Perspective scintillation electron detectors for S(T)EM

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Any detector is valuable if it doesn't waste the collected signal, doesn't introduce noise, and its response is sufficiently fast. The important indicator of an image quality is the modulation transfer function (MTF) which describes the ability to show fine image details. Using a scanning imaging system with a scintillation electron detector, the detector bandwidth, which is given especially by the scintillator time response, is the key to the good MTF. Not less important parameters are those affecting the detective quantum efficiency (DQE) which is primarily a measure of image noise. Efficient components with the high bandwidth and dynamic range are the key to the high DQE. To find the neck of a scintillation detection system, one must examine the whole detection path step by step. In fact, only three parameters of currently used standard scintillation electron detectors for S(T)EM can be referred as weaknesses of the system. These are (1) scintillator conversion efficiency, (2) scintillator time response and (3) photon collection efficiency. Unfortunately, there is no great chance to improve the conversion efficiency, because the values for garnet scintillators are close to the theoretical limit. The other two parameters have prospects of improvement.

The detector time response is determined by the kinetics of the scintillator, which is currently intensively studied. Great progress has been made in garnet scintillator research. By alteration the Czochralski crystal growth to the liquid phase epitaxy (LPE) the antisite defects can be eliminated. Composition and defect engineering (Nikl et al., 2014) are another ways to improve the time response of the YAG:Ce scintillators. As a result of these approaches, new LuGAGG:Ce,Mg single crystalline garnet film scintillators were prepared and studied. Using the Monte Carlo (MC) simulation of electron interaction in a solid the active film thickness was analyzed (Fig. 1), which is only about 500 nm for 10 keV signal electrons. As shown in Table 1, the decay time and afterglow (1 µs after excitation) of the LuGAGG:Ce,Mg scintillator are as low as 28 ns and 0.02 %, respectively (Schauer et al., 2017). Utilizing these values the ability to show fine image details was calculated (Bok and Schauer, 2014), and results are compared in Fig. 2. It is seen that YAG:Ce loses the contrast transfer ability at small details already above 0.1 lp/pixel while new LuGAGG:Ce,Mg up above 0.6 lp/pixel. As is shown in Fig. 3, although the new LuGAGG:Ce,Mg films exhibit a little higher optical self-absorption than the standard YAG:Ce crystals, they have a higher photon collection efficiency, since the photon paths in the films are much shorter than in the bulk scintillators. The refractive indexes of the new films, of their substrates and of YAG:Ce are nearly the same, so that the photon collection angles are not very different. An important reserve in the performance of detection systems is also the optimization of their light-guiding part. Especially for the non-optimized BSE detectors, the photon transport efficiency is only in the order of 10^{-2} (Schauer, 2007). This parameter of the scintillation electron detector for S(T)EM has great prospects of improvement.

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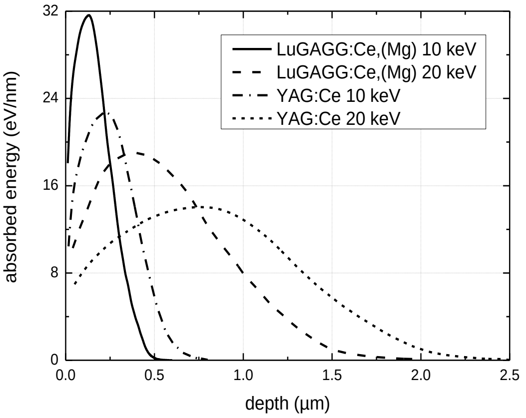

Fig. 1. Monte Carlo simulation of absorbed energy in garnet scintillators for different primary electron beam.

Scintillator	material form	τ_e (ns)	$AG_{1\mu s}$ (%)	LY (a.u.)
YAG:Ce	single crystal	85	0.81	206
YAP:Ce	single crystal	24	0.13	302
LuGAGG:Ce	LPE film	61	0.10	217
LuGAGG:Ce,Mg	LPE film	28	0.02	165

Table 1. CL properties of the new film scintillators compared with the standard YAG:Ce and YAP:Ce single crystal ones. τ_e is the decay time (decay to 1/e value), $AG_{1\mu s}$ is the afterglow at 1 µs after excitation, LY is the relative light yield.

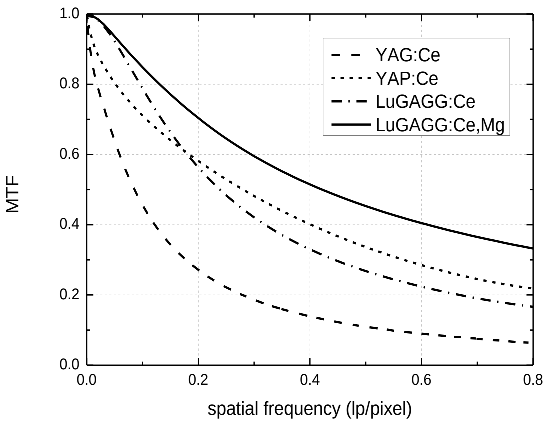

Fig. 2. Modulation Transfer Function of different scintillators in the SEM detector. The time per pixel (dwelltime) during the scanning is 50ns.

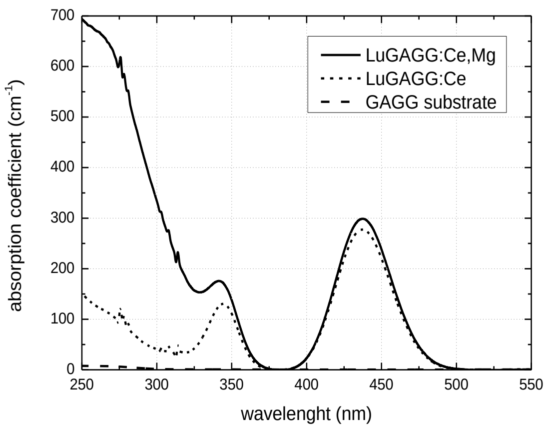

Fig. 3. Optical absorption coefficients of the LPE film scintillators and of their GAGG substrates.