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ELECTRON TRAPS AND TRANSFER EFFICIENCY IN CERIUM-DOPED LUTETIUM OXYORTHOSILICATE SCINTILLATORS

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The ratio of thermoluminescence and scintillation light outputs of Ce : Lu_2SiO_5 (LSO) was measured as a function of gamma-ray dose. Together, they account for only a fraction of the predicted electron–hole pairs. Electron traps saturate rapidly, and their concentration is at least two orders of magnitude less than that of cerium.

Keywords: Scintillation; Thermoluminescence; LSO

The effect of deep electron traps on the efficiency of scintillator response was investigated for four single-crystal samples of Ce : Lu_2SiO_5 (LSO). An electron van de Graaff accelerator, operated at 1 MV and 1 μA with the electron beam stopped by a thin copper target, was employed as the gamma-ray source. Scintillation and thermoluminescence light outputs were compared by utilizing a common apparatus and detection scheme for both measurements [1]. The thermoluminescence glow curves for LSO have been characterized by Dorenbos *et al.* [2]. Light output was recorded as a function of time for radiation times ranging from 15 s to

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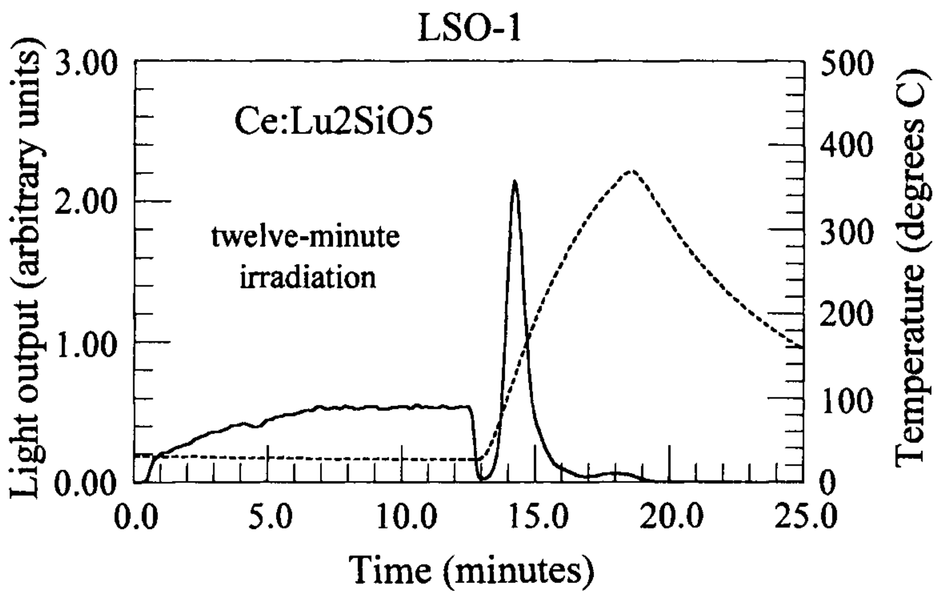

FIGURE 1 Light output (continuous curve) and sample temperature (dashed curve) as functions of time for a 12-min irradiation of sample LSO-1.

16 min, as exemplified by Fig. 1. The branching ratio, G/S, of integrated thermoluminescence and scintillation light outputs, corrected for thermal quenching, is plotted as a function of radiation dose in Fig. 2.

With simplifying assumptions, the analysis of experimental results proceeds from a single rate equation [1],

$$\frac{d\tilde{n}}{dt} \cong \frac{\gamma(1-\tilde{n})}{(1/\alpha)(1+(N/n_{h0})\tilde{n})+(1-\tilde{n})}, \tag{1}$$

where $\tilde{n}$ is the ratio of the trapped-electron concentration n to the electron-trap concentration N, n_{h0} is the initial trapped-hole concentration, $f(=\gamma N)$ is the rate of electron–hole pair production and $\alpha(=NA/n_{h0}A_r)$ is the initial value of G/S. With the additional assumption that cross-sections for trapping, A, and recombination, A_r, are equal, the solution is

$$\tilde{n} = 1 - \exp(-\beta t), \tag{2}$$

$$\beta \equiv \alpha\gamma/(1+\alpha), \tag{3}$$

$$\frac{G}{S} = \frac{\tilde{n}}{\gamma t - \tilde{n}} = \frac{1-\exp(-\beta t)}{\gamma t - 1 + \exp(-\beta t)}. \tag{4}$$

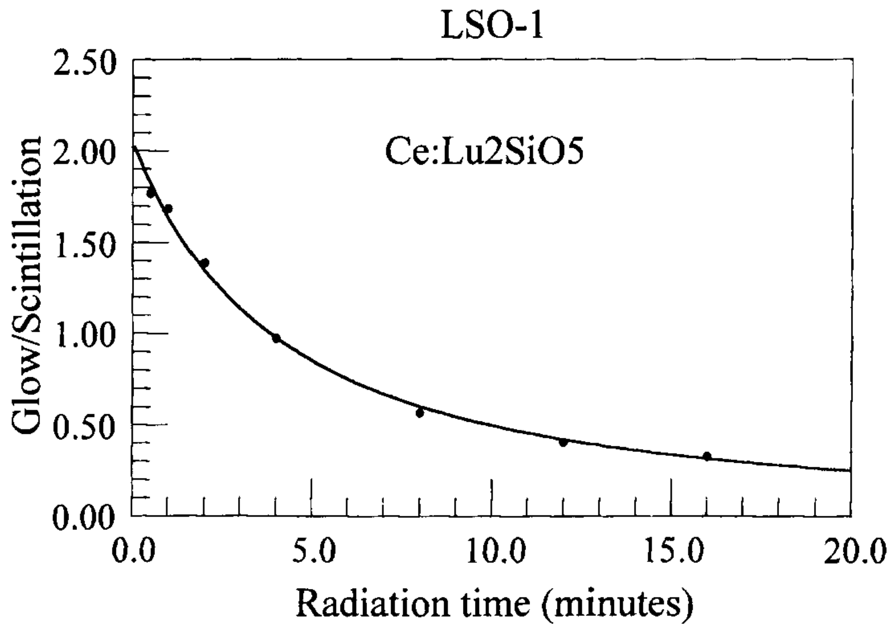

FIGURE 2 Ratio of integrated thermoluminescence and scintillation light outputs as a function of radiation time for sample LSO-1. Experimental data are represented by filled circles and the curve is a plot of Eq. (3) with optimized parameters.

TABLE I Summary of optimum parameter values, concentrations and efficiency

Crystal	α	γ (min^{-1})	N (cm^{-3})	n_{h0} (cm^{-3})	η (%)	ε (%)
LSO-H	0.086	1.64	4×10^{16}	5×10^{17}	36	≥ 39
LSO-L	4.39	0.097	6×10^{17}	1×10^{17}	1	≥ 6
LSO-1	2.02	0.242	2×10^{17}	1×10^{17}	19	≥ 58
LSO-2	0.426	13.1	4×10^{15}	1×10^{16}	1	≥ 2

Parameters α and γ were adjusted for a least-squares fit of G/S to the data, as shown in Fig. 2. Optimized parameters are listed in Table I for all four samples, together with derived values of N and n_{h0}; efficiency η calculated as the measured prompt scintillation light output [2,3] divided by the theoretical number [4] of electron–hole pairs/MeV, 69,444; and the radiative fraction of recombination events, including thermoluminescence and both fast and slow scintillation, $\varepsilon\,[\geq \eta(1+\alpha)]$.

Evidently, the four samples represent four distinct combinations of scintillation and thermoluminescence light output levels. Although deep traps play a prominent role in LSO, scintillation and thermoluminescence together account for only a fraction of the electron–hole pairs, and the residual inefficiency must be attributed to some combination of slow scintillation components and radiationless recombination. Electron traps saturate rapidly; their highest concentration is two orders of magnitude less than that of cerium.

Low temperature thermoluminescence induced by ultraviolet radiation reveals shallow traps which affect the temperature dependence of light output [3].

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