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Dosimetric characterization of MgB_4O_7:Ce,Li as an optically stimulated dosimeter for photon beam radiotherapy☆

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Summary Currently there is a growing interest in the development of optically stimulated luminescence (OSL) dosimeters that may be useful for assessing the neutron flux contribution on the doses in radiotherapy due to neutrons produced in the interaction of megavoltage photon beams. In this work, OSL responses of MgB_4O_7:Ce,Li with ^{11}B are presented for some photon beams, including 6 MV and 10 MV. For 10 MV, the behavior of the phosphor containing ^{10}B was also evaluated. The material with ^{10}B exhibited an OSL response slightly more intense than that with ^{11}B, indicating a possible application of this new material for dosimetry in photon radiotherapy.

Introduction

Nowadays, linear accelerators used for medical purposes (linacs) are the most common devices employed in radiotherapy. Linacs operating in a photon mode or electron mode may produce unwanted fast neutrons during the radiation therapy by photonuclear reactions, due the beam interactions with high density elements such as W (tungsten) and Pb (lead) used in the accelerator head. It is expected that photon beam energies slightly greater than 7 MeV can be enough to produce fast neutrons when W or Pb are used in the head of the accelerator [Loi et al., 2006; Yücel et al., 2016]. Neutron flux may have harmful effects on the patient, since neutrons have a high radiation quality factor compared to X and gamma radiations, for the dose deposited in tissue or organs [Yücel et al., 2016].

The use of optically stimulated luminescence (OSL) in medical dosimetry has increased considerably due to photon and electron clinical beams [Yukihara et al., 2015]. Although this dosimetric technique has some advantages over

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thermoluminescence (TL), its use in radiation dosimetry is still restricted due to the limited availability of suitable materials that can be used as dosimeters [Yukihara et al., 2017]. Among the few commercially available OSL detectors, none of them is suitable for neutron dosimetry without the use of neutron converters since they have low cross-section for this type of particle [Oliveira and Baffa, 2017].

MgB_4O_7 with distinct dopants is widely used in thermoluminescence dosimetry and recently its applicability as an OSL dosimeter has been investigated [Prokic, 2007; Souza et al., 2017; Yukihara et al., 2017]. The main features that make it attractive is that it has a low effective atomic number (Zeff ~ 8.4), which is similar to soft tissue. Recent studies have shown that among all the rare earths used as dopants for this host matrix, Cerium (Ce^{3+}) results presented the most intense TL and OSL emissions and the incorporation of lithium as co-dopant enhanced the sensitivity of this phosphor [Souza et al., 2017]. Then, the application of MgB_4O_7:Ce,Li as a OSL dosimeter in radiotherapy may be somewhat innovative and prospective, given the lack of OSL phosphors to quantify neutron flux in radiotherapy. The MgB_4O_7:Ce,Li produced with enriched Boron (Boron-10) represents a possibility of material for use as detector for neutron dosimetry by TL or OSL [Prokic, 2007; Yukihara et al., 2017]. Boron-10 has a high neutron cross section (σ = 3837 barns) compared to Boron-11, which has a negligible neutron cross section (σ = 0.0055 barns) [Fernandes et al., 2008].

As far as is known, OSL evaluations and the dosimetric properties of MgB_4O_7:Ce,Li when exposed to X-ray beams have not been reported in the literature. Thus, the present work aims to investigate the dosimetric response of this material to some X-ray energies used in radiotherapy and to evaluate if the substitution of ^{11}B for ^{10}B changes the OSL response of MgB_4O_7:Ce,Li when exposed to 10 MV beams from linacs.

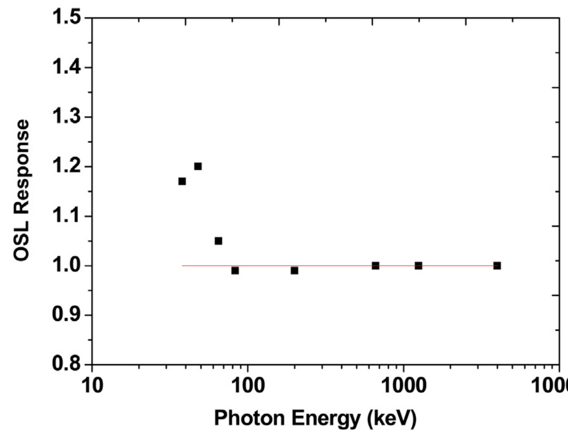

Figure 1 MgB_4O_7:Ce,Li — OSL energy dependence (absorbed dose = 0.1 Gy). The data was normalized to the response of the OSL detector irradiated with the ^{137}Cs.

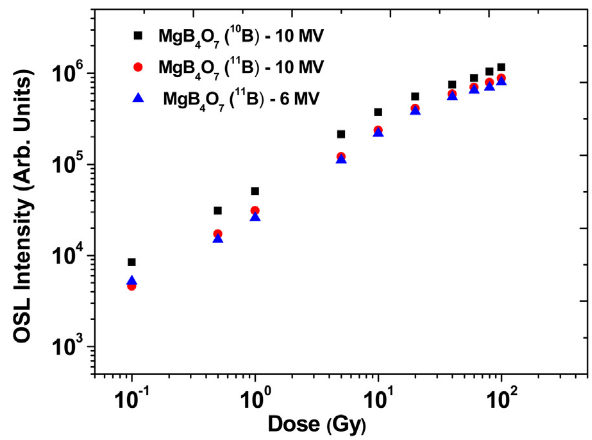

Figure 2 MgB_4O_7:Ce,Li — OSL response.

Materials and methods

Solid-state synthesis was the chosen method to obtain the doped tetraborate phosphors. This synthesis and the production route of the samples in the experimental format (pellets) were previously described in other recent studies (Souza et al., 2015, 2017). For the production of MgB_4O_7:Ce,Li analytical grade MgO (Merck, 99.9% purity), H_3BO_3 (Merck, 99.9% purity), cerium carbonate ($Ce_2(CO_3)_3xH_2O$ Sigma—Aldrich, 99.9% purity) and lithium carbonate ($LiCO_3$ — Sigma—Aldrich, 99.9% purity), were used. The dopant (Cerium) and co-dopant (Lithium) concentrations were 0.5% and 0.1% respectively, related to the total MgB_4O_7 weight.

For the energy dependence analyses, the irradiations were also performed with X-ray beams from a Pantak/Seifert machine, using the standard radiation qualities for conventional diagnostic radiology and radioprotection energies; the samples were exposed to tube voltages of 38, 48, 65 and 83 keV. We also irradiated samples with gamma rays of ^{137}Cs (662 keV) and ^{60}Co (1250 keV). In all cases, the samples were irradiated with an absorbed dose of 100 mGy.

The irradiations with 6 MV and 10 MV photon beams were performed in a Clinac Varian 21EX, in a $10 \times 10\,cm^2$ field, and the pellets were positioned on a solid water phantom. The dose—response of the pellets was estimated over an absorbed dose range from 0.1 to 100 Gy.

All the OSL measurements were performed in a Risø TL/OSL equipment, using continuous-wave (CW) mode, with blue LEDs stimulation (centered at 470 nm, irradiance of 30 mW/cm). For all the measurements, the uncertainty was lower than +/—5%.

Results and discussion

Fig. 1 shows the OSL response of pellets containing ^{10}B and ^{11}B as a function of the photon beam energy. The energy dependence was calculated by the mean of the evaluated dose of 5 pellets normalized to the dose evaluated for ^{137}Cs. The OSL response of the pellets presented maximum of 17% of energy dependence, when exposed to energies below 100 keV, at this energy range the photoelectric effect is more pronounced, and since the probability of occurrence of this type of effect is strongly influenced by the Z_{eff} of the material, the OSL behavior showed is expected. Above 100 keV, no energy dependence was observed.

The dose response of the MgB_4O_7:Ce,Li samples is shown in Fig. 2, considering irradiations with a 10 MV photon beam.

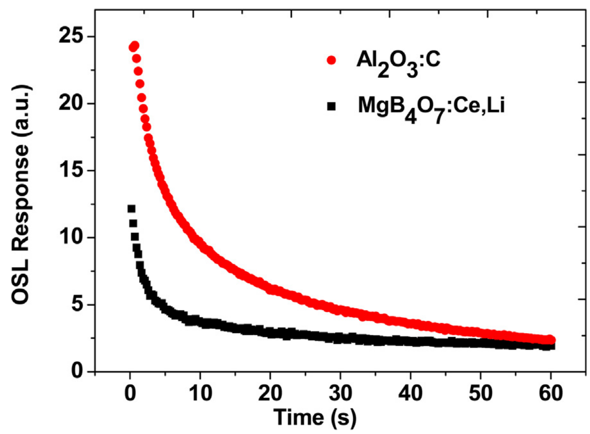

Figure 3 Comparison between the OSL response of a Al_2O_3:C commercial dosimeter and a MgB_4O_7:Ce,Li pellet (^{10}B).

For the whole dose range (0.1—100 Gy), MgB_4O_7:Ce,Li (^{10}B) showed higher OSL intensity compared to MgB_4O_7:Ce,Li (^{11}B), leading us to believe that neutrons produced in the interaction of 10 MV photon beams with the accelerator head are contributing to an additional dose, detected by MgB_4O_7:Ce,Li (^{10}B) due to its higher cross section for slow neutrons. No significant difference was observed among the MgB_4O_7:Ce,Li (^{11}B) irradiated with 6 MV and 10 MV. Above 20 Gy, there is a slight decrease (<10%) in the proportionality of the OSL intensity as a function of the dose, possibly due to a tendency to saturation of the OSL response.

Fig. 3 shows a comparison between the OSL response of a Al_2O_3:C commercial dosimeter and a MgB_4O_7:Ce,Li pellet (^{10}B). Both samples were irradiated with 0.5 Gy of 10 MV photons. The OSL signals were corrected for the dimensions of the samples. Although the commercial dosimeter shows a more intense signal than the MgB_4O_7:Ce,Li pellets, the distinct OSL responses observed between the pellets containing ^{10}B and ^{11}B may represent an advantage for dosimetry in photon radiotherapy.

Conclusion

The pellets produced with MgB_4O_7:Ce,Li showed an OSL response proportional to the dose in 6 MV and 10 MV photon beams. In the dose range between 0.1 and 20 Gy this response was linear, which means that both types of pellets present utility for dosimetry in photon radiotherapy. For photon beams of 6 MV the pellets with ^{10}B showed a slightly more intense OSL signal than those containing ^{11}B. It can be concluded that the difference between the responses may help in the definition of the contribution on the doses in radiotherapy due to neutrons produced in the interaction of megavoltage photon beams.

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