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Thermoluminescence Study of 210°C Glow Peak in Synthetic Quartz and their Application in High Gamma Dosimetry

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Abstract— The thermoluminescence (TL) properties of laboratory grown quartz have been studied for its possible high gamma dosimetric applications. The variation of 210°C glow peak is observed in different annealed samples followed by gamma irradiation near room temperature. The peak was found very sensitive to the pre-thermal treatments. The radiation induced effects in quartz have been studied in detail. The linear response of 210^{0}C glow peak has been observed between 100 gray to 3.5kGy gamma dose thereafter it exhibits supralinear behavior. The experimental results obtained are discussed on the basis of present understanding of the TL in quartz.

Keywords— *Thermoluminescence, synthetic quartz*

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1. INTRODUCTION

Quartz and raw sand have been widely studied for measuring accident gamma dose using thermoluminescence property. The interest in quartz for dating and retrospective dosimetry applications has led to many studies on its thermoluminescence (TL) characteristics [1-2]. The peak near 110°C usually shows a high sensitivity compared to the other glow peaks. Zimmerman [3] was one of the first to report an increase in the sensitivity of this peak using γ doses of few hundred Gy and heat treatment at 500-900°C.

Rendell et al [4], studied the effects of high temperature annealing on the sensitization as well as on emission spectra of various types of quartz of different origins. They found that the TL signal was enhanced by factors up to 1000 times and that the emission spectra were influenced by rate of cooling of the samples to room temperature. Kitis et al [5-6] in a series of papers studied the effect of annealing temperature and irradiation temperature on the TL properties of high purity synthetic quartz. Benny et al [7], studied the sensitization of the 110^{0}C TL peak in quartz separated from sand. They studied amount of pre-dose irradiation, effect of annealing temperature and annealing time on sensitization factor. They concluded that the radiation induced sensitization could be due to elimination of the competing traps.

In this paper, the dose-dependent TL characteristics of 210^{0}C glow peak and the other glow peaks in laboratory grown synthetic quartz have been reported. The linear response of 210^{0}C glow peak has been observed between 100 gray to 3.5kGy gamma dose thereafter it exhibits supra-linear behavior. This has been explained on the basis of the competition of the radiative transitions with transitions into non-radiative centers either during the excitation or during the heating (or both).

2. MATERIAL AND METHODS

The laboratory grown quartz crystal was powdered to the uniform grain size for the record of TL [8]. TL glow curves have been recorded by means of NUCLEONIX model TL 1007 which is a compact, self-contained PC-based TL system. For each measurement, 5 mg of the synthetic quartz sample was taken. For excitation purpose, Co^{60}–gamma source was used. Annealing of the samples was performed in an oven at various elevated temperatures of 200^{0}C, 400^{0}C and 600^{0}C for 3 hour in air. Immediately after the end of annealing, the samples were cooled quickly to room temperature by placing them on a copper block. Such samples are designated as Annealed and Quenched (A.Q.).

3. RESULTS ANS DISCUSSION

Figure 1 and 2 represents thermoluminescence glow curves with various gamma irradiations. It is seen that gamma doses generate a well-defined intense peak around 110°C. As the excitation with gamma increases, quartz sample generates a well-defined isolated and stable second peak at higher temperature around 210^{0}C. The material does not show large number of peaks with comparable intensities and therefore not problematic for

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its possible use in dosimetry. It is found that 210 °C peak is stable in structure and peak temperature position under the range of radiation dose of interest [High level radiation dosimetry, 100Gy to 6kGy].

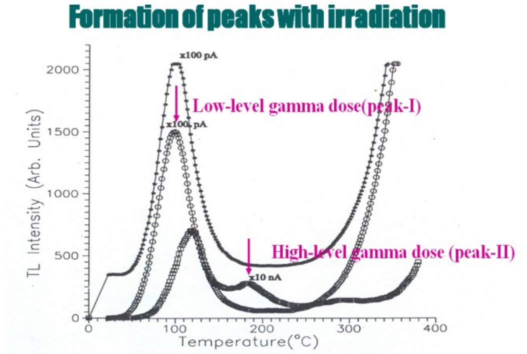

Fig. 1: Thermoluminescence glow curve of synthetic quartz samples at various gamma doses. (1) 50 Gy(****) (2) 100 Gy (oooo) (3) 200 Gy (****)

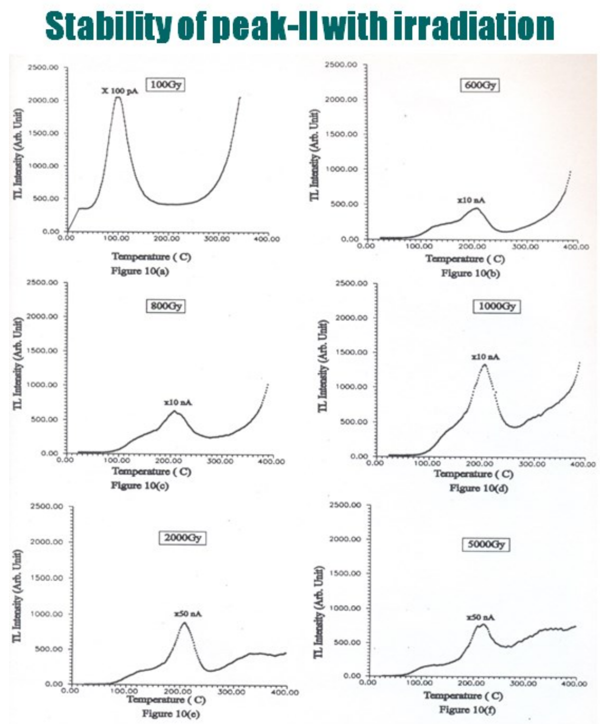

Fig. 2: TL glow curves of synthetic quartz samples at various gamma doses

The enhancement of the peak intensity with increase in incident radiation dose could be on account of a variation either in the number of available traps or in the number of recombination centers.

Figure: 3 represents TL glow curves for (1)0.1kGy,(2)1kGy and (3)5kGy of gamma dose. It is found that 110^0C peak disappears and 210^0C peak appears and grows in intensity with rise in gamma dose. The peak at 325^0C is also discernible in higher dose.

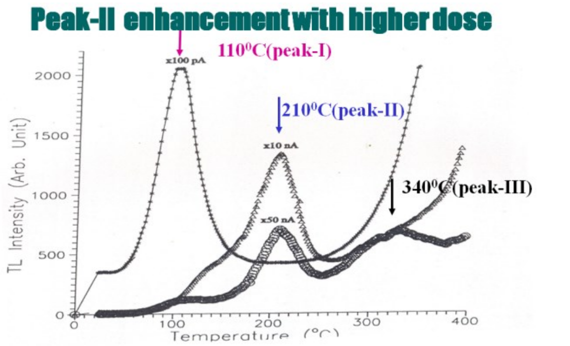

Fig. 3: TL glow curves of synthetic quartz samples at three different gamma doses (1) 0.1 kGy (****), (2) 1.0 kGy (ρρρρ), (3) 5.0 kGy (oooo)

As suggested by earlier workers, M^+ ions (Alkali ions) are always unavoidably present in natural as well as synthetic quartz material with whatever pure may be the crystal. This M^+ ions in association with Al^{+3} form a complex referred as (Al-M^+ centre); which resite substantially at Si^{4+} sites. On the basis of our experimental conditions and the present understanding of TL of quartz, the mechanism suggested for occurrence of 110^0C peak is as follows: In virgin synthetic quartz material, the alkali ions (M^+) serve as charge compensators for the ever present substitutional Aluminium(Al^{3+}) impurities. In such condition, Aluminium (Al^{3+}) and alkali (M^+) impurities are associated with each other in the form of $[AlO_4/M^+]^0$ centres. The excitation of synthetic quartz with gamma irradiation induces holes to become trapped at $[AlO_4/M^+]^0$ centres and known as $[AlO_4/M^+]^+$ centres. This later defects have an interstitial alkali ion on one side of the substitutional Aluminium and a hole trapped at an oxygen ion on the other side of aluminium. The liberated electron, upon irradiation also gets trapped at such alkali ion sites, which referred as an electron trapping site. While heating the irradiated sample, the trapped electrons are released at 110°C from the centre which in turn leads to thermally stimulated peak on recombining a hole trapped at another site in the lattice.

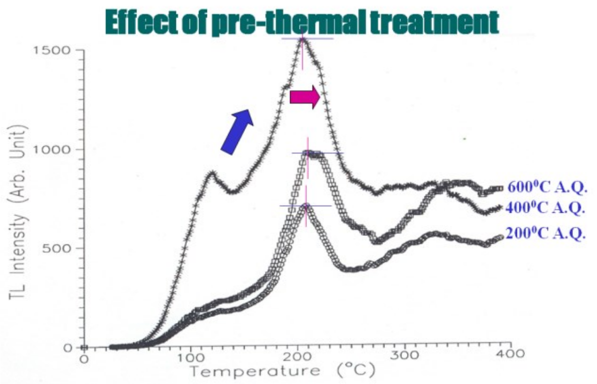

Fig. 4: TL glow curve of 4 kGy gamma irradiated synthetic quartzwith thermal preheat treatment of (1) 200°C A.Q. (oooo), (2) 400°C A.Q. (****) (3) 600°C A.Q. (****)

Figure: 4 represents the thermoluminescence glow curves of 4kGy gamma irradiated synthetic quartz with pre-thermal treatment of 200^0C annealed and rapidly air-quenched samples, 400^0C-A.Q. and 600^0C-A.Q. samples respectively. The two types of changes in glow-peaks are clearly noticed; (i) enhancement in the intensities of the peaks and (ii) shifting of the peak temperatures towards higher temperature side. The pre-thermal treatment facilitates the competitors to associate with the proposed centre. This will encourage radiative electron-hole recombination at the proposed luminescence centre site, rather than competing electron trap. This may be the reason for the enhancement in TL intensity with increase in annealing temperature up to 400°C. The observed drastic increase in the intensity of TL at 600°C annealed and air-quenched synthetic quartz sample is believed to be due to change of phase from α-quartz to β-quartz [9-10].

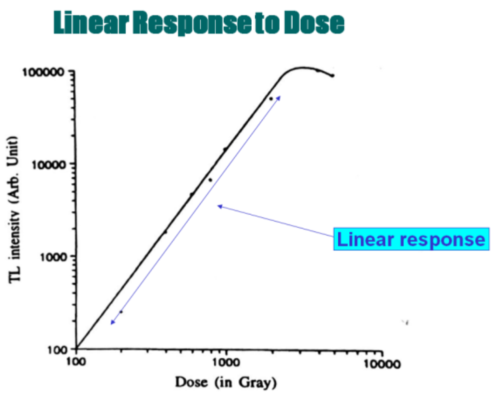

Fig. 5: Dose vs TL response of virgin synthetic quartz samples

The characteristic of the TL material that made it applicable in TL Dosimetry is the precise and exact relationship between TL intensity and incident dose. Figures: 5 reports the TL glow peak response of 210^0C peak with dose given. It is seen that 210^0C peak of laboratory grown quartz has linear response up to 3.5kGy than after in it exhibits supralinear behavior. Thus, material is found suitable for high-level radiation dosimetry [100Gy-3.5kGy] generally required in radiation processing.

An explanation for the observed supralinearity of 210^0C peak can be given as electrons released during the heating phase may recombine with trapped holes yielding TL, get retrapped or trapped in a competing state. Further, peak 210°C have dose thresholds which are higher than doses where the supralinearity of the peak 110°C appears. At this juncture, it is considered that competitor concerns the supralinearity which has close correlation with sensitivity.

4. CONCLUSION

The study of thermoluminescence properties of laboratory quartz suggests that,

- The variation of the 210°C peak after irradiation and subsequent pre-thermal treatments was found very sensitive to the effect of gamma radiation.
- Glow peak 210°C is very stable with higher irradiation of gamma dose.
- Found linear response in the range 100Gy-3.5kGy.
- Thus can be used for its practical utility in high dose gamma dosimetry.

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