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100 MeV silver ions induced defects and modifications in silica glass

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ABSTRACT

A few silica glass samples having 1 cm^2 area and 0.1 cm thickness were irradiated with 100 MeV energy Ag^{7+} ions for the fluences ranging from 1×10^{12} ions/cm^2 to 5×10^{13} ions/cm^2. The optical properties and the corresponding induced defects were characterised by the techniques such as UV–Visible, Photoluminescence (PL), Fourier transform infrared (FTIR), and Electron spin resonance (ESR) spectroscopy. The UV–Visible absorption spectra show two peaks, one at 5 eV and another weak peak at 5.8 eV. A peak observed at 5.0 eV corresponds to B_2 band (oxygen deficiency in SiO_2 network) and the peak at 5.8 eV is due to the paramagnetic defects like E′ centre. The intensities of these peaks found to be increased with increase in ion fluence. It attributes to the increase in the concentration of E′ centres and B_2 band respectively. In addition, the optical band gap energy, Urbach energy and the defects concentration have been calculated using Urbach plot. The optical band gap found to be decreased from 4.65 eV to 4.39 eV and the Urbach energy found to be increased from 60 meV to 162 meV. The defect concentration of nonbridging oxygen hole centres (NBOHC) and E′ centres are found to be increased to 1.69×10^{13} cm^{-3} and 3.134×10^{14} cm^{-3} respectively. In PL spectra, the peak appeared at 1.92 eV and 2.7 eV envisage the defects of nonbridging oxygen hole centres and $B_{2\alpha}$ oxygen deficient centres respectively. ESR spectra also confirms the existence of E′ and NBOHC centres. FTIR spectra shows scissioning of Si—O—Si bonds and the formation of Si—H and Si—OH bonds, which supports to the co-existence of the defects induced by Ag^{7+} irradiation.

1. Introduction

Silica glass is being widely used in various high-tech applications for its uniquely useful properties such as high optical transmittance in IR and UV region, low dielectric loss and low thermal expansion. It is the best glassy material both for ultraviolet (UV) optics and for high-power pulsed laser optics since it has the highest UV transparency of all glasses [1]. It is also an important key material in variety of scientific and technological fields due to its multiplicity of electrical, mechanical, piezoelectric and optical properties [2]. Due to its large band gap and very low conductivity, it is used in microelectronics and telecommunications. Moreover, radiation induced defects in silica glass deserve special attention in modern electronic technology. The solar cells, MOSFETs etc. used in the satellite are enclosed with silica glass to insulate electrically and held transparent for the solar radiation. When the solar cells and MOS structures with thin insulating silica glass comes under space radiation environment, they change their properties due to generation of defects, hence understanding of defects in silica is a key factor in providing device performance and material quality. The point defects in silica are often detrimental for device applications, since they can cause apparent absorptions in the energy range and play very important role in the electronic properties of the materials and modifies the characteristics of the electronic devices [3]. Therefore, the generation of point defects in amorphous silica by irradiation with high energetic particles such as electrons, protons, ions and gamma radiation is very much useful to understand their origin and the mechanisms for the future development of SiO_2 systems [4]. High energy swift heavy ion (SHI) makes enlastic collisions with atoms of the solid and loses its energy through electronic processes called electronic energy loss (S_e), and nuclear processes called nuclear energy loss (S_n) [5]. Especially, in glass materials, point defects, defects clusters and ion tracks, can be formed along the ion projected range and at the end of the trajectory when passed through it.

Fig. 1 shows electronic energy loss $(dE/dX)_e$ and nuclear energy loss $(dE/dX)_n$ of 100 MeV Ag ion along the projected range using TRIM calculations. The stopping power and the range of 100 MeV Ag ions in silica glass are estimated around to be 33.64 MeV cm^2/gm and 14.50 μm respectively. In case of ion irradiation, the contribution of electronic energy loss (S_e) is much more than that of nuclear energy loss (S_n) [6]. For 100 MeV energy Ag ions, the value of electronic energy loss, $(dE/dX)_e = 11.125$ eV/μm, is large as

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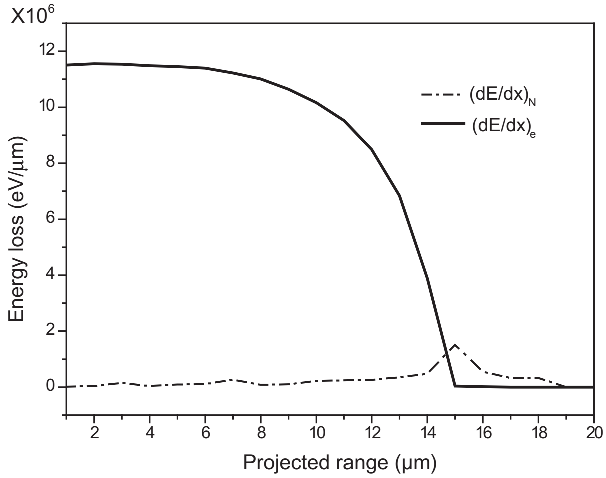

Fig. 1. Electronic energy loss $(dE/dX)_e$ and nuclear energy loss $(dE/dX)_n$ of 100 MeV Ag ion along the projected range using TRIM calculations.

compared to the nuclear energy loss, $(dE/dX)_n = 4.74 \times 10^{-2}$ eV/µm for silica glass. It has been suggested that the defects formation in silica glass under high energy heavy ions irradiation is highly related to the electronic energy losses [7]. However, small effect of nuclear energy loss has also been observed in some cases. Moreover, an absorption band can be induced in the silica glass mainly by X-ray, gamma ray and electron irradiation. The energies of the maxima and the full widths at half-maximum (FWHM) of most of these bands are known [8]. The most investigated fundamental radiation induced defects (or colour centres) in silica glasses are, nonbridging oxygen hole centres (NBOHC: ≡Si—O*), E′ centre (: ≡Si*), oxygen deficiency centre (ODC (II): ≡Si—Si≡), peroxy radical (: ≡Si—O—O*) and B_1 band. The symbol '*' denotes unpaired electrons. The optical absorption of NBOHC is at 620 nm (2.004 eV), E′ centre shows absorption at 214 nm (5.808 eV), POR has an optical absorption near 260 nm (4.780 eV), ODC (II)—II at 247 nm (5.03 eV) and B_1 band appears at 300 nm (4.1433 eV). Three luminescence bands peaked at 4.4 eV (α band), 3.1 eV (β band) and 2.7 eV (γ band) [9] and can be excited by excitation at 5 eV.

From the literature survey, it also appears that the effects of ion irradiation on glasses are extremely specific to the ion species, with their energy, the type of glasses and the irradiation environment. Thus, each ion and its irradiation of a particular glass becomes a specific case for investigation. Also, the yield of defect production and the nucleation rate of defects are directly proportional to the energy of the ions and cross section of ions. For 100 MeV Ag ions, the cross section and range in silica glass is $\sim 10^{16}$ cm^2 and 14.50 µm respectively, which signifies the choice of Ag ion for the defect production. In the present work, we study the silica glass irradiated with 100 MeV Ag^{7+} ions. The aim is to investigate the generation mechanisms of various defects in silica glass by 100 MeV Ag ions and also identify other possible defects produced during irradiation and compare with the experimentally observed ones. Moreover, optical modifications made in the glass during irradiation are also been reported.

2. Experimental

Optically polished high purity SiO_2 synthetic fused silica was taken for the experiment. The plane sheet was then cut into many pieces having dimensions of $1 \times 1 \times 0.1$ cm. The samples were washed with acetone, distilled water and then finally with methyl alcohol to remove any surface ambiguities. These samples were then dried with absorbent papers as well as wrapped into aluminium paper and stored in the dust free environment. These samples were irradiated by 100 MeV energy Ag^{7+} ions with fluences varying from 1×10^{12} to 5×10^{13} ions/cm^2 uniformly at room temperature and in the vacuum using 15 UD Pelletron tandem accelerator at IUAC, New Delhi [10]. The vacuum level in the chamber was 10^{-8} torr. The pre and post irradiated samples were characterised by the techniques such as UV–Visible, photoluminescence (PL), Fourier transform infrared spectroscopy (FTIR) and Electron spin resonance (ESR). The heavy ion induced changes in the optical properties were measured using UV–Visible spectroscopy. UV–Visible spectra in the absorption mode were recorded on Perkin Elmer Lambda-950 in the range of 200–700 nm keeping virgin sample as the reference. In order to study the defect levels in the network of the silica, photoluminescence spectra of the irradiated samples were carried out using Perkin Elmer LS-55 luminescence spectrometer with excited wavelength of 240 nm. The spectrum was taken in the wide range of the wavelength from 200 nm to 700 nm. To study the nature of bond formation, breaking and scissioning of Si—O—Si and Si—OH bonds, the FTIR measurements were made on SHIMADZU FTIR 8400 spectrometer. The spectra were recorded in the range of 400–4000 cm^{-1} by keeping air as the reference. Each spectrum was taken with 30 scans. ESR experiments were performed on EPR spectrometer (JOEL-FE-1X) operating in the X-band frequency (≈9.205 GHz) with field modulation frequency of 100 kHz. The magnetic field was scanned from 3000 Gauss to 3500 Gauss with scan speed of 625 Gauss/min and the microwave power used was 5 mW. An irradiated and non irradiated silica glass samples were crushed into powder of 100 mg and taken in the quartz tube for EPR measurements. $CuSO_4 \cdot 5H_2O$ with *g* value of 2.14 was used as a standard to calculate the spin concentrations.

3. Results and discussion

3.1. UV–Visible analysis

The UV–Visible spectra for virgin and 100 MeV Ag^{7+} ion irradiated silica glass samples for the different fluences 1×10^{12} ions/cm^2, 5×10^{12} ions/cm^2, 1×10^{13} ions/cm^2 and 5×10^{13} ions/cm^2 is shown in Fig. 2. The silica glasses turned to violet colour after the irradiation due to the characteristic absorption bands in the visible region. Two peaks are observed in the absorption band, one appeared at 248 nm (5 eV) and the additional

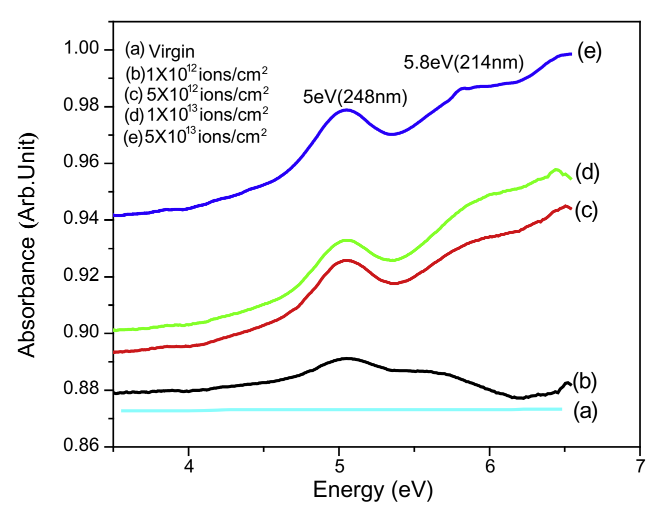

Fig. 2. UV–Visible absorption spectra for virgin and 100 MeV Ag ion irradiated fused silica glass at different ion fluences.