Radiation trapping in $Rb_3Lu(PO_4)_2$:Ce

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The term „radiation trapping'' is attributed to a process, in which a photon emitted by a luminescence center is subsequently absorbed by another center of the same kind. If only the emission and absorption bands of the center overlap, any once emitted photons are likely to be absorbed („trapped'') and emitted again and again before they leave the crystal. As a result, serious changes in luminescence spectra and time profiles can be observed.

Among the literature examples of radiation trapping cerium-activated materials seem to dominate, what is due to a distinct overlapping of the $5d$-$4f$ emission and $4f$-$5d$ absorption bands. Three effects associated with radiation trapping have already been reported: *i)* the conversion of the short-wavelength (SWL) luminescence to the long-wavelength (LWL) one (Wojtowicz *et al.* [1], $Ce_xLa_{1-x}F_3$); *ii)* the prolongation of the observed $5d$-$4f$ emission decay time (Drozdowski and Wojtowicz [2], BaF_2:Ce); *iii)* the dependence of the observed $5d$-$4f$ emission decay time on cerium concentration and sample thickness (Visser *et al.* [3], BaF_2:Ce). The degree of these effects increases in function of temperature, as the thermal broadening of the emission and absorption bands induces their stronger overlapping.

In this note we compare the shapes of the Ce^{3+} $5d$-$4f$ luminescence bands and time profiles in a new potential scintillator material, $Rb_3Lu(PO_4)_2$ [4], recorded at room and liquid helium temperatures. We argue that the apparent differences are caused by radiation trapping (effects *i* and *ii*). The measurements have been performed at the Superlumi station of HASYLAB. A small sample with a nominal cerium concentration of 1% has been examined.

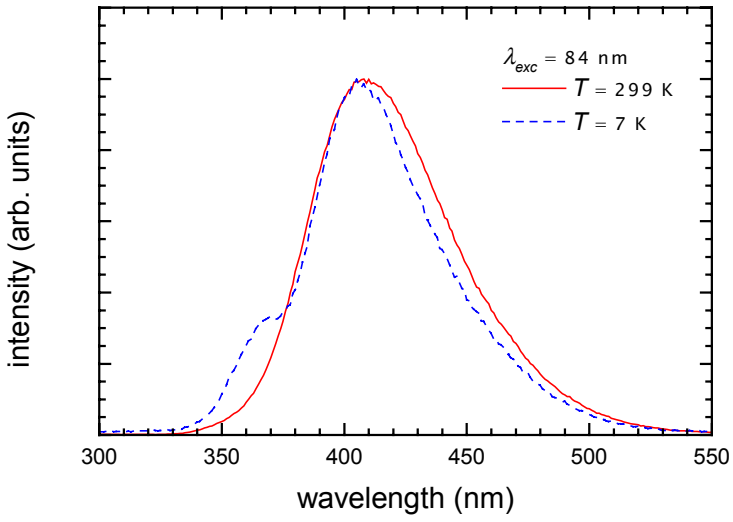

Figure 1: RT and LT emission spectra of $Rb_3Lu(PO_4)_2$:Ce

The $4f$-$5d$ absorption bands in $Rb_3Lu(PO_4)_2$:Ce are localized at wavelengths longer than 320 nm, thus mostly outside the sensitivity range of the Superlumi primary monochromator. Nevertheless, high-quality spectra and time profiles have been recorded at more energetic excitation, for the VUV response of the studied material is very high [4]. *Figure 1* compares two luminescence spectra excited at 84 nm, measured at different temperatures and normalized to unity in their maxima. The room temperature (RT) spectrum consists of a single band with a maximum at about 410 nm, while at the low temperature (LT) one an extra band peaking at about 370 nm appears. The double structure at LT is due to the spin-orbit split $^2F_{5/2}$ and $^2F_{7/2}$ levels of the $4f$ configuration. As this is the short wavelength component of the emission band which overlaps with the absorption band, the 370 nm photons are subjected to radiation trapping. Therefore they are expected to be absorbed by any Ce^{3+} ions and then emitted not only as retarded 370 nm photons, but partly as retarded 410 nm ones as well. The multiplication of such sequences reduces the relative intensity of the 370 nm component, particularly at higher temperatures. We also note that the typical thermal broadening of the 410 nm band is visible in the long wavelength slope which is not affected by radiation trapping.

The luminescence time profiles presented in *figures 2* and *3* show further peculiarities caused by radiation

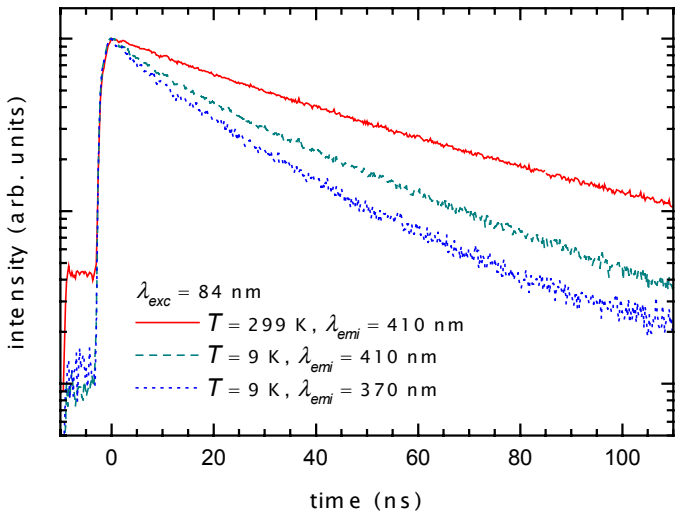

Figure 2: Time profiles of cerium luminescence in $Rb_3Lu(PO_4)_2$:Ce excited at 84 nm

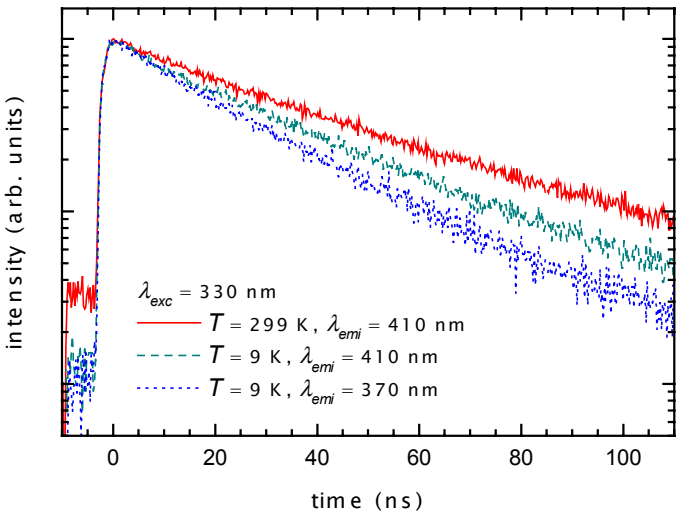

Figure 3: Time profiles of cerium luminescence in $Rb_3Lu(PO_4)_2$:Ce excited at 330 nm

trapping. Although in several cerium-activated materials longer decay time constants at RT comparing to LT have been explained by influence of charge traps [5], in case of the $Rb_3Lu(PO_4)_2$:Ce crystal we are sure that we deal with no trap-related effects, as its thermoluminescence glow curve reveals no peaks between 10 and 300 K [6]. Regardless of the excitation wavelength (84 or 330 nm) we observe that: *a)* the 410 nm emission is faster at LT than at RT; *b)* at LT the 370 nm is faster than the 410 nm one. Indeed, the following decay time constants $\tau = \tau(T; \lambda_{emi})$ have been derived from single-exponential fits:

$$\tau_1 = \tau(\mathrm{RT};\ 410\ \mathrm{nm}) \approx 39\ \mathrm{ns}$$

$$\tau_2 = \tau(\mathrm{LT};\ 410\ \mathrm{nm}) \approx 26\ \mathrm{ns}$$

$$\tau_3 = \tau(\mathrm{LT};\ 370\ \mathrm{nm}) \approx 22\ \mathrm{ns}$$

Besides a remarkable difference $\tau_1 - \tau_2 = 13$ ns we get a smaller one $\tau_2 - \tau_3 = 4$ ns. Both of them are associated with photons which are first emitted at 370 nm. At LT only a *part* of them whilst at RT *all* of them are subjected to radiation trapping and leave the crystal as retarded 410 nm photons.

Undoubtedly for fast scintillator applications the effect of radiation trapping is highly undesirable. Thus crystals with other cerium concentrations have been grown and will be examined.

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[6] W. Drozdowski, unpublished results