Visible photoluminescence of color centers in LiF crystals exposed to 6 MV x-ray clinical beams

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Point defects (impurity ions, colour centres (CCs) etc.) in insulating materials are successfully used for radiation detection and dosimetry [1]. Pure and doped lithium fluoride (LiF) materials have been successfully used as a Thermoluminescence (TL) dosimeter for more than 50 years. In the last 20 years optically stimulated luminescence (OSL) dosimetry has been commercially adopted, taking advantage of availability of materials (although still limited in comparison with TL), mainly Al_2O_3:C [2]. Among the advantages of OSL dosimetry there are simplicity, accuracy, wide dynamic range of measured dose, ease of automation, re-read capability and ability to perform imaging for dose mapping. However oxides (with the exception of BeO) have tissue equivalence significantly higher than water, making them more difficult to use in clinical dosimetry. The effective atomic number, Z_{eff}, of a material is often used to describe the extent to which a material approximates or deviates from soft tissue (tissue equivalence) in its interaction with a radiation field, which is an important parameter, particularly in medical applications. LiF has a good tissue equivalence (LiF Z_{eff} = 8.3 vs. Al_2O_3:C Z_{eff} = 11.3 to be compared with H_2O Z_{eff} = 7.3).

Lately, photoluminescence (PL) of radiation-induced light-emitting color centers (CCs) has also been explored in pure and doped LiF [3]. Among them, F_2 and F_3^+ electronic defects, stable and laser-active at room temperature (RT) , are produced in LiF crystals and films by different kinds of radiation. Under blue optical pumping in their broad overlapping absorption bands, the efficient optical emission spans over the green-red visible spectral range. In the last decade they were proposed for novel solid state luminescent imaging detectors with submicrometric spatial resolution for soft x rays up to 80 keV [4]. Recently, their use was extended to advanced proton beam characterization and imaging [5].

In this work, the results of the optical investigation of radiation-induced CCs in 6 MV x ray irradiated pure LiF crystals in the clinically relevant dose range of 1-100 Gy are presented. Even at these low doses, optical absorption and laser-excited PL spectra were measured at RT using a conventional optical fluorescence microscope for reading of the integrated visible PL signal [6].

Polished commercially available LiF crystals 5x5x0.5 mm^3 were irradiated using 6 MV x rays produced by a clinical linear accelerator at the Tom Baker Cancer Centre, Calgary, Canada. The doses (absorbed dose to water) covered the 1-100 Gy range. Under modulated continuous wave Argon laser excitation at 458 nm at low power and by using a lock-in technique, the corrected PL spectra of the irradiated LiF crystals clearly exhibited the characteristic F_2 and F_3^+ visible broad emission bands (Fig.1). A background correction was applied: the net PL spectra were obtained by subtracting a blank spectrum (the spectrum of an unirradiated LiF crystal, used as "zero" dose reference) from every measured photoemission spectrum obtained for each irradiated LiF crystal. PL spectra were fitted as the sum of two Gaussian bands (Fig.2), whose spectral parameters (peak position and FWHM) are in agreement with well-assessed literature in LiF crystals. Their sum intensity is linearly proportional to the absorbed dose in the investigated range (Fig.3). PL integrated intensity was also measured using a conventional fluorescence optical microscope under blue lamp illumination. The relationship between the absorbed dose and the integrated F_2 and F_3^+ PL intensities, represented by the net average pixel number in the optical fluorescence images, is also fairly linear [6]. Optical absorption spectra (Fig.4) show stable formation of primary F defects peaked at around 247 nm at highest doses, while no significant M absorption band at around 450 nm was unambiguously detected. Even at the low electronic defect densities (F and F_2 concentrations below $2x10^{16}$ cm^{-3} and $6x10^{14}$ cm^{-3}, respectively) obtained at the investigated doses, the PL signal was stable in ambient lighting, a good reproducibility (within 5%) was achieved and dose response linearity in the 1-70 Gy range was found also for irradiation with ^{60}Co gamma rays and 60-200 MeV proton beams used for hadrontherapy. Further work is in progress to increase the PL reading sensitivity and to investigate the potential role of impurities.

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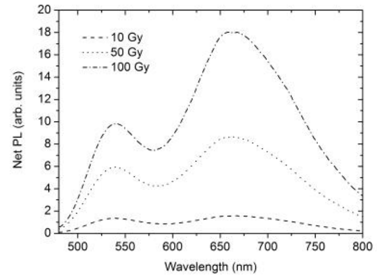

Figure 1. RT laser induced (458 nm) PL spectra of 6MV x-ray irradiated LiF crystals at 10, 50 and 100 Gy.

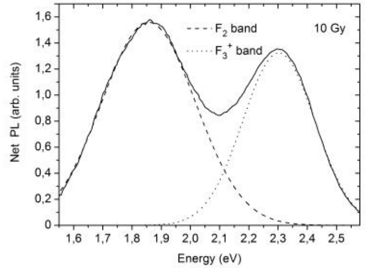

Figure 2. Net PL spectrum of the 6 MV x-ray irradiated LiF crystal at 10 Gy, best-fitted as the sum of two Gaussians bands, ascribed to the F_2 and F_3^+ CCs emission bands.

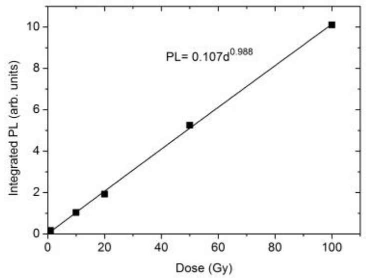

Figure 3. Integrated PL intensity as a function of the absorbed dose for all the 6 MV x rays LiF irradiated crystals and linear best fit (solid line).

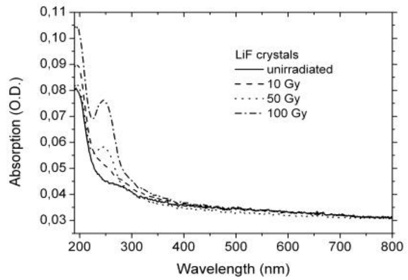

Figure 4. RT optical absorption spectra of 6 MV x rays irradiated LiF crystals at several doses. The spectrum of a blank crystal is reported for comparison (thickness 0.5 mm).