OPTICAL PROPERTIES AND RADIATION DAMAGES OF CERIUM FLUORIDE CRYSTALS DOPED WITH ALKALI-EARTH AND RARE-EARTH ELEMENTS

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Crystals of CeF_3 were grown in State Optical Institute (SOI) by the Stockberger method in vacuum. The raw material was doped with 4% PbF_2 or CdF_2 to decrease the content of oxygen in samples and improve transparency. The X-ray fluorescence analysis showed presence of 0.1% cadmium or 0.01–0.05% of lead in the grown crystals. Such small concentration of PbF_2 doesn't affect the optical properties and radiation hardness of CeF_3 crystals and from this point of view such crystals can be considered as pure.

In total, about 200 experimental samples were grown and doped with different elements — Ca, Ba, Sr, Pb, Cd, La, Nd, Zr, and Hf in the range of concentrations from 0.005% up to 5%.

Emission spectra of CeF_3 crystals were recorded under UV-flashlight excitation in the wavelength range (200–400) nm with the help of a standard monochromator MDR-2 with the resolution of 1 nm. Luminescence decay curves after pulsed X-ray excitation were measured using single photon counting method. The time resolution was approximately 100 ps. To study radiation damages of crystals, ^{60}Co γ-ray sources were used in the range of dose rate of (0.5–10.0) krad/min.

Photo and Roentgen-luminescence (RL) spectra of both pure CeF_3 crystals and those doped with different elements have been measured. RL spectrum of pure sample has one band at $T = 300$ K peaked at 305 nm, doped crystals have more wide spectra — (305–450) nm, time decay curves for RL have two components: fast with $\tau_f \leq 10$ ns and slow with $\tau_s \simeq 30$ ns. Parameters of two-exponential fits to experimental data and light yields (LY) of some studied samples are given in Table.

Table

Parameters of exponential fit to the luminescence decay curves of doped CeF_3 crystals

Doped comp., percents	Relative LY	Fast comp., τ_f,ns	Slow comp., τ_s,ns	Fast/Total, percents
BaF_2 2.5	1.06	6.5±0.3	34.0±2.0	26±4
CaF_2 2.5	0.95	2.8±0.3	31.0±2.0	12±2
HfF_4 0.01	2.11	5.5±0.4	43.5±3.0	10.0±1.5
LaF_3 0.1	1.57	4.0±0.3	38.0±2.0	10.0±2.0
BaF_2 0.3 & HfF_4 0.01	1.16	6.7±0.3	39.0±2.0	14±2

All light yields are normalized on the LY of our "undoped" CeF_3 crystal (CeF_3 + 0.01% PbF_2).

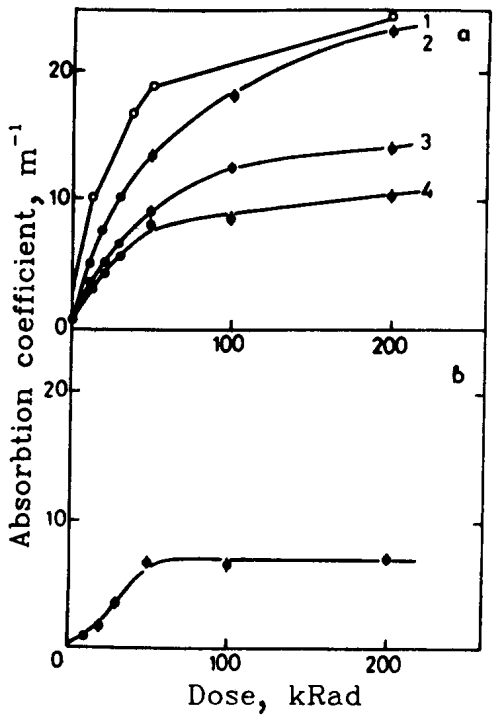

Fig.1. Absorption coefficient at 340 nm as function of dose for CeF_3 crystals:
a) 1 — $-CeF_3 + 0.5\%Ba$ (OPTOVAC); 2,3,4 — CeF_3 (SOI) doped with $2.5\%Ca$, $0.3\%Ba$, $0.5\%Ba$ corr.
b) CeF_3 doped with $0.5\%Ba$ & $0.01\%Hf$

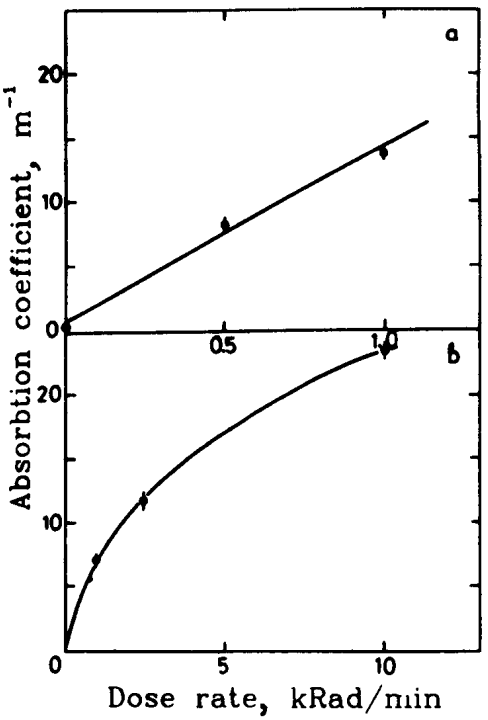

Fig.2. Absorption coefficient at 340 nm as function of dose rate for two samples:
a) $CeF_3 + 2.5\% Ca$ was irradiated to 50 krad,
b) $CeF_3 + 0.3\% Ba + 0.01\% Hf$ was irradiated to 200 krad

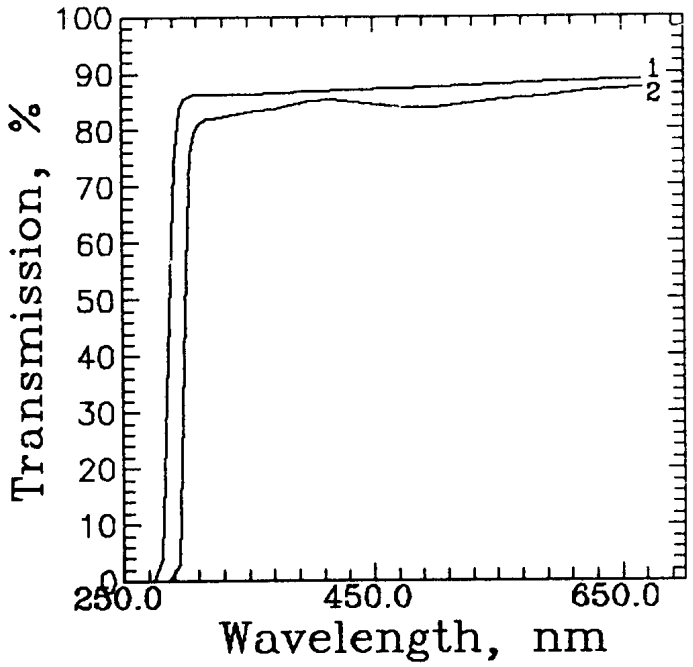

Fig.3. Transmission spectra of two CeF_3 crystals:
1 — Pure CeF_3 (OPTOVAC) after irradiation by the dose 100 krad,
2 — $CeF_3 + 0.3\%\, Ba + 0.01\%\, Hf$ (SOI) after irradiation by the dose 200 krad

Transmission spectra of the base crystal ($CeF_3 + 0.1\%\ PbF_2$) were measured as a function of doped elements concentration in wide range of concentrations. Samples doped with (0.3–3.0)% Ba, (2–5)% Ca have approximately 100% transmission at $\lambda = 340$ nm with a short wavelength edge at (290–295) nm. Small doping with 3 or 4 valence elements such of crystals improves essentially the radiation hardness of crystals (Figs.1,2). CeF_3 crystals as well as BaF_2 studied by us earlier [1] have the most essential appearance of radiation damages at small doses — (10–20) krad showing then the saturation effect for higher doses. Besides, radiation hardness (Fig.2) depends apparently on the dose rate, increasing with the reduction of the latter. The very important feature of CeF_3, especially for samples doped with 0.5% and 0.01% Hf, 0.1% La, 0.01% Zr and 0.01% Nd, is a fast self-recovery at room temperature. Together with small level of radiation damages caused to the crystals in experiments performed with low dose rates, fast spontaneous recovery makes CeF_3 doped with elements like Ba, Hf, Zr and Nd very perspective heavy scintillators for electromagnetic calorimeters. In Fig.3 the comparison of radiation hardness for the crystals manufactured by OPTOVAC and SOI is given. The figure demonstrates approximately similar properties of purified expensive sample from OPTOVAC [2] and the less expensive crystal (SOI) made from ordinary raw material.

REFERENCES

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