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# Applicability of natural colourless topaz as a high-energy beam dosimeter

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ABSTRACT

Thermoluminescence characteristics of colourless topaz collected from Pakistan were studied. The objective of this study was to design and develop a TL dosimeter for high-energy beams. Samples were irradiated with $^{60}$Co, $^{137}$Cs and linear accelerator (6 MV, 15 MV). Glow curves of the chips revealed four trapping levels at temperature ranges 71–82 °C (Peak 1), 173–185 °C (Peak 2), 197–210 °C (Peak 3) and 225–260 °C (Peak 4). Peak 4 is stable and rose linearly with increase of exposure levels. The TL response vs. exposure showed linear behaviour between 1 and $10^2$ Gy. Initial fading is rapid in first 24 h and becomes 8% in next 19 days. The variation in response of the last 20th cycle with respect to the 1st cycle was found to be 4% with a maximum variation of 15% within all data points. The thermoluminescence response was observed to be higher at low energy. The chips remained mechanically intact during handling in all experiments. Topaz chips can effectively and efficiently be used as a TLD for high-energy beams.



## 1. Introduction

Topaz is a naturally occurring silicate crystal with a chemical formula of $Al_2SiO_4(F,OH)_2$. It exhibits thermoluminescence (TL) upon heating (Nishita et al., 1974). Topaz has an orthorhombic structure and falls in the space group "Pbnm" (Anthony et al., 1995). Moss and Mcklveen (1978) and Azorin et al. (1982) also studied various TL characteristics of topaz and concluded that topaz exhibits favourable TL characteristics which make it suitable to use as a TL dosimeter. Souza et al. (1995) studied various topaz samples obtained from different parts of Brazil. However, the latter authors used the powder or composites of topaz and did not use solid chips of size comparable to commercial TLDs. They reported that topaz has sensitivity much less than that of commercially available TLD-100 and are favourable for use as TL dosimeters. The sensitivity of topaz's composites is low due to the addition of another binder and then sintering at high temperature.

According to Keifer et al. (1969), a good TLD should have the following: (a) sensitivity in the range of $10^{-4}$–$10^2$ Gy, (b) a linear absorbed dose response, (c) known dependence of response on radiation type and energy, (d) a minimum fading rate of TL signal, (e) a response independent of absorbed rate, and (f) a good TL reproducibility at repeated use.

The purpose of the present work was to study some TL characteristics of colourless topaz of the Nyit mine, Skardu, Pakistan, by irradiating with high energy beams. It is the first study as far as topaz of this mine is concerned.

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## 2. Experimental

Samples of colourless topaz were collected from the Nyit mine near Skardu in Gilgit-Baltistan region of Pakistan. These samples varied in size from about 35 to 45 mm. Lumps of topaz were cleaned with 50% water and 50% Aqua Regia ($3HCL+HNO_3$) solution, according to the procedure adopted by Lima et al. (1986), to remove the unnecessary impurities and dirt. The samples were cut into chips of size 3.2 mm × 3.2 mm × 0.9 mm using an Accutom Precision Cut-off machine (Model: Accutom 50, Stucers) with positioning accuracy of 5 μm. The dimensions of the chips were equivalent to commercial LiF dosimeter (TLD-100).

The samples were annealed at 400 °C for 1 h using an autocontrol oven (Model: D237.131.0/2, PTW-FREIBURG, Germany). The samples were irradiated at different exposure levels using $^{60}$Co, $^{137}$Cs and linear accelerator (Model: Oncor: Impression, Siemens, Germany) having x-ray beams of energies 6 MV and 15 MV (effective 2 and 5 MeV). The readout of the samples was carried out using TLD reader/analyser (Model: RA'94, Mikrolab, Poland). A heating rate of 10 °C/s was employed throughout the study. All measurements were made at room temperature and all samples were wrapped in black paper after annealing and irradiation.

## 3. Results and discussion

The glow curve of topaz irradiated for the exposure range corresponding to 5 Gy is presented in Fig. 1. This glow curve was deconvoluted using OriginPro 8 software. The deconvolution of the glow curve revealed four peaks at temperatures 71–82 °C (Peak 1),

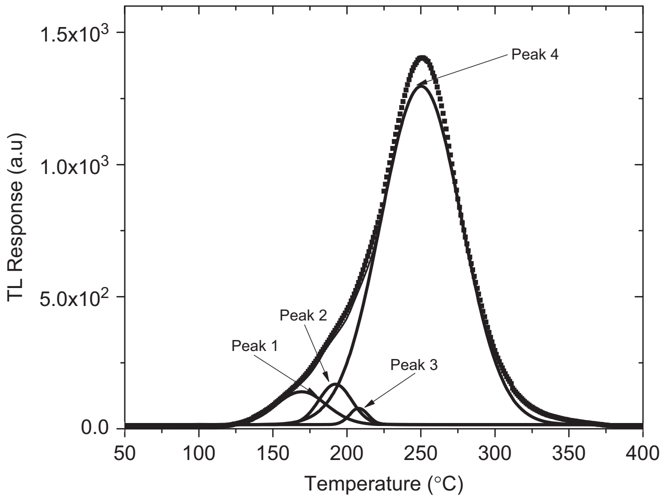


**Fig. 1.** Deconvoluted glow curve analysis of topaz annealed at 400 °C irradiated at the exposure level of 5 Gy.

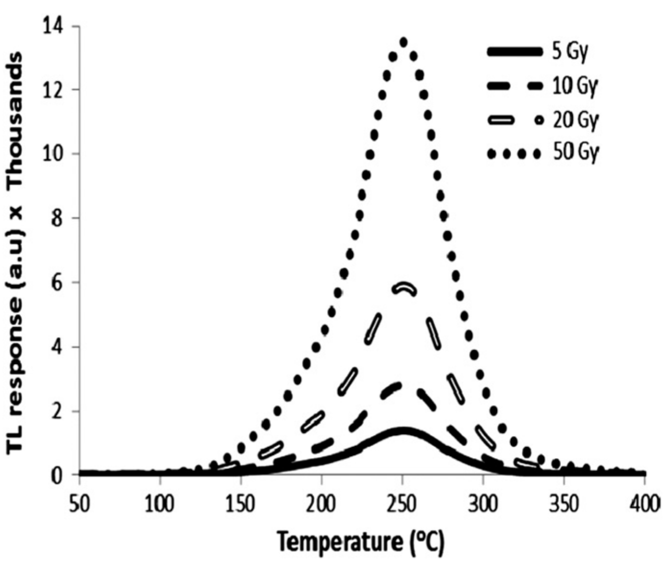


**Fig. 2.** TL glow curve of topaz samples from Nyit mine for various exposure levels at heating rate of 10 °C/s.

173–185 °C (Peak 2), 197–210 °C (Peak 3) and 225–260 °C (Peak4). The four peaks in the glow curves correspond to four levels for electrons trapping in the crystals of topaz from the Nyit mine. The behaviour of the glow curve for exposure levels 5, 10, 20 and 50 Gy is shown in Fig. 2. Peak 4 rose linearly with increasing exposure level with slight variation in position, and a maximum of 12% variation in its position was observed. Moss and Mcklveen (1978) observed glow peaks at 210 °C and 350 °C before thermal treatment and 180 °C and 285 °C after thermal treatment. Lima et al. (1986) investigated the peaks at 100 °C and 130 °C in topaz samples collected from two different locations in Brazil. Souza et al. (2000) studied the TL emission curves of topaz samples, both as pellets and powder, and observed the main TL peaks at 110 °C, 170 °C and 250 °C. The existence of peaks in natural topaz seems to depend on its location of occurrence and presence of impurities. The number and position of peaks in the glow curve also depends upon time lag between irradiation and the measurements of TL output (Azorin et al., 1982). The topaz of the mine under study can be considered as a suitable TLD, due to the existence of a stable peak in the glow curves at temperature of about 250 °C and this temperature can easily be attained in a commercial TLD Reader-Analyser without fading.

The TL response (integrated counts) of the mine under study irradiated with $^{60}$Co calibrator from exposure range of $10^{-1}$ to $10^2$ Gy is presented in Fig. 3. It shows a nonlinear response in the low exposure region with $R^2$ (coefficient of correlation) value of 0.98. The behaviour for topaz in the high exposure range was found to be linear with $R^2$ value of 0.99. Linear TL response of topaz samples with exposure level was also observed by Moss and Mcklveen (1978) and Azorin et al. (1982). Moss and Mcklveen (1978) found that there is a linear response up to saturation $3 \times 10^5$ Gy for topaz colourless crystals of size. 3.2 mm × 3.2 mm × 0.9 mm and Azorin et al. (1982) indicated that there is a linear response between $10^{-2}$ and $10^{+3}$ Gy for topaz samples of size 3.2 mm × 3.2 mm × 0.9 mm collected from various localities in Mexico. Lima et al. (1986) reported linearity for the absorbed dose range 7–10,000 mGy for topaz samples of size 3.0 mm × 3.0 mm × 1.0 mm collected from two different locations in Brazil mountains. Souza et al. (1995) showed that the absorbed dose dependence is not linear for peaks at 80 °C, 150 °C and 180 °C, and they observed that response started to saturate above 400 Gy. They used topaz powder with grain size varying from 25 to 75 μm.

The exposure rate dependency of the samples was carried out by irradiating at various exposure rates, ranging from 50 mGy/min to 300 mGy/min, using $^{60}$Co calibrator. The exposure rate response is shown in Fig. 4. A fitted line was passed through the average of the multiple readings of integrated counts. The overall standard deviation of data was found to be 5%. These results indicate that topaz chips of the mine under study show a slight exposure rate dependency.

The fading behaviour of topaz irradiated for 1 Gy with $^{60}$Co at heating rate 10 °C/s is presented in Fig. 5. It was found that initial fading is more rapid in first 24 h and reaches 8% in next 19 days, which is less than the acceptable limit as recommended for a good dosimeter (CEI/IEC 1066, 1991). Moss and Mcklveen (1978) reported a loss of 30% within the first 24 h, another loss of 9% for 30 days and projected loss of 5% per year. Souza et al. (2003) reported a fading of 7% in 30 days for topaz based composite dosimeters. De Magalhaes et al. (2004) found that there is a decrease in integrated area of the peak by 8% from its initial value in 30 days for the topaz composites.

The reproducibility behaviour of topaz samples for 20 cycles of annealing, irradiation and readout is presented in Fig. 6. The

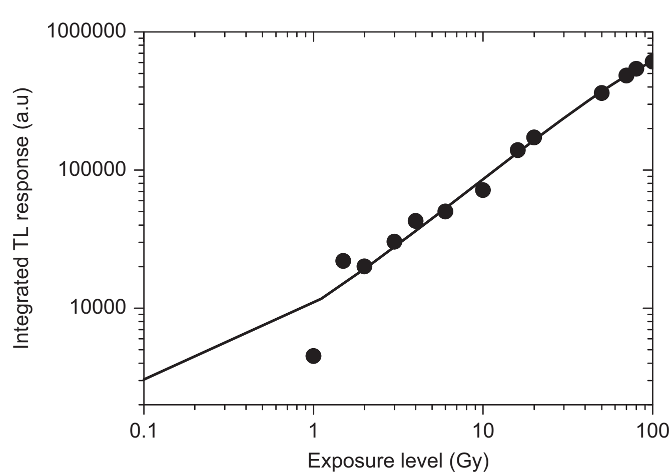


**Fig. 3.** Average TL response of the understudy topaz irradiated with $^{60}$Co at different exposure levels for heating rate 10 °C/s. The fitted line was passed through the average of multiple integrated counts (response) with errors 2% and 1% for low and high exposure levels respectively.