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Abstract:

New radiotherapy techniques, as those using flash irradiations, requires developing innovative dosimeters capable of measuring high, pulsed dose rates. Our FIDELIO project aims at developing miniaturized silica fiber-based RL dosimeters optimized for pulsed photon and proton beams. The proportionality of their RL plateau level to dose rate is well established and is no longer an issue. Critical problems for pulse dosimetry, much less addressed, rather concern RL rise and fall times and the stability of the RL response over time and cumulated dose. We studied these characteristics experimentally for Gd3+- and Ce3+-doped silica fibers. The probes, 1 cm long and 220 µm in diameter, were connected to a photodetector through radiation-hard silica fibers. They were irradiated under 30kV X rays (pre-clinical investigations) at dose rate 0.8-11.3 Gy/s, but also in the 65 and 226 MeV proton beams of the anti-cancer center of Nice. To identify the parameters affecting RL kinetics and stability, we also used a model suited to rare-earth-doped silica glasses including a quasi-continuous distribution of traps and a single type of recombination centers. To study the effect of short exposure times on RL kinetics, 1 to 10 s X-ray irradiations were sequentially applied at constant dose rate, separated by rest periods of 10 s. As exposure time increases along successive irradiations, the rise time of the RL is only slightly changed and the RL plateau remains stable. An increasing phosphorescence is however observed between irradiations for both Ce and Gd-doped probes, due to a slower and slower phosphorescence decay. This observation is reproduced by simulation and shown to be due to detrapping from "shallow" traps, whose depth is around a demarcation level that continuously sinks into the bandgap with time. As a complement to simulations, analysis of the model in two limit cases (no trapping and trapping without detrapping) allowed us to establish formal solutions between which all real cases lie. Important properties are thus demonstrated: 1) The minimum rise time corresponds to the 'no trapping' case, which is in fact a case with trapping but undelayed (instant) detrapping. Inversely proportional to the square root of the dose rate, it is about a few tens of microseconds at 10 Gy s-1; 2) The 'no detrapping' case leads to the longest rise time which is inversely proportional to the dose rate. It can reach hundreds of seconds at 10 Gy s-1; 3) Detrapping from shallow traps shortens rise time while increasing fall time. Pre-existing filling of these traps, determined by previous doses and time elapsed since them, unavoidably impacts RL kinetics without affecting its plateau; 5) Regardless of detrapping delay, the initial RL growth (at much smaller times than the rise time) is always proportional to the square of the dose rate. This offers opportunities for efficient, radiative-history independent, pre-plateau dose rate assessment for short pulse dosimetry.