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FTIR studies of buried oxide layers formed by oxygen ion implantation in silicon

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Abstract: The synthesis of buried silicon oxide insulating layers was carried out by SIMOX process using implantation of 140 keV oxygen ($^{16}O^+$) ions at high fluence levels ranging from 1.0×10^{17} to 1.0×10^{18} ions-cm^{-2} into <111> single crystal silicon substrates at room temperature. The structures of ion-beam synthesized buried silicon oxide insulating layers were identified by Fourier transform infrared (FTIR) spectroscopy. The FTIR spectra of implanted samples reveal absorption band associated with the stretching vibration of Si-O bonds indicating the formation of silicon oxide. The integrated absorption band intensity is found to increase with increasing ion fluence. The FTIR studies show that the structures of ion-beam synthesized buried oxide layers are strongly dependent on total ion fluence.

Keywords: SIMOX, FTIR, Implantation, Silicon.

I. INTRODUCTION

High fluence ($\geq 10^{16}$ ions-cm^{-2}) reactive ion-implantation in silicon at medium energy can produce buried layers of new materials with compositions and structures unattainable by conventional techniques. The synthesis of buried insulating layers to produce silicon-on-insulator (SOI) structures by SIMOX (separation by implanted oxygen) process using high fluence oxygen ion implantation into silicon has scope of potential applications in semiconductor device technology for masking, passivation, isolation, diffusion barrier, gate insulator, dielectric layer etc. Tula Jutarosaga et al. [1] have reported infrared spectroscopy of Si-O bonding in low-fluence low-energy (65 and 100 keV) implanted silicon wafers held at temperature of 560 ^{0}C at fluence levels ranging from 2.0×10^{17} to 8.0×10^{17} O^+-cm^{-2}. Haruhika Ono et al. [2] have reported infrared studies of silicon oxide formation in silicon wafers implanted with oxygen at 180 keV at fluence levels ranging from 0.5×10^{17} to 7.0×10^{17} O^+-cm^{-2}. Kenji Kajiyama et al. [3] have reported the Si-0 bond formation by oxygen implantation at 90-360 keV with fluence range $2\text{-}15\times10^{17}$ O^+-cm^{-2} into silicon. In this paper, we present the synthesis of buried silicon oxide insulating layers by implantation of oxygen ($^{16}O^+$) ions at high fluence levels ranging from 1.0×10^{17} to 1.0×10^{18} ions-cm^{-2} into silicon substrates at medium energy of 140 keV. The structural characterization of ion-beam synthesized SIMOX structures have been carried out using Fourier transform infrared (FTIR) spectroscopy.

II. RESEARCH METHODOLOGY

Single crystal p-type <111> silicon wafers of resistivity 10-15 Ω-cm were used as substrate material. The silicon wafers were thoroughly cleaned adopting standard cleaning procedures of RCA-I and RCA-II using electronic grade chemicals and distilled deionized (DI) water. These wafers were then cut into 1cm x 1cm size samples for loading onto the sample holder of the implanter. To synthesize the buried silicon oxide insulating layers, samples were implanted at 140 keV with oxygen ($^{16}O^+$) ion beam to fluence levels 1.0×10^{17}, 2.5×10^{17} and 5.0×10^{17} ions-cm^{-2} using 150 KV ion accelerator facilities at Materials Science Division, IGCAR, Kalpakkam with current density of 1-2 µA cm^{-2}. The scanned beam was further collimated through a collimator of diameter 12.5 mm. The vacuum of order of 1×10^{-6} mbar was maintained in the target chamber during implantation. The higher fluence implantations of samples (7.5×10^{17} and 1.0×10^{18} ions-cm^{-2}) were performed using Low Energy Ion Beam Facility (LEIBF) at Nuclear Science Centre, New Delhi at 140 keV energy with current density of 55-65 µA cm^{-2}. A vacuum of 10^{-7} mbar was maintained in the target chamber during implantation. The ion beam was scanned over 1cm x 1cm to cover large area of sample for implantation. The identification of structure of ion-beam synthesized buried silicon oxide insulating layers was carried out using FTIR spectroscopy 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 spectra were calibrated with respect to an etched (490 Å) reference silicon sample for background correction.

III. RESULTS AND DISCUSSION

Fourier Transform Infrared Spectroscopy Studies

The FTIR spectra of the silicon sample implanted at room temperature with 140 keV $^{16}O^+$ at high fluence levels of 1.0×10^{17}, 2.5×10^{17}, 5.0×10^{17}, 7.5×10^{17} and 1.0×10^{18} ions-cm^{-2} are shown in Fig.1. The sample implanted to a fluence of 1.0×10^{17} ions-cm^{-2} shows absorption band centered at 949 cm^{-1} indicating partial oxidation. The higher fluence implantation shows higher degree oxidation of silicon. In 2.5×10^{17} ions-cm^{-2} implanted silicon sample, the absorption band is observed to be centered at 963 cm^{-1}. The band is shifted to 970 cm^{-1} for the sample implanted with 5.0×10^{17} ions-cm^{-2}. The sample implanted with 7.5×10^{17} ions-cm^{-2} shows an absorption band in the wavenumber range 1166 – 771 cm^{-1} centered at 974 cm^{-1}. The sample implanted with fluence 1.0×10^{18} ions-cm^{-2} shows absorption band in the wavenumber range 1193 – 793 cm^{-1} centered at 978 cm^{-1}. It is evident from Fig.1 that a considerably broad

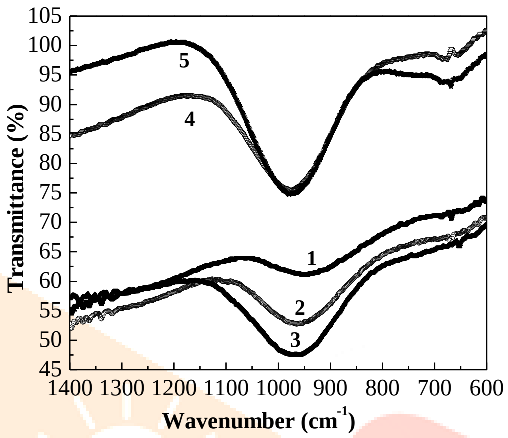

Fig.1. FTIR spectra of silicon samples implanted at room temperature with (1) 1.0×10^{17}, (2) 2.5×10^{17}, (3) 5.0×10^{17}, (4) 7.5×10^{17} and (5) 1.0×10^{18} O^+cm^{-2} at 140 keV.

Table 1. FTIR absorption band range and peak position at different ion fluence

Fluence (ions-cm^2)	FTIR band range (cm^{-1})	Peak Position (cm^{-1})
1.0×10^{17}	1076-763	949.7
2.5×10^{17}	1122-765	963.6
5.0×10^{17}	1142-768	970.7
7.5×10^{17}	1166-771	974.8
1.0×10^{18}	1193-793	978.6

absorption band is observed for low fluence implantation. The band becomes more intense and sharper when the implantation fluence is increased. The range of the IR absorption band and its area also increase (Table 1) with increasing ion fluence. The centre of the absorption band peak position shifts towards higher wavenumber (Fig.2). These changes in the FTIR spectra are more pronounced for low implantation fluence than for high implantation fluence. The FTIR absorption band observed in the present work is associated with the stretching vibration of the Si–O bond and indicates the formation of silicon oxide [2]. The increase in the area of the band with increase in the ion fluence shows the formation of more and more Si-O bonds with increasing oxygen concentration. The implantation at smaller fluences shows SiO formation and leads towards transformation into stoichiometric SiO_2 as the fluence increases. The observed shift towards higher frequencies and sharpening of the transmission band with increasing ion fluence indicate the transformation of oxygen implanted layer towards the formation of SiO_2.

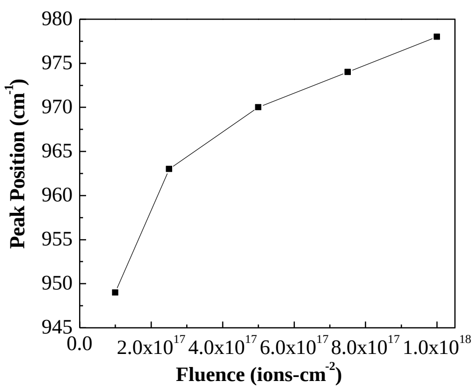

Fig.2. FTIR peak position versus the implanted oxygen fluence in silicon at 140 keV.

IV. CONCLUSION

The buried silicon oxide layers were synthesized by SIMOX process using implantation at 140 keV with oxygen ($^{16}O^{+}$) ions at high fluence levels into silicon substrates. The FTIR studies show the absorption band associated with the stretching vibration of the Si–O bonds indicating the formation of buried silicon oxide layer. The increase in the integrated absorption band intensity and sharpening of the band with increasing ion fluence show gradual chemical transformation of implanted layer towards stoichiometric composition of SiO_2. The FTIR studies show that the structures of ion-beam synthesized oxide layers are strongly dependent on total ion fluence.

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