UNIVERSITY OF CAMBRIDGE

ENGINEERING TRIPOS PART IIB

Friday 6 May 2005 9.00 to 10.30

Module 4B6

SOLID STATE DEVICES

*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.*

There are no attachments.

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

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1 (a) Explain briefly how a metal-insulator-semiconductor (MIS) structure is used in a field effect transistor device. Outline the requirements to make a high-performance device with a fast switching speed. [30%]

(b) Figure 1 shows the small-signal capacitance versus voltage curves for a partially characterized MIS structure with curves corresponding to various intensity levels of illumination by white light. The x-axis is the voltage applied to the metal with respect to the semiconductor. What does the phrase 'small-signal' mean in this context and how small is small for this case? Explain whether the semiconductor is n-type or p-type, and use energy-band diagrams to explain why the MIS structure is most sensitive to light in certain bias voltage ranges. Would the measured capacitance depend upon the ac measurement frequency? [30%]

(c) Taking the relative permitivity of the insulator to be 5 and the MIS capacitor area to be 2×10^{-8} m^2, use the data in Figure 1 to calculate the insulator thickness. If the relative permitivity of the semiconductor is 10, estimate the maximum depth of the depletion region. Can the semiconductor be depleted to a greater depth? [40%]

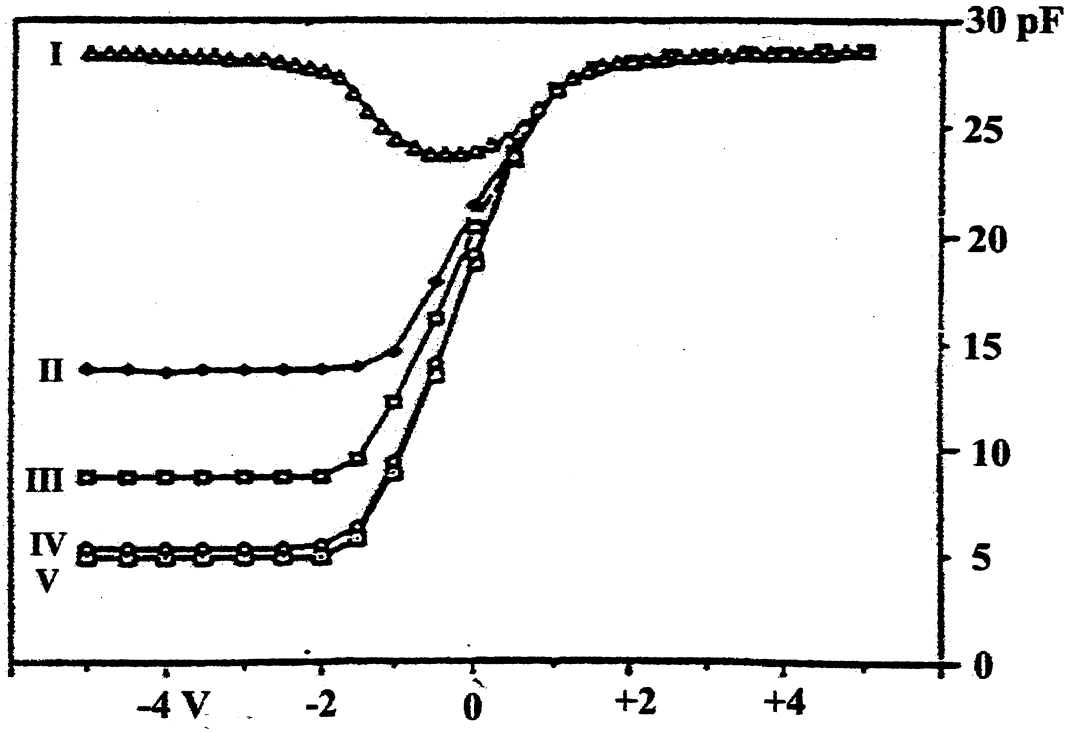

Fig. 1

2 (a) Explain briefly how ferroelectric materials can be used in ferroelectric random access memory (FRAM) devices for silicon-based integrated circuit technology. [30%]

(b) With reference to the partially completed device cross section in Figure 2, explain how a one-transistor one-capacitor (1T/1C) ferroelectric memory cell operates, and the electric function of the layers I - IV in Figure 2. Outline briefly a possible device fabrication process, identifying the most critical steps. [50%]

(c) Discuss the present status of FRAM technology, the performance relative to competing technologies, and likely future developments. [20%]

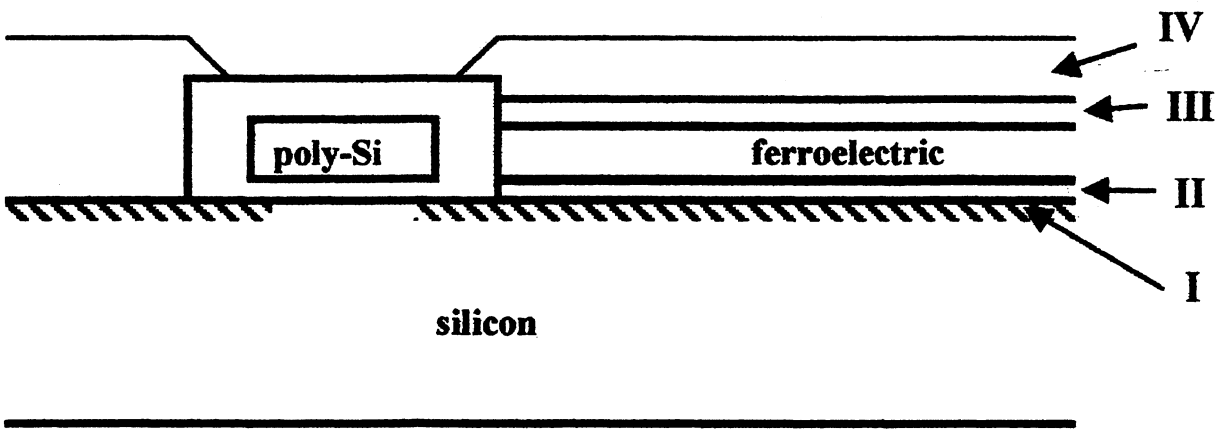

Fig. 2

3 (a) Outline briefly the benefits of scaling metal-oxide-semiconductor field effect transistors (MOSFETs) to small dimensions for logic circuit applications. [30%]

(b) Figure 3 shows two partially labelled FET device cross sections with applied gate voltages 3 V and 1.5 V, respectively. With reference to Figure 3, describe what is meant by punchthrough in a MOSFET. Explain the parasitic bipolar effect. [40%]

(c) Outline briefly the physical and technological challenges in miniaturizing MOSFET circuits in VLSI, and the prospective limitations to scaling. [30%]

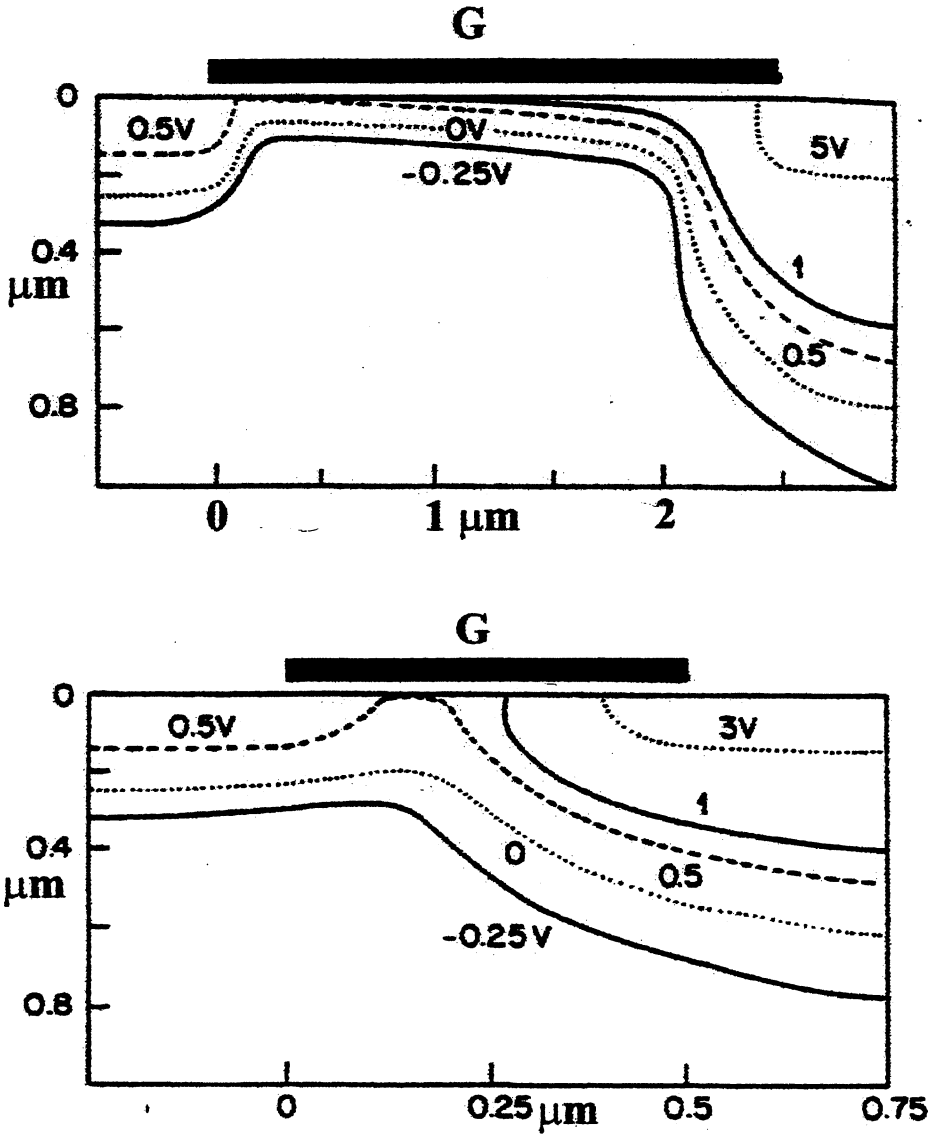

Fig. 3

4 (a) Discuss briefly the requirements for projection displays for giving presentations, and outline the performance characteristics of two commercially available technologies, including brightness, contrast and speed. [50%]

(b) Figure 4 contains partially labelled electron micrographs of a digital micromirror display chip, and a partially dismantled chip. What is the approximate size of the mirrors used in commercial displays? With the help of sketch cross sections, explain the construction of the chip, the mode of operation, and the function of the FET circuits under the mirrors. Explain the main factors determining the maximum display switching speed. [50%]

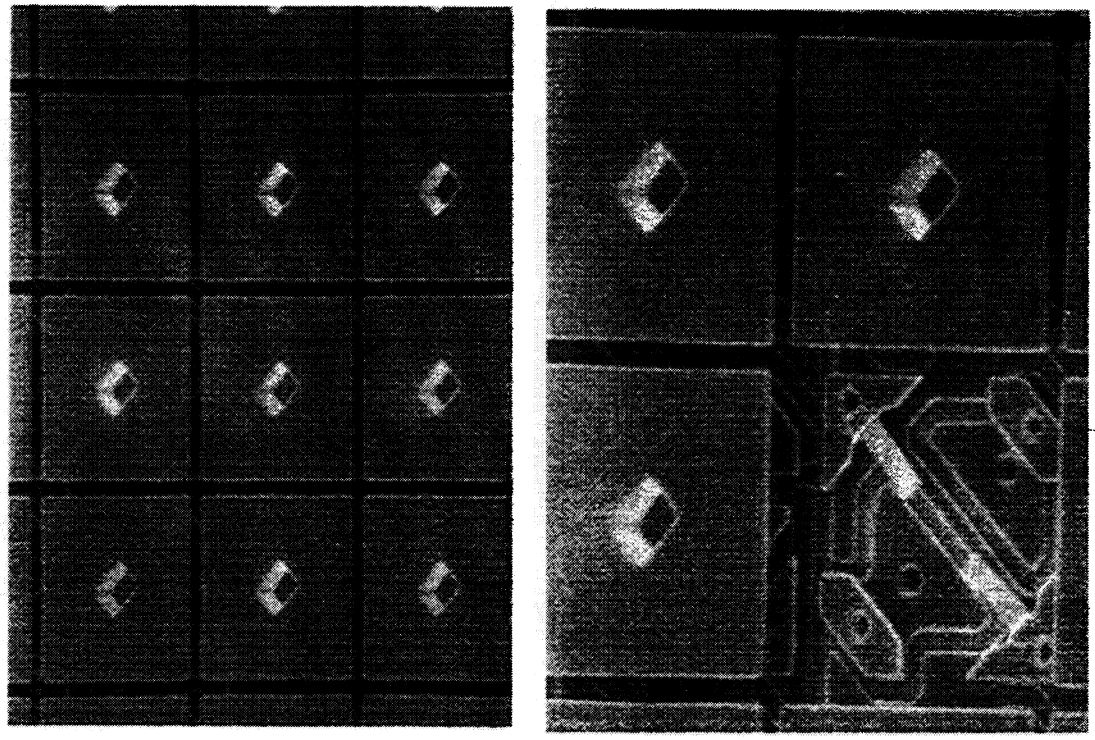

Fig. 4

(TURN OVER

5 (a) Discuss briefly what is meant by a MOS based chemical sensor, taking a hydrogen ChemFET as an example. Explain what material is used as the gate electrode and make a sketch of the electrical characteristics showing the effect when hydrogen is detected [50%]

(b) Explain the use of pH in describing hydrogen ion concentration. Describe the operation of an ion-sensitive field effect transistor (ISFET) as a biosensor and the relevance of pH. With reference to the partially completed diagram showing the cross section of an ISFET in Figure 5 identify the functions of the connections I - IV and the electrical functions of the various layers in the device. [50%]

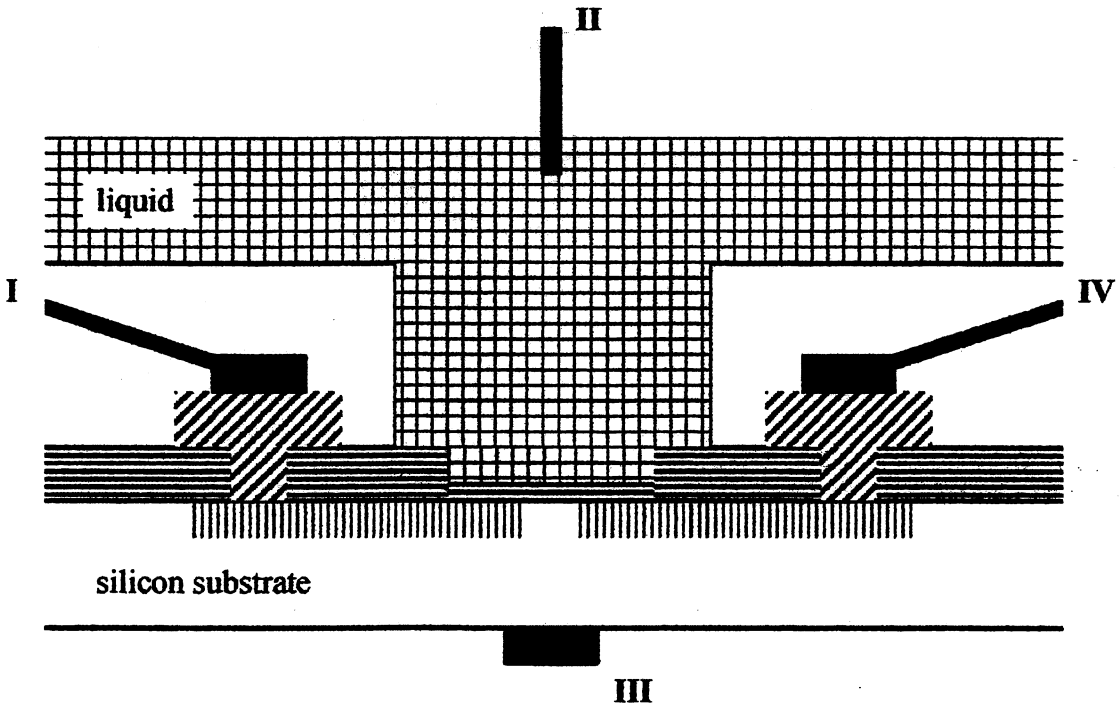

Fig. 5

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