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Gamma and neutron irradiation effects on the structural and optical properties of potash alum crystals

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ABSTRACT

The effects of gamma and neutron irradiation on the structural and optical properties have been presented in this article. The potash alum crystals were grown by the slow evaporation technique. The crystals were then exposed with ^{60}Co gamma rays and Am-Be neutron source. The radiation induced effects were analysed using XRD, UV–visible techniques. The refractive index was determined by the Brewster's angle method. There has been an increase in the diffraction peak intensity with the increase in irradiation doses, which indicates an increase in crystalline perfection of crystals. There has been a marginal change in dislocation density, micro strain and distortion parameter, which is attributed to deformation of the structure due to irradiation. The UV visible study reveals a shift in transparency cut off wavelength towards lower wavelength up to 70 kGy of gamma dose and this has resulted in an increase in optical band gap energy with increase in gamma dose. There is a considerable increase in the optical band gap after five hour neutron irradiation.

1. Introduction

The interest in the effects of radiation on materials has captured the imagination and interest of the researchers. Nuclear engineers, materials engineers, metallurgists, mechanical engineers, physicists and chemists are concerned with the phenomena associated with irradiation of materials by neutrons, gamma rays, fission fragments, alpha particles or other energetic particles for scientific and practical interests. Radiation damage has imposed an additional parameter on the selection and use of materials for various applications. The studies on mechanism of radiation effects in crystal enhance our knowledge of the physics of crystals under radiation environment.

The irradiation studies are the only way of understanding the degradation mechanisms and estimation of the lifetime of the crystals in radiation environments [1]. Extensive attention has been given on a study of the electronic excitation dynamics, radiation-induced processes and defect generation [1–3]. The radiation energy is mainly dissipated by excitation of the electron subsystem of the crystal along with the ionizing of the matter. Ionisation processes may lead to change the charge state of growth (native) defects and forms metastable defect centres including the colour centres [4,5].

The study the effects of different radiations on solid state materials is the only way of understanding degradation mechanisms. It was shown that swift heavy ion irradiation on crystalline materials are changing its physical and chemical properties of the specimens [6–12]. The energy deposited in electronic excitation may result in the creation of defects and modification the material properties [6,7–9,13–17]. Depending on kinetic energy, mass and nuclear charge, an ion can create changes within a thin surface layer or can penetrate far into the bulk to produce long and narrow zone along its trajectory [17,18]. The swift heavy ion irradiation recently has been widely used as a powerful technique to change the refractive index of the crystals, by which waveguides can be therefore fabricated [19–22]. In this regard, we made an attempt to understand the Co-60 gamma radiation and neutron irradiation effect on potash alum crystals, which is not much explored with respect to irradiation effects.

Gamma rays primarily interact by three interaction mechanisms namely photoelectric effect, Compton scattering and pair production. In common with gamma rays, neutrons carry no charge and therefore cannot interact in matter by means of the Coulomb force, which dominates the energy loss mechanisms for charged particles and electrons. When a neutron undergoes interaction, it is with a nucleus of the absorbing material. As a result of the interaction, the neutron may either totally disappear and be replaced by one or more secondary radiations, or else the energy or direction of the neutron is changed significantly.

The collision between an incoming particle and a lattice atom subsequently displaces the atom from its original lattice position. A single incident particle can cause a cascade of collisions to occur to a

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portion of the affected material lattice atoms. These collisions are produced by both incident "heavy" particles like neutrons and secondary particles. Defects created in crystals like vacancies, interstitials, Frenkel pairs, dislocations are produced along the tracks of the secondary particles and in clusters at the end of these tracks. This intern can induce structural changes in the crystal.

In the present work, potash alum crystals are grown by slow evaporation method in the laboratory. Prepared crystals are characterized for structural and optical properties. Grown crystals are irradiated with gamma radiation and neutrons. Structural and optical were studied after irradiation. Comparisons of above properties were made between pristine with that of irradiated crystals. An effort has been made to understand the radiation stability of the potash alum and the process that lead to the structural and optical changes. The knowledge of gamma and neutron irradiation effects on structural, optical and thermal behaviours and modifications caused by the irradiation on the crystals is important from the viewpoint of their ability to tune their properties [4].

2. Methodology

The bulk singe crystals of aluminium potassium sulphate (potash alum) have been grown from aluminium potassium sulphate solution by the slow evaporation technique. The well-polished good quality single crystals of potash alum were subjected to gamma as well as neutron irradiation. The crystals were irradiated in ^{60}Co gamma chamber-5000 which is a compact, portable, self-shielded type of a ^{60}Co gamma irradiator located at The Centre for Application of Radioisotopes and Radiation Technology (CARRT), Mangalore University, India. A 592 GBq Am–Be neutron source which emits 4×10^7 neutrons per second was used to irradiate samples.

The pristine and irradiated crystals were subjected to powder X-ray diffraction (XRD) by using X-ray diffractometer with a scan speed of 5°/min with Cu-Kα radiations (λ = 1.5406 Å). The absorption spectrum was recorded using UV–visible spectrophotometer in the range of 200–800 nm covering the entire near ultraviolet and visible regions. The refractive index (n) was determined by the Brewster's angle method using a red (He-Ne) laser of wavelength 633 nm. The refractive index was calculated using the equation $n = tan\theta_p$, where θ_p is the polarizing angle in degree.

3. Results and discussions

3.1. XRD analysis

XRD pattern were obtained for pristine and irradiated potash alum crystals. The grown crystals were irradiated at 50 kGy, 70 kGy and 100 kGy gamma radiation doses. Similarly different set of crystals were irradiated with neutrons for three and five hour duration. The powder XRD pattern of gamma and neutron irradiated crystals is shown in the Fig. 1 and Fig. 2 respectively. The well-defined Brag reflections at definite 2θ angles in the diffraction pattern confirm the crystallinity of the sample.

There is an increase in intensity of diffraction peaks after irradiation. This can be explained by improvement in the crystallinity due to irradiation. Improvement in the crystallinity upon irradiation is due to energy deposition during the irradiation which is similar to thermal annealing. It can also be inferred as reduction in the defect density which leads to the release in the strain and hence the shift in the peak is expected. After irradiation the intensity peaks are found to shift marginally. Similar trend has been observed for both gamma and neutrons irradiation.

The crystallite size (L), inter planar distance (d), micro strain (ε), dislocation density (δ) and distortion parameters (g) were calculated as follows [23–26]:

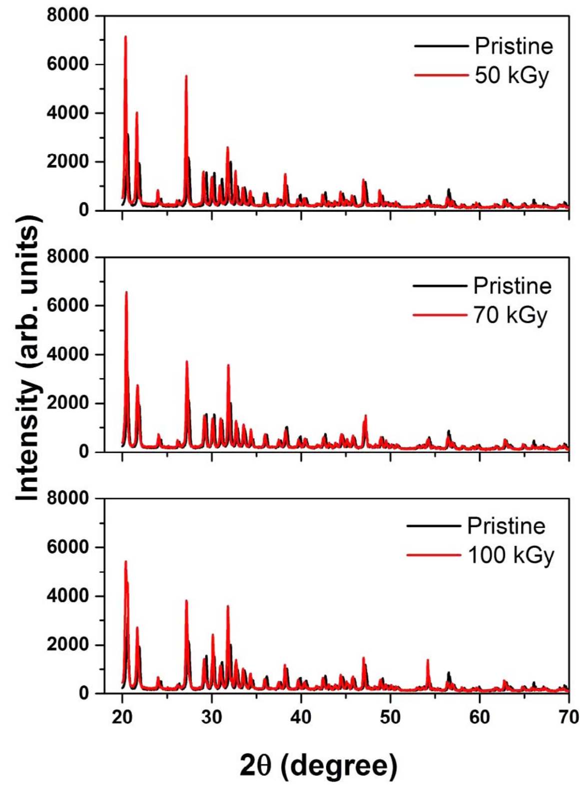

Fig. 1. Powder XRD pattern of pristine and gamma irradiated potash alum crystals.

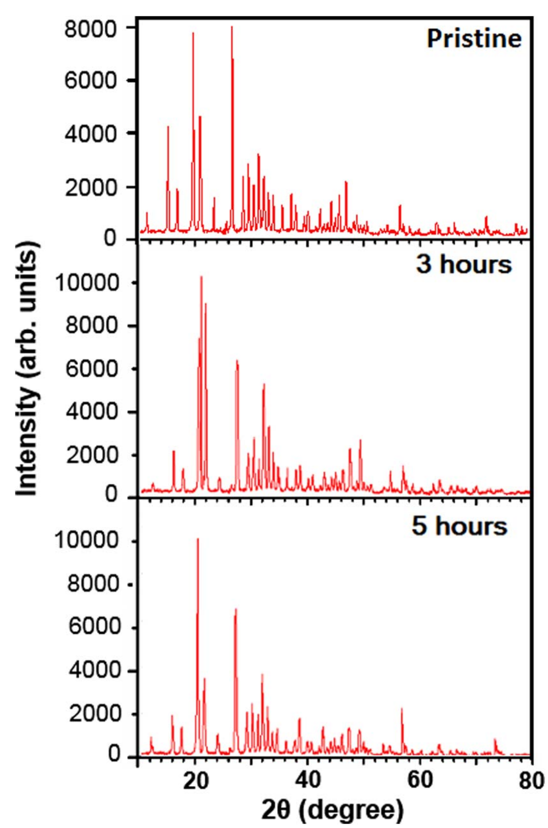

Fig. 2. Powder XRD pattern of neutron irradiated potash alum crystals.

$$L = \frac{k\lambda}{b\cos\theta} \quad (1)$$