Radiation Measurements 90 (2016) 265–268

Contents lists available at ScienceDirect

Radiation Measurements

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

Investigations of OSL properties of $LiMgPO_4$:Tb,B based dosimeters

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HIGHLIGHTS

- A compact OSL dosimetric system was developed.
- Dosimetric cards are based on $LiMgPO_4$ (LMP) material.
- LMP dosimeters show high sensitivity and linear dose response.

ARTICLE INFO

Article history:
Received 22 October 2015
Received in revised form
29 January 2016
Accepted 4 February 2016
Available online 9 February 2016

Keywords:
Optically stimulated luminescence
Luminophor
Dosimeter
OSL reader

ABSTRACT

Lithium magnesium phosphate $LiMgPO_4$ (LMP) doped with Tb and B is one of new materials intended for use in optically stimulated luminescence (OSL) dosimetry. LMP doped with Tb and B luminophors were synthetized at IFJ PAN in Krakow. The investigations were carried out on self-developed dosimeters consisting of a slide with four LMP detectors and a light tight cover. LMP detectors were investigated in regard to their OSL properties using OSL reader named HELIOS adopted to the readouts of dosimetric cards. New LMP detectors showed high sensitivity to the ionizing radiation, good repeatability of OSL signal and good dose response, 25% of fading in the first two weeks after irradiation. Also, the pronounced dependence of OSL response on the energy of the measured radiation requires to apply the compensation filters.

1. Introduction

Nowadays, optically stimulated luminescence is a fast developing dosimetric method due to the technical progress in stimulation technology, LED evolution, improvement of electronic and optical components. In opposite to thermoluminecence (TL), which offers a variety of luminophors, material resources for OSL method are rather poor. The number of commercially available OSL materials is basically limited only to two of them, namely Al_2O_3:C and BeO [Akselrod et al., 1998; Jahn et al., 2014]. This limited availability stimulates efforts for development of new OSL dosimetric materials. Some literature references indicated that lithium magnesium phosphate $LiMgPO_4$ (LMP) is a material which can compete with such well known OSL materials like BeO or Al_2O_3. TL and OSL properties of LMP activated by Tb or both Tb and B were investigated by Kumar and Menon [Menon et al., 2012; Kumar et al., 2011, Singh et al., 2012]. Gai [Gai et al., 2015] has investigated OSL properties of $LiMgPO_4$:Eu,Sm,B. LMP doped with Eu was the object of the study of Baran [Baran et al., 2014] and Zhang [Zhang et al., 2010]. Enciso-Maldonado [Enciso-Maldonado et al., 2015] studied lithium vacancy introduction into LMP.

The research on the optimization of Tb and B concentration in regard to obtain the best OSL properties of LMP has been carried out also at IFJ PAN in Krakow [Wróbel et al., 2014]. Our present work was aimed on the developing of a compact dosimetric system consisting of the LMP in a form of thin foils, dosimeters in a form of dosimetric cards with 4 detectors inside a plastic cover and an OSL reader adapted to the measurement of each detector in covered dosimeters. We report here our latest results of the OSL readout tests, such as sensitivity, repeatability, dose and energy response, which were investigated for the developed LMP material tested in a new dosimetric system.

2. Material and methods

2.1. Material

$LiMgPO_4$:Tb,B phosphor has been prepared by solid state reaction between $LiOH\cdot H_2O$ (Alfa Aesar 99,995%), $Mg(NO_3)2\cdot 6H_2O$ (Alfa Aesar 99,999%) and $NH_4H_2PO_4$ (Sigma–Aldrich 99,99%) in air.

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http://dx.doi.org/10.1016/j.radmeas.2016.02.004

Tb_4O_7 (terbium oxide) and H_3BO_3 (boric acid) or $Na_2B_4O_7$ (sodium borate) were used to introduce terbium (Tb) and boron (B) dopants into the phosphor during synthesis. Stoichiometric quantities of the starting materials were ground together in an agate mortar. The resulting mixtures were heated in an open crucible at 200 °C for 1 h and next were cooled down and triturated in a mortar. Subsequently the powdered mixtures were thermally processed in following steps: 300 °C for 1 h then at 600 °C for the next 1 h. This process was followed by further heating at 750 °C for 20 h with an intermediate regrinding after 10 h. The final products were cooled down to room temperature. In this way more than 20 different samples of LMP were manufactured. The Tb concentration was varied between 0.5 mol% and 1.2 mol %, and B concentration between 5 mol% and 10 mol%. After preliminary investigations in regard to the sensitivity and signal stability, three samples, named LMP10, LMP14 and LMP20 were selected for further studies - see Table 1.

The final result of the synthesis was a white powder, which had to be turned into a solid form, in order to be mounted in dosimeters. For this purpose a technique of making fluoropolymer foils containing a powdered luminophor, originally developed for manufacturing of large area 2D TL detectors [Olko et al., 2006], was used. The foils of 0.1 mm thickness were made from a mixture of LMP powder and ETFE (ethylene-tetrafluoroethylene) polymer (1:2 ratio by mass) by hot pressing. Finally, 6 mm diameter discs were cut out of the foils.

2.2. Dosimetric cassettes and OSL measurements

A new dosimetric badges were developed in frame of the present project. The slides with 4 positions for detectors and the lightproof covers were designed (Fig. 1B) and manufactured from black ABS plastic using technique of high resolution 3D printing. These covers were used during the tests, but is planned that the final version will be equipped with energy compensation filters of chosen materials (Fig. 1C). The quality of 3D printed cassettes was found satisfactory, as the tests showed that the cards and covers were mechanically stable and resistant to deformation during multiple cycles of opening and closing. The tests of light tightness were also performed and proved that there was no light leakage.

The initial measurements of all new synthesized powder samples, as well as discs cut from the foils were performed using Risø DA-20 TL/OSL reader (Risø DTU, Denmark). DA-20 reader detection system is equipped with a band pass filter U-340 (Hoya) allowing to register the light with the wavelength from 300 to 400 nm (UV range). The irradiations were conducted using beta source (Sr-90/Y-90) built in the DA-20 reader. For optical stimulation 28 blue LEDs (peak emission at 470 nm) were used. TL and OSL signals of powders were normalized to the mass of samples.

For the readouts of the dosimeters a modified version of HELIOS-1 OSL reader [Mandowski et al., 2010; Piaskowska et al., 2013] was applied. The OSL reader (Fig. 1A), originally developed for readout of single samples, is equipped with 5 W blue diodes, photomultiplier H7360 and UG-11 filter for light detection (transmission 300–400 nm). The reader was adapted for readouts of the dosimeters by installing a specially designed mechanical system for manual transport of dosimeters into the reader, their opening inside the reader and movement of the slide to consecutive reading positions. It is planned that the final version of the system will consist of both manual and automatic readers.

Table 1
The detailed composition of the selected LMP samples. Tb was always added in form of Tb_4O_7.

Sample	Terbium	Boron
LMP10	0.8 mol%	5 mol% (H_3BO_3)
LMP14	0.8 mol%	10 mol% (H_3BO_3)
LMP20	0.8 mol%	10 mol% ($Na_2B_4O_7$)

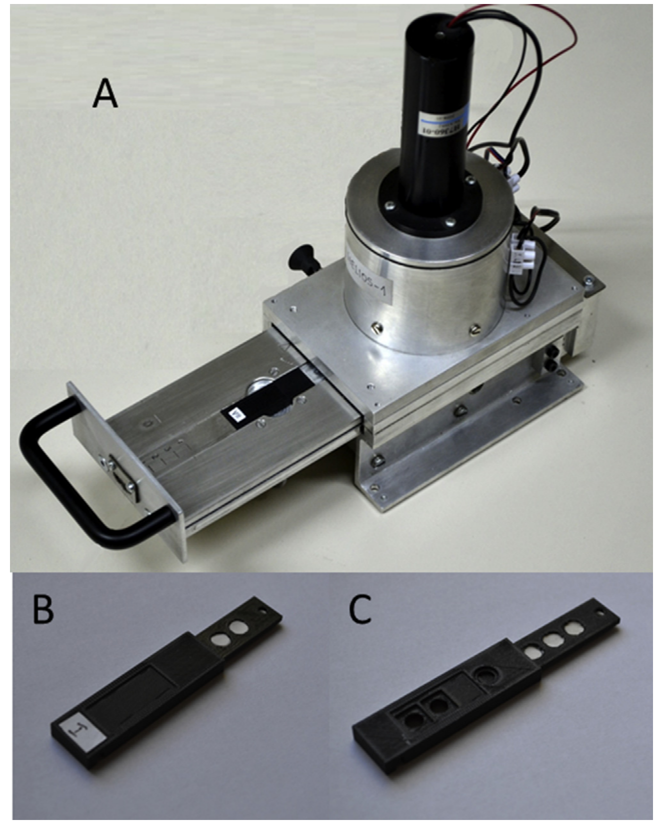

Fig. 1. A photo of HELIOS OSL reader with a dosimeter inside the measurement drawer (A) and the photos of dosimetric cassettes made of black ABS with a lightproof cover (B) and with cover with openings foreseen for filters (C).

The readouts were proceeded with the CW-OSL stimulation mode. The signal was recorded every 0.1 s during a typical measurement period of 60 s. As a final result, the total sum of OSL was taken, after subtracting the background, which was measured for non-irradiated detectors.

Irradiations of the dosimeters were done mostly with Cs-137 gamma-rays at the calibration laboratory of the IFJ PAN in Kraków. X-rays at the Institute of Occupational Medicine in Łódz, Poland were used as well to study the dependence of the OSL response on the energy of the incident X-ray photons.

3. Results

Fig. 2 presents the OSL decay curves (normalized to the mass of samples) for LMP10, LMP14 and LMP20 in comparison with Al_2O_3:C. OSL sensitivity of LMP powders is similar or even higher than that of Al_2O_3:C. It should be however noted that the applied measuring conditions (detection wavelengths) were not optimal for aluminum oxide. The LMP OSL signal was found to be unstable and to decay spontaneously after irradiation. The loss of the signal during 2 weeks after irradiation, with respect to the signal after 24 h is 25% for LMP14 and LMP20 and then stabilizes.

The bleaching conditions were optimized using several discs cut from LMP10 foils and performing OSL readout in the HELIOS reader. All detectors were irradiated in uniform radiation field of gamma rays with a dose of 0.5 Gy and next bleached for 30 min under