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Figure of Merit of Silicon Photomultiplier/Scintillator Electron Detector

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Silicon photomultipliers (SiPM) are small size, solid state, high gain, magnetic field insensitive, and fast detectors of light. Their spectral response can be modified without significant loss of sensitivity. They can be combined with a scintillator to form backscattered electron detectors with small form factors allowing flexible and multisignal detection in scanning electron microscopes. The scanning of the e-beam sets the limitation for collecting the signal from the SiPM in DC mode. This mode of operation was not studied extensively in the literature, in contrary to the pulsed mode of operation.[1] We report on our characterization of two types of SiPMs in DC mode. We combine these results with light emission studies of scintillators and establish methodology for finding the figure of merit for combining SiPMs with scintillators.

SiPMs have been selected with enhanced sensitivity in the near UV spectral range, NUV, and in the red-green spectral range, RGB. Our electrical studies resulted in values for the quenching resistance, cell capacitance, and breakdown voltage in agreement with the specifications. The response of the SiPMs in combination with the subsequent electronics is linear over four orders of magnitude, Figure 1. This ensures that the spectral response measurements will be not affected by additional non-linearity effects. We define the photon detection efficiency (PDE) in the DC mode as the ratio between the number of electron-hole pair, which trigger an avalanche, and the number of photons arriving in front of the detector. Reflections losses, cell fill-factor, etc. are included in this quantity. The PDE DC should be equivalent to the PDE measured in the pulsed mode. Figure 2 shows the PDE DC for the NUV and RGB SiPMs, which was calculated using the manufacturer's avalanche gain.

The response of the SiPM was compared with the cathodoluminescence spectra of several conventional scintillators, Figure 3. All spectra are corrected for the spectral sensitivity of the detection systems. This comparison enables us to predict the performance of any combination of SiPM and scintillator. The comparison between different pairs, however, requires the knowledge of the interaction of the electrons with the scintillator. We have measured the electron beam current using a Faraday cup for each cathodoluminescence spectrum. We define the Figure of Merit (FM) for the combination SiPM/Scintillator as the current delivered by the SiPM divided by the number of electrons arriving at the surface of the scintillator each second, or current divided by the electron flux. The FM for the spectra presented in Figure 3 is given in Table 1. The highest FM for the combination RGB/YAG is consistent with our experience with this type of backscattered electron detectors.

Further improvement of the FM can be achieved if scintillators are combined with the goal of overcoming the limitation by the top thin conductive layer, which is typically ITO or Al. Previously,[2] we have reported on the use of thin film scintillator, zinc tungstate (ZT), as efficient detector of electrons below 3 kV. Combining a conventional bulk scintillator, YAG or YAP, with a thin film scintillator is expected to extend the sensitivity to electrons below 2 kV. By stacking the two types of scintillators, the bulk scintillator collects the high energy electrons, and the thin film scintillator detects primarily the electrons below 5 keV. Figure 4 shows the cathodoluminescence spectrum of such stacked scintillator where the emission of YAP at 350 nm and of ZT at 480 nm is simultaneous. Using the results from Figure 3, we predict that a more successful combination would be between ZT and YAG, since the FM of ZT/RGB is higher than of ZT/NUV.

References:

[1] C Piemonte et al, IEEE Transactions on Nuclear Science 54 (2007), p. 236.
[2] NC Barbi *et al*, M&M Conference, Portland, OR 2015.

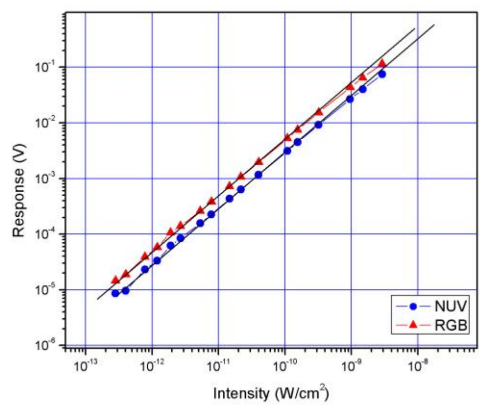

Figure 1. Response of the system SiPM/preamplifier vs. light intensity at 510 nm..

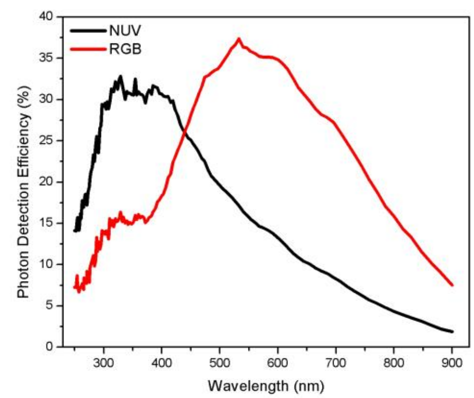

Figure 2. Photon detection efficiency in DC mode for NUV (black curve) and RGB (red curve).

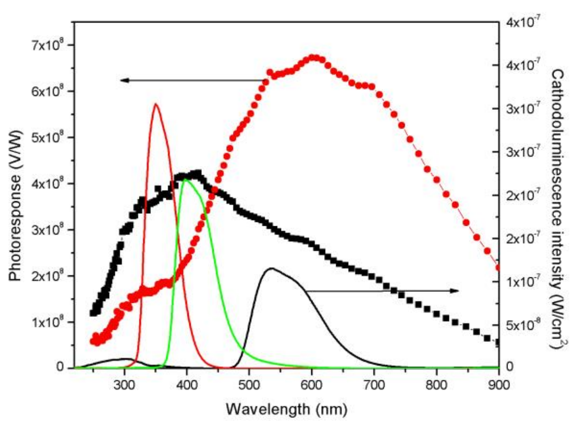

Figure 3. Photoresponse of NUV (black) and RGB (red) SiPM, compared with the cathodoluminescence spectra of conventional scintillators, YAG (black), YAP (red), and CRY18 (green).

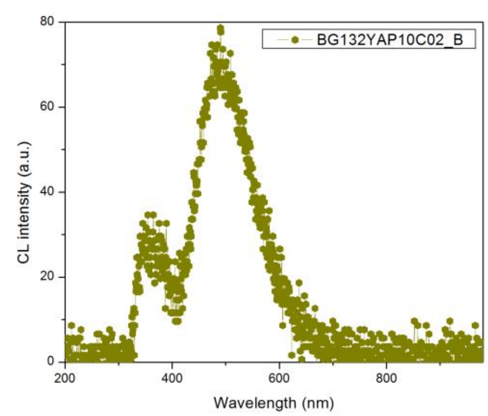

Figure 4. Cathodoluminescence spectrum of the combined scintillator YAP/ZT excited by electrons accelerated at 10 kV.

Table 1. Figure of merit in (pA.s) for a combination SiPM/Scintillator.

	CRY18	YAG	YAP
RGB	4.4	7.4	2.7
NUV	5.5	3.3	5.5

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