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Applied Radiation and Isotopes 58 (2003) 85–88

Applied Radiation and Isotopes

www.elsevier.com/locate/apradiso

Properties of sintered amethyst pellets as thermoluminescent dosimeters

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Received 14 March 2002; received in revised form 20 May 2002; accepted 20 August 2002

Abstract

The main dosimetric characteristics of amethyst, Brazilian natural semi-precious stone, were investigated in this work, in order to verify the possibility of its use for gamma-radiation detection using the thermoluminescent (TL) technique. The samples were tested in X- and gamma-radiation beams, and their TL glow curves, dependences of the response on the absorbed dose and radiation energy, and the response reproducibility were investigated. The preliminary results show the usefulness of this material in dosimetry for radiation processing.

Keywords: Amethyst; Sintered pellets; Thermoluminescence; Dosimetry; High doses

1. Introduction

Radiation processing is a growing industrial activity that deals with high radiation doses. It is used, in particular, for sterilization of medical and pharmaceutical products, water purification, sludge treatment, and delaying ripening.

Dosimetry is a fundamental part in quality programs assuring that the irradiation procedure is carried out according to standard specifications. In order to minimize errors in radiation doses, it must be accurate. The absorbed doses in these processes range from 50 Gy to 10 kGy. In such applications, low doses from 50 to 450 Gy can be determined by a Fricke dosimeter, while higher doses from 500 Gy to 10 kGy can be measured by electron spin resonance or luminescence techniques (McLaughlin et al., 1989). New techniques and materials have been studied worldwide (Farrar, 2000; McLaughlin et al., 1989). Among these materials, quartz is one of the most popular ones; it has many applications, such as in thermoluminescent (TL) dosimetry (de Lima et al., 2002; Ichikawa, 1968; Hashimoto et al., 1998; Milanovich-Reichhalter and Vana, 1991; Santos et al., 2001) and dating (Huntley et al., 1988; McKeever, 1991), and also electronic instrumentation.

The TL glow curves of natural quartz are composed of a number of peaks between 100°C and 450°C (de Lima et al., 2002; Santos et al., 2001). These variations are expected due to possible variations in the impurity content of the crystals collected that change the TL characteristics of the materials (Azorín et al., 1982). Some authors have shown that the peaks around 200°C are subject to optical influences, which result in TL signal decreases (McKeever, 1991; Morris and McKeever, 1994).

Amethyst, the purple variety of α-quartz (α-SiO_2), is a popular gemstone, and has received considerable attention in recent years from the point of view of characterization and technological applications (Balitsky et al., 2000; Cortezão and Blak, 1998; Zhang et al.,

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0969-8043/02/$ - see front matter
PII: S0969-8043(02)00266-X

1994). Natural amethyst shows both red and infrared thermoluminescence (TL) around 740–750 nm and blue TL around 440 nm (Zhang et al., 1994).

In this work, the properties of amethyst sintered pellets were investigated using the thermoluminescent technique in order to verify the usefulness of this material for gamma-radiation detection. The samples were tested in X- and gamma-radiation beams, and their main dosimetric characteristics were evaluated (TL glow curve, response as a function of absorbed dose, energy dependence and response reproducibility).

2. Materials and methods

Brazilian natural amethyst crystals were used to produce sintered pellets at the Laboratory of Dosimetric Material Production of IPEN. The amethyst samples were crushed, ground, sieved, and grains of dimensions 74 μm were selected to produce sintered pellets 5.0 mm in diameter and 0.8 mm in thickness. The pellets were sintered at 300°C for 30 min and at 400°C for 90 min. In order to determine the TL characteristics of the samples, we irradiated them under electronic equilibrium conditions (in the case of gamma-radiation), that is, the samples were placed between 3 mm thick polymethyl methacrylate (Lucite) plates. To avoid optical influence, the samples were protected by opaque aluminium foils during irradiation and transportation to the TL reader. The amethyst samples were tested using Gammacell 220 (^{60}Co) and X-radiation beams of two different systems: (i) Rigaku Denki generator, Model Geigerflex, with Philips tube Model PW/2184/00 (Tungsten target and Beryllium window, 60 kV), and (ii) Pantak, Model HF 320, (Tungsten target and Beryllium window, 320 kV). Specifications of these systems are shown in Tables 1 and 2.

Prior to each irradiation, the samples were thermally treated at 300°C during 75 min. The readout of the samples was made on a Harshaw Nuclear System, Model 2000A/B, with a linear heating rate of 10°C/s. The TL readout procedure was performed within 45 s, with a constant flux of N_2 of 4.0 l/min. The integral areas were recorded between 50°C and 350°C. The output data were recorded at an x-t register ECB, model RB-101, with one channel. The readings were always taken after the same post-irradiation time interval of 15 min. No pre-heat treatments were performed, and no modifications were made on the original filter system of the TL reader.

3. Results and discussion

3.1. Glow curve

Fig. 1 shows the TL glow curve for an amethyst sintered pellet irradiated with 1 kGy (^{60}Co). The TL glow curve exhibits a very well defined dosimetric peak at about 210°C.

3.2. Reproducibility

The reproducibility of the TL response of the amethyst sintered pellets was obtained by their TL evaluation after 10 repeated cycles of standard annealing

Table 1
Specifications of the Rigaku Denki X-ray generator used in the experiments

Voltage (kV)	Half-value layer (mm Al)	Additional filtration (mm Al)	Effective energy (keV)	Air kerma rate (Gy/min)
25	0.26	0.45	14.3	0.38
30	0.37	0.55	15.5	0.41
45	0.65	0.73	18.7	0.55
50	0.91	1.02	21.2	0.47

Table 2
Specifications of the Pantak X-ray system used in the experiments

Voltage (kV)	Half-value layer (mm)		Additional filtration (mm)		Effective energy (keV)	Air kerma rate (Gy/min)
	Al	Cu	Al	Cu		
100	3.76	—	1.21	—	37.9	83.41
135	—	0.47	—	0.23	66.0	80.14
180	—	0.95	—	0.48	82.2	112.59
250	—	2.39	—	1.57	143.2	113.55

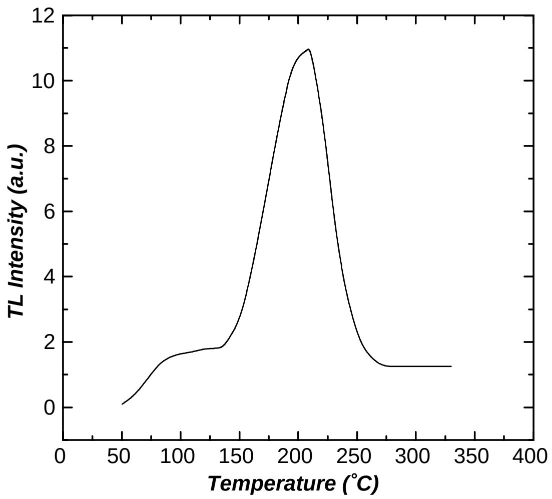

Fig. 1. TL glow curve of a sintered amethyst pellet irradiated to 1 kGy (^{60}Co).

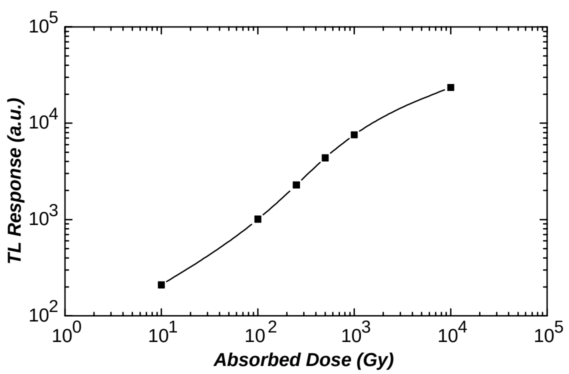

Fig. 2. TL response of sintered amethyst pellets as a function of absorbed dose (^{60}Co). The measurements represent the integral areas between 50°C and 350°C. Uncertainties were within 5.0%.

and irradiation with the ^{60}Co source. The TL response spread of each pellet, after 10 readout cycles, was less than 4.5%.

3.3. Calibration curve

The TL response of the amethyst sintered pellets was obtained as a function of absorbed dose of ^{60}Co gamma-radiation (Fig. 2). The curve shows its usefulness in the whole tested dose interval. A tendency to saturation of the response can be observed about 10 kGy. Measurement uncertainties were always within 5.0%.

3.4. Lower limit of detection

The lowest detectable absorbed dose of the amethyst pellets was determined from the variability of TL readings of non-irradiated pellets. It was taken as

$$D_{\min} = [TL(0R) + 3\sigma]f,$$

where $TL(0R)$ is the mean value of 10 replicate zero-dose readings of a set of five pellets; σ is the standard deviation, and f is the calibration factor of the pellets. The lowest detectable absorbed dose obtained was found to be 50 mGy.

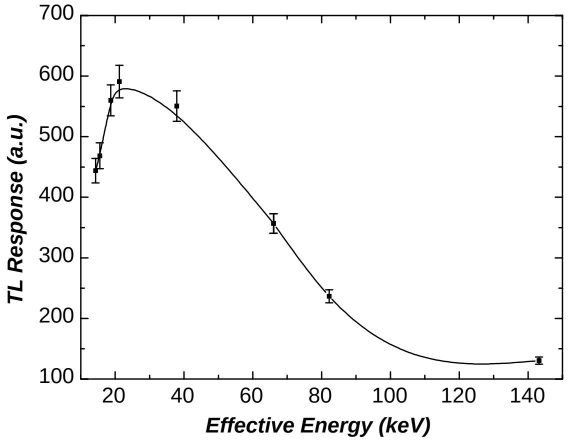

Fig. 3. X-ray energy dependence of the response of sintered amethyst pellets.

3.5. Energy dependence

X- and gamma-ray energy dependences of the response of the sintered amethyst pellets were studied with the aim of evaluating their performance characteristics. The TL response was measured from samples exposed to 10 Gy in X-radiation beams of 25, 30, 45 and 50 kV (Rigaku Denki system) and 100, 135, 180 and 250 kV (Pantak system) in air (Fig. 3). Measurements were also taken of the samples irradiated to 10 Gy in a ^{60}Co gamma-beam under electronic equilibrium conditions; the response was (179.4 ± 8.1) in the same arbitrary units shown in Fig. 3. These samples exhibit great energy dependence at low energies. Similar results were reported by Azorín et al. (1982) for Mexican amethyst samples.

4. Conclusions

The tests performed in this work show that sintered amethyst pellets offer good reproducibility of the TL response, an adequate TL peak temperature, a proper dose response and an acceptable energy dependence. Studies of the room-temperature fading and of the effects of various thermal treatments are in progress. The results obtained so far indicate the feasibility of the use of Brazilian natural amethyst as a thermoluminescent dosimetric material for high doses in radiation processing.

Acknowledgements

The authors are thankful to Mr. Vanderlei Inocêncio Souto for the preparation of the sintered pellets, to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and to Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), Brazil, for partial financial support of this work.

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