Radiation Measurements 72 (2015) 66–69

Contents lists available at ScienceDirect

Radiation Measurements

journal homepage: www.elsevier.com/locate/radmeas

High- and very-high-dose dosimetry using silicate minerals

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HIGHLIGHTS

- The TL dose responses of eight different natural silicate minerals have been investigated.
- All minerals show a more or less linear thermoluminescence signal with gamma ray dose.
- The saturation dose varies from 5 kGy up to 1000 kGy.

ARTICLE INFO

Article history:
Received 27 May 2014
Received in revised form
6 November 2014
Accepted 13 November 2014
Available online 15 November 2014

Keywords:
High dose
Dosimetry
TL
Silicates

ABSTRACT

In the present study, certain natural silicate minerals such as aquamarine (AB), morganite (PB), goshenite (WB), white jadeite (JW), green jadeite (JG), pink tourmaline (PT) and two varieties of jadeite-like quartz, denoted here by JQ1 and JQ2, were investigated using the thermoluminescence technique to evaluate their potential for use as very-high- and high-dose dosimeters. These minerals respond to high doses of γ-rays of up to 1000 kGy and often to very high doses of up to 3000 kGy. The TL response of these minerals may be considered to be satisfactory for applications in high-dose dosimetry. Investigations of electron paramagnetic resonance and optically stimulated luminescence dosimetry are in progress.

1. Introduction

A number of materials have been investigated not only for low-dose dosimetry, which is useful in medical applications, but also for high-dose dosimetry, which is important in retrospective or industrial dosimetry (Mesterházy et al., 2012; Inrig et al., 2008; Wieser et al., 1994; Rocha et al., 2003; Teixeira et al., 2011; Vila and Caldas, 2011). There are various scenarios in which very high doses are involved, such as very-high-energy particle accelerators, nuclear power plants and very-high-dose irradiation facilities for food preservation or the modification of the properties of solid materials. One such type of detector is based on LiF, doped either with Mg and Ti or with Mg, Cu and P (Bilski et al., 2007; Obryk et al., 2008, 2011).

A group of physicists at the Institute of Nuclear Physics (IFJ), Krakow, Poland, has been investigating the effects of high radiation doses on LiF doped with Mg and Ti (called MTS) and with Mg, Cu and P (called MCP) since the beginning of this century; the low-dose regime has been under investigation at the IFJ since the 1960s in the case of MTS and the 1980s in the case of MCP materials. This group has tested these materials under irradiation with γ-rays, electrons, protons, alpha particles and also neutrons. Their most important result is that these materials, particularly the MCP materials, exhibit interesting and unexpected behavior when irradiated with high doses of up to 500 kGy. A high-temperature TL peak is observed at above 300 °C, and this peak shifts to higher temperatures of up to 460–470 °C as the dose reaches approximately 500 kGy. These authors refer to this peak as peak B (Obryk et al., 2009). High neutron fluences on the order of 10^{15} per cm^2 also produce similar results. In the article published by Obryk et al. (2014), references prior to that date can be found.

Camargo and Isotani (1988) have measured the optical bands in natural pink tourmaline and have identified bands at 8500, 14,800, 19,500 and 25,500 cm^{-1}, with intensity of all of them growing up to 13,000 kGy. These authors irradiated tourmaline at this very high dose value, and their results indicated that with further irradiation,

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http://dx.doi.org/10.1016/j.radmeas.2014.11.004
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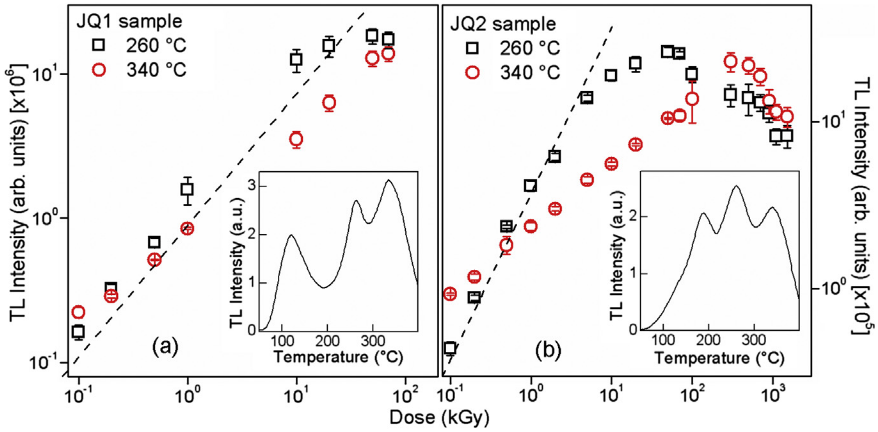

Fig. 1. TL intensity versus γ dose for the TL peaks of (a) JQ1 and (b) JQ2; the dashed line indicates linearity. In the insets are presented the glow curves of JQ1 and JQ2 samples irradiated with 2 kGy of γ-rays.

these bands could continue to intensify. This is an extraordinary result; no other researchers have performed similar ultra-super-high-dose irradiation experiments.

In the study reported here, we investigated certain natural silicate minerals and found that some of them responded to high to very high radiation doses. Here, 'high dose' refers to a dose of up to 1000 kGy, whereas 'very high dose' refers to doses above this value; such doses are typically of up to 2000 or 3000 kGy, but in one case a much higher dose has been applied. In this work, we report high-dose dosimetry conducted using several silicate minerals; these materials were irradiated with γ-ray doses from a few tens of kGy up to 3000 kGy.

2. Materials and experiments

The following natural silicate minerals were acquired from stone dealers in Teofilo Ottoni, State of Minas Gerais, Brazil, for the present study: morganite (PB), goshenite (WB), aquamarine (AB), white jadeite (JW), green jadeite (JG), pink tourmaline (PT) and two varieties of jadeite-like quartz (JQ1) and (JQ2).

Here, we studied the TL of these crystals to determine their dosimetric behavior. For this purpose, we first crushed the samples and then sieved them, retaining grains of between 0.080 and 0.180 mm in size. These powders were then annealed at 500 °C for 30 min and subsequently irradiated with γ rays at doses in the range of hundreds of kGy up to 2000 kGy.

The TL measurements were performed in a nitrogen atmosphere using a model 4500 Harshaw TL reader equipped with two photomultiplier tubes, which could record luminescence signals independently. The reader was controlled by WinREMS Software, which was supplied with the spectrometer and was run on a Windows computer. The heating rate used in the TL measurements was 4 °C/s. Each point in the glow curve represents an average of five readings.

3. Results

Samples JG, JW, JQ1 and JQ2 we acquired as samples of jadeite. X-ray fluorescence analysis indicated that JG and JW were in fact jadeite, but JQ1 and JQ2 were much more similar, although not identical, to quartz. The JQ1 glow curve exhibited TL peaks at 110, 260 and 340 °C, whereas JQ2 presented peaks at 190, 260 and 340 °C. Both these materials were initially irradiated with γ rays up to 70 kGy. Subsequently, however, JQ2 was irradiated to a higher dose of 3000 kGy. Fig. 1 presents the TL response of the 260 and 340 °C peaks as functions of the dose for JQ1 and JQ2. The maximum peak height was used to quantify the TL response. The TL glow curves of JQ1 and JQ2 samples that were pre-heated at 500 °C

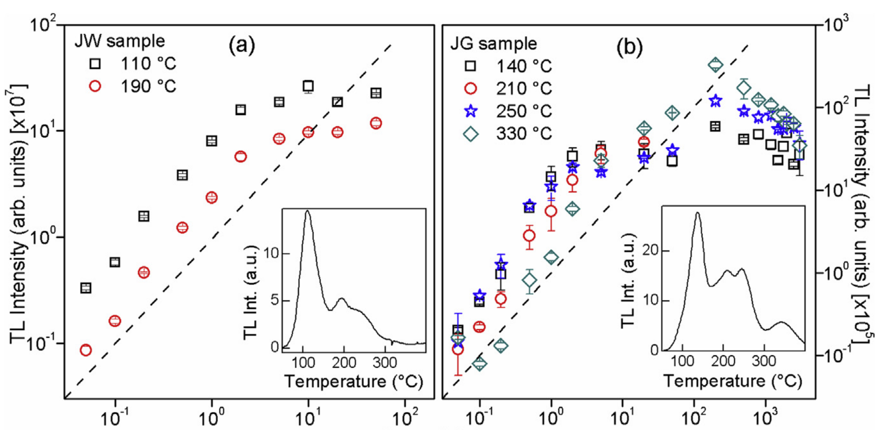

Fig. 2. TL intensity behavior of the TL peaks as a function of γ radiation dose for the JW and JG samples, respectively; the dashed line indicates linearity. In the insets are presented the TL glow curves of JW and JG samples pre-annealed at 500 °C in air and then irradiated with a γ dose of 2 kGy.