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The Silicon photomultiplier for application to high-resolution gamma cameras for PET applications

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Positron Emission Tomography (PET) for small animal studies requires high-resolution gamma cameras with high sensitivity. Traditionally, inorganic scintillators are used and, in recent times, coupled to position sensitive PMTs. Such PSPMTs are costly, operated at high voltage and have a relatively low packing fraction. However, their advantage, compared to current solid state photodetectors, is their high signal-to-noise ratio.

The Silicon Photomultiplier (SiPM) is a silicon diode detector that shows great promise as a photodetector for scintillators and hence application in nuclear medicine imaging applications. The MRS (Metal-Resistor-Semiconductor) structure of the SiPM leads to a self-quenching, Geiger-mode avalanche photodiode (GAPD), that produces a large gain (106) at low bias voltage (50V). The standard operation of a GAPD is such that each signal produced in the depletion region, regardless of the original number of photoelectrons, produces the same fixed amplitude output signal, the magnitude of which is determined by the quenching resistance. In this way a GAPD performs as a digital counter, giving no information of the number of original photoelectrons produced and thus prohibiting the possibility of having analogue information for spectroscopy. The SiPM structure overcomes this inherent limitation by dividing the silicondiode surface area into a large number of regions called microcells, each of which acts like an independent and identical GAPD. This is achieved by forming the p-n junction in ˜20 x 30 μm2 cells, separated by a gap of a few microns, that defines the detector structure. Thus, the avalanche region is localised to each cell. If the outputs of all these microcells are summed together then the output signal is proportional to the number of microcells activated. In the MRS SiPM, the microcell signals are multiplexed by the common metal electrode contact layer. In this way, the SiPM provides a large, proportional signal for low to moderate photon flux (Nphotons< Ncells), such that even a single optical photon can be easily detected and resolved. The preliminary studies we have made of the MRS SiPM have demonstrated a very promising photodetector that is stable and rugged, has excellent single photoelectron resolution, fast recovery time and a high gain at low bias voltage. Experimental results demonstrating these performance characteristics will be presented. The fabrication is fairly simple and does not require special high-resistivity silicon, therefore having the potential to be a low cost detector solution. There is no requirement for special, low-noise electronics since the gain is sufficient to give a large signal-to-noise ratio. Its dimensions are ideal for

forming high-resolution matrices for PET or other scintillator imaging applications.

The disappointment with the original SiPM that was studied was that the quantum efficiency was found to be very low. For this reason the light yields measured with scintillation pixels was found to be small, of the order of 25 photoelectrons for a 511 keV photopeak in LSO. However, in the meantime, SiPM development has focused on the improvement of the quantum efficiency to obtain better light yields. In fact, with a blue sensitive version of this device we have measured an energy resolution at 511 keV with a LSO pixel of 25% which is approaching that measured with position sensitive PMTs. Such a compact silicon detector, with a performance similar to a PMT, is obviously well disposed to being developed into a close-packed array in order to have a position-sensitive detector surface. We propose a miniature, high-resolution detector head for a small-animal PET imaging system that is based on such an array of SiPM. The design is based upon the classic Anger camera principle; one detector module layer consists of a continuous slab of scintillator, viewed by a matrix of SiPM. A detector head of 5×5 cm2 in area is proposed, constructed from three module layers of the continuous detector described above. The stacked layers would give the system intrinsic depth of interaction (DOI) information. Results of a simulation, using the Monte Carlo package GEANT4 are presented. The simulation results are used to determine the performance of a single detector head and to optimize the geometry of the detector, resulting in a high spatial resolution of up to ˜0.6 mm full-width at half maximum (FWHM) and a sensitivity determined by the number of layers used.

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