ENGINEERING TRIPOS PART IIB

Wednesday 25 April 2012 9 to 10.30

Module 4M6

MATERIALS AND PROCESSES FOR MICROSYSTEMS (MEMS)

Answer not more than ***three*** *questions.*

All questions carry the same number of marks.

The ***approximate*** *percentage of marks allocated to each part of a question is indicated in the right margin.*

Attachments: 4M6 Data Book (14 pages).

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

ajf03

1 A silicon nitride beam of 10 μm width, 50 μm length and 0.5 μm thickness is to be produced above the surface of a crystalline silicon wafer. The beam is to be tethered to the silicon wafer at its ends, but the middle 8 μm length is to be suspended 500 nm above the surface of the silicon. The suspension gap must be accurate to within 50 nm. It is decided to achieve this by having a layer of boron atoms 500 nm below the surface of the crystalline silicon wafer which will act as an etch stop for a 10% aqueous KOH etch of the crystalline silicon to release the silicon nitride beam.

(a) Explain how each of the following techniques could be used to produce the layer of boron atoms, highlight the relative advantages and disadvantages of each approach, and sketch the variation in boron atom concentration with depth into the silicon wafer that would result:

(i) ion implantation; [20%]

(ii) a *combination* of impurity diffusion and molecular beam epitaxy; [20%]

(iii) molecular beam epitaxy *only*. [20%]

(b) If ion implantation is chosen as the method for producing the etch stop, calculate the implantation ion energy and dose required using the data in Fig. 1 and Fig. 2 and your understanding of wet etching of silicon by KOH. [30%]

(c) Quantitatively estimate whether ion implantation will be able to achieve the 50 nm tolerance in suspension gap that is required. [10%]

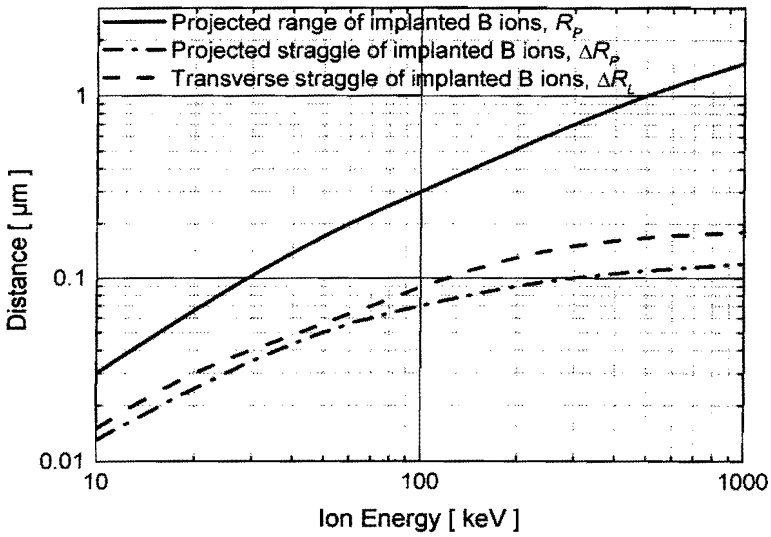

Projected range of implanted B ions, R_P
Projected straggle of implanted B ions, ΔR_P
Transverse straggle of implanted B ions, ΔR_L
Distance [μm]
1
0.1
0.01
10
100
1000
Ion Energy [keV]

Fig. 1

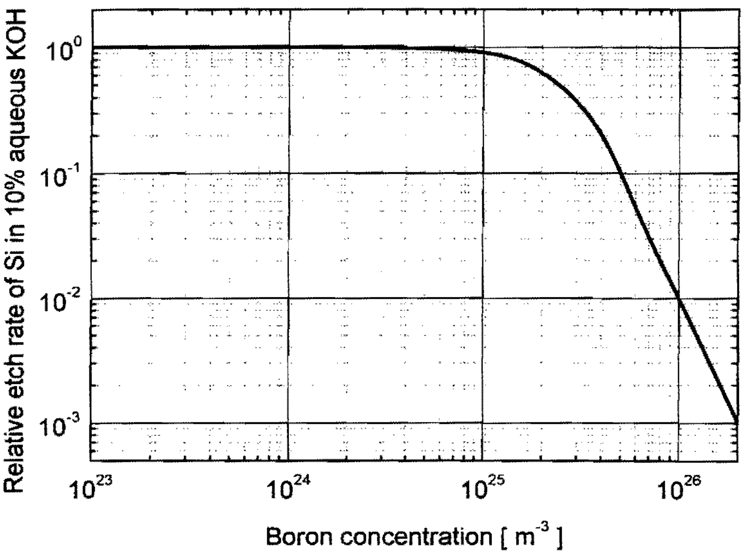

Relative etch rate of Si in 10% aqueous KOH
10^0
10^{-1}
10^{-2}
10^{-3}
10^{23}
10^{24}
10^{25}
10^{26}
Boron concentration [m^{-3}]

Fig. 2

2 (a) Describe the process of *electroplating* by which metallic layers can be produced on a surface. Use the plating of copper from a copper sulphate solution to exemplify your answer and include a schematic diagram of an electroplating system. [25%]

(b) Explain how thick layer photoresists, such as SU8, can be used with electroplating to produce high aspect ratio structures made from metals. [15%]

(c) An array of copper pillars are to be produced on the surface of a crystalline silicon wafer which has been thermally oxidised so that it is covered with a layer of silicon dioxide of 200 nm thickness. The copper pillars have a circular cross-section with a diameter of 10 μm. Each pillar is 60 μm high. The distance between the centres of neighbouring pillars is 100 μm.

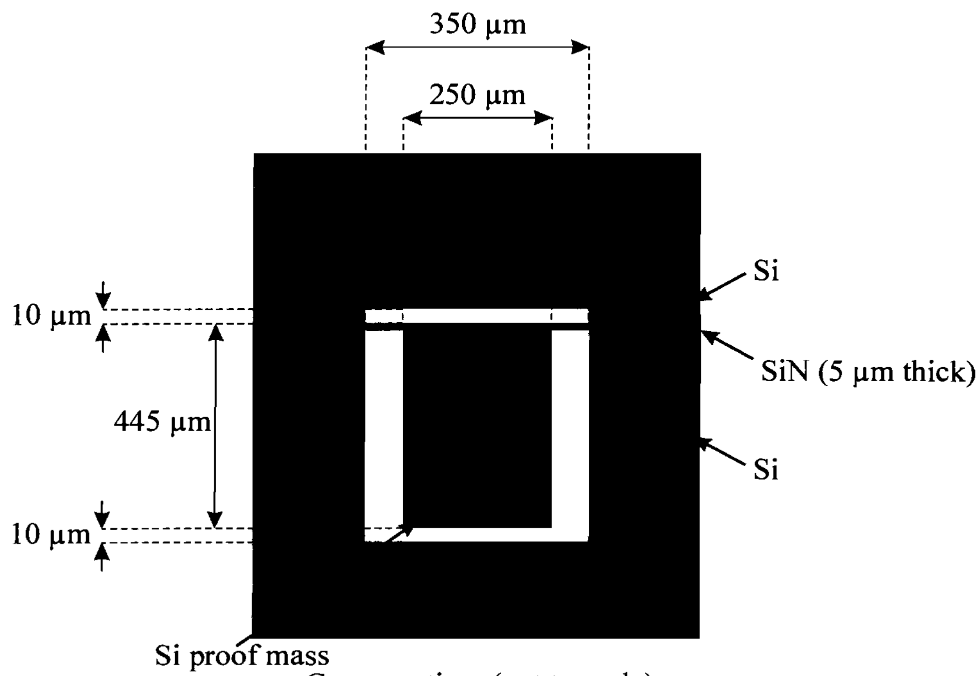
(i) Describe a process flow for producing the array of copper pillars starting from the bare, silicon dioxide-coated silicon wafer. [40%]

(ii) Calculate the current density due to copper ions required during the electroplating process if the electroplating time is to be 20 minutes. The density of copper is 8940 kg m^{-3} and its valency in solution is 2. [20%]

3 (a) Describe the process of *direct (fusion) bonding* by which two silicon wafers can be joined together. [25%]

(b) Why might it not be possible to achieve the optimum bond strength (~2.6 J m^{-2}) between two silicon wafers when fabricating a real MEMS device using direct bonding? [15%]

(c) A simple MEMS accelerometer is to be fabricated by suspending a crystalline silicon proof mass inside a cavity as shown in Fig. 3. The proof mass has a cylindrical shape with a circular cross-section of 250 μm diameter in the plane of the silicon wafer from which it is fabricated. The cylinder is 440 μm high and is attached to the surrounding silicon wafer all round its circumference by a 5 μm thick membrane of silicon nitride. There is to be a gap both above and below the proof mass of 10 μm. The cavity is also cylindrical with a diameter of 350 μm. Describe the process flow for producing the accelerometer starting from a supply of 100 mm (4") diameter silicon wafers which have a thickness of 450 μm and are polished on both sides. [60%]



Cross section (not to scale)
Fig. 3

4 (a) Explain what is meant by the term *yield* in the context of MEMS device manufacture. [20%]

(b) A particular MEMS device process flow has twenty process steps. If two steps are known to have a yield of 95%, calculate the yield that must be achieved for each one of the other eighteen steps if an overall yield of 80% is required. You may assume that each of the other eighteen steps all have the same yield. [10%]

(c) *Stiction* is a common cause of poor yield.

(i) Describe the physical origin of stiction and the conditions under which it may occur. [30%]

(ii) Give three methods for reducing the likelihood of stiction leading to poor yield in the fabrication of a MEMS device. [15%]

(d) Another common cause of poor yield is a failure to achieve designed tolerances in processes (such as etch times, deposition times or resolution in lithography). Apart from such failure and stiction, describe five other factors which can lead to poor yield. [25%]

END OF PAPER

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Module 4M6 – NUMERICAL ANSWERS

1 (b) 2.26×10^{19} m^{-2}

2 (c) (ii) 10.66 A m^{-2}

4 (b) 0.993