Vol.2 No.1 NUCLEAR SCIENCE AND TECHNIQUES Feb. 1991

APPLICATION OF THE $^{16}O(\alpha,\alpha)^{16}O$ RESONANCE ELASTIC SCATTERING IN OXYGEN DEPTH PROFILING OF SIMOX STRUCTURES

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(Received November 1989)

ABSTRACT

The resonance nuclear elastic scattering $^{16}O(\alpha,\alpha)^{16}O$ at 3.045 MeV has been used to profile oxygen distributions in SOI material synthesised by SIMOX technique. The buried SiO_2 layer is produced by 1.8×10^{18} at./cm^2 oxygen implantation at 500°C and high temperature annealing at 1405°C for 30 min. The experimental results show that after annealing sharp SiO_2/Si interfaces at both sides of buried layer and a very good quality of top Si single crystal layer are obtained. The formation mechanism of the buried layer, correlated with SiO_2 precipitates and dissolution, radiation enhanced diffusion and epitaxial growth, is discussed.

Keywords: Resonance elastic scattering Oxygen depth profiling SIMOX structure

Ⅰ. INTRODUCTION

The fabrication of buried insulating layers in silicon has attracted increasing attention in the last decade[1, 2]. The technique has been applied in VLSI. Small geometry CMOS devices fabricated in this material exhibit characteristics much better than that of similar devices formed in bulk Si[3]. One of most promising technique for producing devices worthy SOI structure is SIMOX[4] (separation by implanted oxygen).

It has been demonstrated that with 200 keV oxygen implantation to dose higher than 1.4×10^{18} cm^{-2}, a stoichiometric SiO_2 layer can be formed[5]. Usually a high temperature (1300°C) post implantation annealing is required for oxygen redistribution. In order to restrain the building up of radiation damage and to preserve the crystal quality of the Si surface layer, ion implantation has to be carried out at elevated temperature, typically above 500°C. Since oxygen concentration in silicon on either side of the burried oxide layer is far beyond the solubility limitation in the as- implanted state, generation of oxide precipitate takes place throughout the ion bombardment.

In order to characterize SIMOX structure, SIMS and AES are used commonly to determine oxygen redistribution. But both methods are limited by absolute scaling of depth and concentration and charge accumulation in the insulator layer. Ion beam

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analysis techniques have also been used extensively to characterize SIMOX structure.For example, RBS has been applied to measured the thicknesses of buried SiO_2 layer and oxygen distributions and channeling technique has been performed to examine the quality of top single crystal silicon layer[5]. Due to the low RBS cross section of oxygen it is not easy to obtain oxygen distribution exactly. In this paper we first report results on oxygen depth profiling in SIMOX structures by the nuclear resonance in the $^{16}O(\alpha,\alpha)^{16}O$ elastic scattering at 3.045 MeV. The mechanism of SIMOX formation, including ion implantation, radiation enhanced diffusion and epitaxial growth, is discussed.

Ⅱ. EXPERIMENTAL

The buried oxide structures were prepared in University of Surrey by the implantation of O^+ ions at an energy of 200 keV to a dose of 1.8×10^{18} O^+/cm^2 (detail in [5]). The Si substrates were device grade (100) wafers. The substrate temperature was maintained at 500°C during implantation. Following implantation the top surface of each wafer was encapsulated with SiO_2 of thickness 300 nm in order to avoid surface oxidation and pitting. The capped samples were annealed just below the melting point of silicon at 1405°C for 30 min.

The measurements were performed at the 4MV Van de Graff accelerator in Shanghai Institute of Nuclear Research. The nuclear resonance in the $^{16}O(\alpha,\alpha)^{16}O$ elastic scattering at 3.045 MeV has been used[6] to measure the oxygen depth distribution at a laboratory scattering angle $\theta=170°$. An energy scanning is performed by subsequently increasing the energy of incident α - particels from 3.405 MeV to the energy for obtaining oxygen nuclear resonance scattering at different depthes. In order to determine oxygen concentration, we chose a silicon wafer with a 500 nm thickness of thermal oxide layer as a standard sample for calibration.

Oxygen composition of SOI buried layer are determined by calculating the ratio of the area of SOI oxygen signal to that of the standard sample under resonance region.

Ⅲ. RESULTS AND DISCUSSION

The 2 MeV He^+ channeling- backscattering spectra for the sample implanted with 1.8×10^{18} O^+/cm^2 at 200 keV are shown in Fig.1. The curves *a*, *b* and *c* represent random spectrum, as- implanted and annealed, respectively. In curve *b*, the high yield and high dechanneling rate show that after implantation the silicon overlayer is composed of highly defective single crystal silicon. After annealing at 1405°C for 30 min, the channeling spectrum *c* has been improved remarkably. The low channeling minimum yield $X_{\min}=4\%$ reaches that of perfect single crystal and indicates that the entire top silicon layer is high quality single crystal. The random spectrum shows the implanted buried layer has been $\sim SiO_2$ composition. Because that RBS cross section of oxygen is only one third of silicon and oxygen signals are superimposed on silicon signals, the interfaces of either side of buried layer could not be clearly displayed in the spectrum.

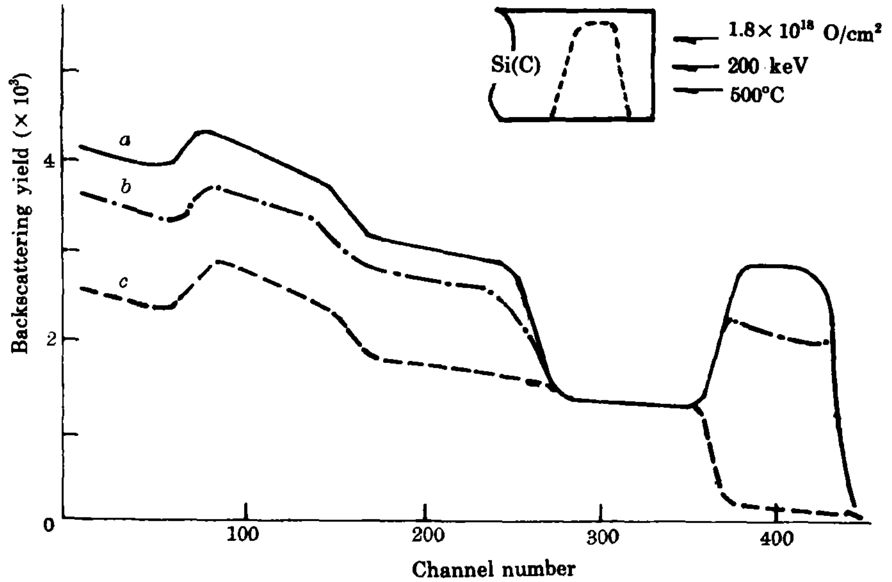

Fig.1 2MeV He$^+$ channeling—backscattering spectra for the oxygen implanted SOI sample

The curves *a*, *b* and *c* represent random spectrum, as- implanted and annealed, respectively

Fig.2 shows a backscattering spectrum at the resonance energy of 3.045 MeV from the standard sample. It can clearly be seen from the very high oxygen signal at ~1.1 MeV that there is an obvious gain of the oxygen yield. In our geometry the gain is ~ 7. The thickness of 500 nm is confirmed by RBS. Using the energy scanning the profile of oxygen in the standard sample is obtained and shown in Fig.3. We find the same

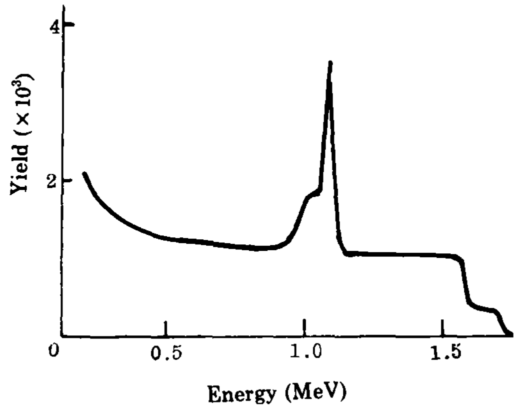

Fig.2 The spectrum of nuclear resonance elastic scattering $^{16}O(\alpha,\alpha)^{16}O$ at 3.045 MeV for the standard sample (500 nm thermal oxide larger SiO_2)

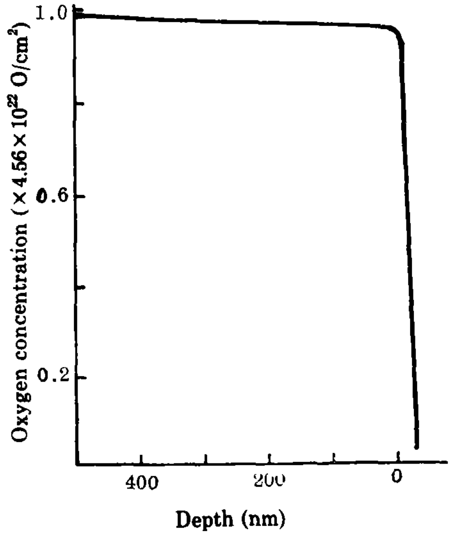

Fig.3 ^{16}O concentration profile for the standard sample

oxygen count area at different depthes. It means that the energy straggling is not important in the studied region. Assuming that the density of the standard sample is the same as in that bulk 2.28×10^{22} SiO_2/cm^3 and using Bragg rule of stopping cross section, we get the scaling of depth and concentration.

A typical backscattering spectrum with nuclear resonance of elastic scattering for the oxygen implanted SOI sample is shown in Fig.4. Using the same energy scanning and the same treatment as for the standard sample, we can obtain the oxygen depth profiles of as– implanted and annealed sample (at 1405°C for 30 min) as shown in Fig.5. From the curve of as– implanted, the stoichiometric compound SiO_2 is formed at the middle of buried layer. The high diffusion coefficient of oxygen in SiO_2 (10^{-17} cm^2s^{-1}) and the effect of radiation enhanced diffusion facilitate the migration of excess oxygen to the wings of the distribution. The asymmetry of the distribution might be caused by radiation enhanced diffusion which mainly happened at top interface region. A small dip near 580 nm from the surface reflects the lack of oxygen at deeper interface. The oxygen profile of annealed sample (1405°C, 30 min) reveals that most of oxygen in top surface Si layer has migrated into the buried layer to form SiO_2. The migration of oxygen near the deeper interface is much less than that of the top Si layer, but sharp SiO_2/Si interfaces of both sides are formed.

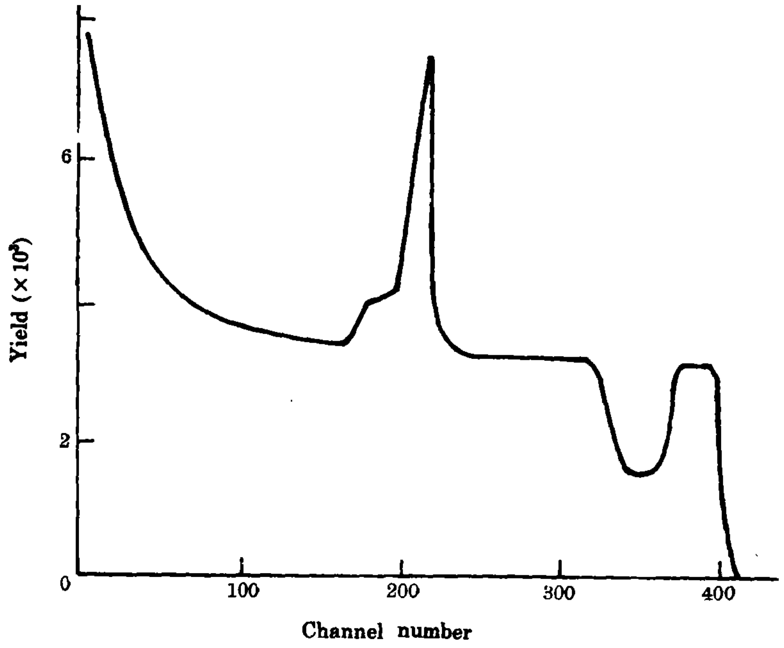

Fig.4 The spectrum of nuclear resonance elastic scattering $^{16}O(\alpha,\alpha)^{16}O$ for 200 keV 1.8×10^{18} O^+/cm^2 implanted SOI sample

So far the mechanism of the oxygen redistribution and defect annealing are not clearly nuderstood. Our results appear to qualitatively consistent with the observations by Yoshino et al[7]. During the implantation oxygen atoms implanted into the silicon wafer are accumulated and reach chemical stoichiometric composition at R_P project range firstly. Then as increasing oxygen dose, the excess oxygen could not stay in formed layer because of the high diffusion coefficient of oxygen in SiO_2 and the effect of radiation enhanced diffusion at top Si layer. So large amount of excess oxygen atoms migrate to both sides of the distribution (especially in top Si layer) to form SiO_2 precipitates. The thermal stability of SiO_2 precipitates strongly depends on their sizes. In the as- implanted specimen there is a gradation in the size of precipitates from the Si surface to the buried SiO_2 layer[7]. At the same time high implantation temperature (500°C) facilitates recovery of implanted damage at the top layer and even consecutive epitaxial growth near the deeper interface. Due to the low solid solubility of oxygen in Si, part of oxygen near the deeper interface are pushed out off the epitaxial layer to form a small dip near 580 nm from the surface. When the sample is annealed (1405°C) those small precipitates near surface become unstable and the oxygen atoms released from their dissolution migrate inward. At high enough temperature the buried layer will be the most stable precipitate. The driving force for the inward epitaxial growth at this stage facilitates the rearrangement of Si- O bonds in the oxide precipitates to coalesce with the buried oxide layer. Therefore, the entire top silicon single crystal layer and homogeneous SiO_2/Si abrupt interface are formed.

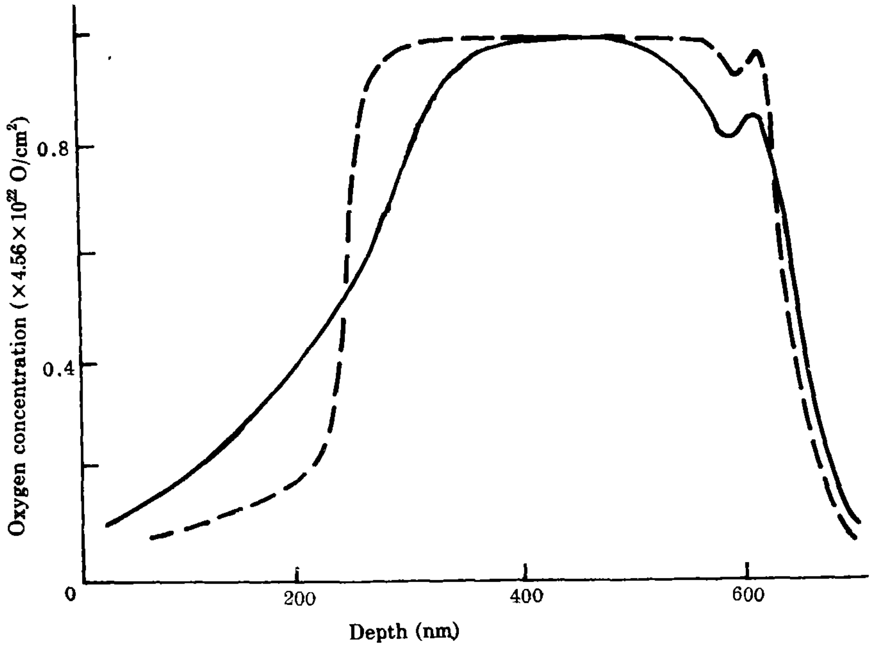

Fig.5 The oxygen concentration profiles of as—implanted and annealed samples

The solid line and dash line represent as- implanted and annealed samples, respectively

IV. CONCLUSIONS

Our results has demonstrated that the $^{16}O(\alpha ,\alpha)^{16}O$ resonance elastic scattering is a very powerful technique for absolute quantitative oxygen profiling in SIMOX structure. The formation mechanism of SOI with SIMOX correlates with SiO_2 precipitate and dissolution, radiation enhanced diffusion and epitaxial growth.

ACKNOWLEDGEMENT

The authors gratefully acknowledge Prof. P.L.F.Hemment at University of Surrey for sample preparation and ion implantation. We are also grateful to Prof. Yang Fujia for his support and helpful discussions.

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