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Abstract. Thermally induced fading of the thermoluminescent (TL) detectors in the form of $YAlO_3$:Mn ceramics prepared from the nanocrystalline materials synthesized by the solution combustion method have been measured and analyzed in comparison with the single crystalline $YAlO_3$:Mn detectors studied previously. The observed differences in thermoluminescent and dosimetric properties of nanoceramic and single crystalline detectors are discussed in terms of peculiarities of the nanoceramic material.

1. Introduction

Application potential of Mn^{2+}-doped $YAlO_3$ (YAP) for thermoluminescent (TL) dosimetry of ionizing radiation has been shown previously (see [1] and references herein). For this purpose, one of two types of detectors can be used. The first type produces green emission near 530 nm (caused by Mn^{2+} ions) in the main TL peak at 200 °C, whereas the second type produces an orange emission around 640 nm in the TL peak near 350 °C.

Main features of the single crystalline $YAlO_3$:Mn^{2+} detectors are as following: high thermochemical and time stability, high resistance to radiation damage, high sensitivity to ionizing radiation, extremely wide range of linearity (from few μGy up to few kGy), high effective atomic number (Z_{eff} = 31.4) and consequently high energy response, low thermal fading of single crystalline detectors. In such a way the material is a good candidate for wide-range dose measurements, especially when tissue equivalence is not required, as well as for a purpose of the radiation quality determination if used alongside with other low-Z materials.

The Mn-doped YAP mainly in the form of single crystals grown by the Czochralski method has been studied previously. However, an easy, cheap and practical method is preferred for synthesis of an efficient material applicable for TL dosimetry. The solution combustion synthesis is an appropriate method for obtaining of the Mn^{2+}-doped YAP nanoceramic detectors which have thermoluminescent properties [2,3] comparable with the corresponding single crystalline material. However, the thermally induced fading of the ceramic samples has not been studied yet.

Therefore, the purpose of the present work was detailed study of thermoluminescent and dosimetric properties of YAP:Mn ceramic detectors, in particular thermal fading, and analyze the results in comparison with the single crystalline detectors of similar nominal composition studied previously.

2. Experimental

As object of investigation, YAP:Mn^{2+} detectors in the form of ceramics prepared from the YAP:Mn,Hf nanocrystalline material synthesized by the solution combustion method using urea as a fuel were used The synthesis method of the nanocrystalline YAP:Mn,Hf powders was described in details in [2]. The Hf^{4+} co-doping was made for the charge compensation of Mn^{2+}. Samples of ceramic TL detectors were produced by pressing of the nano powders into pellets of 12 mm diameter and 3 mm thickness. After sintering in an oven at 1600 °C in air, the pellets were cut into the bits of the same size as single crystalline samples studied previously in [4] – 3×3×1 mm. TL readout of the detectors was performed using the Risø TL/OSL Reader Model DA-20 with a bialkali EMI 9235QB photomultiplier with β-($^{90}Sr/^{90}Y$) and α-(^{241}Am) irradiation sources, the heating rate of 2 °C/s was used.

For studying of thermally induced fading of the YAP:Mn detectors, the samples were stored in darkness (wrapped in aluminium foil) at room temperature. Before the irradiation procedure, the samples were annealed at 450 °C during half of an hour in air to erase any possible TL signal due to previous irradiation. An irradiation of the detectors similarly as storage was done in darkness.

3. Results and discussion

The studied YAP:Mn ceramic samples similarly to single crystalline YAP:Mn detectors have a main dosimetric TL peak near 200 °C (see [3] for details).

The figure 1 and figure 2 demonstrate thermally induced fading of the TL signal during dark storage of ceramic and crystalline YAP:Mn detectors at room temperature. As it is seen from the figure 1, ceramic detectors lose a half of TL signal magnitude already after 10 h of dark storage and up to 90 % of the signal after one-month dark storage. For comparison, the TL signal from crystalline YAP:Mn detectors lose no more than 20% during one-year dark storage (figure 2).

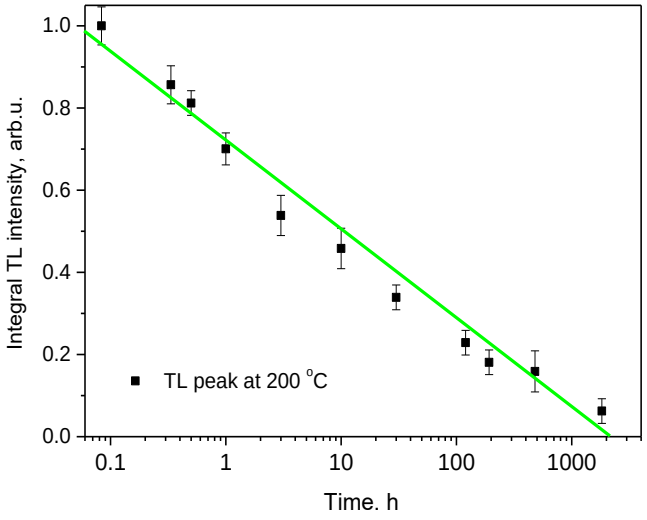

Figure 1. Thermal fading of the TL peak at 200 °C measured on ceramic YAP:Mn detectors after β-irradiation (from $^{90}Sr/^{90}Y$) and dark storage at room temperature.

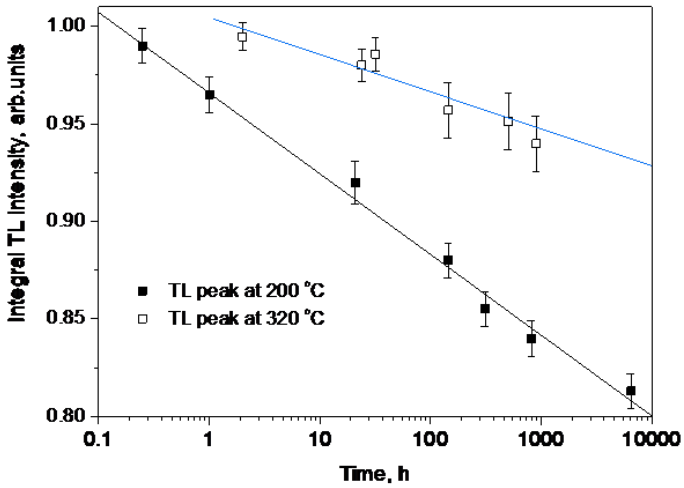

Figure 2. Thermal fading of the TL peak at 200 °C measured on single crystalline YAP:Mn detectors after γ-irradiation (*D*=100 Gy) and dark storage at room temperature [4].

Similar anomalous fading was also observed previously for Al_2O_3:Mg,Y ceramic detectors (see [5] and references therein). This common feature for the polycrystalline materials can be considered as typical for the oxide materials with large surface of grain boundaries and is caused most probably by recombination processes involving defects on grain boundaries.

4. Conclusions

The thermally induced fading of the nanoceramic YAP:Mn-based detectors has been studied and compared with results obtained on the single crystalline detectors.

The YAP:Mn-based ceramic TL detectors are found to have significant thermally induced fading (up to 90 %/month) anomalous for the TL peak at 200 °C, that is caused most probably by recombination processes involving defects on grain boundaries. By this reason, an applicability of nanoceramic YAP:Mn detectors in dosimetry of ionizing radiation is essentially limited when compared to the single crystalline YAP:Mn.

References

[1] Zhydachevskii Ya, Morgun A, Dubinski S, Yu Yan, Glowacki M, Ubizskii S, Chumak V, Berkowski M and Suchocki A 2016 *Radiat. Meas*. **90** 262-264.
[2] Zhydachevskii Ya, Kamińska I, Berkowski M, Twardak A, Bilski P, Ubizskii S and Suchocki A, 2014 *Opt. Mater*. **37** 125-131.
[3] Zhydachevskii Ya, Kamińska I, Berkowski M, Twardak A, Bilski P, Ubizskii S and A Suchocki 2014 *Proc. Int. Conf. on Oxide Materials for Electronic Engineering (Lviv, Ukraine)* (IEEE) p 261-262.
[4] Zhydachevskii Ya, Suchocki A, Berkowski M, Bilski P and Warchol S 2010 *Radiat. Meas.* **45** 516-518.
[5] Chen R and McKeever S W S 1997 *Theory of thermoluminescence and related phenomena* (Singapore: World Scientific).

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