Optimization of scintillation detector for SEM

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Keywords: SEM detector, scintillator, light-guide, optimization

Detective quantum efficiency (DQE) [1] is the best quantity for characterisation of the detector quality. Unfortunately, low DQE of a poor detector gives nearly no information about the limiting component. To enhance the bad scintillation detector, one has to divide its performance into particular events. Electron collection, photon generation, escape from scintillator, coupling to light-guide, losses in light-guide, photoelectron generation, as well as collection and multiplication in a photomultiplier tube (PMT) are the most significant events in the scintillation detector for SEM. To analyse these events and optimise the detector, a lot of important quantities of detector components (such as conversion efficiency, decay time, intrinsic noise and optical reflectivity, transmittance and matching) must be known. Thereafter, properties of each component can be calculated from individual quantities, and properties of the whole detector can be determined using a convolution.

The first step of detector optimization is an analysis of the scintillator. Important properties of some single crystal scintillators are listed in Table I. Of course, high conversion efficiency of a scintillator is the most crucial quantity, but it can be totally degraded if the scintillator is slow, possesses high self absorption, has extremely high index of refraction, emits light in the spectral region of the low light-guide transmittance or of the low photocathode sensitivity. It is seen from Table I as well as from Figure 1 and Figure 2 of the optical transmittance and of the photocathode sensitivity, respectively, the most often used (relatively cheap) YAG:Ce single crystal is not the most optimal scintillator. The better choice is the YAP:Ce one.

In the next steps of optimization the materials of the light-guide, photocathode, conductive and reflective films and of the optical cement have to be evaluated. The optical characteristics shown in Figure 1 and Figure 2 are utilised at these steps of optimization. In fact, the PMT choice, including its photocathode matching, is a relatively simple task, because PMTs are well developed commercial components with precise data sheets.

Table I. Properties of single crystal scintillators for SEM. [1]Quantities dependent on the crystal annealing. [2]Peak of the main emission band. [3]Full width of the half maximum of the main emission band. [4]Matching to the spectral response of S20 photocathode. [5]Matching to the spectral response of S11 photocathode.

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	formula	density (g/cm^3)	index of refract.	relative efficiency[1]	decay time[1] (ns)	emission max.[2] (nm)	FWHM[3] (nm)	S20 PMT matching[4] (%)	S11 PMT matching[5] (%)
YAG:Ce	$Y_3Al_5O_{12}$:Ce	4.57	1.83	100-120	70-100	560	122	73	45
YAP:Ce	$YAlO_3$:Ce	5.37	1.95	142	38	366	52	60	58
P47	Y_2SiO_5:Ce	n/a	n/a	126	34	420	77	85	80
CaF_2:Eu	CaF_2:Eu	3.18	1.44	131	1200	426	30	92	88

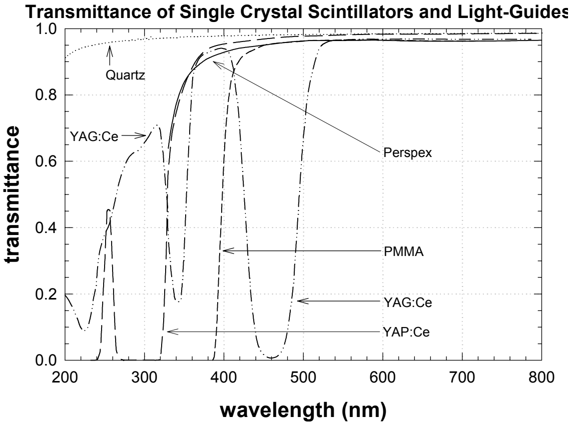

Figure 2. Optical transmittance of the YAG:Ce (thickness 0.41 mm) and YAP:Ce (0.37 mm) single crystal scintillators and of the PMMA (50 mm), Perspex (52 mm) and quartz (50 mm) light-guiding materials.

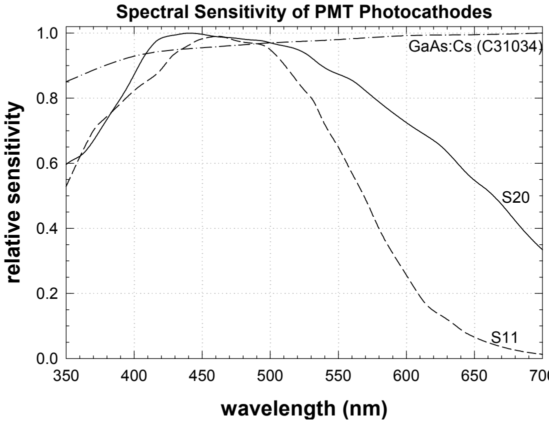

Figure 1. Normalized spectral response of the sensitivities of PMT photocathodes. **S20**: THORN EMI 9558B, **S11**: TESLA 65PK415, **GaAs:Cs**: BURLE C31034.

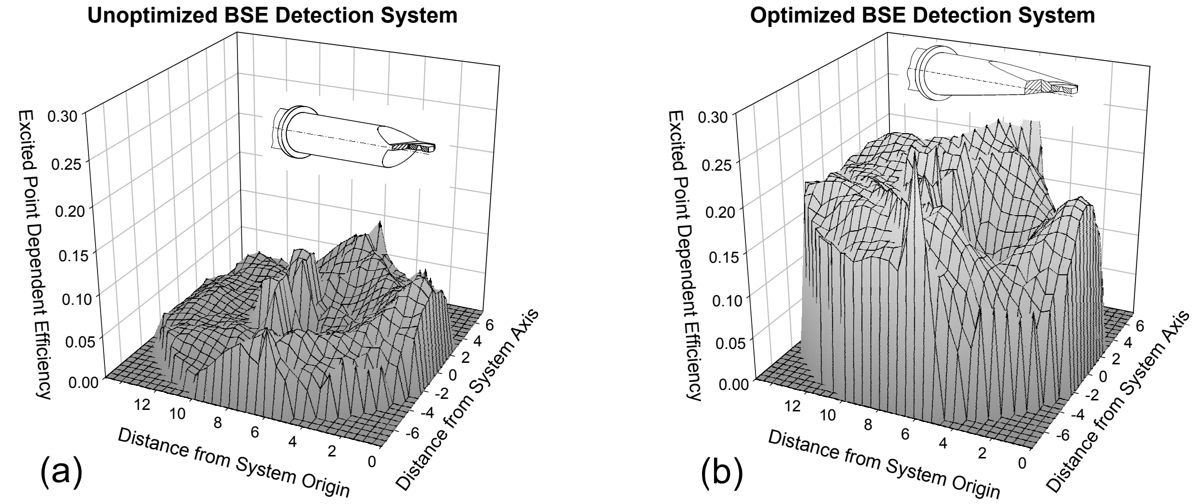

Figure 3. Monte Carlo simulation of the efficiencies of the photon transport through whole scintillation detection systems possessing **(a)** the bad **(b)** the good geometry. 3D graph represents the dependence of the photon transport efficiency on the coordinates of the excitation point at the surface of the scintillator.

Omitting the electron collection at the scintillator, the design of the system geometry is the most demanding step of optimization. The efficient geometry is dependent on a lot of optical quantities of all components used, and no simple method is available for this step. To determine the photon transport efficiency, the Monte Carlo simulation method has been developed [2,3]. In Figure 3, the significance of this step of optimization is demonstrated by presenting the efficiency of the bad and good geometry of BSE scintillation detector for the S 4000 Hitachi SEM. The good system possesses transport efficiency of about 400 % compared with the bad one.

This work was supported by the grant No. 102/04/2144 of the Grant Agency of the Czech Republic.

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