(x) = \frac{Q_i}{\Delta R_p \sqrt{2\pi}} \exp\left(\frac{-(x-R_p)^2}{4\Delta R_p}\right)^2$$

Hence, the peak concentration ~~dose~~ at $x = R_p$ is

$$N_{max} = \frac{Q_i}{\Delta R_p \sqrt{2\pi}}$$

and so, the required dose is

$$Q_i = \Delta R_p \sqrt{2\pi} . N_{max}$$ [5%]

From figure 1, ΔR_p is ~0.11 μm, so [5%]

$$Q_i = 0.11 \times 10^{-6} . \sqrt{2\pi} . 10^{26}$$

$$Q_i = 2.76 \times 10^{19}\ m^{-2}$$ [5%]

ii. We know that we will get an appreciable drop in etch rate to 10% when $N_{boron} = 4 \times 10^{25} m^{-3}$. If we say that the etch stops here then, [5%]

$$N_i(x) = \frac{Q_i}{\Delta R_p \sqrt{2\pi}} \exp\left(-\left(\frac{x-R_p}{4\Delta R_p}\right)^2\right)$$

$$\therefore \left(\frac{x-R_p}{4\Delta R_p}\right)^2 = -\ln\left(\frac{N_i \Delta R_p \sqrt{2\pi}}{Q_i}\right)$$

$$= -\ln\left(\frac{\overset{5}{\cancel{4}} \times 10^{25}\ 0.11 \times 10^{-6} . \sqrt{2\pi}}{2.76 \times 10^{29}}\right)$$

$$= 0.917$$ [5%]

$$\therefore x - R_p = 4\Delta R_p (0.917)^{1/2}$$

$$= 4 \times 0.11 \times 10^{-6} . (0.917)^{1/2}$$

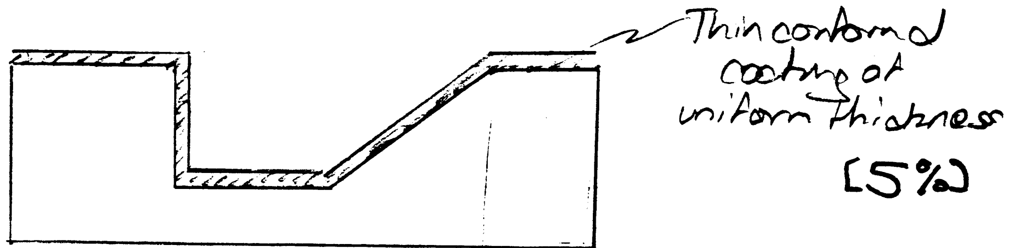
$$x - R_p = 0.42 \mu m$$ [5%]

So the error ~~of~~ could be as great as $0.4 \mu m$.

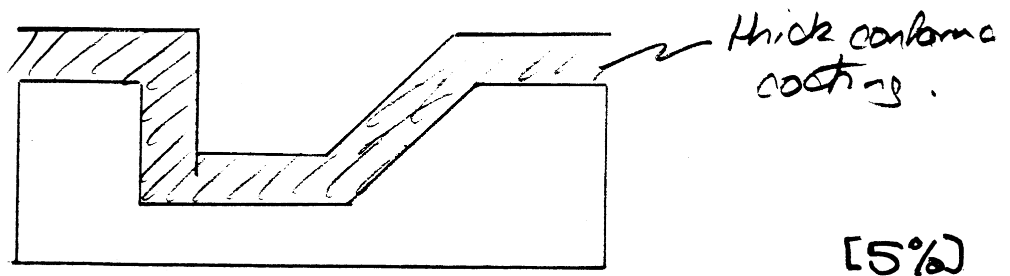
iii. Lateral straggle is $\sim 0.2 \mu m$ [5%] The groove width should be at least twice this ~~, so the minimum feature size is 2.05μm. [5%]~~ plus the width of the feature $= 2 \times 0.2 \mu m + 2 \mu m = \underline{2.4 \mu m}$ [5%]

QUESTION 2

a i. In immersion plating, the surface to be coated is dipped in a solution containing a more noble (less electropositive) metal than the surface species [5%], resulting in a galvanic displacement [5%] which ~~~~ stops when the surface is coated.



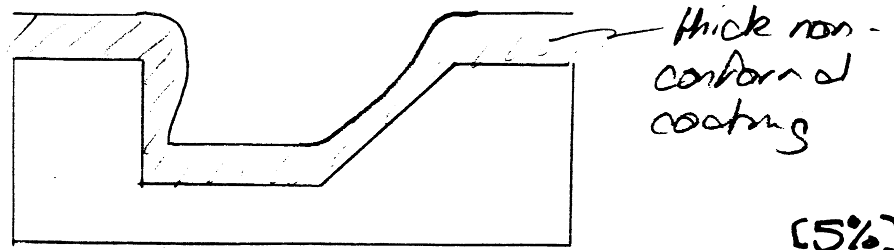
ii. In electroless plating, the plating solution contains a reducing agent which is oxidised in the presence of the metal surface and catalyses the deposition reaction [5%]. The reactions will continue until the solution is used or the sample removed, resulting in a thick conformal coating [5%]



[5%]

iii. In electroplating, the conducting substrate is placed in a solution of the metal salt to be deposited with another conducting plate and are connected as the cathode and anode respectively to a low voltage dc power supply [5%]. In solution, the metal salt will dissociate, and the positive metal ions will be deposited onto the surface of the cathode. [5%]

2 a iii



[5%]

b i. We know that deflection is given by

$$\delta = \frac{3FL^3}{2Ewh^3}$$

where F is the uniformly applied force due to the acceleration, a. Hence, from Newton's laws,

$$F = ma$$ [5%]

where m is the cantilever mass which is related to density ρ by

$$m = \rho L w h$$ [5%]

Hence, assuming small angle deflection

$$\delta = \frac{3(\rho L w h a) L^3}{2Ewh^3}$$

$$\delta = \frac{3}{2} \cdot \frac{L^4}{h^2} \cdot \frac{\rho}{E} \cdot a$$ [5%]

So, the material selection metric is that ρ/E should be maximised. [5%]

2 b ii. We need a low E/ρ ratio. A spin on polymer would therefore be suitable, such as polyimide ~~[5%]~~ or a soft metal, such as lead ~~[5%]~~ which could be electroplated to 5μm ~~[5%]~~. [5% for a material, 5% for a processing method and ~~iii.~~ 5% for explanation].

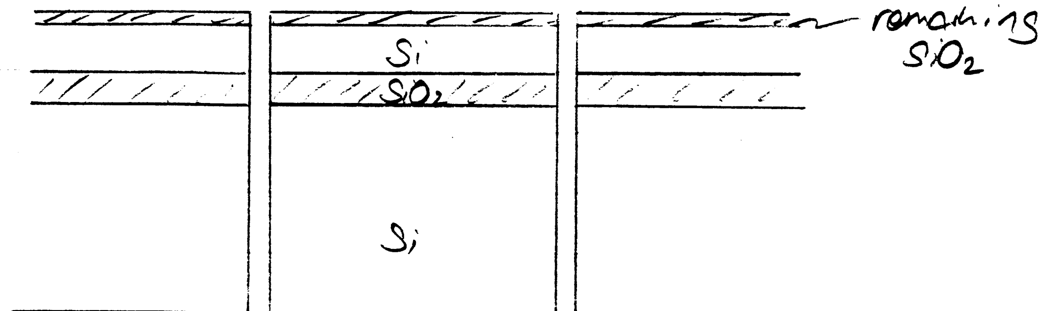
iii. From the result to part b(i), the geometry metric is that L^4/h^2 should be maximised [5%]. This implies a long and thin cantilever. However, such cantilevers are prone to stiction effects [5%]. Hence, whilst we can try to minimise this by roughening the substrate surface under the cantilever or by applying an anti-stiction coating, this will tend to limit this metric [5%]. In addition, we must ensure that the gap beneath the cantilever is greater than its maximum deflection to eliminate stiction during operation [5%]

QUESTION 3

a. The BOSCH process uses a cyclical process to achieve a highly anisotropic etch of bulk silicon [5%]. In the first stage of the process, a dense SF_6 plasma is used to etch a thin layer of silicon [5%]. In the second stage, a C_4F_8 plasma is used to deposit a thin fluorine polymer over the whole etched surface. [5%]. When SF_6 is reintroduced into the system, it preferentially removes the polymer at the bottom of the etch structure, exposing the silicon in this region and allowing the etch to proceed vertically downwards [5%]. Sidewalls remain protected and are not significantly etched [5%]. In this way, the dense SF_6 plasma allows high rate etching, but the passivation step means that underetching, which would normally occur in dense plasmas, does not take place. [5%]. Very deep, high aspect ratio structures may then be produced [5%]. The SF_6 plasma is a highly selective silicon etch and so hard mask materials remain largely in tact [5%].

3 b. We need to etch through 400μm of bulk silicon, so this will require a surface oxide layer of greater than 2·67μm, so we will use 3μm (both layers to ensure etch stop).
A standard $CF_4 + CHF_3 + H_2$ etch removes $Si : SiO_2$: Photoresist in a ratio of ~2:1:1. Hence, to etch through 6~~3~~μm of SiO_2 will require a photoresist layer greater than 3~~1.5~~μm, ~~so we will use 7μm~~.
[15%] + protection for 50μm of Si (0·6μm), so 4μm will do.
Process flow:

1) Perform an RCA wafer clean.
2) Spin on 4μm of positive resist.
3) Proximity print the 10μm diameter holes using UV lithography.
4) Etch the exposed resist.
5) RIE through 3μm SiO_2 using a $CF_4 + CHF_3 + H_2$ mixture.
6) DRIE through 50μm of silicon.
7) RIE through 3μm SiO_2 using a $CF_4 + CHF_3 + H_2$ mixture.
8) DRIE through 400μm of silicon.



10) Spin on 4μm of positive resist.
11) Proximity print the 200μm holes, aligning to the 10μm holes, using UV lithography.
12) Etch the exposed resist.
13) RIE through 3μm of SiO_2 using a $CF_4 + CHF_3 + H_2$ plasma etch.
14) DRIE through 50μm of silicon
15) Remove remaining photoresist (solvent clean).

[45% for process]

The SiO_2 RIE step 7 is most likely to affect yield due to undercutting and the risk of loss of etch rate deep in the 53μm deep pit. [5%]

QUESTION 4

4 a Additional material selection criteria include:
- Cytotoxicity
- Genotoxicity.
- Cost
- Disposability
- Means of sterilisation.
- Functionality
- System-specific factors (sensitisation, irritation, toxicity, carcinogenicity, hemocompatibility).

[5% each up to 35%]

b i. Photoresist is patterned onto a silicon substrate in the negative of the pattern to be micro contact printed. [5%]. The surface is spin coated in PDMS, which is dried, cured and peeled away from the substrate to produce the stamp [5%]. ~~The PDMS treated with an oxygen plasma to make it hydrophilic [5%]~~ The PDMS will then be coated in the hydrophobic end of the long chain molecule. [5%] This is pressed onto the substrate leaving the molecule with its hydrophilic end attached to the substrate [5%].

In lift-off printing, the substrate is again patterned with photoresist in the inverse of the desired pattern. [5%] The exposed hydrophilic SiO_2 will attract the hydrophilic end of the long-chain molecule, leaving a monolayer coating. [5%] The photoresist may then be removed by a solvent [5%].

4 b ii. Although PDMS printing is more complicated in terms of stamp production [5%] it allows almost nanometer scale resolution [5%], and the stamp, once made, can be used many times [5%]. The lift-off technique also requires the use of a solvent which, while removing photoresist, will not attack the ~~m~~ biological molecule [5%]. However, accurate alignment is only really possible by lift-off [5%].

iii. Printing is suitable for producing simple arrays for electrofluorescence, where no alignment is necessary [5%]. The sensitising of a cantilever array would require lift-off due to the need to align to the cantilever position accurately [5%]

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