The Detection of Minimum Ionising Particles with Scintillating Fibres using Multi-pixel Hybrid Photodiodes

C.P. Datema, L-J. Meng, D. Ramsden
Department of Physics and Astronomy, University of Southampton, UK

Abstract

Recent measurements of the performance of the newly available multi-pixel Hybrid Photodiode (M-HPD) have demonstrated their particular value in the detection of very low light-level signals in the visible region. The single and multiple photo-electron response characteristics of these devices is unmatched by any other room-temperature device. This characteristic, coupled with their speed of response and the availability of an internally-generated trigger signal when one or more of the pixels detect an event, makes them particularly interesting as possible photo-detectors for fast plastic scintillators and, in particular, as detectors for reading out scintillating fibres.

The results of tests made when Minimum Ionising Particles (MIPs) pass through single and multi-clad plastic scintillating fibres have confirmed the usefulness of these devices in particle-tracking applications. The technique used to read-out 61 channels of data is described along with a way to view as many as 2000 fibres with just two 61-pixel M-HPDs. Finally, an outline concept for a new high energy gamma-ray telescope is described. This could use multiple planes of scintillation fibres read-out by M-HPDs.

I. INTRODUCTION

Scintillating fibres have been used in a number of quite different applications, mainly in new instruments for the future generation of experiments for High-Energy Physics research [1], [2], [3]. However, the successful application of scintillating fibres in track-chambers depends on the development of multi-channel read-out devices able to detect reliably, the few photons that reach the end of the fibres. These fibres must be fine enough to provide adequate spatial resolution for the reconstruction of the tracks of minimum ionising particles.

The aim of this paper is to show that M-HPDs are a viable and very interesting option for use in the read-out of small diameter scintillating fibres. In particular, this paper suggests the possible application of large area M-HPDs to read out several thousands of fibres such as is required in a new tracking-chamber for high energy gamma-ray astronomy.

II. EQUIPMENT AND METHOD

A. The Multi-pixel Hybrid Photodiode

The hybrid photodiode principle is based on the use of a silicon PIN-diode in a vacuum enclosure with either a quartz, glass or fibre entrance window on which the photocathode is deposited. A high potential accelerates the photo-electrons generated at the photocathode onto the reverse-biased silicon diode where they typically produce a few thousand electron-hole pairs. More information on the characteristics and principle of operation of the HPD device can be found in [4], [5], [6].

In the Multi-pixel Hybrid Photodiode (M-HPD) [7], the lower-side of the silicon PIN-diode is segmented. Each pixel is bump-bonded to a vacuum-tight ceramic/metal interface which brings the electrical connections to a standard plug interface as shown in Figure 1. The upper common electrode is also brought out to one of these pins. This connection is used to supply both the bias voltage for the PIN-diode and to bring out the 'common' signal from the diode. This is important because this signal can be used as a trigger signal to initiate the read-out of the charge detected by each of the anode segments.

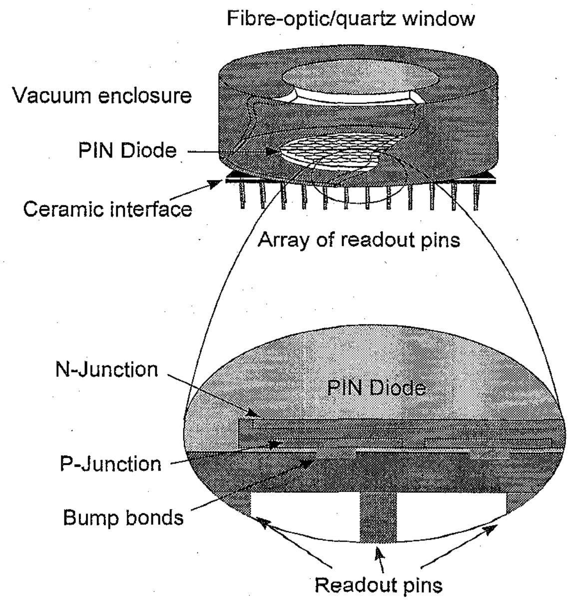

Figure 1: Schematic drawing of the 61-pixel HPD.

The M-HPD used in the experiments was a 61-pixel device manufactured by Delft Electronic Products [8]. This particular tube has a photocathode diameter of 18mm and a pixel size of 2mm across the flats.

B. Experimental arrangement

To demonstrate the capability of the M-HPD for the detection of Minimum Ionising Particles in various scintillating fibres, the set-up shown in Figure 2 was used.

0018-9499/98$10.00 © 1998 IEEE

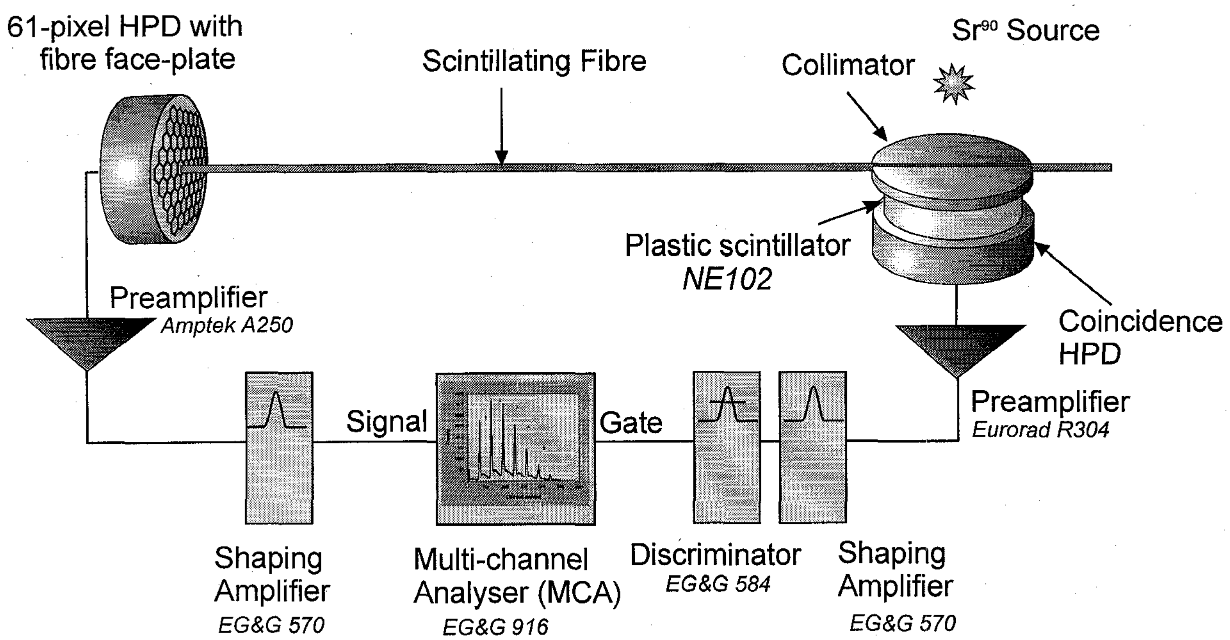

Figure 2: Test arrangement for the scintillating fibre tests. Both a single and a multi-pixel HPD have been used to read out the fibres with very similar results.

One 61-pixel HPD views a three meter long scintillating fibre, whilst another HPD coupled to a fast plastic scintillator (NE102) is used as a coincidence detector. A Strontium (Sr^{90}) beta-source is placed on one side of the scintillating fibre whilst the coincidence detector is placed behind it. A metal disc with a slit for the fibre is used to make sure that the electrons that generate a signal in the coincidence detector have passed through the fibre. The Strontium source has an end-point energy of 2.27 MeV. The threshold used for the coincidence detector was set to approximately 600 keV. The fibres used in this experiment are listed in Table 1.

C. *Multi-channel read-out electronics*

Although not used in the fibre test set-up, the multi-channel read-out electronics will be an important factor in the success of the multi-fibre read out with M-HPDs. Preliminary results with just seven pixels connected have shown that the system is fully functioning.

The read-out technique used with the 61-pixel HPD is based on the VA-2 ASIC made by Integrated Detectors and Electronics [9]. It is a 128-channel low-noise charge-sensitive preamplifier/shaper circuit with a simultaneous sample-and-hold and multiplexed analogue output. The signal from the common side of the diode is amplified and passed through a discriminator unit. The discrimination level on the 'common' amplifier signal may be set at the level of 5000 electrons which corresponds to less than two photo-electrons. Although the fast rise-time of the common signal is not critical in this case, this rise-time, after amplification with a fast amplifier, was measured to be 10 ns.

Table 1.
Overview of tested fibres

Fibre	Dimensions	Peak emission	T_{decay}	Numerical Aperture	Trapping efficiency	Multi-cladding?
Pol.hi.tech 0046-100	1mm, round	435 nm	3 ns	0.57	4 %	N
Kuraray SCSF-38M	1mm, round	428 nm	2.3 ns	0.72	5.35 %	Y
Kuraray SCSF-81M	1mm, round	437 nm	3.4 ns	0.72	5.35 %	Y
Kuraray SCSF-38	2mm, square	428 nm	2.3 ns	0.55	4.2 %	N
Kuraray SCSF-81	2mm, square	437 nm	3.4 ns	0.55	4.2 %	N

The signal from the discriminator initiates the read-out sequence. A NIM-based sequencer provides the necessary 'hold' signal for the VA-chip after a delay appropriate to its peaking time, which can be varied between 1 and 3 μs. The sequencer then provides a pulse-train to shift out the serial data to the ADC mounted in the PC. The sequencer has the facility to adjust the number of channels to be read out whilst the clock speed can be varied between 40 kHz and 10 MHz.

III. Results

Figures 3, 4 and 5 show the Multi-Channel Analyser (MCA) spectra from the output of the HPD when viewing various fibres. The source, in all three cases, was positioned at a distance of 50 centimetres from the end of the fibre viewed by the HPD. As best seen from Figure 3, a Poissonian distribution in the number of photo-electrons is clearly evident. Each peak in this spectrum represents a certain number of photo-electrons produced in an event. In the case of Figure 3, the average number of photo-electrons produced by an electron passing through the Pol.hi.tech, 1mm diameter fibre at this distance is about three.

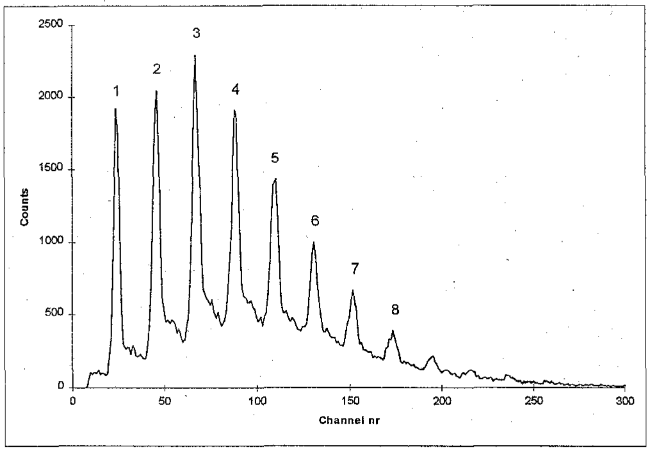

Figure 3: Light output (number of photo-electrons) of the Pol.hi.tech 0046-100, 1mm fibre with the beta-source placed 50 cm from the end viewed by the HPD.

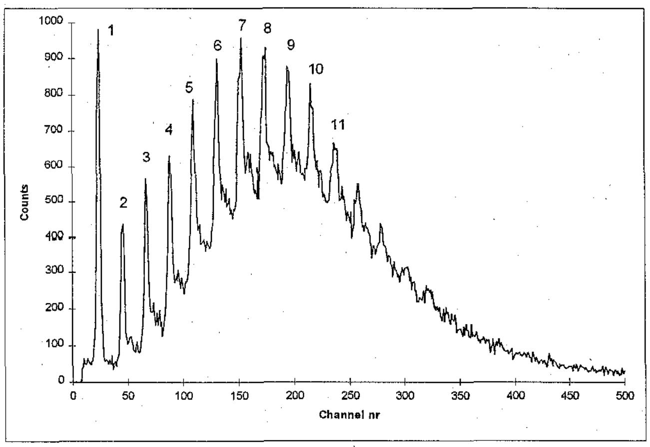

Figure 4: Light output (number of photo-electrons) of the Kuraray SCSF-38M, 1mm fibre with the beta-source placed 50 cm from the end viewed by the HPD.

Figures 4 and 5 show similar plots, but in these cases the average number of photo-electrons is much higher, 8 and 17 respectively. The semi-Gaussian continuum underlying the Poissonian distribution is caused by the backscattering of some of the photo-electrons that hit the silicon anode of the HPD.

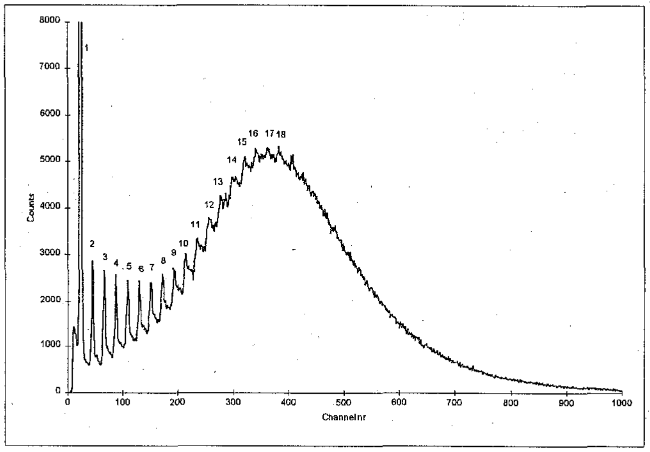

Figure 5: Light output (number of photo-electrons) of the Kuraray SCSF-38, 2mm fibre with the beta-source placed 50 cm from the end viewed by the HPD.

Measurements were made at a number of distances from the HPD in order to confirm the attenuation length data provided by D'Ambrosio et al. [10] and the manufacturers. These measurements indicated that if one were to use the multi-clad Kuraray 1mm diameter fibre, lengths of up to 1.5 metres could be used provided that the discrimination level could be set to two photo-electrons. At the two photo-electron level, the expected detection efficiency would be approximately 90%. It should be noted that in the application described in the outline below, each fibre would be viewed by two M-HPDs and at least eight coincidence trigger signals would be available prior to the decision to read out the signals from a pair of X-Y fibre planes. It should therefore be possible to use signals corresponding to a single photo-electron without introducing noise.

IV. Discussion

An important consequence of the results described above, is the obvious potential for using M-HPD devices to read out a very large number of fibres. This may be achieved by appropriately encoding the signals derived from the two ends of the fibre using two suitably selected M-HPDs. For example, if the individual pixels in each pair of M-HPDs were sufficiently large to view a number of 1mm fibres, say 40, then a bundle of fibres couples to pixel-1 in detector A, could then be coupled to 40 different pixels in detector B as indicated in Figure 6.

Clearly, in this case, the number of unique combinations of signal addresses provided by the outputs from the two M-HPDs would enable 2400 fibres to be read-out using just two detectors. The range of possibilities for viewing multiple fibres based on the use of existing DEP devices, or those that are near to market, is illustrated in Table 2.

Table 2.
An estimate of the area of a fibre tracking-chamber using 1mm fibres coded using various types of M-HPD

M-HPD photocathode Diameter	Number of pixels	Pixel size mm across flats	No of fibres per pixel	Maximum number of fibres	Dual coded capacity**	Approx. surface area (square) per detector plane**
18 mm	61-hexagonal	2	4	240	240	0.12 m^2
40 mm*	61-hexagonal	4	10	600	600	0.3 m^2
72 mm*	61-hexagonal	8	40	2400	2400	1.2 m^2
72 mm*	127-hexagonal	5.5	18	2400	2400	1.2 m^2

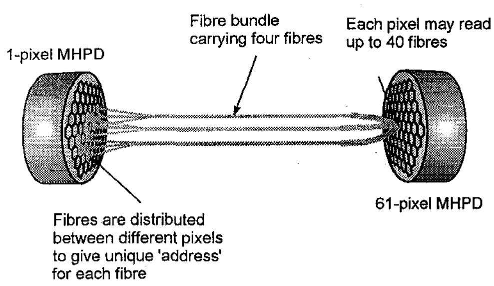

Figure 6: The coding principle using fibres on the M-HPDs.

V. A POSSIBLE APPLICATION

One area for the possible application of the detector technique outlined above is in the field of high-energy gamma-ray astronomy. During recent years, the EGRET telescope which forms a key part of the Compton Gamma-ray Observatory [11], has produced some excellent results in the energy-band above a few hundred MeV. This telescope is based on the use of a spark-chamber with a wire-read-out system to record the tracks of the electron-pair produced by the incident photon in the conversion material which interleaves the track-measurement planes. The trigger for the spark-chamber is provided by an external time-of-flight counter-telescope whilst the photon energy may be derived from the measurement of the energy deposited in the massive CsI calorimeter.

One of the most exciting outcomes from the EGRET observation has been the detection of a new class of high-energy gamma-ray emitter, the Blazar. These objects flare on time scales ranging between days to 100s of days. There is clearly now a strong motivation to extend the catalogue of such objects from the 50 or so examples that have been identified so far. In particular, there is a need for a new telescope design that will have a wider field-of-view than EGRET in order to increase the probability of detecting these flaring objects during each pointed observation in a particular direction in space. A greater detection efficiency is also highly desirable in order to increase the sensitivity of the telescope. However, in the case of EGRET, this cannot be achieved since the products of the photon-conversion process must also emerge and pass through the trigger telescope. Another consequence of this is that one would also like to design a tracking-detector in which the track-reconstruction accuracy is high enough to determine the photon energy from measurements of the scattering and range of the electrons.

One candidate for such a follow-on mission is the Gamma-ray Large Area Space Telescope (GLAST) [12]. This track-chamber fulfils, in principle, the objectives agreed for the next gamma-ray astronomy mission. The telescope design is based on the extensive use of silicon-strip detector technology that is well able to meet the requirement for track-reconstruction precision. However, the detector system appears to very expensive compared with the scintillating-fibre tracking detector (SIFTER) proposed by the group at the Marshall Space Flight Centre [13]. Their concept is to use multiple planes of scintillating fibres and plan to reconstruct the trajectories of the electron-pair by viewing the fibres using a number of image intensifiers each equipped with a CCD readout. The techniques described in this paper might provide a more appropriate solution to the problem of reading out ~1000 fibres for each X and Y plane using the coding technique explained above.

VI. ACKNOWLEDGEMENTS

We would like to acknowledge the support provided to Mr C.P. Datema by a EU contract No ERBCHR-XCT940586 and by Delft Electronic Products. We also thank Dr. R. DeSalvo for his help in developing the M-HPD device.

VII. REFERENCES

[1] R.D. Appuhn et al., "The H1 lead/scintillating fibre calorimeter", Nucl. Inst. & Meth. A, vol. 386, pp.397-408, 1997.

[2] P. Finocchiaro et al., "A scintillating fibre beam profiler for low intensity ion beams", Nucl. Inst. & Meth. A, vol. 385, pp.31-36, 1997.

[3] G. Alverson et al.,"The performance of the L3 plastic scintillation fibre calorimeter system", Nucl. Inst. & Meth A, vol. 380, pp.555-561, 1996.

[4] L.K. van Geest et al., "Hybrid phototube with Si target", Nucl. Inst. & Meth. A, vol. 310, pp.261-266, 1991.

[5] R. DeSalvo et al., "First results on the Hybrid Photodiode Tube", Nucl. Instr. & Meth. A, vol. 375, pp.375-384, 1992.

[6] R. DeSalvo, "Why people like the Hybrid PhotoDiode", Nucl. Inst. & Meth A, vol. 387, pp.92-96, 1997.

[7] L. Waldron et al., "Characterization of multi-pixel HPD tubes", Nucl. Inst. & Meth. A, vol. 387, pp.113-116, 1997.

[8] Delft Electronic Products, Dwazziewegen 2, 9300 AB Roden, the Netherlands.

[9] Integrated Detectors and Electronics A/S, Veritasveien 9, N-1322 Høvik, Norway.

[10] C. D'Ambrosio et al, "Further results on photoelectron counting with small diameter fibres", Nucl Instr. & Meth. A, vol. 345, pp.279-283, 1994.

[11] R.C. Hartman et al, *The Compton Observatory Science Workshop*, NASA-Conference Publications **3137,** (1991), pp.116.

[12] Prof P. Michelson, GLAST Principal Investigator, Stanford University.

[13] Private communication, Dr M Pendleton, Marshall Space Flight Centre, NASA-Huntsville.