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Annealing Studies of Buried Oxide Layers Synthesized by SIMOX Process

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Abstract

Silicon oxide (SiO) buried layers were synthesized by SIMOX process using 140 keV O^+ ion implantation at low fluence levels ranging from 1.0×10^{16} to 7.0×10^{16} cm^{-2} into <111> single crystal silicon substrates at room temperature. The samples were study before and after annealing at temperature (1200 ºC for 30 min) in argon ambient. The FTIR spectra of the samples revealed absorption band associated with one bending vibration in addition to the asymmetric stretching vibration of Si-O bonds on annealing. The XRD studies revealed the formation of silicon oxide (SiO_2) at all ion fluence.

Keywords: Silicon oxide, FTIR, XRD.

1. Introduction

The synthesis of buried insulating layers to produce silicon-on-insulator (SOI) structures by SIMOX (separation by implanted oxygen) process using low fluence oxygen ion implantation into silicon has scope of potential applications in semiconductor device technology. In this paper, we report the synthesis of silicon oxide insulating layers by implantation of $^{16}O^+$ at 140 keV to low fluence levels ranging from 1.0×10^{16} to 7.0×10^{16} cm^{-2} into silicon substrates at room temperature. The structural characterizations of ion-beam synthesized SIMOX structures have been carried out using Fourier transform infrared (FTIR) spectroscopy and X-ray diffraction (XRD) measurements before and after annealing.

2. Experimental Details

Single crystal silicon wafers (p-type, 10-15 Ω-cm resistivity and <111> orientation) were used as substrate material. The silicon wafers were thoroughly cleaned adopting standard RCA-I and RCA-II cleaning procedures using electronic grade chemicals and distilled deionized (DI) water. These wafers were then cut into sizes of 1cm × 1cm samples for loading onto the sample holder of the implanter. To synthesize the silicon oxide insulating layers, samples were implanted at 140 keV with oxygen ($^{16}O^+$) ion beam to fluence levels ranging from 1.0×10^{16} to 7.0×10^{16} cm^{-2} at room temperature. The 150 KV ion accelerator facility at Materials Science Division, IGCAR, Kalpakkam was used for implantation. The ion-beam current density was 1 to 3 µA cm^{-2}. The scanned beam was collimated through a collimator of diameter 12.5 mm. A vacuum of 1.0×10^{-6} mbar was maintained in the target chamber during implantation. The samples were annealed at temperature (1200 ºC for 30 min) in argon ambient. The identification of structural studies of ion-beam synthesized buried silicon oxide insulating layers was carried out using FTIR spectroscopy and XRD studies. The FTIR spectra were recorded in the spectral region 6000 - 400 cm^{-1} in transmission mode at normal incidence on JASCO-610 FTIR spectrometer at the Department of Physics, University of Mumbai. The XRD measurements on the samples were carried out at Department of Physics, University of Mumbai on X-ray diffractometer (JEOL model JDX-8030) with Cu-K_α radiation source. X-ray source was fixed and sample and detector were moved throughout the given range by θ, 2θ geometry. The primary excitation electron current for the experiments was 35 mA at 35 kV. Bragg diffraction profiles were measured, performing 2θ scans for each sample in the range from 20º to 80º in 2 theta geometry.

3. Results and Discussions

3.1. FTIR Studies

Fig.1 shows FTIR spectra of silicon samples implanted at 140 keV with $^{16}O^+$ at fluence levels ranging from 1.0×10^{16} to 7.0×10^{16} cm^{-2} and annealed at temperature (1200 ºC for 30 min). The FTIR results of 1.0×10^{16} cm^{-2} as-implanted sample shows absorption band in the wavenumber range 1037-721 cm^{-1} centered around 931 cm^{-2}. As the fluence increases, the range of IR absorption band and the peak position both shifts towards higher wavenumber as given in Table 1. The changes in the FTIR spectra are more pronounced for implantation at low fluence than high fluence. This observed absorption band is associated with the stretching vibration of the Si-O bond indicating the formation of silicon oxide [1]. At low fluence level, the observed absorption band is relatively weak and

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rather broad due to random distribution of Si-O stretching bonds and/ formation of suboxides of silicon. It is observed that the implantation at smaller fluences shows SiO formation, which leads toward transformations into SiO_2 as the fluence increase. The FTIR spectra of the annealed samples showed two transverse optic phonon bands: first, the lower frequency band in the range from 780 cm^{-1} to 820 cm^{-1} derived from the Si–O bending vibration and the second in the range from 1000 cm^{-1} to 1300 cm^{-1} ascribed to Si–O asymmetric stretching vibrations [2]. The changes observed in the FTIR spectra on annealing are associated with the structural transformations and the reduction of radiation damage effects in the ion beam synthesized oxide layer.

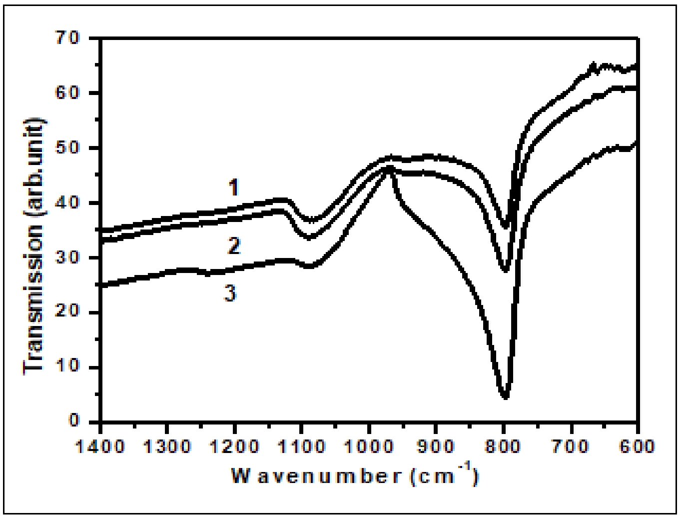

Fig 1: FTIR spectra of the silicon samples implanted with 140 keV ($^{16}O^+$) room temperature to different fluences levels (1) 1.0×10^{16}, (2) 3.0×10^{16} and (3) 7.0×10^{16} cm^{-2} and annealed at 1200 °C for 30 min.

Table 1: FTIR peak position for as-implanted and annealed samples.

Fluence (cm^{-2})	As Implanted Peak Position (cm^{-1})	Annealed at 1200 °C Peak Position (cm^{-1})	
1.0×10^{16}	930.1	797.5	1087.6
3.0×10^{16}	940.6	799.2	1093.4
7.0×10^{16}	943.2	801.0	1094.1

The observed shift towards higher frequencies and sharpening of the bands with increasing ion fluence indicated a transformation of oxygen implanted layer towards the formation of stoichiometric SiO_2. The results show formation of additional Si-O bonds at 1200 °C due to enhanced reactivity of oxygen with silicon at higher temperature.

3.2. XRD Studies

The XRD spectra of room temperature implanted samples and annealed at 1200 °C for 30 min as shown in Fig. 2 shows the characteristic peak of crystalline silicon at $2\theta=28.48°$ corresponding to <111> reflection at all fluence [3]. The peaks at d~3.4580 Å – 3.4664 Å matches with <400> reflection of SiO_2 (O) phase and the hump at d ~1.5670 Å – 1.5663 Å matches with <211> reflection corresponds to SiO_2 (H) phase. The second order silicon peak is also observed at $2\theta = 58.9°$ and corresponds to <222> reflection. The intensity of the XRD peak was found to increase with increase in the ion fluence. These results indicate increase in the concentration of the oxide phase formation as the fluence increases. The observed d values are slightly higher than the standard d values in most of cases as seen from Table 2. The XRD studies revealed the formation of silicon oxide (SiO_2) at all ion fluence.

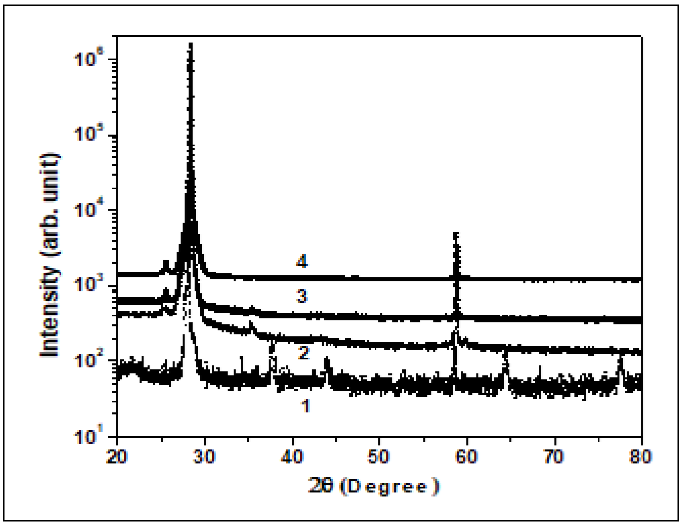

Fig 2: XRD diffractogram of the silicon samples implanted with O^+ at room temperature at 140 keV (1) Silicon Reference, (2) 1.0×10^{16}, (3) 3.0×10^{16} and (4) 7.0×10^{16} cm^{-2} and annealed at 1200 °C for 30 min.

Table 2: Implanted samples annealed at 1200 °C.

Experimental d (Å) Fluence (cm^{-2})			Std. d (Å)	hkl	Phase
1.0×10^{16}	3.0×10^{16}	7.0×10^{16}			
3.4645	3.4664	3.4580	3.4650	400	SiO_2(O)
3.1315	3.1333	3.1294	3.1354	111	Si(C)
1.5623	1.5590	1.5671	1.5642	222	Si(C)
1.5665	1.5670	1.5663	1.5670	211	SiO_2(H)

4. Conclusion

The buried silicon oxide layers were synthesized by SIMOX process using 140 keV oxygen ($^{16}O^+$) ion implantation at low fluence levels into silicon substrates at room temperature. The FTIR studies show that the structures of ion-beam synthesized oxide layers are strongly dependent on total ion-fluence and annealing temperature. The XRD studies further confirm the formation of silicon oxide (SiO_2) at all ion fluence. The FTIR and XRD data show increase of concentration of silicon oxide with increase in fluence as well as annealing temperature.

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