Multicomponent garnet film scintillators for SEM electron detectors

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With an Everhart-Thornley (ET) scintillation detector in SEM, an image is formed by signal electrons emerged after an interaction of focused scanning electron beam with the specimen surface. In such a case a scintillator plays an important role as a fast electron-photon signal conversion element. A selection of fast scintillation materials is very limited, because the only mechanism for scintillators applicable in SEM ET detectors consists in allowed 5d-4f transitions in lanthanide ions. Unfortunately, the widely used Czochralski grown single crystal YAG:Ce scintillators suffer from an afterglow, which deteriorate the ability to transfer high image contrast. The mentioned afterglow in the bulk single crystal is caused by inevitable structural defects, such as antisite defects. These trap states are responsible not only for delayed radiative recombination causing the afterglow, but also for a degradation of the light yield. The aim of this study is to introduce new multicomponent garnet film scintillators for SEM electron detectors that due to the substitution of Al by Ga in the $Gd_3Al_5O_{12}$:Ce garnet extensively supress the shallow traps resulting in a significant increase of the cathodoluminescence (CL) efficiency and in improvement of the afterglow characteristics.

To avoid the defective bulk scintillators, isothermal dipping liquid phase epitaxy was chosen as a method for garnet single crystalline film preparation [1]. The high purity Ce activated GAGG ($Gd_3Al_{1.7}Ga_{3.3}O_{12}$:Ce) film of the thickness of 11 µm, grown on the single crystal YGG ($Y_3Ga_5O_{12}$) substrate, was chosen to assess its applicability as the scintillator in the scintillation detector in SEM. Results of Monte Carlo (MC) simulation of electron interaction [2] in the GAGG:Ce film as well as in the YAG:Ce bulk scintillator in different depth of the scintillator are shown in Fig. 1. It is evident from the MC simulation that electron interaction active layers of the garnet scintillators are much thinner than 10 µm for standard signal electron energy. Furthermore, it is seen that the GAGG:Ce scintillators may be even thinner than the YAG:Ce ones. Comparison of optical absorption coefficients of the GAGG:Ce film, YAG:Ce crystal and YGG substrate is in Fig. 2, and CL emission spectra of these scintillators obtained using the apparatus for the cathodoluminescence study [3] are shown in Fig. 3. The optical self-absorption together with the refractive index and the emission spectra of the scintillators are very important quantities for an assessment of the signal photon transport in the both examined scintillators. Although the GAGG:Ce film exhibits higher optical absorption, it has a higher collection efficiency of signal photons, since the path of photons in this film is much shorter than the path of photons in the bulk YAG:Ce scintillator, which was verified by MC simulation of a light transport [4] in the scintillation detector for SEM. As seen in Fig. 3, the CL efficiency of both scintillators is approximately the same. However, the GAGG:Ce film do not suffer from parasitic UV host emission. Regarding the scintillator-PMT matching, for both scintillators the photocathode S20 should be used. CL decay characteristics of both examined scintillators, measured using the CL apparatus [3], are shown in Fig. 4. The decay time as low as 22 ns and the afterglow of only 0.043 % at 0.5 µs after the end of excitation predetermines the GAGG:Ce film scintillators for extremely fast and efficient electron detectors in SEMs.

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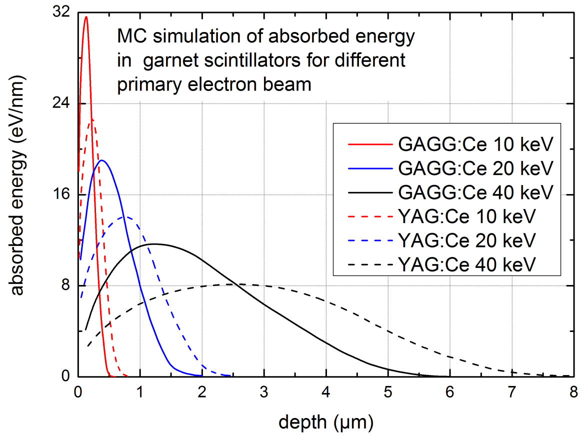

Fig. 1. Monte Carlo simulation of electron absorbed energy distribution in GAGG:Ce and YAG:Ce scintillators for different primary electron beam.

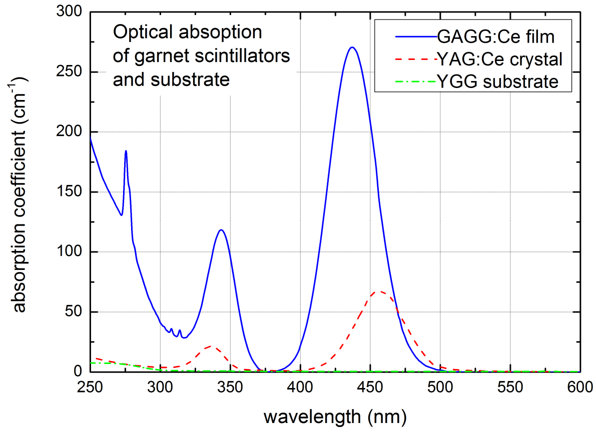

Fig. 2 Optical absorption spectra of GAGG:Ce film scintillator, YAG:Ce single crystal scintillator and of YGG single crystal substrate.

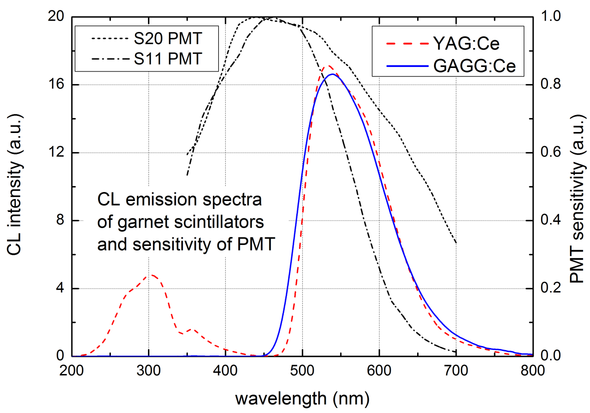

Fig. 3 Cathodoluminescence emission spectra of GAGG:Ce film and YAG:Ce single crystal scintillators together with sensitivities of standard PMT photocathodes.

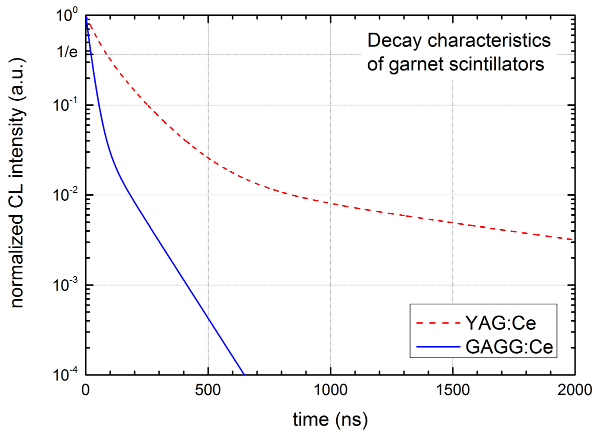

Fig. 4 Cathodoluminescence decay characteristics of GAGG:Ce film scintillator and YAG:Ce single crystal scintillator.