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Multi-Anode Square Microchannel Plate Photomultiplier Tube

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Abstract: Photek has developed a high performance 4096-anode photomultiplier tube using microchannel plates as the gain medium. The detector has been designed in a square format to maximise the active area and allow for easy tiling to cover large areas using multiple units. This paper analyses the detector performance in terms of gain and photocathode uniformity, single photon timing accuracy, count rate capability, cross talk and magnetic field susceptibility.

Keywords: Photon detectors for UV, visible and IR photons (vacuum); Cherenkov detectors; Timing detectors

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1 Introduction

Photek is a well-established manufacturer of vacuum-based photodetectors using microchannel plates (MCPs) as the gain medium. We have provided round single channel photomultiplier tubes (PMTs) for the diagnostics in inertial confinement fusion for many years [1], with the main performance criteria being the analogue instrument response function, gating ability and dynamic range. In these facilities the PMTs are detecting multi-photon, low repetition rate signals.

In 2012 we began the development of a new multi-anode PMT as part of the TORCH development for a new particle identification system proposed for the upgrade of LHCb at CERN [2]. This had to be in a square format, have long lifetime and work in a single photon, high rate mode. Due to the demanding position resolution required in one dimension, a novel anode was developed which A.C. coupled the signal and deliberately introduced a controlled level of charge sharing to allow interpolation between the anode pads of the photon arrival location, the results have been shown elsewhere [3]. Lifetime was also a significant issue which we were able to address early in the project by demonstrating $> 5\,\mathrm{C{\cdot}cm^{-2}}$ of accumulated anode charge [4] using a conformal coating of the MCP pores by Atomic Layer Deposition (ALD). This layer has the additional advantage of increasing the MCP collection efficiency from $\sim 60\%$ to $\sim 90\%$.

As a simultaneous development we produced a traditional DC coupled anode using the same anode pattern as the TORCH anode: 64×64 anode pads within a 53×53 mm working area. This paper analyses the performance of this new MAPMT253. The mechanical dimensions are shown in table 1. The large number of anodes allows us to choose different anode formats by ganging groups of pads together, e.g. by connecting 8×8 pads electrically, we effectively produce an 8×8 anode array over the whole detector.

Table 1. Mechanical details of the MAPMT253 PMT.

Mechanical Properties	MAPMT253
Input Window Material	Fused Silica or Sapphire
Input Window Thickness (mm)	5.0
Photocathode area (mm)	53×53
Photocathode — MCP Gap (mm)	1.6
MCP-Anode Gap (mm)	3.0
MCP Pore Diameter (µm)	15
Bare Tube Dimensions (mm)	$59 \times 59 \times 13$
Housed Tube Dimensions (mm)	$60 \times 61 \times 13$
Native Anode Pattern	64×64
Native Anode Pitch (mm)	0.828

2 Uniformity

2.1 Photocathode

The photocathode area covers 28.1 cm^2, a significantly larger area than our usual 18-, 25- or 40-mm diameter devices. To assess the uniformity of the photocathode response we used the Photek production photometer which uses a wide band UV / visible / IR light source and narrow band filters. It has a spot size of 11 mm diameter which was moved to five positions within the active area to compare the output and is shown on figure 1. We consider the variation observed to be within the 10% measurement error of the photometer.

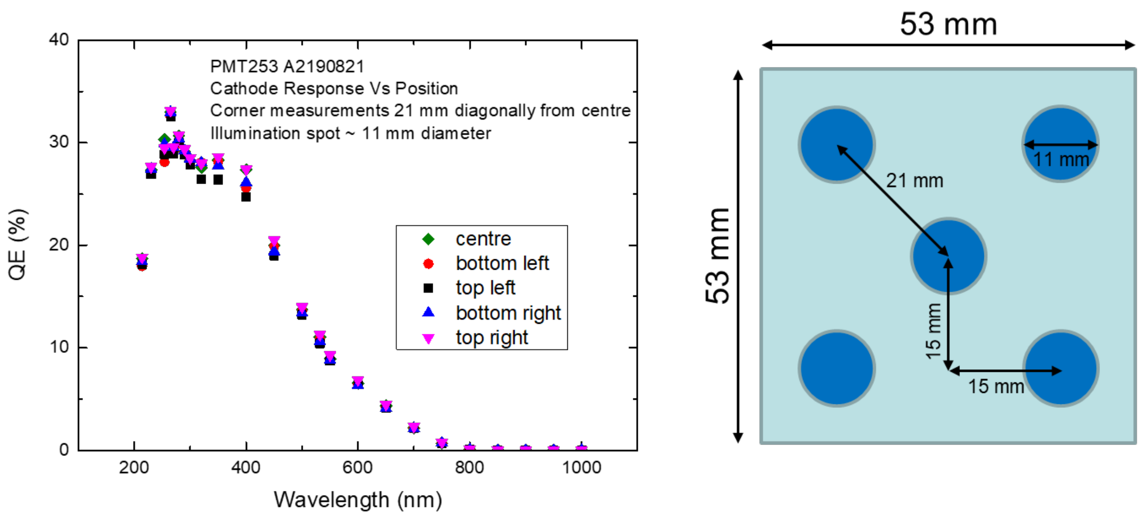

Figure 1. Photocathode uniformity of an MAPMT253.

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2.2 Electron gain

The double MCP chevron stack was designed to produce an electron gain average of 1×10^6, but with the capability of up to 3×10^6 if needed. This provides a good single photon signal above the noise pedestal but also allows for a respectable count rate capability. The uniformity of the gain across the MCP surface is dictated by the consistency of the MCPs themselves plus the electron scrubbing (or preconditioning) that occurs during tube production. We analysed the gain of a PMT configured into an 8×8 anode pattern by sampling four anode outputs, with attention paid to the perimeter anodes as this is the usual location of gain non-uniformity. The Pulse Height Distribution (PHD) histogram of the gain variation in each channel is shown on figure 2. It shows a peak / valley ratio on all four channels of > 4, and a min / max ratio of the gain peak of 1.5.

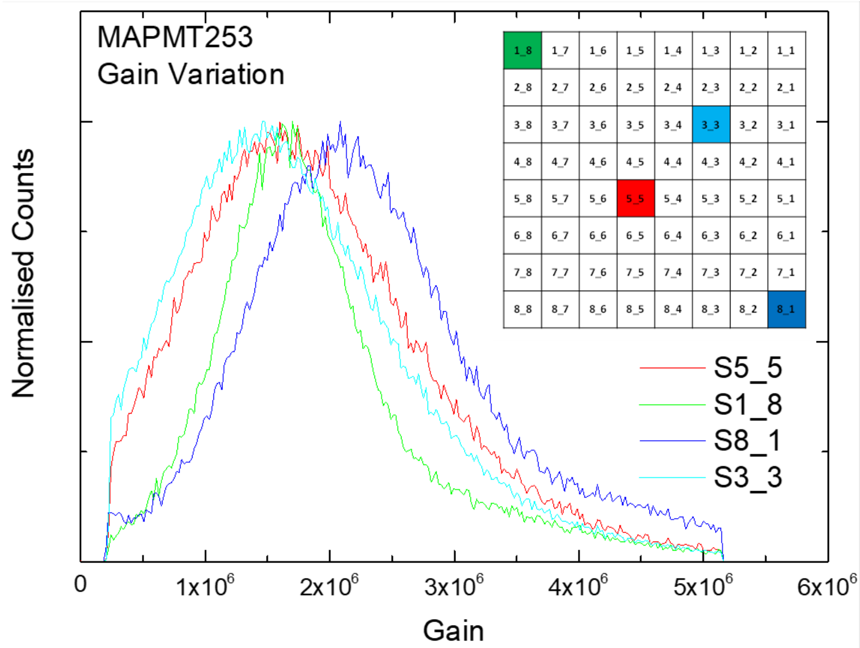

Figure 2. Electron gain uniformity of an MAPMT253.

3 Single photon timing accuracy

MCP-PMTs are the current state-of-the-art for single photon timing accuracy with jitter in the region of 30 ps rms. The accuracy of the MAPMT253 was measured on a single channel of a tube configured with an 8×8 anode pattern. The laser source was a Photek LPG-650, emitting light at 650 nm with a pulse FWHM of 40 ps. The photon signals were measured on a LeCroy Wavemaster 808Zi-A (8 GHz, 40 GS·s^{-1}), measuring each pulse's timestamp at 50% of peak amplitude on the leading edge to correct for amplitude walk. A Photek PD010 photodiode was used as the reference signal. The result is shown on figure 3.

The analysis is complicated by the presence of two populations of events that occur after the main peak; the recognized phenomena of backscatter caused by photoelectrons bouncing off the webbing of the MCP input and generating a later event, plus an after-pulse that is inherent in the

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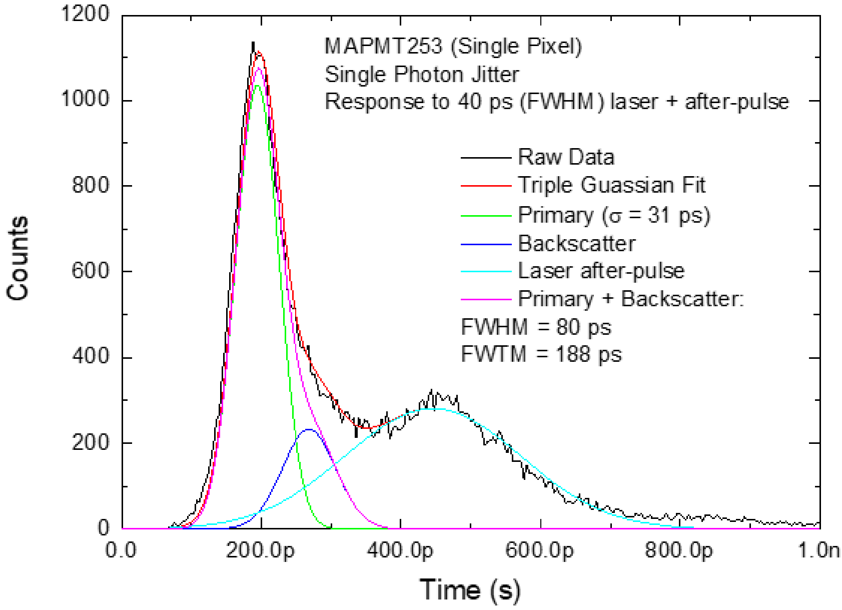

Figure 3. Single photon timing accuracy of an MAPMT253.

laser output, these have been identified on figure 3. We were able to identify the source of the two after-pulses by varying the photocathode-MCP voltage; the backscatter peak shifted, the laser after-pulse did not. After fitting gaussians to these curves we are left with a main peak σ of 31 ps.

4 Rate capability

One of the MAPMT253s was analyzed by the group of Melikyan et al. [5] to assess the behavior under heavy signal current extraction. They measure the signal amplitude as a function of the average anode current and show the MAPMT253 to have an extended usable region of $> 1\,\mu\text{A}\cdot\text{cm}^{-2}$, equivalent to $> 6\,\text{Mcounts}\cdot\text{s}^{-1}\cdot\text{cm}^{-2}$ and beyond that of its competitors. There is an unexplained increase in the signal amplitude prior to the saturation roll-off, we are provisionally suggesting this may be due to the unique nature of the ALD coating used on the MCPs in the MAPMT253. The test device was in the mid-range of available MCP strip-currents which is the limiting factor of rate capability, meaning that the top range would be $\sim 50\%$ higher.

5 Cross talk

A key parameter in multi-anode PMTs is how much signal from one channel bleeds into the neighboring anodes. For this measurement we focused the LPG-650 down to a spot size of $\sim 150\,\mu$m FWHM and scanned across two anodes at the native pitch of 0.828 mm. The PMT was configured with a 64×8 anode configuration to access the native anode pitch. The single photon gain peak was 1.2×10^6 and the threshold was 50% of the peak. The results are shown on figure 4.

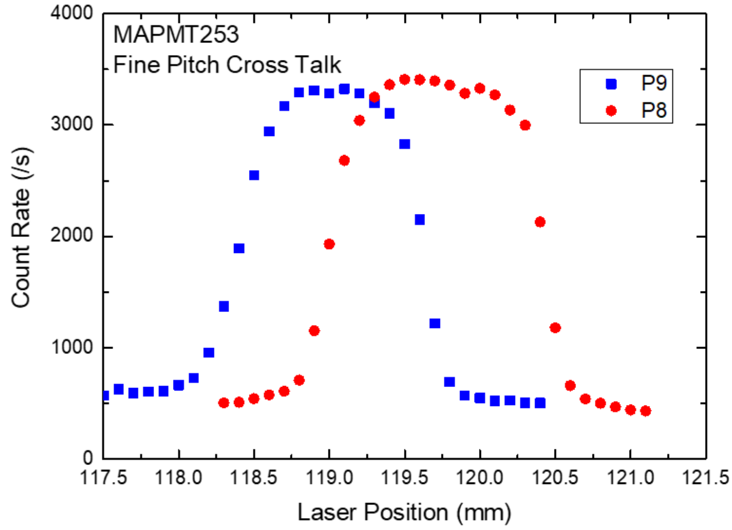

Figure 4. Fine pitch cross talk of the MAPMT253.

6 Edge effects

A common feature in MCP-PMTs where the active area is very close to the vacuum envelop (i.e. the tube wall) is the impact of reflections in the signal trace in the perimeter anodes. To assess this, we stimulated one of the centre anodes (S5_5) only with a multi-photon pulse and analysed the noise pick-up on a selection of other anodes, as shown on figure 5.

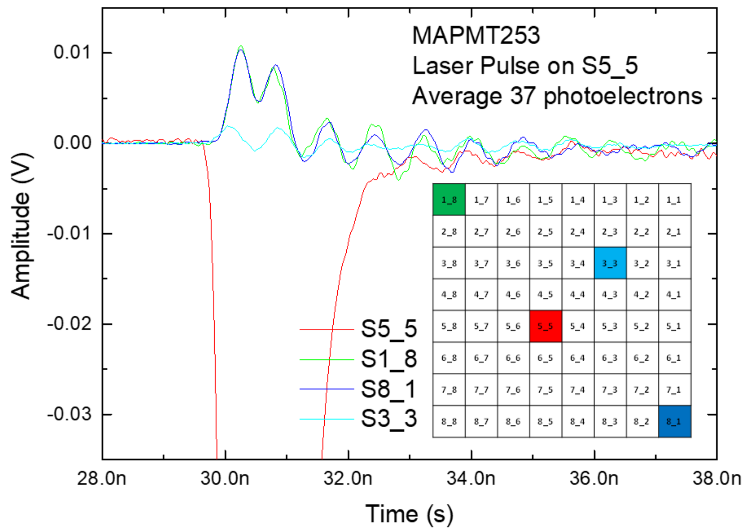

Figure 5. Edge effects from a multi-photon pulse in an MAPMT253.

The perimeter anodes show an inverted signal at $\sim 3\%$ amplitude of the main pulse. This did not change when the amplitude of the multi-photon pulse was varied. As the pick-up is inverted, we believe there is no danger of generating false triggers due to this effect. The intermediate anode (S3_3) only shows a small level of oscillation.

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7 Magnetic field susceptibility

This type of PMT is often required to operate in areas of high magnetic field. Previous results have shown that the gain in MCPs decreases with magnetic field and that larger pores suffer from greater susceptibility [6]. An MAPMT253 was placed into the magnetic field facilities at Argonne Labs in a test set-up described by Hattawy et al. [7] and the influence on the gain is shown on figure 6. The gain drops by a factor of ~ 3 at a magnetic field of 1 T, with the trend of decline appearing to be consistent up to the maximum measured field of 1.25 T. Argonne considered the acceptable angle to be $60° < \theta < 60°$ for 0.5 T and $30° < \theta < 30°$ for 1.0 T. Argonne was also able to confirm that the magnetic field does not affect the position of the electron shower. Future work will assess the performance of 6 µm pore MCPs which are expected to perform significantly better in magnetic fields.

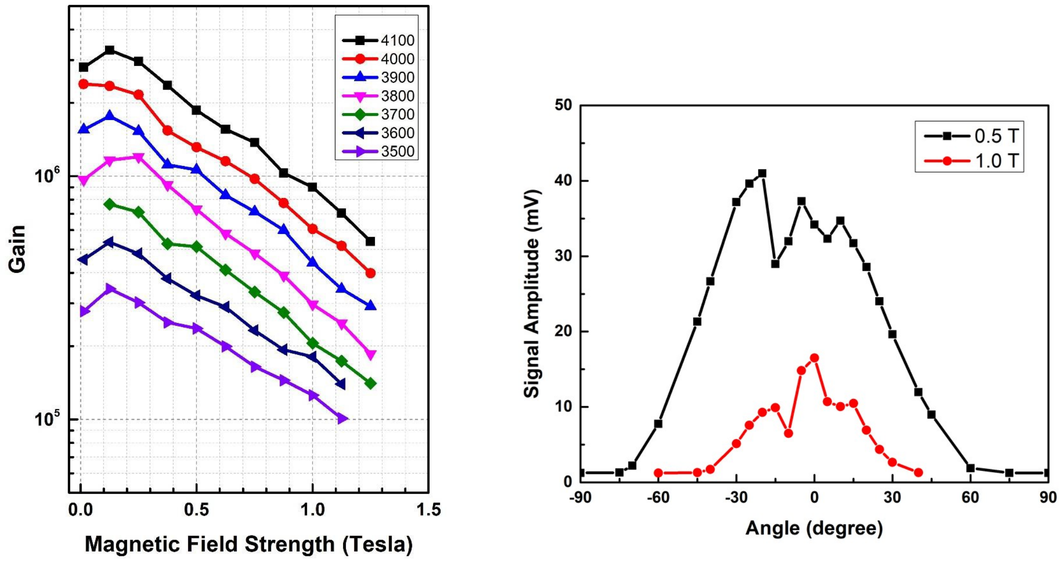

Figure 6. Magnetic field susceptibility of an MAPMT253 showing the influence of the magnetic field on the gain at various total PMT voltages (left) and the influence of the magnetic field angle (right), operated at −4100 V, with 0° being normal to the input window.

Acknowledgments

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