EGT3
ENGINEERING TRIPOS PART IIB

Friday 2 May 2014 2 to 3:30

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.*

Write your candidate number ***not*** *your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Attachment: 4M6 Data Book (14 pages).
Engineering Data Book

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

1 (a) Describe how *thermal evaporation by resistive heating* can be used for the deposition of metallic thin films. Your answer should include a description of the equipment used together with an accompanying schematic diagram. What are the most important process conditions? What are the most important considerations if this process is being used to coat a metallic thin film on a patterned layer of photoresist on a substrate? [35%]

(b) Thermal evaporation is to be used to coat a 150 mm diameter silicon wafer with a layer of aluminium. The aluminium layer must be no less than 100 nm thick at any point. The evaporator is designed such that the substrate sits a distance of 400 mm away from the resistive filament and parallel to the plane of the filament.

(i) If the density of aluminium is 2643 kg m^{-3}, estimate the minimum mass of aluminium that must be loaded into the filament to deposit this layer in one run, stating any assumptions that you make. [35%]

(ii) At the end of the deposition, the thickness of the aluminium layer at the edge of the wafer is measured to be 120 nm. Estimate the thickness of the aluminium layer at the centre of the wafer. [15%]

(iii) State an alternative method that could be used to thermally evaporate this aluminium layer. Under what circumstances might you choose this alternative method to resistive heating? [15%]

2 (a) Describe a process flow for the production of a 6 inch diameter *silicon-on-insulator (SOI) wafer* consisting of a 5 µm thick layer of silicon dioxide sandwiched between two layers of silicon of 450 µm and 20 µm thicknesses starting from two bare 6 inch silicon (100) wafers. [45%]

(b) The SOI wafer described in part (a) is to be used to fabricate free-standing cantilever structures in the 20 µm thick silicon layer by patterning this layer and undercutting the silicon dioxide. If the silicon-silicon surface energy is 0.1 J m^{-1}, what is the longest length of cantilever that could be produced which would never permanently adhere to the 450 µm thick silicon layer through stiction? [15%]

(c) Describe the process flow for the production of the cantilever structure described in part (b) starting from the SOI wafer of part (a). [30%]

(d) State a method by which cantilevers longer than the length calculated in part (b) could be fabricated without the risk of permanent adhesion of the two silicon layers. [10%]

NOTE: $s^{*4} = \frac{3Eh^3g^2}{2\gamma}$ where all symbols have their usual meanings.

3 (a) Thin films of silicon nitride can be deposited by *radio frequency plasma enhanced chemical vapour deposition* (rf-PECVD), *low pressure chemical vapour deposition* (LPCVD) or *radio frequency magnetron sputtering*. For each of the following scenarios, which deposition technique would you select? In each case, justify your answer:

(i) A 500 nm thick silicon nitride layer is to be deposited onto a crystalline silicon substrate. The silicon nitride will then be patterned and undercut to leave free-standing cantilevers which must have no apparent stress gradient. [15%]

(ii) A 200 nm thick silicon nitride layer is to be deposited on top of a 200 nm thick layer of aluminium on a silicon substrate. The bilayer will later be used to make a thermal bimorph actuator. [15%]

(iii) A 100 nm thick layer of silicon nitride is to be deposited on top of a crystalline silicon wafer which has a 10 µm thick layer of SU8 photoresist on the surface that has been patterned to form a 10 µm wide microfluidic channel, as shown in Fig. 1. The silicon nitride is required to provide a diffusion barrier to prevent ingress of any fluid in the channels into or out from the SU8. [15%]

(b) The inside surface of the microfluidic channel shown in Fig. 1 is to be lined with a biological receptor molecule which has an alkane thiol group attached to it so that it can be immobilised onto a surface. Describe a process flow that would allow this to be achieved without any biological molecule being immobilised on the surface of the silicon nitride outside of the channel. You may assume that the SU8 layer has already been patterned and coated in the layer of silicon nitride described in part (a) (iii), but you should include a sterilisation step before the biological molecule is immobilised. [55%]

(cont.

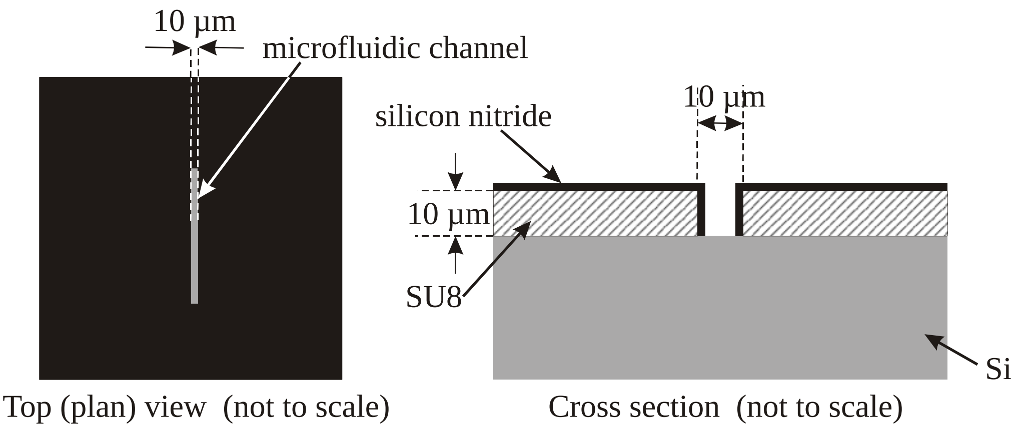
10 µm
microfluidic channel
silicon nitride
10 µm
10 µm
SU8
Si
Top (plan) view (not to scale)
Cross section (not to scale)

Fig. 1

4 Describe the following physical effects. In each case explain the physical origin of the effect and describe how the effect may be utilised in MEMS devices:

(a) The *anisotropic etching* of crystalline materials. [25%]

(b) The *shape memory effect*. [25%]

(c) The *piezoelectric effect*. [25%]

(d) The *piezoresistive effect*. [25%]

END OF PAPER

Version AJF/2

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NUMERICAL ANSWERS

1 (b) (i) 275 mg

(ii) 128.6 nm

2 (b) 870 µm