Investigation of Electron Traps in YAP:Ce

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Although cerium doped yttrium aluminum perovskite (YAP:Ce) has been widely used and studied one peculiar feature of this system, namely a difference in radiative (~18 ns) and scintillation decay times (25-38 ns) at room temperature remained unexplained and unexplored for a long time. Only recently it has been shown that this feature can be interpreted in the frame of a simple model that includes one recombination center (Ce^{3+}) and one shallow electron trap [1].

There has been a continued effort in the area of wide bandgap scintillator materials at the Hasylab's I beam SUPERLUMI station. In this note we report on measurements that contribute to that effort. We used superior VUV and timing features of the SUPERLUMI to measure emission time profiles of YAP:Ce under pulsed synchrotron excitation of 78 nm wavelength at various temperatures. We demonstrated that all important parameters of time profiles such as rise and decay times, amplitude of the dominant component and the background are altered by interference from a single electron trap. In particular these parameters assume characteristic thermal dependencies that are approximately described by a simple one-trap model of Wojtowicz et al. [1].

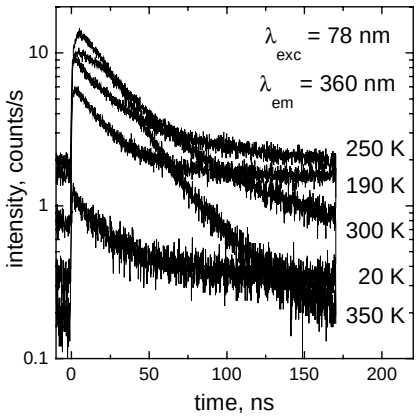

Figure 1: Time profiles of Ce-emission (360 nm) measured at various temperatures under 78 nm excitation.

In Fig. 1 we present a set of selected time profiles of YAP:Ce emission measured at 360 nm at various temperatures under pulsed 78 nm synchrotron excitation representative of general trends. At this wavelength optical excitation is likely to create electrons and holes that are able to separate. Presumably most of the mobile holes are almost immediately captured by cerium ions (creating Ce^{4+} ions) whereas the conduction band electrons can be trapped either by one of those Ce^{4+} ions (creating an excited Ce^{3+} ion and completing a cycle) or by one of electron traps that delay recombination at Ce ions and subsequent emission of light. Since at a given temperature T an electron will stay at the trap for a time: $\tau = (s \exp(-E/kT))^{-1}$, where E is the trap depth and s the frequency factor, the rate of the trap mediated contribution will strongly vary with temperature. At 20 K this rate is so low (much lower than the synchrotron repetition rate) that there is practically no contribution from the trap and emission is almost entirely due to a fast direct radiative recombination of *e-h* pairs at Ce^{3+} ions. At higher temperatures, however, the trap lifetime τ becomes eventually short enough to produce a measurable background which, at 190 K, is almost an order of magnitude higher than at 20 K. At still higher temperatures of 250 and 300 K the trap mediated component decay time at, say, 150 ns or less, is fast enough to modify the decaying part of the profile and contribute to the pulse itself and not to the background. At 350 K the trap lifetime becomes shorter than the Ce^{3+} radiative

lifetime of 18 ns. When this happens the trap component starts to interfere with the rising, instead of decaying, part of the profile. Both direct and trap mediated contributions to Ce^{3+} emission decay fast.

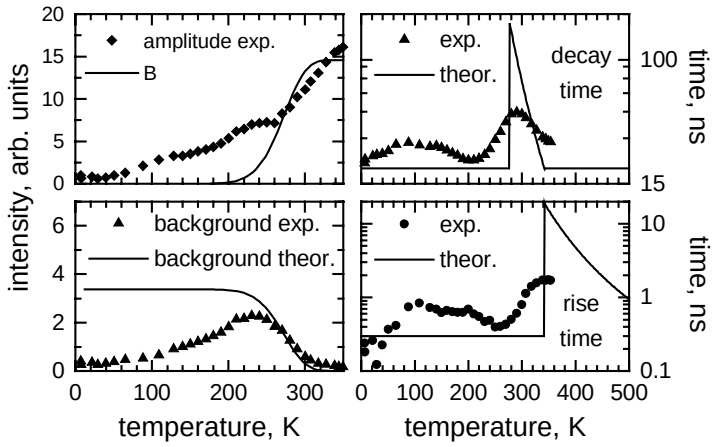

Figure 2: Fit parameters *A* (amplitude), *B* (background), τ_D (decay time) and τ_R (rise time) of Ce^{3+} emission time profiles under pulsed 78 nm synchrotron excitation.

In Fig. 2 we present four parameters, *A*, *B*, τ_D, and τ_R characterizing all of the measured time profiles. These parameters were obtained by a fitting procedure that employed a following function: $A\,[\exp(-t/\tau_D) - \exp(-t/\tau_R)] + B$. The first exponent stands for the decaying, trap mediated component (with a time constant of τ_D) and the second one for the rising component (with a time constant of τ_R). The form of the fitting function is based on approximation in which there is no distinction between the direct and fast trap mediated contributions. This approximation should be adequate to follow changes in relatively narrow time range determined by the synchrotron rep rate. Solid lines represent model calculations for which we have assumed the trap depth, $E = 0.28$ eV, and frequency factor, $s = 7 \cdot 10^{11}$ s^{-1} [1]. We have also, somewhat arbitrarily, assumed that for τ longer than 170 ns the trap contributes to the background and not to the emission pulse itself. Therefore we have set the decay time as equal to the Ce^{3+} radiative lifetime of 18 ns for all temperatures lower than the temperature for which τ is equal to 170 ns (about 290 K). Similarly, as long as the trap lifetime τ is longer than 18 ns it does not contribute to the rise time. Therefore we have set the rise time to 0.3 ns, approximately the instrumental response time, for all temperatures lower than about 320 K at which τ equals 0.3 ns. Consequently for higher temperatures the background drops, $B \sim \exp(-170\text{ ns}/\tau)$, whereas the amplitude *A* must then increases proportionally, $A \sim (1-B)$.

Clearly the simple one-trap model describes approximately, but reasonably well the thermal dependencies of our all four parameters. We conclude that scintillation mechanism in YAP:Ce is based on radiative recombination of charge carriers via Ce^{3+} ions. Electron traps, in particular the trap of 0.28 eV energy depth and $7 \cdot 10^{11}$ s^{-1} frequency factor, play an important role in kinetics of this system determining, at room temperature, scintillation decay times.

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References

[1] A.J. Wojtowicz, J. Glodo, A. Lempicki and C. Brecher, J. Phys: Cond. Matter 10 (1998) 8401.