

Photoluminescence study of swift heavy ion (SHI) induced defect centers in sapphire

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Abstract

Single crystals of sapphire (Al_2O_3 : Fe, Ti, Cr) were irradiated at room temperature with different fluence of 100 MeV Ni ions. Photoluminescence (PL) spectra of pristine and irradiated sapphires were recorded at room temperature under 2.8 eV blue excitation. A broad emission band consists of two bands centered at 516 nm corresponding to F_2 defect center and 546 nm corresponding to F_2^{2+} defect center was observed. The intensity of these defect centers was found to vary with the fluence. F_2^{2+} defect center develops at low fluence reaching maximum at 5×10^{16} ions/ m^2 and finally decreasing at higher fluence. The behavior is interpreted in terms of creation of defect centers, their clustering and annihilation.

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1. Introduction

Alumina (sapphire) possesses a wide band gap and is a radiation hard insulator. It can be applied in the field of optics, fusion reactors as an insulator and for optical window [1,2]. The optical properties of this material can be modified by point and extended defects, created due to different type of particle irradiation [3–5]. The defect centers induced by ion irradiation in sapphire are mainly F center, F^+ center, F_2 centers, F_2^+ centers and F_2^{2+} centers. These centers are associated with luminescence

bands centered at 415, 330, 518, 385 and 550 nm, respectively [4]. Understanding of radiation induced processes (light emission and defect production) is the important issue for prospective use of optical and insulating materials based on Al_2O_3 , for example, in the diagnostic systems of fusion reactors [6]. Although, a number of such studies using low energy heavy ions irradiation in sapphire [7–9] have been made, there is a lack of sufficient and systematic work to correlate the defects center formation due to swift heavy ions. High-energy ions upon entering a medium lose their energy initially through the process of electronic excitation and ionization known and at the end of its range by nuclear loss [10]. It is established that the concentration of primary defect centers (F and F^+ centers) increases as a result of irradiation by energetic ions [11,12]. It

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is suggested that an increase in the production of these defect centers could give rise to enhanced oxygen vacancy mobility and hence lead to vacancy aggregation. This vacancy aggregation gives rise to formation of F_2 -type defect center i.e. F_2 and F_2^{2+} defect centers [12].

To study the defect centers formation in sapphire systematically, we plan to consider irradiation of sapphire with different transition metal ions at various energies of MeV order [13]. As a part of this study, we present here the photoluminescence measurements to understand the behavior of defect center formation in sapphire induced by 100 MeV Ni ions at five different fluences. This technique is very useful due to its high resolution and non-destructive nature. The results are interpreted in terms of concentration of defect centers, their cluster formation and annihilation processes.

2. Experimental procedures

The natural sapphire samples of South Africa origin are prepared by cutting a piece of sapphire to a size of $5 \times 5 \times 1 \text{ mm}^3$ and cleaning using ethanol in an ultrasonic vibrator before irradiation. It contains 1500 wt ppm of Fe, 750 wt ppm of Ti and Cr in traces. The samples were irradiated with 100 MeV Ni ion beam at room temperature under high vacuum (6×10^{-6} torr) using the 15 UD pelle-

teron tandem accelerator at the Nuclear Science Center, New Delhi, India. The ion beam was magnetically scanned on an area of $10 \times 10 \text{ mm}^2$ for uniform irradiation. The samples were mounted on a copper target ladder with silver paste giving good thermal conductivity between them in order to prevent the heating/melting of samples. The ion flux was 10^{13} ions/($\text{m}^2 \text{ s}$). Samples were irradiated at fluence ranging from 1×10^{15} ions/ m^2 to 1×10^{17} ions/ m^2 . One un-irradiated sample was kept as a control. The ion beam fluence was measured by integrating the ion charge on the sample. The pristine and irradiated crystals were characterized with photoluminescence technique. PL measurements were carried out using Mechelle-900 spectrograph, using 442 nm He–Cd laser excitation at the Nuclear Science Center, New Delhi, India.

3. Results and discussion

Fig. 1 shows the PL spectra of pristine and samples irradiated with 100 MeV Ni ions at fluence 1×10^{15} , 5×10^{15} , 1×10^{16} , 5×10^{16} and 1×10^{17} ions/ m^2 . All PL spectra exhibits a broad band consists of two-emission bands at 516 nm due to F_2 defect center [4,14] and 546 nm due to F_2^{2+} defect center [13–16]. The intensity of these bands shows change with the fluence. One weak emission band corresponding to second order F^+ is also observed

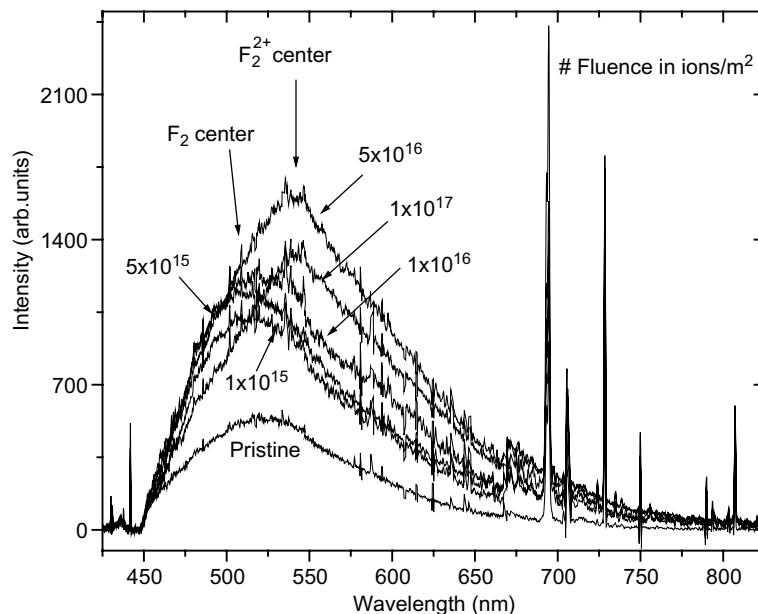


Fig. 1. Photoluminescence spectra of pristine and sapphire irradiated with 100 MeV Ni ions (fluence are expressed in ions/ m^2).

at 670 nm [1,13]. Other luminescent centers (F or F_2^+ centers) that appearing below 442 nm could not be seen, as our excitation wavelength used is 442 nm.

The intensity of F_2^{2+} defect center (two oxygen vacancies with two electrons) increases with fluence in the beginning and exhibits a maximum at fluence 5×10^{16} ion/m². At still higher fluence, it starts decreasing up to 1×10^{17} ion/m². The concentration of primary defect center (F and F^+) increases as a result of irradiation by energetic ions [11,12]. These defect centers start aggregating once their concentration become high on ion irradiation and gives rise to pairs of oxygen vacancies (F_2 -type centers) [12] or one can say that F^+ defect centers act as precursor for the generation of F_2^{2+} defect centers [13,15,16]. Therefore, the continuous increase in intensity of F_2^{2+} defect center (546 nm) in our samples at initial fluence can be assigned to the increased concentrations of F^+ defect centers (oxygen vacancies) as a result of Ni ion irradiation [11]. The decrease in the intensity of this defect center at higher fluence can be attributed to annihilation of F^+ defect centers resulting from a higher disorder induced by irradiation or due to the irradiation induced clustering (growing the sizes of defects) of defect centers [6,17]. Diffusion of defect centers (F^+), as a result of enhanced production, in the lattice could also be the probable reason for this reduction [6]. The initial luminescence could be due to the pre-existing defect centers present in the sample [7].

The band at 516 nm is related to F_2 -type anion vacancy (two adjacent oxygen vacancies), due to aggregation of pre-existing defect centers (F-centers) in pristine material [4]. The intensity of this band starts increasing up to 1×10^{16} ion/m². This suggests that the concentration of primary defect centers increases on Ni irradiation in sapphire [11,12], which on aggregation providing a higher intensity of F_2 defect center. Above fluence 1×10^{16} ion/m² the intensity is found to decrease. This decrease in intensity may be associated with the clustering or diffusion of defect centers or their conversion into F^+ or F_2^{2+} defect centers at higher fluence [6,17].

4. Conclusions

Photoluminescence induced by different fluence of 100 MeV Ni ions were measured at room temperature. Mainly two emission features such as F_2 and F_2^{2+} defect centers were observed. From the PL

behavior of the defect centers in sapphire, it is possible to conclude the followings:

1. Subsequent increase of the luminescence due to F_2 and F_2^{2+} defect centers at initial fluence is attributed to the produced primary defect centers (F and F^+).
2. Radiation induced clustering, diffusion and annihilation of defect centers may assume to be the main contributor to the reduction in intensity of F_2 and F_2^{2+} defect centers at higher fluence.

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