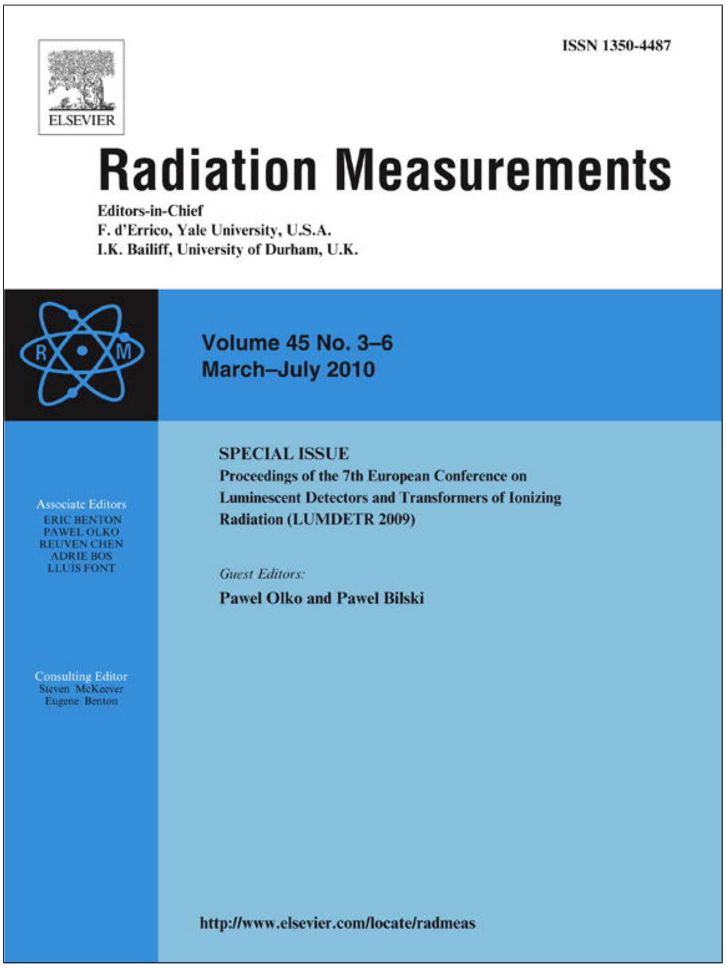
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Effect of dopants on TL characteristics of LiF:Mg,Cu,P detectors

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A B S T R A C T

LiF:Mg,Cu,P detectors produced at the Institute of Nuclear Physics in Krakow have shown very good dosimetric characteristics. Understanding of the effect of the concentration and type of dopants is important in the characterization of TL materials. The aim of work was to investigate the influence of the type and concentration of the dopants on the photon energy response of these detectors by irradiations "in air" and on the ISO water phantom in the range of mean photon energies between 33 and 164 keV. The influence of dopants on the glow curves, sensitivity and reproducibility was also examined. Results showed that measured energy dependence values are lower compared to the theoretical values both "in air" and on phantom. The type and concentration of the dopants influence the shape of the glow curves and sensitivity while for energy dependence is more important the presence of certain activators, namely copper.

1. Introduction

LiF material doped with Mg, Cu and P has been very well accepted for different dosimetric applications mainly due to its high sensitivity and reliability in the range of low doses. The influence of type and concentration of dopants were studied by several authors (Bilski et al., 1998, 1997; Bos et al., 1996; Shoushan, 1988). The main aim of this study was to determine the influence of type and concentration of dopants on the photon energy response of LiF:Mg,Cu,P detectors. The influence of dopants on the glow curves, sensitivity and reproducibility of these detectors was also systematically examined.

2. Materials and methods

The detectors (sintered pellets, Φ 2 $\times$ 0.7 mm) made of LiF:Mg,Cu,P were prepared with different dopant concentrations at the Institute of Nuclear Physics in Krakow. The concentrations varied over the ranges: Mg (0–0.2 mol%), Cu (0–0.5 mol%) and P (0–3.75 mol%). The optimum concentrations of dopants according to manufacturer were Mg 0.2 mol%, Cu 0.05 mol% and P 1.25 mol% (Bilski et al., 1997). For comparison standard LiF:Mg,Ti (TLD-100) detectors were used. Annealing of LiF:Mg,Cu,P detectors was performed in controlled conditions at 240 °C/10 min, with rapid cooling on an Al plate. Before each reading the dosimeters were externally annealed at 100°/20 min. In the reader (TOLEDO 654, Vinten) detectors were preheated at the temperature of 100 °C/6 s; the maximum readout temperature was 240 °C with the heating rate of 10 °C/s.

For calibration purposes ^{137}Cs gamma ray source was used and for the energy dependence investigations detectors were irradiated "free in air" and on the ISO water phantom with narrow spectra X-ray beams (ISO Standard 4037-3, 1999). The used mean energies were: 33, 48, 65, 83, 118 and 164 keV.

3. Results and discussion

3.1. The influence of dopants on the glow curves, sensitivity and reproducibility

Glow curves of LiF:Mg,Cu,P detectors in dependence on different type and dopant concentration are presented in Fig. 1 (a–c). The glow curve structure of LiF:Mg,Cu,P detectors usually consists of three parts: low temperature 2 and 3 peaks, peak 4 or main dosimetric peak and high temperature peak (Bilski et al., 1997). In Fig. 1 low temperature peaks are not present because they are removed by preheating. The main peak intensity increases with the Mg concentration (Fig. 1a). Without presence of Mg TL intensity (area under peak 4) is very small and it is 300 times lower compared to TL intensity of detectors with 0.2 mol% Mg. No significant change of TL intensity with different Cu concentrations was found (Fig. 1b) because without Cu maximum of the main peak and the TL intensity is only 1.5 lower than for other concentrations. Without the presence of P (Fig. 1c) the TL intensity is 50–65 times lower and it is practically negligible compared to other investigated concentrations. With

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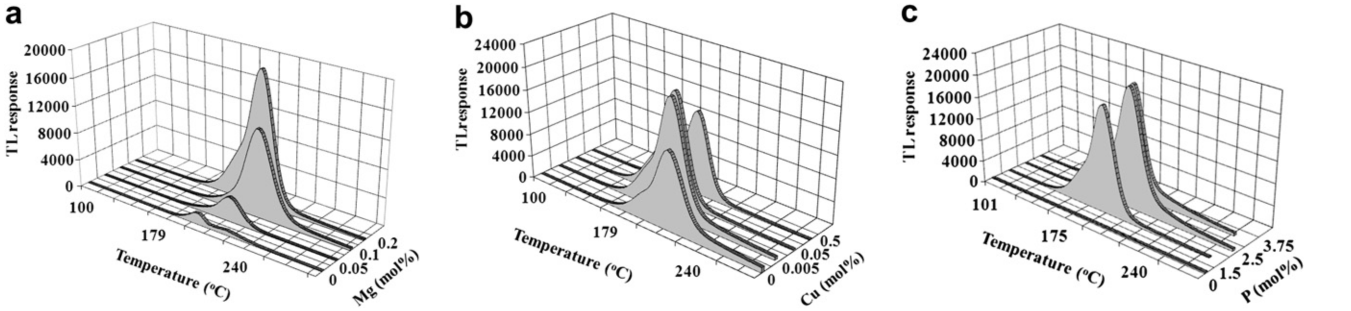

Fig. 1. (a–c): Glow curves of LiF:Mg,Cu,P with: (a) various Mg (Cu = 0.05 mol%, P = 1.25 mol%) (TL intensity of Mg = 0 mol% is increased 10 times in the figure), (b) various Cu (Mg = 0.2 mol%, P = 1.25 mol%) and (c) various P (Mg = 0.45 mol%, Cu = 0.05 mol%) concentrations.

increasing P concentration up to 2.5 mol% TL intensity increases and after that it remains the same. Without the presence of P relative TL sensitivity compared to TLD-100 is 10 times lower; while for the other investigated P concentrations sensitivity is 5–6 times higher.

Relative sensitivities of all investigated LiF:Mg,Cu,P detectors with dosimetry system used in this work are shown in Table 1. The sintering procedure as well as the complete evaluation process affects the sensitivity of TL detectors (Miljanić et al., 2002).

Reproducibility of detectors (expressed as ±1 standard deviation of the mean values in %) through all measurements was in the range 0.53–14%. Reproducibility of detectors with optimum concentration of dopants was 0.53% which represents good reusability of the detectors in personal and environmental dosimetry.

3.2. Influence of dopants on energy dependence in air and on the phantom

Measured energy responses of LiF:Mg,Cu,P detectors with different dopant concentrations irradiated "free in air" as a function of the mean photon energy are shown in Fig. 2 (a–c). Measured values relative to air normalized to 662 keV photons (^{137}Cs) were

Table 1
Sensitivity of LiF:Mg,Cu,P with different dopants compared to TLD-100.

Dopant[a] Mg (mol%)	TL sensitivity relative to TLD–100	Dopant[b] Cu (mol%)	TL sensitivity relative to TLD–100	Dopant[c] P (mol%)	TL sensitivity relative to TLD–100
0.0	0.02	0.0	3.3	0.0	0.1
0.05	0.78	0.005	5.0	1.25	5.1
0.10	3.7	0.05	5.1	2.5	6.1
0.2	5.1	0.5	3.8	3.75	6.2

[a] Cu = 0.05 mol%, P = 1.25 mol%.
[b] Mg = 0.2 mol%, P = 1.25 mol%.
[c] Mg = 0.2 mol%, Cu = 0.05 mol%.

compared with calculated values of mass–energy absorption coefficients for pure LiF and for LiF with different dopant concentrations. Theoretical values are calculated according to the mass energy-absorption coefficients taken from National Institute of Standards and Technology (NIST, 2008).

In Fig. 2a measured energy responses for detectors with different Cu concentrations are shown. Theoretical values of coefficients for 0 and 0.005 mol% Cu concentrations as well as for 0.05 and 0.5 mol% are the same and therefore only two curves are shown in the Fig. 2a. The measured values are the lowest for 0 mol% and increase with increasing Cu concentration in the energy range between 33 and 118 keV.

Calculated values for the Mg concentrations 0, 0.05 and 0.1 mol% are the same and they are shown as one curve in Fig. 2b. Measured values did not show significant differences for different Mg concentrations; they are within experimental error and cannot be attributed to the influence of Mg. Compared to theoretical values measured values are lower.

Minimum for all investigated Cu and Mg concentrations is at about 80 keV and the values are about 20 and 40% lower comparing theoretical values for pure LiF and LiF with different Cu and Mg concentrations, respectively. The position of minimum is in agreement with data from the literature for the optimum dopant concentrations (Olko et al., 1993). Measured values for different P concentrations shown in Fig. 2c are significantly lower comparing to the theoretical values for pure LiF and LiF with different P concentrations. The results show that different concentrations of P have no significant influence on energy absorption characteristics except in the case when concentration of P is 0 mol%. Without P the measured values are at energy of 33 keV 15–20%, at 48 keV 7–13% and at energy of 65 keV 8–17% lower compared to other concentrations of P. Experimental curves for all investigated dopant concentrations have the same shape and they overlap at higher energies. The differences between theoretically predicted curves

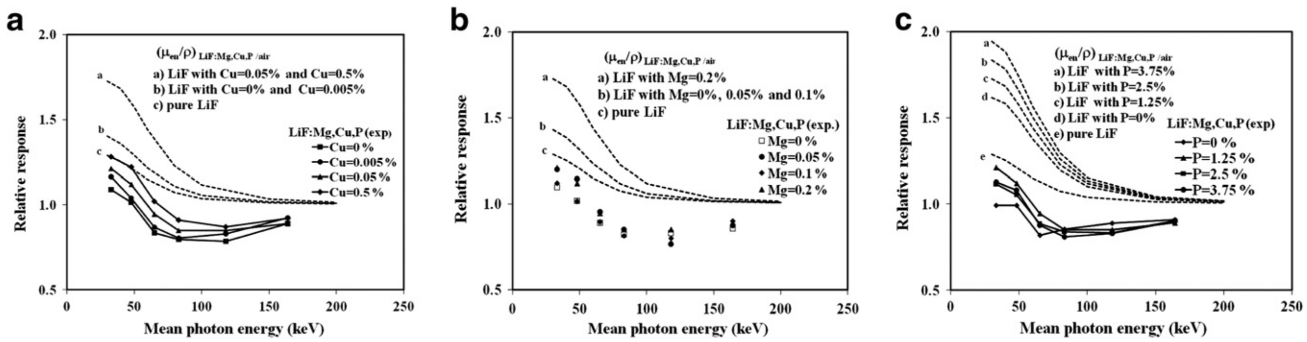

Fig. 2. (a–c): Measured energy responses (in air) of LiF:Mg,Cu,P detectors relative to air compared to calculated ratios of mass–energy absorption coefficients for pure LiF and LiF with different dopants and air (normalized to ^{137}Cs photons) for various: (a) Cu, (b) Mg and (c) P concentrations.

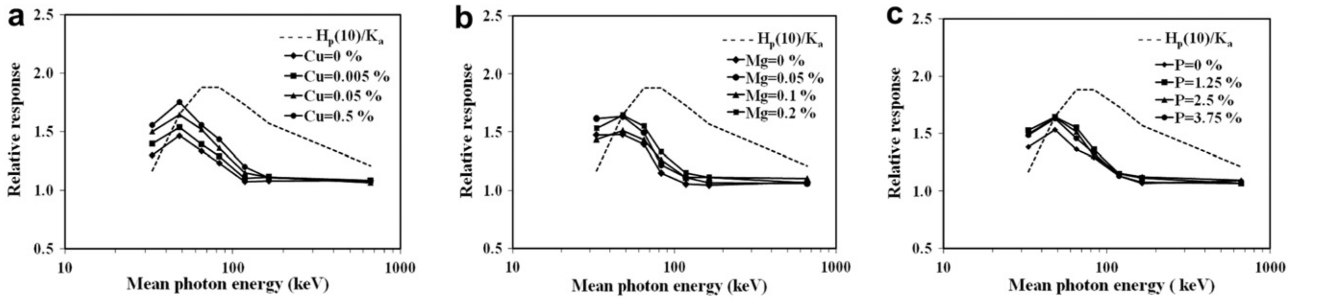

Fig. 3. (a–c): Measured energy responses (on phantom) of LiF:Mg,Cu,P detectors compared to caluculated values of $H_p(10)/K_a$ (normalized to ^{137}Cs photons) for various: (a) Cu, (b) Mg and (c) P concentrations.

and measured values show that LiF:Mg,Cu,P detectors have the anomalous photon energy response which has been explained as an ionization density effect (Olko et al., 1993).

In Fig. 3 (a–c) results for irradiations on phantom are shown. Measured results for different types and concentrations of dopants are expressed as the mean values of dose measured on phantom relative to delivered doses specified as ‘‘air kerma free in air’’. The measured values are compared to personal dose equivalent $H_p(10)/K_a$ values. Measured results on phantom for all dopant concentrations are in agreement with the results obtained with measurements in air. The results show that Cu has influence on the energy response measured on phantom in the energy range between 33 and 83 keV (Fig. 3a). Differences between Cu = 0 mol% and Cu = 0.5 mol% at energies 33, 48, 65 and 83 keV are 20, 21, 16 and 16%, respectively. Differences between investigated concentrations of Mg and P are within experimental error and cannot be attributed to the influence of Mg and P as a dopant (Fig. 3b,c) except in the case when concentration of P is 0 mol% where the measured values are the lowest (Fig. 3c). Compared with theoretical values of $H_p(10)/K_a$, measured values in the energy range from 65–164 keV are up to 56% lower which have been explained as an ionization density effect (Olko et al., 1993.). At the lowest energy (33 keV) maximum of absorbed dose is about 10–21% higher than the theoretical values for all dopants concentrations.

4. Conclusions

Type and concentration of dopants influence the glow curve and sensitivity of the LiF:Mg,Cu,P, while for the energy dependence the more important is the presence of certain dopants. Small changes in Mg concentrations influence on the main dosimetry peak intensity. P is responsible for the high sensitivity while various Cu concentrations did not influence the main peak. For the energy dependence investigation both in air and on the phantom, measured results show that Cu influence on the energy response. Measured values for investigated Mg and P concentrations did not show significant differences except in the case when concentration of P is 0 mol% where the measured values are the lowest.

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