High-Z TL/OSL detectors based on Mn-doped rare-earth aluminates

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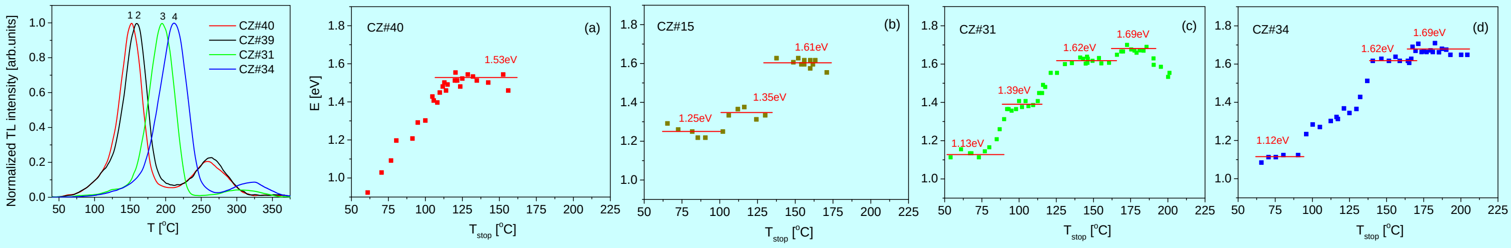
Motivation and aim of the work

Mn^{2+}-doped $YAlO_3$ (YAP) is known as a perspective high-Z material applicable for thermoluminescent (TL) or optically stimulated luminescent (OSL) dosimetry of ionizing radiation (see [1] and references therein). In particular, the green emission from Mn^{2+} ions occurring at the main TL peak at about 200 °C can be used for this purpose. This TL signal fades strongly at daylight (bleaching effect), therefore an optical stimulation by blue-green light can be used for its readout [2].

Detector materials having high effective atomic number (Z_{eff}), for which the photoelectric effect dominates especially for lower radiation energies, possess considerable energy dependence. This energy dependence can be used for characterization of spectral composition of radiation fields, which can be used in radiological emergencies and/or in high dose rate workplace fields [3].

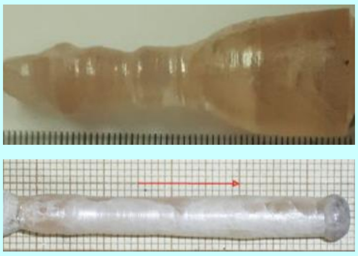
The present study deals with further improvement of YAP:Mn-based detector (Z_{eff} ~ 31.4) in order to increase the effective atomic number of the material even more as well as to improve the TL and OSL properties of the material important for its practical application in radiation dosimetry. In particular, the (Y-Lu)AP and (Y-Gd)AP host materials doped with Mn^{2+} ions have been studied and compared with the YAP:Mn^{2+} detectors studied previously.

TSL and trap depths



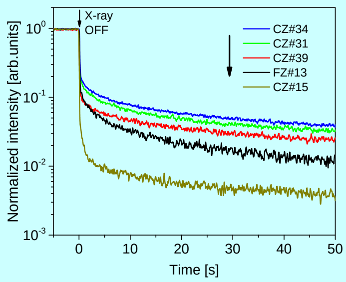
Thermal glow of X-ray irradiated crystals and trap depths estimated by the initial rise method in the partial thermal cleaning procedure for the (Y-Gd)AP:Mn,Hf (CZ#40), YAP:Mn,Si (CZ#15), (Y-Gd)AP:Mn,Hf (CZ#39), YAP:Mn,Hf (CZ#31), and (Y-Lu)AP:Mn,Hf (CZ#34) crystals recorded at 530 nm.

Czochralski (CZ) and floating-zone (FZ) crystal growth



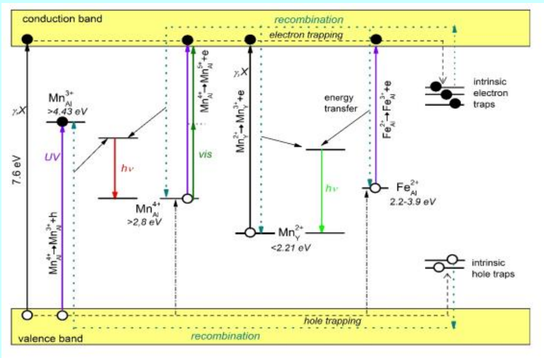
Typical view of (Y,Gd)AlO_3:Mn,Hf crystals grown by the Czochralski (CZ#40) (a) and the floating-zone (FZ#13) (b) methods.

Afterglow

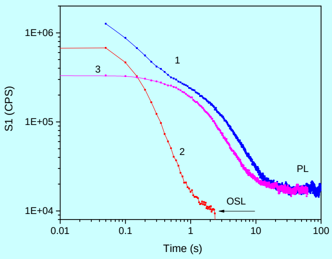


Afterglow decay kinetics measured for selected crystals at 530 nm at room temperature after X-ray irradiation.

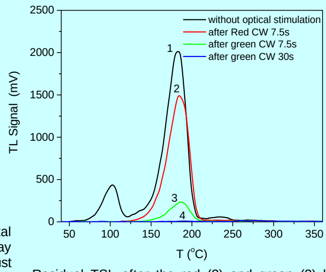
Trapping and recombination mechanisms [4]



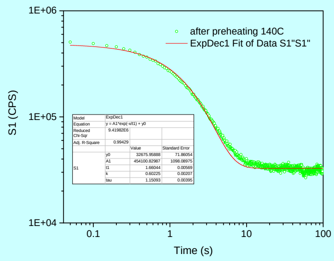
CW-OSL under red or green laser stimulation



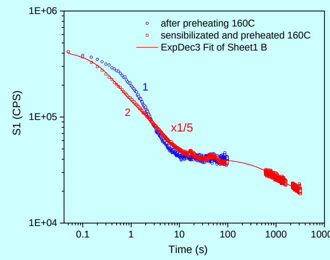
Typical CW-OSL decay kinetics for YAP:Mn,Si (CZ#15) crystal under green laser (532 nm, 0.8 W) stimulation just after X-ray irradiation (1); under red laser (635 нм, 0.5 W) stimulation just after X-ray irradiation (2); under green laser stimulation after the 2.5 s red laser stimulation (curve 2). Optical registration through the bandpass filter MF 497-16.



Residual TSL after the red (2) and green (3) laser stimulation of the X-ray irradiated YAP:Mn,Si (CZ#15) crystal.



CW-OSL decay curve of the YAP:Mn,Si(CZ#15) crystal under the green laser stimulation after previous depopulation of shallow traps.



CW-OSL decay of the YAP:Mn,Si(CZ#15) crystal after relatively small dose of X-ray irradiation under the green laser stimulation of the preliminary fully warmed crystal (1) and of the "sensitized" crystal (2). Curve 2 is divided by 5.

Summary

♦ Various kinds of (Lu,Y,Gd)AlO_3:Mn^{2+},Si(Hf) crystals grown by the Czochralski (CZ) and the floating-zone (FZ) techniques have been studied.

♦ The band-gap engineering (replacement of Y by Lu or Gd) allows to change significantly temperature of the main TSL peak position in the studied crystals by changing energy depths of the main traps.

♦ At the same time it was revealed that the partial replacement of Y by Lu or Gd does not influence significantly on presence of shallow traps responsible for the afterglow of the crystals at room temperature. Much greater influence on the afterglow was found for different codopants used (Si^{4+} or Hf^{4+}).

♦ The CW-OSL decay under a green laser stimulation contains at least three components. The first one with a decay constant ~0.1 s (0.8W- 532nm-laser) corresponds to optical depopulation of shallow traps. The second (main) component with a decay constant of few seconds corresponds to depopulation of the dosimetric traps (TSL @ ~200 C) mainly, while the third longest one – depopulation of deep traps, population of which sensitizes the main dosimetric traps.

References:

[1] Ya. Zhydachevskii et al., Energy response of the TL detectors based on $YAlO_3$:Mn crystals, *Radiat. Meas.* 90 (2016) 262-264.
[2] Ya. Zhydachevskii et al., Time-resolved OSL studies of $YAlO_3$:Mn^{2+} crystals, *Radiat. Meas.* 94 (2016) 18-22.
[3] V. Chumak et al., Passive system for characterization of spectral composition of high dose rate workplace fields: potential application of high Z OSL phosphors, *Radiat. Meas.* 106 (2017) 638-643.
[4] H. Przybylińska et al., Electron Paramagnetic Resonance and Optical Studies of Thermoluminescence Processes in Mn doped $YAlO_3$ Single Crystals, *J. Phys. Chem. C* 126 (2022) 743-753.

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