PHOTON ENERGY DEPENDENCE OF SENSITIZED LiF (TLD-700) PHOSPHOR

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ABSTRACT

The TL readout ratio of high- and low-temperature peaks in radiation-sensitized (UV/thermal-annealed) LiF (TLD-700) is considerably lower than that of virgin phosphor. This is a result of lower sensitization of peak 7 as compared to peak 5. However, the readout ratio in both phosphors does not vary with photon energy in the range 29-130 keV, hence it cannot provide the information on photon energy. The photon energy dependence of high-temperature readout is higher than that of the low-temperature readout in virgin and sensitized phosphors, as a consequence of the two-hit nature of peak 7 TL traps.

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1. INTRODUCTION

The usefulness of radiation-induced sensitization in LiF:Mg,Ti thermoluminescence dosimetry (TLD) phosphor after a gamma dose of 10^3 Gy and 300°C , 2 h UV/thermal annealing in low-dose measurements, is now well established¹⁻³). Our earlier studies have shown that in view of the dependence of this sensitization on the LET of the test-radiation, the photon energy dependence of the sensitized LiF phosphor is considerably different from that of the virgin phosphor⁴). However, this study⁴) was i) made with the sensitized but dark-annealed (300°C , 1 h) sample and not with the UV/thermal-annealed sample, and ii) included only the dosimetric peak ($\sim 200^\circ\text{C}$) and not the high-temperature peak ($\sim 270^\circ\text{C}$). Charles and Wells⁵ have recently studied the photon energy response of sensitized and UV/thermal-annealed LiF (TLD-700) chips. But this study covered only the TL output between 130 and 260°C and not the high-temperature readout.

For the 300°C dark-annealed as well as UV/thermal-annealed LiF chips, the sensitization factor of peak 5 ($\sim 200^\circ\text{C}$ peak) to ^{60}Co γ -rays is nearly the same and hence the photon energy response of low-temperature readout ($130\text{--}245^\circ\text{C}$) in both cases is expected to be the same⁶). Since the sensitization of peak 7 ($\sim 270^\circ\text{C}$ peak) to ^{60}Co γ -rays is very much higher in the dark-annealed sample as compared to UV/thermal-annealed sample, the photon energy response of high-temperature readout ($245\text{--}320^\circ\text{C}$) is expected to be different in the two samples⁶). In view of the two-hit nature of peak 7 TL traps, i.e. Z_2 centres, the photon energy dependence of peak 7 in virgin LiF:Mg,Ti is higher than that of peak 5⁶⁻⁸). In spite of this difference, the ratio of these two peak heights in virgin phosphor does not vary much in the photon energy range 29-100 keV^{9,10}). In the sensitized (UV/thermal-annealed) phosphor, peak 7 shows a lower sensitization (as a result of the absence of peak 10, i.e. 400°C peak) than peak 5⁶). Hence in this phosphor, it would be of interest to study the photon energy dependence of peaks 5 and 7 and see if their TL readout ratio varies as a function of photon energy. This study has also become important because the TL characteristics of sensitized (UV/thermal-annealed) LiF chips compare favourably with those of normal ones in personnel and

environmental dosimetry^{11,12}). The major advantages of the sensitized phosphor over virgin phosphor are improved TL sensitivity and tissue equivalence, and extended linearity in TL response versus dose.

2. MATERIALS AND METHODS

LiF (TLD-700) chips ($3 \times 3 \times 0.9 \text{ mm}^3$) were pre-irradiation-annealed at 400°C for 1 h followed by 100°C for 2 h. For sensitization, a gamma dose of 10^3 Gy was given using a ^{60}Co source. The pre-dosed samples were annealed at 300°C for 2 h on a hot plate. Simultaneously, ultraviolet light from an assembly of three germicidal tube lights (Philips, 30 W, 90 cm length) was shone on the LiF chips. After 2 h annealing, the UV light was turned off and the TL samples were removed from the hot plate 5 min afterwards. These samples (henceforth referred to as sensitized) were exposed to X- and γ -rays, along with virgin samples. For X-irradiations, a Philips deep therapy X-ray machine calibrated with a Victoreen-R ionization chamber was used. The kV_p settings, filtration, and effective energies used are indicated in Table 1. A constant exposure of 7 R ($1.8 \text{ mC}\cdot\text{kg}^{-1}$) was given at all energies. The TL chips were sandwiched between two perspex sheets of 1 mm and 5 mm wall thickness for X and ^{60}Co γ -irradiations, respectively. The TL measurements were carried out with a Teledyne Isotopes reader (model TLD 7300B). The heating cycle of this instrument consists of constant preheating, readout, and annealing temperatures with rapid temperature changes in between. Nitrogen was flushed during readout. The first heating cycle consisted of a preheat of 8 s at 130°C followed by a readout of 12 s at 245°C . After cooling down, the dosimeters went through a second similar heating cycle with a readout at 320°C .

3. RESULTS AND DISCUSSION

Table 2 shows the sensitization factor of LiF (TLD-700) chips for the two readouts as a function of photon energy. It is seen that the sensitization of the high-temperature readout is lower than that of the low-temperature one. The sensitization factor in both cases is higher for ^{60}Co γ -rays than for X-rays, but its variation with photon energy in the range 29-133 keV is not very significant.

Figure 1 shows the high-to-low temperature readout ratio for virgin and sensitized phosphors as a function of photon energy. This ratio is considerably lower for sensitized phosphor than for virgin phosphor. This is a result of a higher sensitization of peak 5 than of peak 7 in sensitized phosphor. Unfortunately for both virgin and sensitized phosphors, the readout ratio does not vary significantly with photon energy in the range 30-130 keV and hence it cannot provide any information about the photon energy. This may be a consequence of the near constant mean LET of the secondary electron spectrum in LiF in this photon energy range⁹⁾.

Since the intensity of peak 7 relative to peak 5 is small for the sensitized phosphor as compared to virgin phosphor (Fig. 1), the precision in X-ray measurements using 130-245 °C readout with the former will be better than the latter. Budd et al.⁹⁾, for example, have reported that for virgin LiF, a correction of 10 to 15% above the correction from the difference in mass energy absorption coefficients of LiF and water will be necessary for precise X-ray dose measurements, depending upon the maximum readout temperature. This is probably due to a minor contribution of peak 7 TL intensity during the low-temperature readout, as pointed out in Ref. 7.

Figure 2 shows the photon energy dependence of the two readouts for virgin and sensitized phosphors. The photon energy dependence of high-temperature readout is higher than the low-temperature readout in both virgin and sensitized phosphors. This is a consequence of the two-hit nature of peak 7 (Z_2 centres) TL traps, as indicated earlier. In view of the decrease in sensitization for X-rays as compared to ^{60}Co γ -rays (Table 2), the photon energy dependence of sensitized phosphor (for low- and high-temperature readouts) is less than that of the virgin phosphor.

As pointed out earlier, the energy dependence of 130-245 °C readout in Fig. 2 for UV/thermal-annealed phosphor, matches well with the response reported earlier for dark-annealed phosphor⁴⁾. However, the energy response of 240-320 °C readout

for the sensitized and dark-annealed sample is expected to be different from that of UV/thermal-annealed sample in two ways. After the 300 °C dark-annealing treatment: i) Z_3 centres (peak 10 TL traps) are filled to an appreciable extent, and hence peak 7 TL traps will behave more or less like one-hit (i.e. $Z_3 + e$) and not like two-hit (i.e. $Z_0 + 2e$) traps, and ii) peak 7 exhibits nearly four times higher sensitization than peak 5 to ^{60}Co γ -rays⁶). As a result, the relative TL efficiency of peak 7 to low-energy X-rays as compared to ^{60}Co γ -rays will be lower than peak 5. In other words, the energy response of peak 7 in sensitized but dark-annealed LiF will be the reverse of that in virgin or sensitized but UV/thermal-annealed phosphor. Unfortunately, both the processes mentioned above result in the decrease in TL efficiency of peak 7 for high-LET radiations as compared to low-LET radiations in dark-annealed phosphor, whilst what is desired in high-LET radiation dosimetry is exactly the opposite. However, the high-temperature to low-temperature readout ratio of both virgin and UV/thermal-annealed LiF phosphors to alpha particles has been found to be nearly the same. This could mean that the variation of the TL readout ratio with LET is larger for sensitized (UV/thermal-annealed) phosphor than for virgin phosphor. This difference could be exploited with some advantage in high-LET radiation dosimetry.

4. CONCLUSIONS

- 1) As a result of the increase in sensitization with photon energy of the test radiation, the energy dependence of low- and high-temperature readouts in sensitized (UV/thermal-annealed) LiF (TLD-700) is lower than those of virgin phosphor.
- 2) In sensitized phosphor, the high-to-low temperature readout ratio is considerably lower than that for virgin phosphor in the photon energy range 29 keV to 1.25 MeV as a result of lower sensitization of peak 7 as compared to peak 5. But for both the phosphors, the variation of this ratio with photon energy (29-130 keV) is not significant since the mean LET of the secondary electron spectrum does not vary significantly in this energy range. Therefore, similar

to virgin phosphor, the readout ratio in sensitized phosphor also will not provide the information about photon energy. However, in view of the relatively low contribution of high-temperature readout, the precision of X-ray dose measurements with the sensitized phosphor is expected to be better than with virgin phosphor.

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Table 1

The kV_p setting, additional filtration, and radiation source used for photon energy dependence studies

kV_p setting or radionuclide used	Additional filter	Effective photon energy
80	2 mm Al	29 keV
120	2 mm Al	40 keV
140	0.35 mm Cu	66 keV
200	0.50 mm Cu	79 keV
250	Thoraus	133 keV
^{60}Co	-	1.25 MeV

Table 2

Dependence of sensitization of low- and high-temperature readouts in LiF (TLD-700) chips on photon energy of the test radiation. S: TL sensitivity (area) of sensitized phosphor (10^3 Gy ^{60}Co , γ -dosed and UV/thermal-annealed at 300°C for 2 h); S_0 : TL sensitivity (area) of virgin phosphor. Test exposure = $1.8 \text{ mC}\cdot\text{kg}^{-1}$.

Photon energy (keV)	Sensitization factor (S/S_0)	
	130-245 $^\circ\text{C}$ area	245-320 $^\circ\text{C}$ area
29	5.50	1.30
40	5.67	1.25
66	5.66	1.33
79	5.64	1.30
133	5.75	1.27
1250	7.51	1.56

Figure captions

- Fig. 1 : The high-temperature to low-temperature TL readout ratio in (o) virgin and (●) sensitized (UV/thermal-annealed) LiF TLD-700 chips as a function of photon energy.
- Fig. 2 : The photon energy dependence of low-temperature (○,□) and high-temperature (●,■) readouts in virgin (○,●) and sensitized (□,■) LiF TLD-700 chips.

Fig. 1

Fig. 2