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The formation of buried oxide layers by ion implantation

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An experimental system has been developed, capable of producing buried oxide layers by high dose oxygen ion implantation. A Whickham Engineering implanter has been used with hybrid beam scanning and infra-red pyrometry to produce buried oxide layers. A new spinning disc target chamber, which can handle large wafer batches is described. Nuclear reaction analysis has been used to assess the dose and uniformity of the oxide layers. The technique has been shown to be capable of accurately measuring the oxygen content of films by comparison with ellipsometric measurements.

Introduction

Silicon-on-insulator technology (SOI) has been the subject of considerable interest over several years[1–4] as it offers a number of advantages compared with bulk silicon. These include the reduction of source-drain capacitance, leading to an increase in device speed, the reduction of latch-up between devices, higher packing densities and lower power consumption, as well as enhanced radiation hardness.

At present there are several SOI technologies under investigation[5–7] including: silicon on sapphire (SOS); full isolation by porous oxidized silicon (FIPOS); recrystallization of polysilicon, either by zone melting or by some type of heat source melting the entire wafer surface; formation of a buried oxide or nitride by ion implantation at an energy and dose capable of forming a stoichiometric dielectric layer underneath a residual single crystal surface layer of silicon.

SOS technology is currently the most widely used but due to interface problems mobilities are poor and there are difficulties in dissipating heat. FIPOS yields good quality SOI material but it is not compatible with present semiconductor processing methods and there can be warpage of some wafers. Meanwhile, the recrystallization of polysilicon offers high throughput and low cost but suffers from high defect densities due to large temperature gradients and the need for seed material to form the single crystal surface layer. Lastly, SOI material formed by high dose oxygen ion implantation, although quite costly at present does yield good low defect material and can be widely used in different device technologies. It also has the advantage that it is compatible with existing silicon device fabrication processing methods. Thus the implantation of oxygen is the most promising SOI technology currently being investigated. For further development modified implantation hardware is required. This is because most conventional ion implanters used for semiconductor processing are dedicated machines, optimized to implant a small number of ion species (e.g. B, P, As) and with a limited beam energy (typically 160 keV). Moreover, resist masks require the temperature during implantation to be limited to 100°C. Typical doses of 10^{16} ions cm^{-2} require 2 h implantation times. However, the formation of a buried stoichiometric oxide layer requires a dose $\sim 10^{18}$ ions cm^{-2} at energies up to 200 keV, so a machine capable of mA of oxygen ions at these energies is needed. Additionally, facilities must be available to implant at temperatures of 500–600°C as, in this temperature range, *in situ* annealing is optimized, yielding high quality, low defect material[3,8,9].

In the context of the above, hardware has been developed jointly by AERE, Harwell and Whickham Engineering to meet the above specifications. This paper describes the development of the ion implanter and the associated experimental hardware. We present also some preliminary results on the use of nuclear reaction analysis (NRA) as a method for determination of the retained oxygen dose and uniformity of the implanted wafers. Future developments in equipment design are also discussed.

Experimental

A Whickham Engineering research ion implanter with a Freeman ion source was used, capable of producing mA oxygen ion beams at up to 200 keV (for singly charged ions). A variety of other ion species were also available. Figure 1 shows the Whickham machine in a high voltage enclosure. The ion source chamber in the foreground is followed by the analysing magnet and the post acceleration lens system. The vacuum system, below the table, consists of a diffusion pump on the source and cryopumps under the magnet tank and the experimental tube on the beam line. The power supply, control electronics and gas supplies are in the cabinet on the right. During normal operation the whole machine 'floats' at 150 keV (200 keV for the ion source), while the target chamber remains at earth potential. This facilitates easy access to and operation of beam scan systems and various target chamber diagnostics. The target chamber, shown in Figure 2, is sited in a Class 100 cleanroom and is cryopumped, thus minimizing wafer particulate contamination as required for VLSI wafer handling.

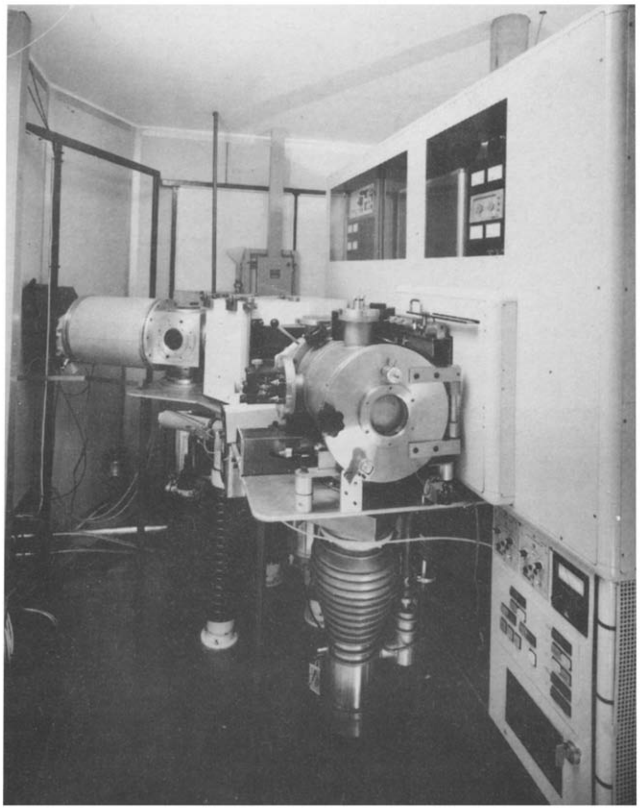

Figure 1. The Whickham Engineering research ion implanter.

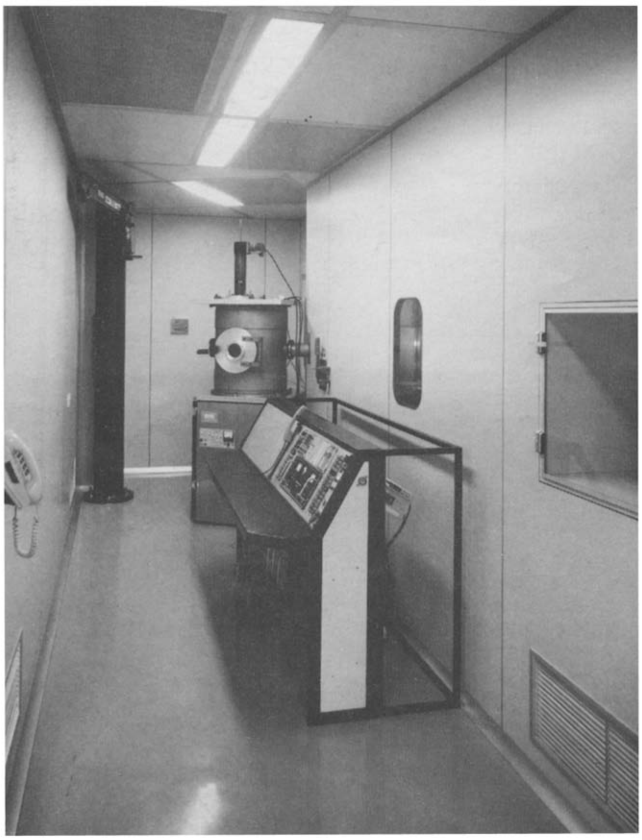

Figure 2. The Harwell ion implantation cleanroom.

The area of the beam at the target is 5 cm (vertically) × 1 cm so that uniform wafer implantation requires some form of beam scanning. This is achieved by mechanically moving the sample through the beam using a stepping motor in the vertical (y) direction, while simultaneously scanning the beam electrostatically in the horizontal (x) direction (see Figure 3). This hybrid system can scan wafers up to 6 in. in diameter.

Wafers are pre-heated using a bank of quartz halogen lamps (Figure 3). During implantation beam heating is significant and limits the beam power to 2 W cm^{-2}, thus fixing the beam current (measured by inserting a Faraday cup) for a 200 keV beam scanned over a specific area. Wafer temperatures are measured using a Vanzetti infra-red pyrometer linked to a Eurotherm temperature controller which regulates the lamp power.

Diagnostic techniques utilized in this work have included NRA[10] to analyse the retained oxygen content and dose uniformity and Rutherford backscattering (RBS)[11] to assess oxide depth and to check contamination levels.

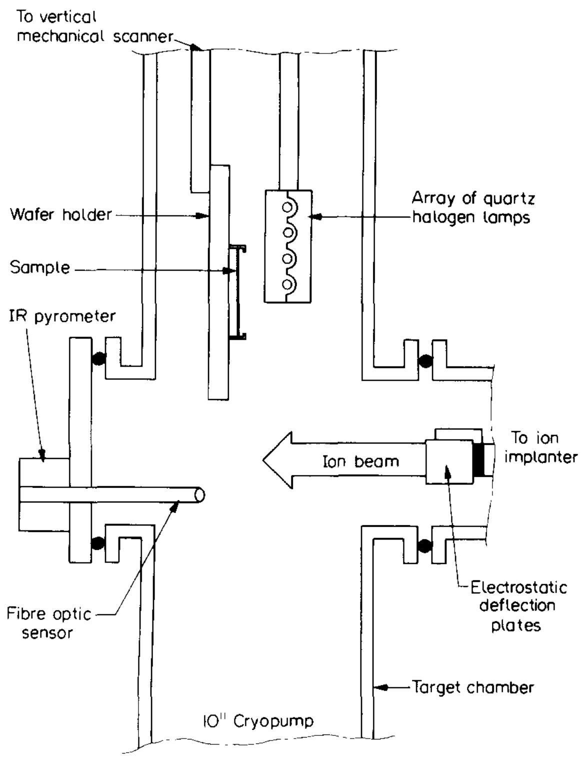

Figure 3. Schematic diagram of the target chamber.

Results and discussion

Initial studies were made using thermally grown oxide film standards ranging in thickness from 600–4000 Å obtained from GEC Hirst Research Centre and a 6000 Å thermally grown oxide from Plessey Research Laboratories (Caswell). These thicknesses were determined using ellipsometry. Additional measurements were made using NRA to assess its reliability as a method for measuring oxygen content (oxide thickness). The NRA measurements were performed on the Harwell IBIS accelerator using 900 keV deuterons. A typical spectrum for the 4000 Å SiO_2 standard, showing several of the reactions, is displayed in Figure 4. Comparison of the results from the two techniques, as shown in Figure 5, is remarkably good, thus justifying the use of NRA for this range of oxide thicknesses.

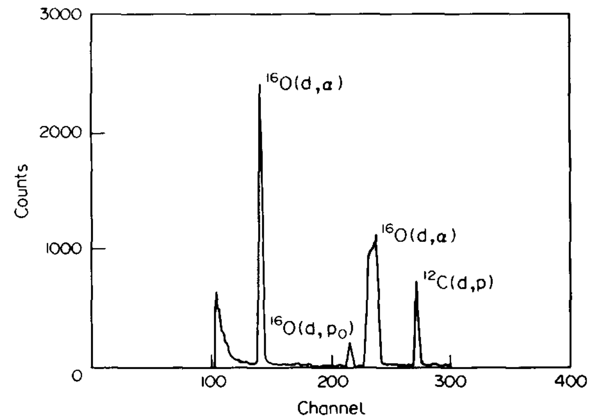

Figure 4. Energy spectrum of charged particles produced by 900 keV deuteron bombardment of 4000 Å SiO_2.

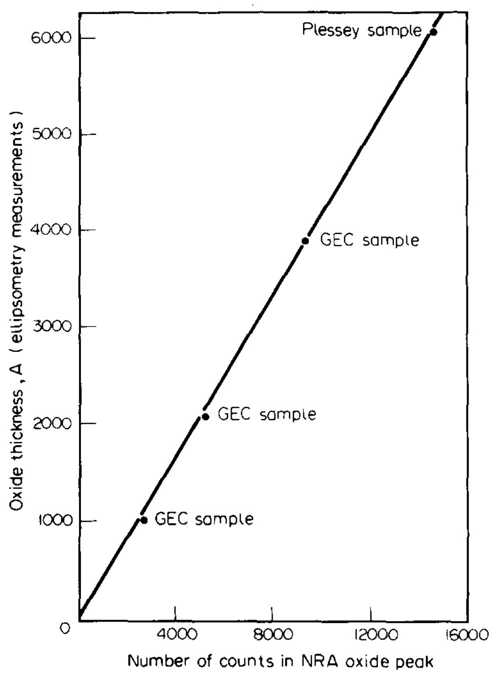

Figure 5. Comparison of NRA and ellipsometric methods of oxide thickness measurement.

Preliminary experiments have indicated that the required implanter characteristics are obtainable in terms of mA beams at the required energy. Moreover, spatial and temporal uniformity are such that high dose implants of 3 in. wafers may be reliably undertaken. However, the 2 W cm^{-2} beam power limitation results in an implantation time of 8–9 h for a 200 keV 2×10^{18} ion cm^{-2} dosage of a 3 in. wafer. This would be unacceptably high in terms of throughput and cost for device material. The problem may be overcome by further development of the target chamber, replacing the present experimental chamber with a spinning disc assembly, as shown in Figure 6. This would allow batches of wafers to be handled, typically nineteen 75 mm dia wafers with implant times ranging from 95 h for a 1 mA beam to 19 h at 5 mA. The spinning disc system will be capable of implanting oxygen, nitrogen, or a combination of both, thus allowing optimization of material quality and parameters.

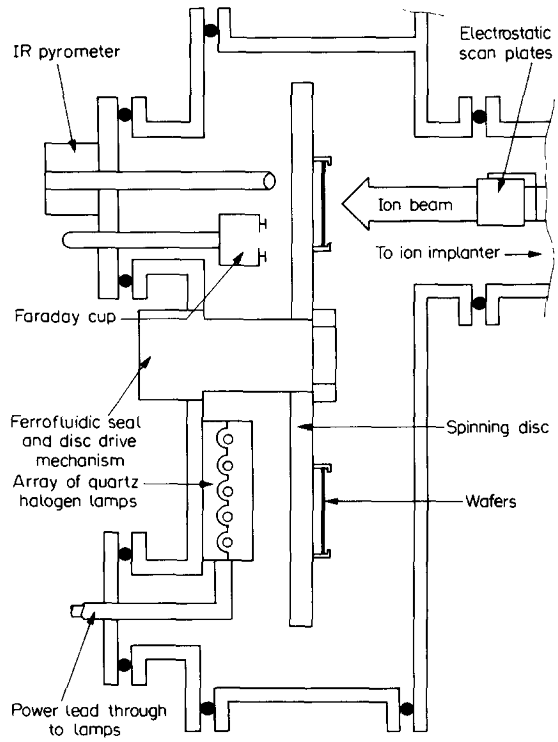

Figure 6. Schematic plan view of the spinning disc target chamber.

Summary

Preliminary studies using the Whickham–Harwell implanter suggest that it has the capability to produce SOI material of the desired characteristics. The use of NRA to characterize material and further development of the system to incorporate a spinning disc assembly allowing batch treatment indicates that the technique offers a viable and in many respects advantageous method of producing high quality, economical buried oxide layers.

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