doi:10.1017/S143192761100540X
Microsc. Microanal. 17 (Suppl 2), 2011

A New Solid State Photomultiplier Device for Electron Imaging

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The Silicon photomultiplier (SiPM), initially developed in the late 1990s [1], is built from an array of Avalanche PhotoDiodes (APDs) on a common substrate, operating in a limited Geiger mode. The individual cells ("microcells") in the array can range from 25 to 100 micrometers in size, resulting in cell densities up to 1600/mm^2. All microcells are connected in parallel through a large series resistor typically implemented as an integrated polysilicon layer. The final device size can be as small as 1 mm^2 or as large as 1 cm^2. Multiple chips can be arrayed to achieve larger total area. The thickness of the chip is that of the starting wafer, usually 450 microns. The recent surge in interest in SiPMs stems from application to integrated PET/MRI instruments as a replacement for Photomultiplier Tubes (PMTs), since the SiPM is insensitive to magnetic fields.

An absorbed electron in the scintillator gives rise to multiple photons, which in turn strike several different microcells in the APD array (Figure 1). The output current is summed from all pixels that fire. The signal resulting from an absorption event in the scintillator is thus readily distinguishable from the normal thermally-induced random triggering of the individual microcells (Figure 2). The magnitude of the current pulse from the SiPM remains proportional to the number and energy of the electrons striking the scintillator until saturation occurs (all microcells fire). Some useful relationships which characterize the device include: 1) the dynamic range increases with the number of microcells; 2) the noise of the device decreases as the cell size decreases; 3) the efficiency of the device increases as the cell size increases, due to higher "fill factor"; and 4) the Signal to Noise Ratio (SNR) of a device increases as the operating temperature of the device decreases.

The SiPM absorbs efficiently over a broad range of wavelengths, with peak response at about 550 nm. This is a perfect match for the green light emission of YAG:Ce, the most commonly used scintillator for Back-Scattered Electron (BSE) detection in electron microscopes. In our implementation, a polished and coated YAG scintillator of the appropriate size is bonded directly to the surface of an SiPM. The integrated Scintillator-SiPM device is thus proposed as an alternative to the scintillator-light pipe-Photomultiplier Tube (PMT) chain used in electron microscopes since the 1960s. Its advantages include very small size, low operating voltage (30-40 volts vs 1000-1500 volts for a PMT), and elimination of the need for a large chamber access port required by traditional PMT-based electron detectors. Moreover, the SiPM enables novel imaging configurations, realized by positioning one or more electron detector(s) inside the vacuum chamber or in the column itself; packaged with other detectors such as SDDs; and mounted on a micromanipulator for extremely close proximity of the detector to specific regions of the sample.

Figure 3 shows our first SEM image obtained with an SiPM device. The left image is from a conventional BSED, while the right image is from an SiPM in a TO8 package, with the window being replaced by a piece of YAG material, mounted on a post inside the SEM chamber. Figure 4 shows the optimized prototype which will enable direct comparison to a conventional BSE detector.

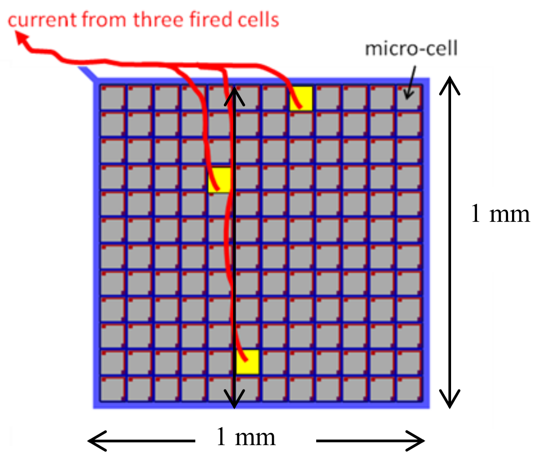

Figure 1: 1mm^2 device with a 12 X 12 array of microcells

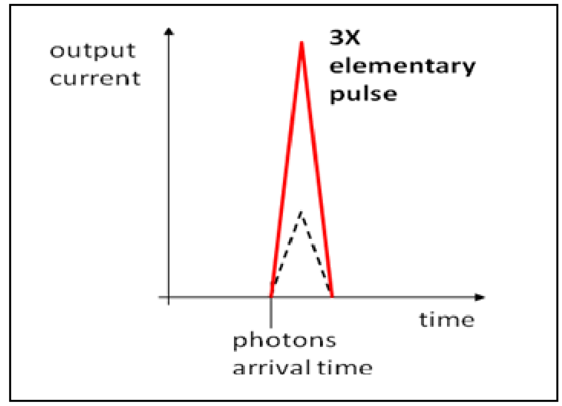

Figure 2: The output pulse from 3 microcells firing compared to a single microcell

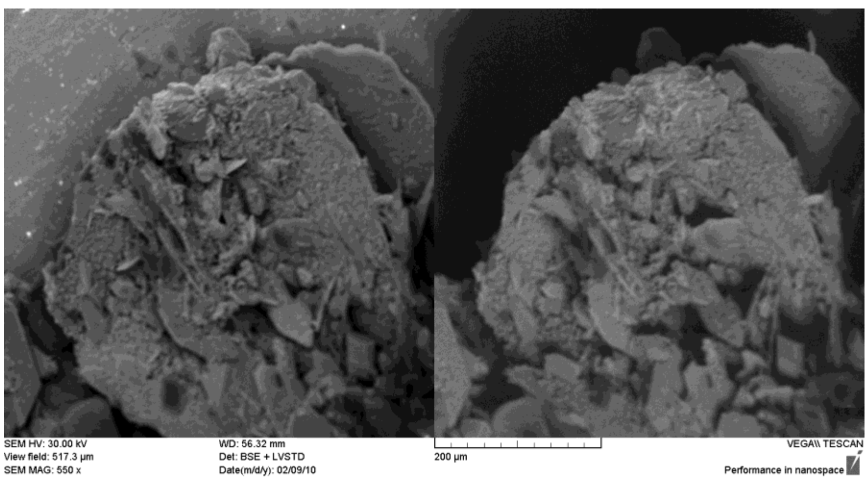

Figure 3: Proof-of-Concept Image
The left image is from a conventional BSED; the right image is from the SiPM

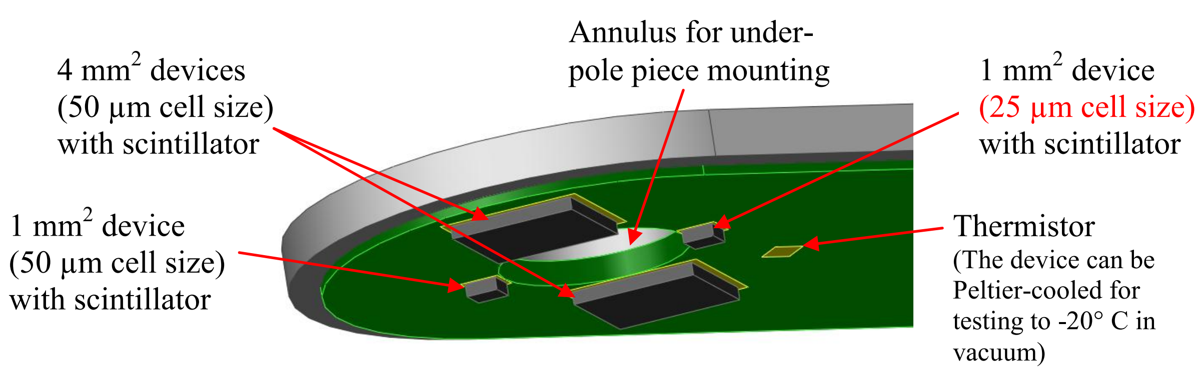

Figure 4: Optimized Device for Performance Testing and Comparison to a Conventional BSED

[1] B. Dolgoshein,et al, *Nuclear Instruments and Methods*, Physics Research A 563 (2006) 368–376

https://doi.org/10.1017/S143192761100540X Published online by Cambridge University Press