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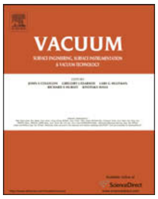

HI-ERDA, Micro-Raman and HRXRD studies of buried silicon oxynitride layers synthesized by dual ion implantation

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ABSTRACT

Silicon oxynitride ($Si_xO_yN_z$) buried insulating layers were synthesized by dual implantation of nitrogen ($^{14}N^+$) and oxygen ($^{16}O^+$) ions sequentially into single crystal silicon in the ratio 1:1 at 150 keV to ion-fluences ranging from 1×10^{17} to 5×10^{17} cm^{-2}. Heavy ion elastic recoil analysis (HI-ERDA) studies of as implanted samples show Gaussian like distributions of nitrogen and oxygen. After annealing at 800 °C, both the nitrogen and oxygen distributions appear as flat plateau like regions near projected range showing the formation of a continuous buried oxynitride layer. Micro-Raman study of as implanted samples shows a broad peak at 480 cm^{-1} for all fluences. It signifies a complete amorphization of silicon due to high fluence implantation. The annealing at 800 °C results in the reduction of the intensity of the broad peak observed at 480 cm^{-1} and also gives rise to an additional peak at 517 cm^{-1}. It shows partial recrystallization of damaged silicon due to annealing. The X-ray rocking curves studies from high-resolution X-ray diffraction (HRXRD) of the samples implanted with different fluences have also further confirmed partial recrystallization of damaged silicon on annealing.

1. Introduction

In recent years, the silicon-on-insulator (SOI) technology has been attracting much attention for device fabrication. SOI offers many advantages over bulk silicon such as radiation hardness, higher operating temperature, low parasitic capacitance and high packing density. The synthesis of buried insulating layers to produce SOI structures by SIMONI (separation by implanted oxygen–nitrogen) process using high fluence ($\geq 10^{16}$ cm^{-2}) oxygen and nitrogen ion implantation into silicon has scope of potential applications in semiconductor technology. Buried insulating layer within silicon containing oxygen and nitrogen incorporates the advantages of both Si_3N_4 and SiO_2 such as high resistance to radiation damage and alkali ion diffusion, low leakage current and low interface state density [1]. Reeson et al. [2] have reported the mechanism of formation and structure of buried oxynitride layers synthesized by implantation of N^+, O^+ and NO^+ at 200 keV investigated by Rutherford backscattering spectrometry (RBS), secondary ion mass spectrometry (SIMS) and transmission electron microscopy (TEM) techniques. Wong et al. [3] studied the depth distribution of oxygen and nitrogen by varying the sequence of oxygen and nitrogen implantation into silicon at 150 keV by SIMS and X-ray rocking curve techniques. Diniz et al. [4] synthesized oxynitride [SiO_xN_y] insulators by using low-energy nitric oxide ion [NO^+] implantation into silicon substrates followed by thermal oxidation. Belogorokhov et al. [5] have reported the behaviour of oxygen and nitrogen implanted at 100 and 175 keV energy in halogen lamp annealed samples. Lee and Kwong [6] have reported the synthesis of silicon oxynitride by nitrogen implantation and high pressure O_2 oxidation of silicon and their characterization by

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I-V and C-V studies on this device. Yi et al. [7] have reported the formation of radiation hardened materials by sequential oxygen and nitrogen implantation. These materials have shown the remarkable total fluence irradiation tolerance before and after irradiation of γ rays. From previous studies, it is observed that for synthesis of SIMONI structures, the fluence, energy and sequence of nitrogen and oxygen implantation greatly affects the structure and properties of SOI. The annealing is essential for the removal of the implantation induced damage to recover the crystallinity of the silicon. The redistribution of implanted oxygen and nitrogen at different temperatures and the recrystallization of silicon on annealing need further studies. Our aim is to study the annealing behaviour of SIMONI structures. In an earlier communication we have reported the rapid thermal annealing (RTA) behaviour of buried silicon oxynitride ($Si_xO_yN_z$) insulating layers synthesized by 150 keV nitrogen ($^{14}N^+$) and oxygen ($^{16}O^+$) ion implantation into silicon and their characterization using Fourier transform infrared (FTIR), electron spin resonance (ESR) and X-ray diffraction (XRD) techniques [8]. FTIR studies have shown the formation of nitrogen-rich silicon oxynitride layers at high fluence levels. The annealing studies introduce significant structural transformations in the ion implanted layers. XRD results reveal the formation of a Si_2N_2O (O) phase in the as implanted samples and synthesis of a complex structure buried layer consisting of Si_2N_2O (O), SiO_2 (H) and Si_3N_4 (H) phases after annealing. The ESR studies show the presence of defect centers at g-value ~ 2.00554 associated with silicon dangling bonds ($\cdot Si\equiv Si_3$) for lower fluences and at g-value ~ 2.00477 ascribed to silicon dangling bonds ($\cdot Si\equiv N_3$) for higher fluence levels. The spin density was found to decrease after high temperature annealing. In this paper, we report the HI-ERDA, Micro-Raman and HRXRD studies of ion beam synthesized silicon oxynitride samples before and after furnace annealing.

2. Experimental details

Single crystal p-type silicon wafers with <100> orientation and 10–50 Ω cm resistivity were used as substrate material. The silicon samples were implanted with nitrogen ($^{14}N^+$) and oxygen ($^{16}O^+$) ions sequentially in the ratio 1:1 at 150 keV energy to synthesize $Si_xO_yN_z$ buried layers of different structures. The Low Energy Ion Beam Facility (LEIBF) at Inter University Accelerator Centre (IUAC), New Delhi was used for implantation. For a given fluence the samples were first implanted with mass analyzed 50% N^+ ions. After this the source was changed and sample was implanted with mass analyzed 50% O^+ ions. The ion beam was scanned to 2.5 cm × 2.5 cm to cover large area for uniform implantation. The ion beam current density for the N^+ beam was 8–16 $\mu A\,cm^{-2}$ and for O^+ beam it was 6.4–25.6 $\mu A\,cm^{-2}$. A vacuum of 10^{-6} mbar was maintained in the target chamber during implantation. The ion current was measured using a current integrator with electron suppressor. The samples were implanted to total ion-fluence levels of 1×10^{17}, 2.5×10^{17} and $5\times10^{17}\ cm^{-2}$. The annealing treatment was given to the samples in the temperature range between 500 and 800 °C for 30 min in the flow rate of dry nitrogen gas. The flow of nitrogen gas was maintained at 1 l/min. The characterization of the ion beam synthesized buried layers was carried out by HI-ERDA, Micro-Raman and HRXRD techniques. HI-ERDA was performed using 15 UD Pelletron accelerator facility at Inter University Accelerator Center (IUAC), New Delhi. The as implanted sample was tilted with respect to the ion beam direction at an angle $\alpha = 25°$ and irradiated with 60 MeV ^{56}Ni ions. The recoil particles were detected in $\Delta E - E$ LAPSDT [9] installed at $\Phi = 45°$ port with a polypropylene stopper foil of 1.5 μm thickness. The ERDA data were recorded event-by-event using CANDLE software in a computer. The ERDA spectra were transformed into depth versus concentration profile using the SIMNRA simulation code [10]. In this code, target was considered to consist of three different layers, each composed of silicon, oxygen and nitrogen for simulation of the spectra. The Micro-Raman spectroscopic measurements were performed on LabRAM HR high-resolution Raman microscope available at Sophisticated Analytical Instrument Facility (SAIF), Indian Institute of Technology (IIT)-Bombay. These measurements were done at room temperature using 514.5 nm line of 4 W argon ion laser. High-resolution X-ray diffraction (HRXRD) spectra were recorded using X-ray diffractometer (Model – Philips X'pert) at Tata Institute of Fundamental Research (TIFR), Mumbai. The diffraction spectra were recorded in the (004) orientation from virgin silicon and the implanted silicon samples.

3. Results and discussions

3.1. ERDA studies

Fig. 1(a) and (b) shows the ERDA depth profile of nitrogen and oxygen implanted in silicon with fluence $1\times10^{17}\ cm^{-2}$. For the as implanted samples, both nitrogen and oxygen concentration peaks lie at depth 383 nm, which is close to the theoretical SRIM

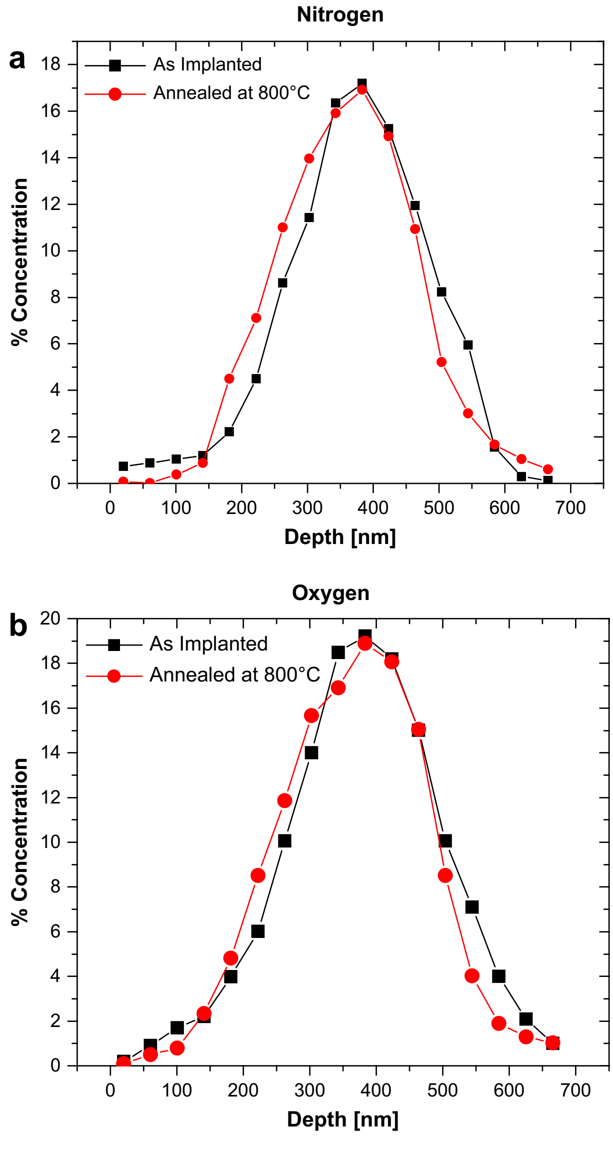

Fig. 1. Depth profile oxygen and nitrogen in silicon sample implanted nitrogen and oxygen with fluence $1\times10^{17}\ cm^{-2}$.