Materials for Ultra Fast PET Scintillators

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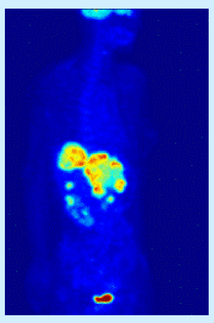
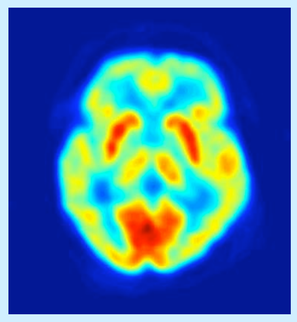
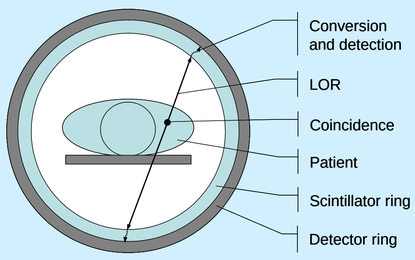
Background

The content of the work was research on inorganic luminescent materials used as radiation converter in Positron Emission Tomography (PET) machines. The research on new scintillator materials allows improving the performance, increasing safety and decreasing the cost of PET scanners. [1]

Host lattices were chosen from the group of already existing Ce^{3+} doped garnets scintillators. As innovation, Pr^{3+} fast ultraviolet (UV) emitting rare-earth ion was introduced as activator, doped into the structure in various concentrations.







PET is a medical imaging technique that allows generating a three-dimensional, cross-sectional image of human body.

Before medical investigation starts, the patient is injected with a radioactive material, so called PET tracer. It cumulates in organs and tumours according to the specific metabolism.

PET tracers emit positrons, which rapidly annihilate with electrons in the body tissue. Each annihilation event produces two gamma rays, which are recorded by the detector system and subsequently translated into a 3D-image.

$YBO_3:Pr^{3+}$

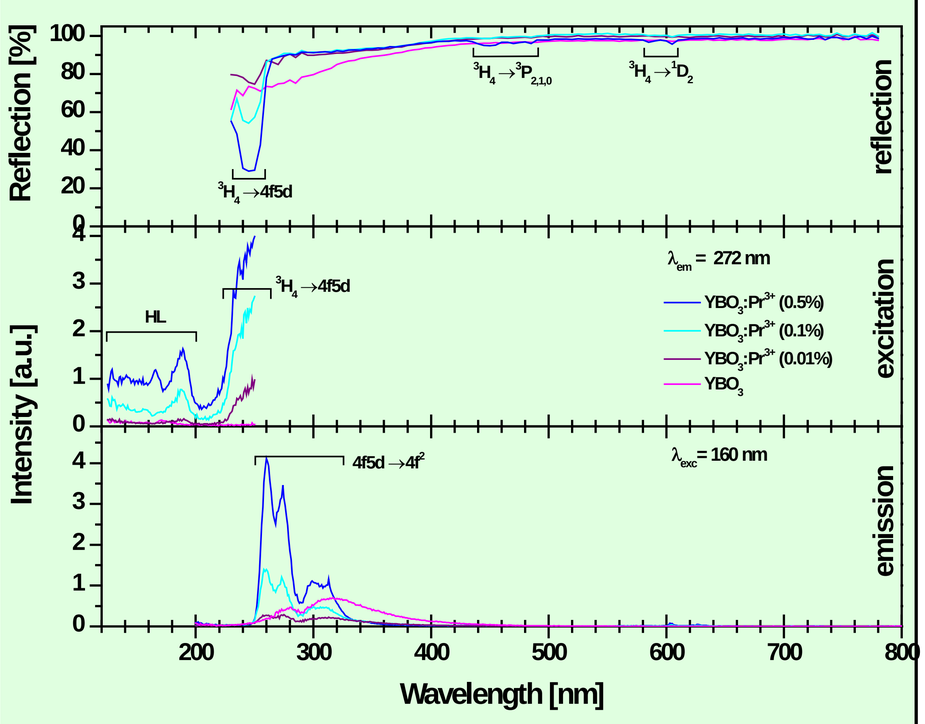


Fig. 1 $YBO_3:Pr^{3+}$ reflection, emission, excitation spectra.

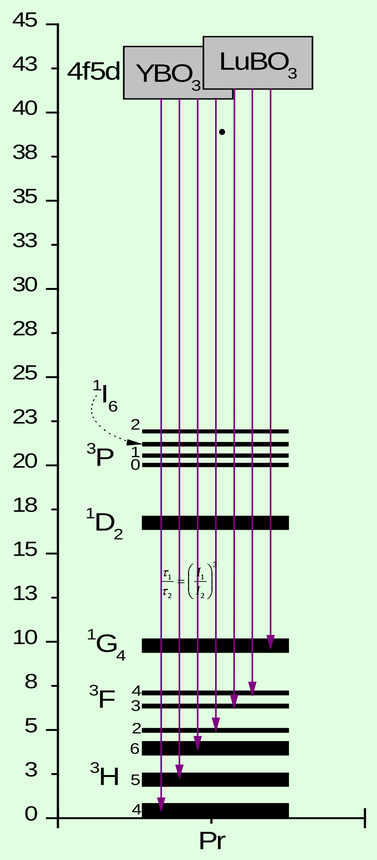


Fig. 2 Energy levels of Pr^{3+}ion in YBO_3 and $LuBO_3$.

$LuBO_3:Pr^{3+}$

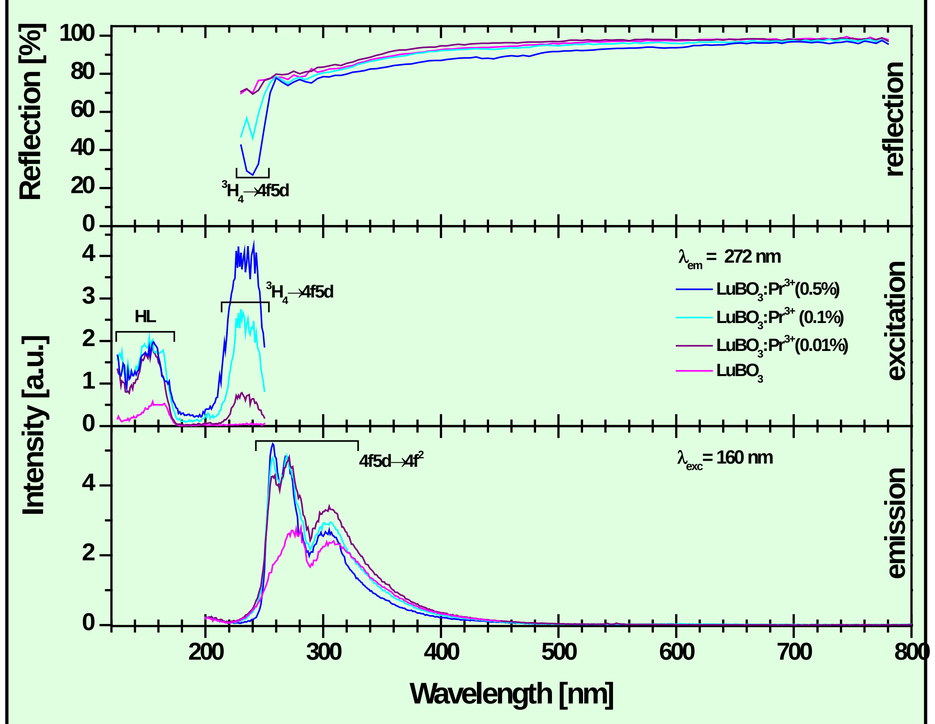


Fig. 3 $LuBO_3:Pr^{3+}$ reflection, emission, excitation spectra.

Experimental part

Praseodymium doped lutetium borate and yttrium borate samples were prepared by conventional solid-state reaction starting form Lu_2O_3 and Y_2O_3 respectively, H_3BO_3 and Pr_6O_{11}. An excess of H_3BO_3 (about 20 mole %) was used. The components were mixed in the agate mortar and placed into the crucibles. The calcinations were performed in two steps at 900°C (1h) and 1200°C (4h) with an intermediate grinding step.

The x-ray measurement was applied to ensure that obtained materials are single phase. Recorded patterns show that the crystallinity of $LuBO_3$ and YBO_3, calcinated at 1200°C, does not depend on the presence of the dopant. One can notice that the obtained powders are phase pure. All samples crystallize in a cubic structure with the space group Ia-3d (230).

Emission, excitation and reflection measurements were performed for all samples. YBO_3:Pr and $LuBO_3$:Pr compositions which show 5d - 4f transitions were selected for further decay time measurements. For those samples short decay time, viz. $\tau_{1/e}$ ~ 15 ns and $\tau_{1/e}$ ~ 13 ns were recorded.

References

[1] Korzhik, M., A. Fedorov, et al. (2007). "Development of scintillation materials for PET scanners." Nuclear Instruments and Methods in Physics Research A 571: 122–125.

[2] Ronda, C., A. Meijerink, et al. (2009) „Ultrafast emitting oxidic Pr^{3+} scintillating material: an overview"

Interpretation

The reflection spectra allowed localising the position of 4f5d levels of investigated samples, thus for $LuBO_3$:Pr 41600 cm^{-1} and for YBO_3:Pr 40800 cm^{-1} were calculated. As shown, the energy difference of those structures is small and is caused by the shift in wavelength of about 5 nm. It stays on the level of 0.1 eV.

As presented in Fig. 2 the 4f5d levels of $LuBO_3$:Pr and YBO_3:Pr are located around 41000 cm^{-1}. Applying the information of 4f5d states in the energy level diagram of Pr^{3+} helps explaining the shape of the 5d – 4f band in emission spectra. Therefore it is understood that broad 5d – 4f band is built form seven bands assigned as transition from 4f5d to $^3H_{4,5,6}$, $^3F_{2,3,4}$ and $^1G_4$ states.

It was surprising not to observe the emission to $^1D_2$ and $^3P_0$ states, which could originate the 4f - 4f transitions in the orange and red part of the spectrum. Neither emission from 4f5d to $^1D_2$ and $^3P_0$ nor 4f – 4f transitions were not registered. [2]

According to Einstein equations for allowed electric dipole transitions: $\tau_1/\tau_2 = (I_1/I_2)^3$, it was expected to record 4f5d transitions to $^1D_2$ and $^3P_0$ with much lower intensity than the other 5d – 4f transitions. The complete absence of emission intensity for these transitions is not understood.

Conclusions

As a result, applications of the examined Pr-doped $LuBO_3$ composition in PET scanners may contribute to reducing the patients exposure to radioactivity. Further advantages are: Improved resolution of the image due to high light yield, faster response time and absence of afterglow, high stopping power by the high density and increased PET availability by reduction of cost of PET machines.