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Effect of oxygen ion irradiation on dielectric, structural, chemical and thermoluminescence properties of natural muscovite mica

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ABSTRACT

Thin cleaved samples (~18 µm) of natural muscovite mica were irradiated with 80 MeV oxygen ion beam at fluence ranging from 1×10^{12} to 5×10^{13} ion/cm^2. The alterations in dielectric, structural, chemical and thermoluminescence properties of irradiated as well as pristine samples have been investigated. Dielectric constant decreases while other dielectric parameters such as dielectric loss, tanδ, ac conductivity, real and imaginary parts of electric modulus increase with increase of ion fluence. Williamson Hall investigation has been utilized to ascertain crystallite size and micro strain of pristine and irradiated samples. The XRD analysis revealed a significant increase in micro strain and dislocation density with an increase of ion fluence. The variations in dielectric properties upon irradiation are collaborated with structural modifications in the muscovite. No appreciable changes in characteristic bands (FTIR) have been observed after irradiation, indicating that natural muscovite mica is chemically stable. Natural muscovite mica has eminent applications in heavy ions dosimetry due to observation of well defined single peak at 303 °C with activation energy of 1.24 eV in TL spectrum.

1. Introduction

In recent years, Swift heavy ion (SHI) induced alteration in polymers, glasses and minerals were being studied in respect of their structural, optical, chemical and dielectric properties to promote their use for the development of insulating systems and dosimeter in radiation rich environment (Kumar et al., 2012a, 2012b; Kaur et al., 2013a). Natural Muscovite mica is structurally significant because it has a layered structure comprising of aluminium silicate sheets weekly bonded together by layers of potassium ions. These potassium ion layers create the perfect cleavage of muscovite. Muscovite mica is one of the most common insulators being used in power electronics capacitors because it exhibits outstanding insulation properties, combined with good mechanical and thermal properties (Blaise et al., 2009). It is a highly reliable material exhibiting low ionizing radiation-induced conductivity and resistant to electrical micro discharges that cause instabilities in electronic circuits and are precursors of electrical breakdown (Blaise et al., 2009).

Heavy ion irradiation of muscovite mica is a subject of scientific interest from last two decades, especially the formation of tracks and morphological studies (Dartyge and Sigmund, 1985; Thibaudau et al., 1991; Wang et al., 1998; Singh et al., 2010; Wang et al., 2012; Mo et al., 2012). Ionizing radiations passing through matter, deposit energy in the material and produces considerable changes in the microstructure of that material which in turn changes its structural, dielectric and optical properties (Singh, 1999). So it is necessary to identify the modifications due to irradiation of muscovite mica with regard to their dielectric, structural, chemical and thermoluminescence properties.

A significant amount of work has been done on the dielectric (Chaudhry et al., 1985; Chaudhry and Jonscher, 1985; Bano and Jonscher, 1992; Dawy, 2002), structural and chemical (Shishelova et al., 1974; Orlova et al., 1974) properties of natural muscovite mica without irradiation. However no study has been accounted so far to explore the impact of heavy ion irradiation on the dielectric, structural and chemical properties of muscovite mica. Therefore, in the present work, the effect of oxygen ion irradiation on dielectric, structural, optical and chemical properties of muscovite mica have been examined to utilize this material for innovative applications in radiation technology and opto-electronic devices.

Thermo luminescence (TL) is a crucial phenomenon that takes place in various irradiated natural minerals (Kaur et al., 2013c, 2014a, 2014b). TL studies of the minerals have been used to examine their potential for TL dosimetry and dating. It was well known that TL properties of minerals which mined from different geographical locations are different. It is also comprehended that the contents of the impurities in minerals play an essential role in TL properties. Generally

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the TL glow curve should have a simple and single peak. The glow peak comprises ionization of traps at respective energy levels (Chen and Mckeever, 1997). The TL properties of gamma irradiated muscovite from different origin have been reported by numerous authors (Mukhlya et al., 1977; Kristianpoller et al., 1988; Barcena et al., 1999; Ige et al., 2006; Soliman and Aziz, 2008; Kaur et al., 2014a, 2014b). But literature survey, on the other hand, revealed no work on ion induced modifications of TL properties of muscovite. So the TL property of oxygen ion irradiated muscovite mica has been investigated for the first time to determine their relevance for magnificent applications in SHI radiation dosimetry.

2. Experimental procedure

The natural muscovite mica used in the present work was procured from Bhilwara area in Rajasthan, state of India and in the form of thin sheets. These natural sheets of muscovite mica were cleaved and cut into small sheets of dimensions 1 cm × 1 cm × 18 µm. These mica samples were further analysed for elemental composition using Energy dispersive X-ray spectroscopy system. EDS analysis indicates that the natural muscovite mica mainly consist of silicon (Si), Aluminium (Al) and with some amount of potassium (K), Magnesium (Mg), sodium (Na), carbon (C), iron (Fe) (Kaur et al., 2013b).

These cleaved sheets were irradiated in a Material Science Beam line from 15UD Pelletron at the Inter University Accelerator Centre (IUAC), New Delhi, India with 80 MeV oxygen ion using various fluences ranging from 1×10^{12} ions/cm^2 to 5×10^{13} ions/cm^2. The electronic (S_e), nuclear (S_n) energy loss and maximum penetrable range of the 80 MeV Oxygen ion in muscovite mica were calculated using Stopping and Range of Ions in Matter (SRIM)-2008 programme and are shown in Table 1. The range of oxygen ion (80 MeV) was found to be more than the thickness (~18 µm) of the sample. It is also clear that the energy transferred from the ion beams to the target was mainly due to electronic process and the nuclear energy loss is quite low to be ignored.

Dielectric measurements were carried out in the frequency range 20 Hz–1 MHz at room temperature using Hewlett- Packard 4284A LCR meter on pristine as well as irradiated samples of natural muscovite mica at IUAC, New Delhi. The accuracy of LCR meter for Capacitance-tanδ measurements is 0.05%–0.005% respectively at all test frequencies. The structural studies were carried out by a XRD-7000 SHIMADZU X-ray (CuK$_\alpha$, λ = 1.54 Å) diffractometer with Cu- K$_\alpha$ radiation (1.54 Å) for a range of Bragg's angle 2θ between 5 and 50. Fourier Transform Infrared (FTIR) spectroscopy was performed with a NEXUS-670 FTIR spectrometer in transmission mode, between 400 and 4000 cm^{-1} to study the chemical change in ion irradiated samples. The sheets of muscovite were crushed and grounded in high energy ball mill to prepare the powder samples for TL properties. TL glow curves were recorded at a heating rate of 5 °C s^{-1} on a Harshaw TLD reader (Model 3500) taking 5.0 ± 0.2 mg of each sample.

3. Results and discussion

3.1. Dielectric properties

The dielectric measurement is one of the practicable method for the characterization of electrical response in crystalline materials. The capacitance and loss factor (tanδ) of the pristine and irradiated samples have been measured directly using Hewlett Packard 4284A LCR Meter. The dielectric constant (ε') and dielectric loss (ε'') of the pristine as well as irradiated samples have been calculated using the equation (Kaur et al., 2013a):

Table 1
SRIM calculated Se, Sn values and range of 80 MeV O^{6+} ion beams for Muscovite mica.

Energy (MeV)	Electronic energy loss S_e (keV/µm)	Nuclear energy loss S_n (keV/µm)	Range (µm)
80	3.78×10^3	2.14	98.24

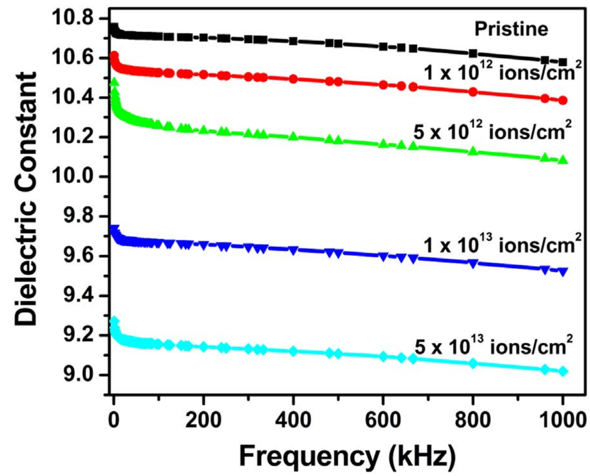

Fig. 1. Frequency dependence of the Dielectric constant (ε') for pristine and oxygen ion irradiated muscovite mica.

$$\varepsilon' = \frac{Cd}{A\varepsilon_o} \tag{1}$$

$$\varepsilon'' = \varepsilon' \tan\delta \tag{2}$$

where ε_o is the free space permittivity, d is the thickness of dielectric, A is the effective area between the electrodes and C is the capacitance of the specimen. Fig. 1 demonstrates the plot of the dielectric constant versus frequency for pristine and irradiated natural muscovite mica. It can be seen from Fig. 1 that the dielectric constant decreases with increase in frequency before and after irradiation. The large values of dielectric constant at low frequency might be attributed to the presence of space charge polarization, however at higher frequency space charge polarization is minimized (Kaur et al., 2013a). Fig. 1 also reveals that the dielectric constant decreases with increase in ion fluence. This decrease in dielectric constant may be attributed to the production of defects in the form of vacancies and dislocations in the sample due to ion irradiation. The variation of loss factor (tanδ) as a function of frequency for pristine and irradiated muscovite is shown in Fig. 2. The loss factor (tanδ) increases with increase in ion fluence and its positive value indicates inductive dominance. The loss factor is defined as the ratio of imaginary part (ε'') and real part (ε') of complex permittivity (Eq. (2)):

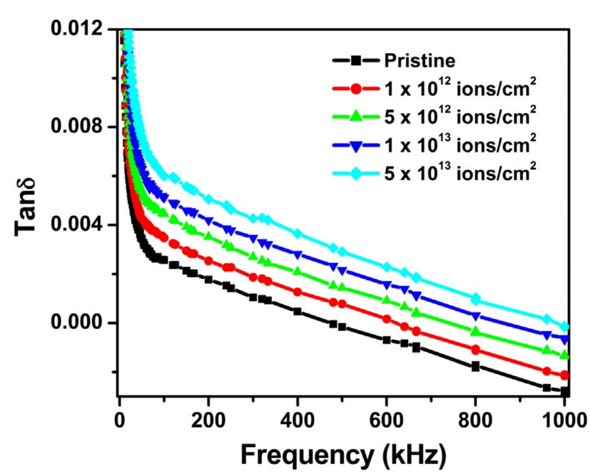

Fig. 2. Frequency dependence of the Tanδ for pristine and oxygen ion irradiated muscovite mica.