Coatings of single crystal scintillators for electron detectors in SEM

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The scintillator in the Everhart-Thornley detector of electrons collects signal electrons and transforms them into photons that are more suitable for signal processing. The surface of the scintillator hit by the signal electrons (input surface) must be conductive enough to prevent charging and must show high internal optical reflectivity in the spectral range of scintillator emission to ensure the collection of signal photons toward the photocathode of the photomultiplier (PMT). All currently used scintillators are non-conductive and it is therefore necessary to provide their input surfaces with a thin conductive coating. The coating must be thin enough not to absorb the energy of signal electrons and at the same time thick enough to be conductive and to show high optical reflectivity. It is difficult to meet these conflicting requirements. Moreover, the choice of the suitable material and thickness of the coating depends on the material and geometry of the scintillator and light guide. The aim of this paper is to analyse the influence of the thin film coating applied to the polished input surface of the YAG:Ce single crystal scintillator on the signal losses in SEM. Optically non-transparent (metal) Al and Ag films (including the Ag-Al double layer) and the transparent indium tin oxide (ITO) film have been investigated. For comparison, layers with ideal reflectivity and no reflectivity, respectively, were included. For experiments, the YAG:Ce single crystal substrate was provided with films prepared by magnetron target sputtering. Results are shown in eight main columns of Table 1. As evident from col. 1, the electrical resistivity measured was three orders lower for metal films than for ITO.

The losses due to the absorption of signal electrons in the thin conductive film cannot be determined according to Bethe's law with sufficient accuracy. During the passage through the film, the electrons are scattered so that the absorbed energy is always higher than Bethe's formula gives. The difference increases with increasing magnitude of the incidence angle of signal electrons. Monte Carlo (MC) simulation was used to evaluate the losses due to the absorption in the films deposited on the YAG:Ce single crystal (col. 3 of Table 1). The single scattering algorithm with the screened Rutherford elastic cross-section and the Bethe continuous slowing-down energy loss were used [1]. At an energy of 10 keV (used for simulation), the signal absorbed in the investigated Al and ITO films is low. For lower energies, it is more advantageous to use Al which has, in addition, higher conductivity. Ag films show too high absorption even for small thicknesses. The Ag-Al double layer is however acceptable. Its properties with regard to energy absorption can be further improved if the Ag layer thickness is decreased. The same MC method was used for determining the signal losses due to the backscattered electron (BSE) energy. It is evident from col. 2 in Table 1 that the films with the atomic number $Z<Z_{YAG}$ have a favourable effect, and compared with the uncoated surfaces, they decrease the BSE energy losses, whereas films with $Z>Z_{YAG}$ increase the BSE energy losses.

Losses due to the reflection of signal photons occurring at the internal scintillator - conductive film boundary are part of losses of the light guiding system. The internal reflectivity of the investigated films was evaluated using the matrix method [2] (col. 4 of Table 1). To verify the results experimentally, the optical reflectivity (col. 5) was measured by the spectroscopic reflectometry method [3] for normal incidence. The knowledge of the value of reflectivity is important but it is not a sufficient prerequisite for the determination of the losses occurring during the photon transport toward PMT. The extent of influence of the film depends strongly on the optical properties and especially on the geometry of the scintillator and light guide. The effect of the film can be determined analytically only for very

Table 1. Signal losses in thin film coating, and scintillator - light guide (LG) system efficiency

FILM	THICK-NESS (nm)	ELECT. RESIS-TIVITY (Ω/□)	MC CALCULATION OF BSE ENERGY (%)			MC CALC. OF ELECTRON ENERGY ABSORBED IN FILM (%)			CALCULATED OPTICAL REFLECTIVITY AT 550 nm (%)		
			tilt 0°	tilt 30°	tilt 60°	tilt 0°	tilt 30°	tilt 60°	tilt 0°	tilt 30°	tilt 60°
Al	50	<10	7.9	10.1	23.7	3.9	4.9	16.4	85.7	85.7	84.8
	35	<10	8.7	10.7	24.4	2.5	2.5	11.2	84.6	84.6	84.0
Ag	30	<10	23.0	28.6	46.2	16.8	25.4	39.5	77.9	79.2	96.7
	15	<10	15.4	19.7	40.8	8.3	10.1	31.2	44.2	50.2	96.0
Ag-Al	15-35	<10	12.5	20.5	38.2	12.4	14.6	36.2	92.3	92.5	93.4
ITO	10	<10000	11.2	15.3	31.2	1.5	2.8	12.1	8.4	17.8	94.2
ideal	---	0	0	0	0	0	0	0	100	100	100
non-reflect.	---	---	BS and absorb. energy losses are considered min. (Al 35 nm)						0	0	0

FILM	THICK-NESS (nm)	MEAS. OPTICAL REFL. (%)	LIGHT COLLECTION FROM SCINTILLATOR - LG SYSTEM (%)			DETECTION EFFICIENCY OF SCINTILLATOR - LG SYSTEM FOR SE (%)			DETECTION EFFICIENCY OF SCINTILLATOR - LG SYSTEM FOR BSE (%)		
			DISC	CONE	HEMISPH.	DISC	CONE	HEMISPH.	DISC	CONE	HEMISPH.
Al	50	84	19.5	24.6	11.5	0.690	0.871	0.407	0.690	0.841	0.355
	35	83	19.5	24.2	11.2	0.694	0.862	0.399	0.694	0.843	0.356
Ag	30	76	21.1	26.0	16.2	0.541	0.666	0.415	0.541	0.554	0.311
	15	42	20.8	18.6	15.9	0.645	0.577	0.493	0.645	0.537	0.401
Ag-Al	15-35	92	21.3	28.7	14.8	0.653	0.880	0.454	0.653	0.779	0.360
ITO	10	8	21.3	12.3	16.8	0.745	0.430	0.588	0.745	0.405	0.511
ideal	---	---	22.7	31.7	18.2	0.908	1.268	0.728	0.908	1.268	0.728
non-reflect.	---	---	8.4	0.7	0.7	0.299	0.025	0.025	0.299	0.024	0.012

simple systems with a high symmetry. The efficiency of collection of light from the scintillator - light guide system (col. 6 in Table 1) was, therefore, simulated using the MC method [4]. The principle of the method is the repeated simulation of the trajectory of a randomly chosen photon. For each interaction of the photon with the boundary, the probability whether the photon reaches the photocathode of the PMT is established. Films deposited on the polished disc scintillator with the matted output surface and films deposited on the conical and hemispherical scintillators with all polished surfaces were used for simulation. The scintillators were connected to a simple cylindrical polymethyl methacrylate light guide without optical cement. It is obvious from the results given in Table 1 that the optical reflectivity of the film affects least the systems with the disc scintillator, more those with the hemispherical scintillator and most the systems with the conical scintillator. With the systems containing the disc or hemispherical scintillator, the magnitude of reflectivity for angles >33° plays the decisive role. Table 1 does not reveal the very important finding [4] that the disc scintillator is suitable only for simple cylindrical light guides and the hemispherical scintillator rather for lower efficiency tapered and/or curved light guides.

The total losses due to a thin conductive film, together with other losses, are included in the detection efficiency of the scintillator - light guide system (cols. 7 and 8 of Table 1). Electron - photon energy conversion efficiency of 4 % was considered. It is supposed that secondary electrons (SE) are incident on the scintillator surface approximately perpendicularly, whereas BSE are incident parallel to the detection system axis. That is why (with the exception of the disc) the quantity is different for different modes of detection. The results obtained by simulation are in agreement with the experiments [4].

References

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