



Analysis of dosimetric peaks of $\text{MgB}_4\text{O}_7\text{:Dy}$ (40% Teflon) versus LiF:Mg,Ti TL detectors

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Abstract. Magnesium tetraborate doped with dysprosium ($\text{MgB}_4\text{O}_7\text{:Dy}$) is known as a good thermoluminophor for personal dosimetry of gamma ray and X-ray radiation because of its high sensitivity and close tissue equivalence. This material can be produced by different routes. The sintered pastilles of magnesium tetraborate mixed with Teflon (40%) used in this work were manufactured at the Federal University of Sergipe, Department of Physics by the solid-state synthesis. Magnesium tetraborate was already used for high-dose dosimetry, exhibiting linearity for a wide range of doses. In this work, the authors examined its main characteristics prior to potential use of detectors in everyday dosimetry, comparing this material to a widely used LiF:Mg,Ti phosphor. The following tests influencing dosimetric peaks of $\text{MgB}_4\text{O}_7\text{:Dy}$ were presented: (1) the shape of the glow curves, (2) annealing conditions and post-irradiation annealing and its influence for background of the detectors, (3) the choice of the heating rates at the read-out and (4) the threshold dose, that is, the lowest possible dose to be measured. Similar tests were performed with LiF:Mg,Ti detectors, produced and widely used in Poland. The results were compared and discussed.

Key words: thermoluminescent detectors • $\text{MgB}_4\text{O}_7\text{:Dy}$ • LiF:Mg,Ti

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Introduction

Thermoluminescence (TL) is the thermally stimulated emission of light of an insulator or a semiconductor that has been exposed to ionizing radiation. During irradiation, electrons and holes are created and some of them are trapped at defect sites. The trapped charge carriers can be liberated by heating the sample and move to lower energy state with the emission of light. A glow curve is a plot of the TL intensity as a function of the sample temperature during read-out. Each trapping level in the material gives rise to an associated glow peak so a glow curve may be formed by several peaks, each related to different trapping levels.

For the purposes of personal dosimetry, a TL phosphor is expected to show certain features such as a relatively simple glow curve having ideally a single peak with its temperature at about 200°C, high sensitivity that includes both a high efficiency of light emission and a low threshold dose, good linearity of the TL signal in the specific useful range of radiation dose and low fading of TL signal. Moreover, for dosimetric purposes, the effective atomic number (Z_{eff}) of TL detectors close to that of the biological tissue is desired if one wants to treat it as a tissue equivalent material.

Few materials that possess all the above features have been found, and thus a search in this area is in constant progress. Tissue equivalent

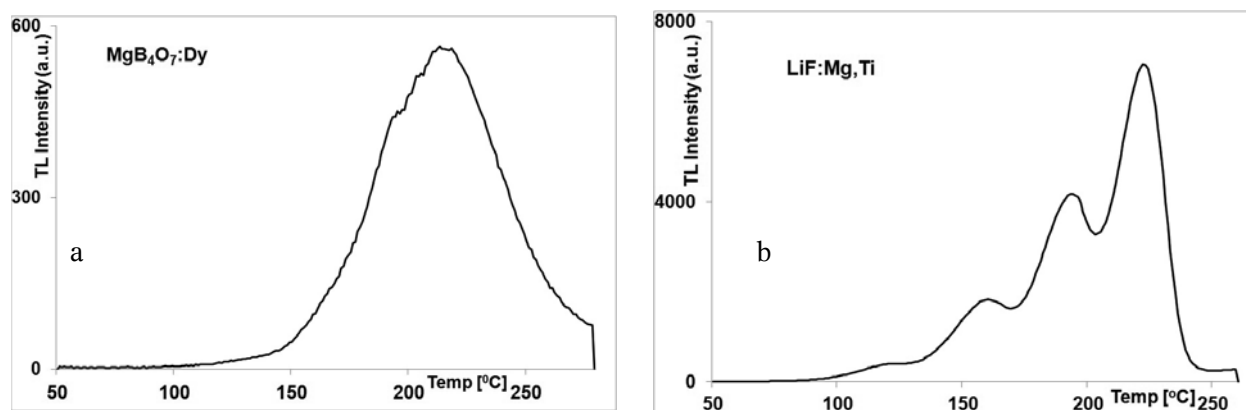


Fig. 1. A typical glow curve of (a) MBO and (b) MTS-N obtained with a the linear heating rate of 5°C/s.

phosphors that in general show good sensitivity to ionizing radiation doses are, for example, LiF:Mg,Ti (MTS-N) or MgB_4O_7 . LiF materials with different dopants characteristics were already described in several publications because this is a material routinely used in both clinical and individual dosimetry [1, 2], environmental dosimetry or low-dose detection (LiF:Mg,Cu,P) [3], high-dose dosimetry in Poland [4, 5] and in the world [6, 7].

Magnesium tetraborate doped with dysprosium (MgB_4O_7 :Dy) is also recognized as a good thermoluminophor for personal dosimetry of gamma rays and X-rays [8, 9]. First reports on the MgB_4O_7 :Dy came from groups in Japan and Serbia [10, 11]. Studies of TL glow curves, which are plots of TL light vs. temperature, were used to determine the trapping parameters. However, the TL response strongly depends on the heating rate, an important parameter in the TL measurements. Influence of the heating rate on TL glow curve has been the subject of study by different scientists [12–15]. There are several possibilities how to produce synthetic magnesium tetraborate, for example, sol-gel method, combustion, wet reaction synthesis, solid-state route and precipitation (crystal growth). The most commonly used synthesis methods are the wet reaction (precipitation) and solid-state synthesis, both are described in detail in [16]. Their TL reproducibility and sensitivity were analyzed after gamma irradiation within doses in a range from 10 to 100 Gy. Studies showed some advantages of solid-state synthesis, so in this work, only pellets obtained in this route were examined. The main goal was to test MgB_4O_7 :Dy (40% Teflon) pellets for low-dose detection and to compare its behavior with MTS-N phosphor.

Methods

The pellets of MgB_4O_7 :Dy (40% Teflon), called MBO, were produced at the Department of Physics at the Federal University of Sergipe [16]. The MTS-N pellets were produced by the TLD Poland company [17]. All pellets were exposed to the air kerma for low-dose rate equal to 100 mGy from ^{137}Cs source (661 keV) gamma radiation. The TL response of pellets was acquired by a RA'04 TLD reader system manufactured in Poland [18]. Prior

to each main read-out, the pellets were annealed in a furnace at a temperature suitable for each material. The schematic for pellets treatment was the following: annealing – TL read-out for background reduction – irradiation – read-out – annealing.

The following tests influencing the dosimetric peaks of MBO detectors were performed:

1. comparison of glow curves of MBO and MTS-N;
2. annealing conditions and post-irradiation annealing and their influence on the background. There are several types of annealing for both the materials published in the literature [19]. The authors tested three different temperature values for 1 h: 400, 450 and 500°C;
3. heating rate (of 2, 5 and 10°C/s) during the read-out;
4. threshold dose, that is, the minimum detectable dose, D_{LDL} , which is defined as three times the standard deviation of the zero-dose reading [19].

Results and conclusions

Figure 1 shows typical glow curves of MBO and MTS-N, respectively, obtained with a linear heating rate of 5°C/s. Comparing their shape, the most striking difference is that MBO presents one main peak whilst MTS-N presents five glow peaks, the two of them being dosimetric (numbered 4 and 5).

Figure 2a shows the background curves of MBO detector obtained for three annealing temperatures (400, 450 and 500°C for 1 h). The goal of annealing study was to find the good combination of annealing temperature and time to erase any effect of previous irradiation, producing the lowest intrinsic background. Besides to that, obtain the highest sensitivity and reproducibility for both TL and background signals [19]. It seems that background for 450 and 500°C are very similar. Temperature of 450°C is advantageous because it diminishes the total background below 230°C in comparison to 400°C and is lower than 500°C that it is clearly an advantage for saving energy and preserve the sample. The only concern is that the treatment above 400°C is dangerous because the sample contains Teflon. More tests are in progress. For MTS-N pellets, only the standard procedure of 400°C for 1 h prior to 100°C for 2 h was applied [17].

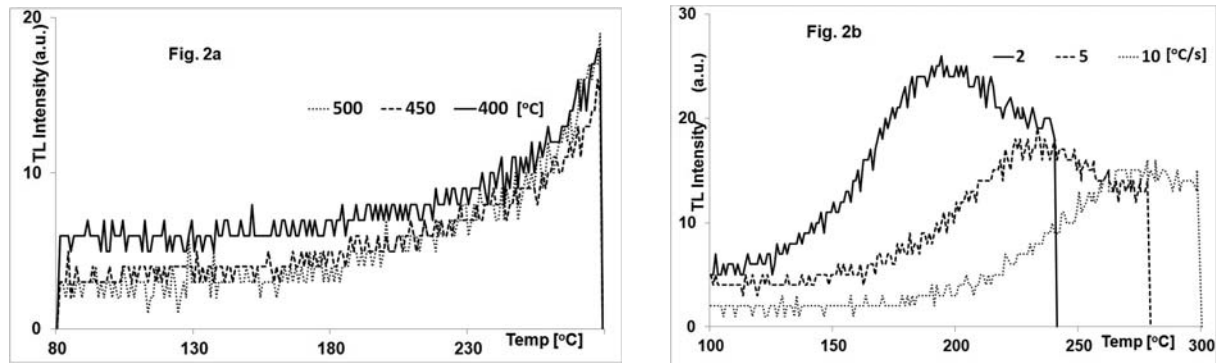


Fig. 2. Glow curves of (a) MBO background signals for three different heating temperatures and (b) MBO obtained with the linear heating rate of 2, 5 and 10 °C/s.

Table 1. A comparison of main characteristics of MBO and MTS-N [17, 19]

Characteristics	Material	
	MgB ₄ O ₇ :Dy (40% Teflon)	LiF:Mg,Ti
Annealing procedure	Pre-irradiation: 450°C for 1 h Post-irradiation: 160°C for 5 s	Pre-irradiation: 400°C for 1 h followed by 100°C for 2 h Post-irradiation: 100°C for 10 min
Form	Solid disc 6 mm diameter	Solid disc 4.5 mm diameter
TL emission spectrum [nm]	470	400
Effective atomic number <i>Z</i>	8.4	8.2
Main peak temperature [°C] for the heating rate of 5°C/s	230	230
Thermal fading [% at room temp.]	<20%/year	<5%/year
Detection threshold [mGy]	50	10

Figure 2a presents the behavior of the MBO glow curves obtained with three linear heating rates of 2, 5 and 10 °C/s. Whilst the heating rate increases, the maximum intensity of the peak moves to higher temperatures and the duration of the read-out decreases. We chose as the best rate of 5 °C/s, which gives the maximum of the main peak in 230 °C and overall measurement time equal to 60 s. For MBO, the post-irradiation annealing procedure reported in literature is 5 s at 160 °C in the reader [19]. The post-irradiation annealing is the thermal procedure having the aim to erase all the low temperature peaks that could be erroneous in the dose estimation because of their high fading rate. Preliminary tests performed in this work showed that this procedure has very little influence on the main result obtained; thus, it was not necessary to perform.

The threshold dose for MBO was calculated according to $D_{LDL} = 3 \cdot \sigma_0 / K$, where K is the calibration coefficient and σ_0 is the standard deviation of the zero-dose reading [19]. It was equal to 50 mGy (see Table 1). More tests are planned to improve this value because the detection limit obtained for MBO detectors is much higher than the one for MTS-N using the same TL reader.

The main features of the detectors are summarized in Table 1. The attractive dosimetric characteristics of magnesium borate solid thermoluminescence dosimeters (TLDs), such as near-tissue equivalence ($Z_{eff} = 8.4$), sensitivity sufficient for clinical dosimetry purposes and other similar features to MTS-N, make this material a good detector for radiation protection dosimetry.

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