Effect of pre-thermal treatments on thermoluminescence of synthetic quartz

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The effect of pre-thermal treatments on the thermoluminescence (TL) characteristics of synthetic quartz has been investigated. Various gamma dose exposure was given to the sample after thermal pre-treatment. The systematic variation in TL glow curves with different pre-thermal treatment is discernible. In a most significant observation it was found that, TL intensity enhanced abruptly, when the specimen was pre-heat treated at 600 °C. This observation is explained on the basis of phase transformation in synthetic quartz.

1 Introduction

A lot of research work is being done using natural quartz material under different physical conditions. So far, very few contributions have been made to establish definite correlation between structure changes and TL emission pattern. Perhaps, natural quartz, single crystals have twins and imperfections; prior knowledge of the defect pattern present in the material is also not known. Recently, efforts have been made to solve this problem by replacing the laboratory-grown synthetic quartz crystal.

Amongst many analytical methods, TL is found to be the most structure-sensitive phenomenon. The phase change in synthetic quartz specimens, when subjected to various pre-heat treatments was investigated systematically, using TL technique. The abrupt change in the TL emission pattern is attributed to the phase transformation of synthetic quartz material.

2 Experimental Details

The synthetic quartz used in the present work was laboratory-grown, quartz crystal, supplied by CGCRI, Jadavpur, Calcutta. The details about the growth conditions and techniques have been discussed elsewhere. In the present paper, the specimen was powdered to the grain size of 230-325 mesh. The uniform grain size powdered specimens were held at different elevated temperatures and then quenched to room temperature. These thermally pre-treated specimens were then irradiated by 60Co source. For every TL measurement, a fresh weighed quantity of 4-6 mg of specimen was heated up to 400 °C, from room temperature (27 °C), on a kanthal heater strip, at the uniform heating rate of 400 °C per min under identical and controlled laboratory conditions. The TLD system used for present experimental work was NUCLEONIX model TL 1007, which is a compact, self-contained PC based thermoluminescent system.

3 Results and Discussion

The pre-thermally treated specimens at various elevated annealing temperatures for three hours were rapidly air-quenched to room temperature (27 °C). Such specimens were designated as annealed and air-quenched (AQ). The thermoluminescence glow curves of 200 Gy and 4kGy gamma irradiated synthetic quartz with pre-thermal treatment of 200 °C–AQ, 400 °C–AQ and 600 °C–AQ are displayed in Figs 1 and 2, respectively. In Fig. 1, the results show that, the 200 °C–AQ specimen exhibits two well-defined peaks, around 110 °C (peak-I) and 210 °C (peak-II). While, 400 °C–AQ quartz samples display glowcurve having enhanced glow peaks, peaking at 120
and 180 °C temperatures. 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 lower temperature side. It is very important to note that, significant changes in the intensity as well as peak positions were observed, when the synthetic quartz samples have been annealed and air-quenched from 600 °C. The glow-curve shows large increase in the intensity along with the shift in temperature position of peak-I and peak-II on lower temperature side.

Fig. 1—TL glow curves of 200 Gy gamma irradiated synthetic quartz with thermal pre-heat treatment of (1) 200 °C A. Q., (2) 400 °C A. Q., (3) 600 °C A. Q.

In order to examine the effect of pre-thermal treatments on TL of quartz in detail, series of experiments have been made in which TL of synthetic quartz was recorded under the exposure of 200 Gy, 400 Gy, 600 Gy, 800 Gy, 4 kGy and 5 kGy gamma dose for the specimens, rapidly quenched to room temperature in air, from 100, 200, 300, 400, 500 and 600 °C, after three hours of annealing duration. They have revealed more or less identical behaviour as mentioned above. The intensity of peak-II was recorded as a function of quenching temperatures. The plot of TL output of peak-II verses quenching temperatures has been drawn and presented in Fig. 3. It is clearly observed that, the peak-II intensity increases with the rise in quenching temperatures. The significant TL output rise is seen in 400 to 600 °C quenching temperature regions.

Fig. 2—TL glow curve of 4 kGy gamma irradiated synthetic quartz with thermal pre-heat treatment of (1) 200 °C A. Q., (2) 400 °C A. Q., (3) 600 °C A. Q.

The internal structure of the material is highly sensitive to the thermal pre-treatment. Annealing the material at various elevated temperatures, resulted in different changes in the internal structure of material. It is reported that, the stability of quartz (also known as α-quartz or low-quartz) goes up to 573 °C, under normal pressure. This low-quartz can convert itself to high-quartz or β-quartz on heating.
beyond 573 °C. The α-β transition is a displacive phase change, involving small adjustments of atomic positions without any re-arrangement of the bonds. As a result, the phase change is very fast and is completely reversible, although crystal twinning occurs as the transition goes from α to β and back to α.

The α-form has a rhombohedral structure while β-form has hexagonal structure. In both forms, the oxygen atoms are tetrahedrally shared between those of silicon. Two of the Si-O bonds in α-quartz make an angle of 66° with the optic axis and have a bond length of 1.598 Å, whilst the other two Si-O bonds make an angle of 44° and have a length of 1.616 Å. Thus, the oxygen atoms occur as two equivalent pairs. It is believed that, the change in intensity, peak position and other features of TL glow-curve in the 600 °C air-quenched samples must be associated with the above mentioned changes in the internal structure of the material.

It is established that, inherently available competing electron-traps in virgin synthetic quartz incorporate with the Al-H substitution centre and form E'-centre as a result of thermal pre-treatment followed by gamma irradiation at room temperature. It seems that, the specimen subjected to different annealing temperature, enhances the possibilities of generating E'-centres, which may be the reason for TL sensitisation. However, the abrupt change in emission pattern can be explained on the premise of phase transformation.

Finally, it is suggested that, pre-thermal treatment facilitate 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 the increase in annealing temperature up to 500 °C. The observed drastic increase in the intensity of TL 600 °C air-quenched synthetic quartz sample is believed to be due to change of phase from α-quartz to β-quartz.

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