A square, multi-anode, long life MCP-PMT for the detection of Cherenkov photons

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ABSTRACT: Photek are currently in a three year development program with CERN to produce a novel square PMT for the proposed TORCH detector which is aimed at the upgrade of the LHCb experiment. The PMT will be microchannel plate based for the inherent timing accuracy that this brings, and has three main novel features that need to be developed: It will be able to produce 5 C/cm^2 of accumulated anode charge without any degradation in sensitivity. It will be able to detect simultaneous photons with an effective spatial resolution of 128 pixels in the "y" direction and 8 pixels in the "x" direction with a total working area of 53 × 53 mm. Finally it should be close packing on 2 opposing sides of a 60 mm wide detector envelope with an active area fill factor of 88% in the "x" direction.

KEYWORDS: Microchannel Plate; PMT; Square; Multi-anode; Lifetime

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1. Introduction

Photek are currently in a three year development program with CERN to produce a novel square PMT for the proposed TORCH detector which is aimed at the upgrade of the LHCb experiment. Photek microchannel plate (MCP) based detectors can achieve a single photon time resolution of < 30 ps RMS [1] and can easily produce spatial resolution of < 100 µm [2]. This PMT development aims for a balance of these performance objectives (that often work in opposition) to meet the technical PMT requirements of the proposed TORCH upgrade at LHCb at CERN. To achieve high resolution in both time and position, and maintain a good level of parallelism in photon detection, a multi-anode approach has to be used. From a detector manufacturing perspective there are three main challenges in this PMT development: long lifetime, multi-anode output and close packing (requiring a square tube envelope).

2. Long Lifetime

Previous work published by Photek [3] and others [4] has demonstrated a significant lifetime improvement in an MCP-PMT when the MCP is coated by Atomic layer Deposition (ALD) [5]. ALD coatings have been used to reduce the out-gassing of some components such as printed circuit boards and wires in vacuum systems, TiO_2 and Al_2O_3 are surfaces suggested in the literature [6] [7]. We have demonstrated a PMT capable of producing over 5 C/cm^2 of anode charge without any detectable reduction in photocathode sensitivity. Figure 1 shows the normalised anode current of an MCP-PMT with two ALD coated MCPs alongside an identical control device that had uncoated MCPs. The photocathode of the control device is severely reduced after a short time period, but the ALD device produces a steady output, only reducing slightly due to a gain drop in the MCP rather than any loss in photocathode response. The various step points on the figure indicate when the life test was stopped in order to monitor the photocathode response and the electron gain of the MCPs. Both devices started at 800 nA/cm^2 and continued with the same fixed white light illumination level.

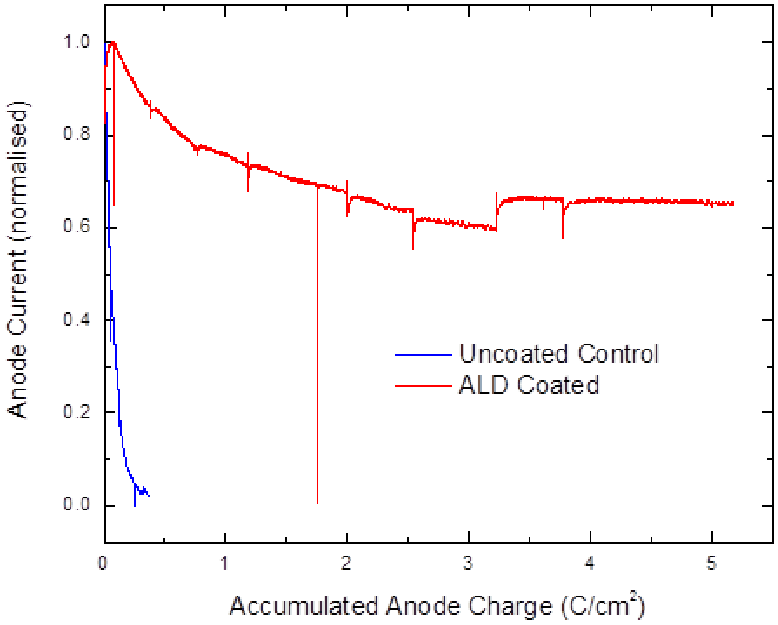


Figure 1. Normalised photocurrent during the life test of two MCP-PMTs, one having ALD coated MCPs

We believe that the ALD layer forms a barrier that prevents the outgassing of material from the MCP under heavy electron bombardment that, from an uncoated MCP, is released and reacts with the photocathode, thus reducing the sensitivity. During the TORCH project we have repeated this experiment with a new set of MCP-PMTs with very similar results: no detectable drop in photocathode response, and only a small drop in electron gain, as shown in Figure 2 and Figure 3. The spread of data at 400 nm is due to a weak reference source and a smaller than normal area being measured. These devices are considered acceptable for the application as the gain is easily recovered by a small increase in the applied voltage.

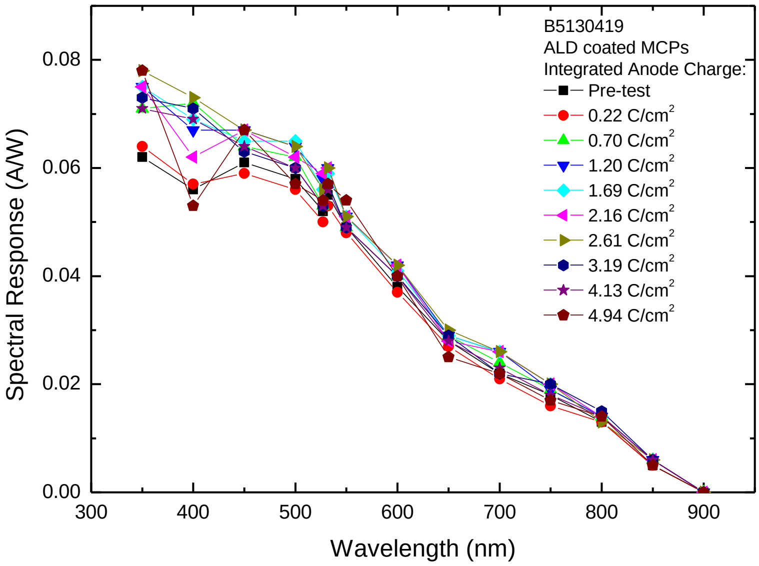


Figure 2. Photocathode response of a sealed MCP-PMT during the life-test showing no detectable drop in sensitivity up to 5 C/cm^2

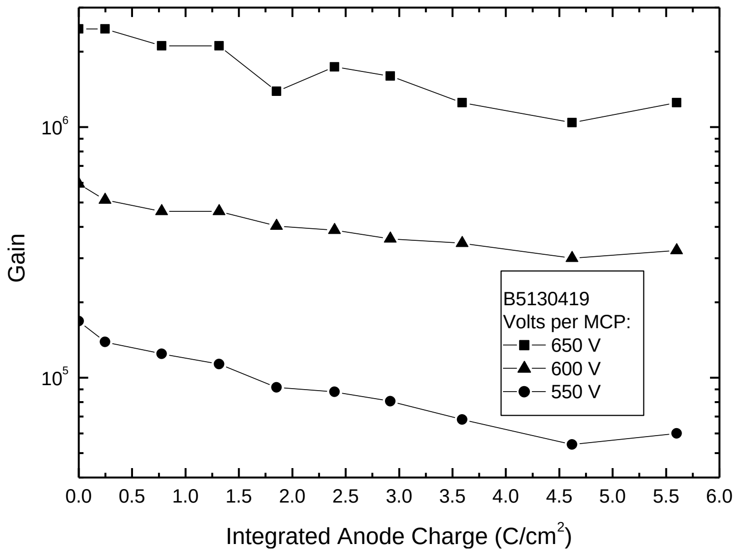


Figure 3. Deterioration of the electron gain of ALD coated MCP during PMT life tests

There were two other noteworthy changes brought by the ALD coating on the MCP: a significant increase in the equivalent electron gain achieved for a given voltage applied, and an increase in the collection efficiency of the photoelectrons from the photocathode being detected by the input face of the MCP. The extra gain obtained is best illustrated in Figure 4, which shows the gain – voltage curves for the batch of PMTs with two coated MCPs manufactured for the TORCH project, along with an equivalent control sample PMT that had un-coated MCPs. We believe the ALD coating has a significantly higher single bounce gain than the traditional MCP pore interior, and the accumulation of many bounces down the MCP pore leads to the gain achieved from a given applied voltage being dramatically higher.

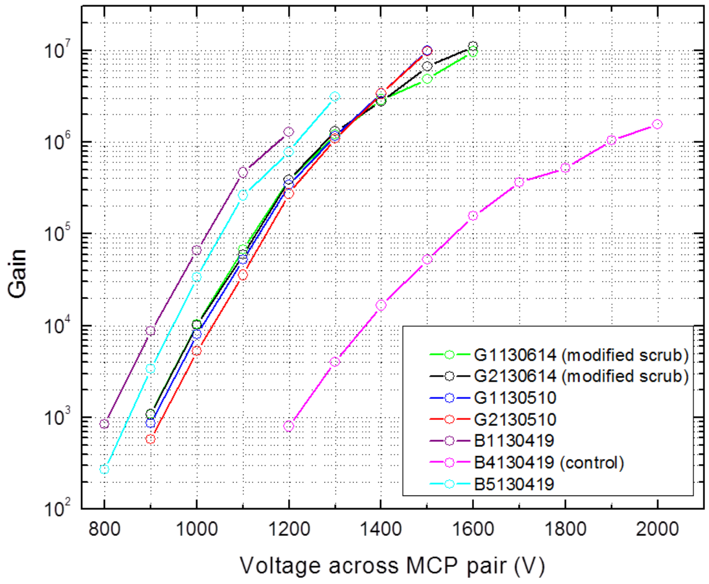


Figure 4. Electron gain for ALD coated MCPs in sealed PMTs, including a control sample

The collection efficiency of the MCP input for each device was measured using a Photek discriminator and single photon counting electronics with a calibrated 500 nm light source, and then comparing with the measured quantum efficiency (Q.E.) of the photocathode of that device at 500 nm to produce a percentage. Figure 5 shows this data compared to previously obtained results from standard MCPs. While the low number of devices with ALD coated MCPs makes it difficult to draw any firm conclusions, it does suggest an improvement is caused by the ALD coating.

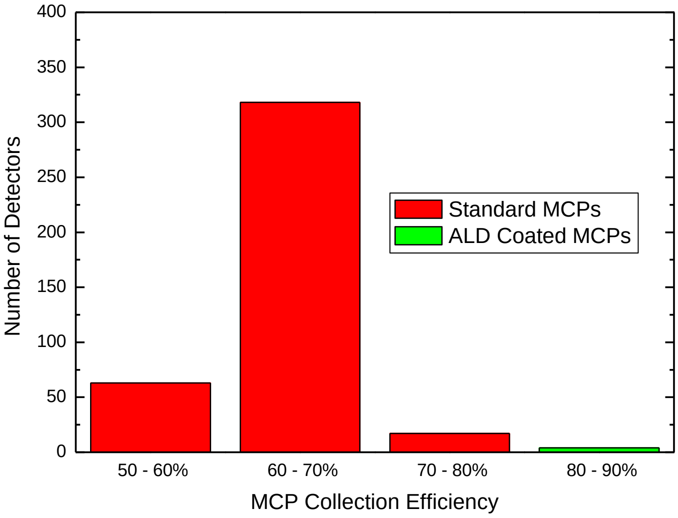


Figure 5. Preliminary histogram of the collection efficiency of ALD coated MCPs

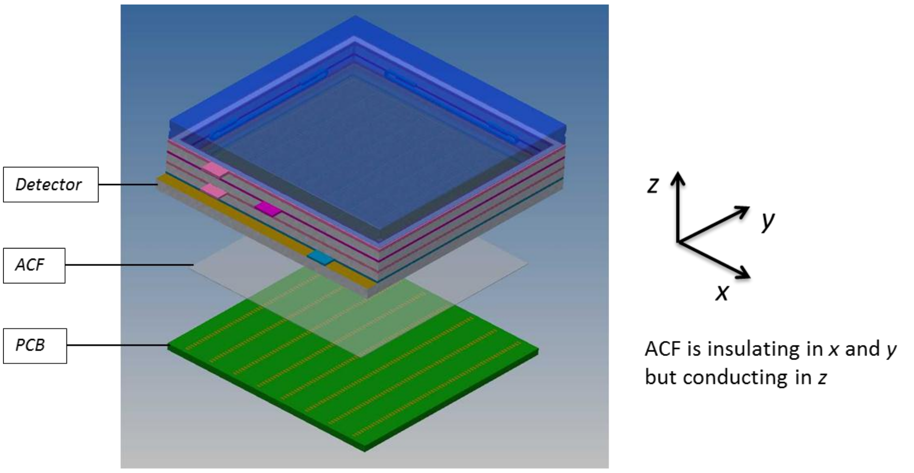
It is believed that the enhanced single-bounce gain from the ALD coating provides an improved statistical chance that the photoelectron from the photocathode will activate an electron avalanche inside the MCP pore, resulting in improved collection efficiency.

3. Multi-Anode Output

The technical requirements of the TORCH PMT require a spatial resolution in the "y" direction of ~ 0.4 mm and ~ 6 mm in the "x" direction, which for a 53 × 53 mm active area is an effective resolution of 128 × 8 pixels, a total of 1024 individual channels. Photek have recently produced a 32 × 32 multi-anode PMT in a 40 mm diameter circular detector envelope, which is currently under assessment. The pads are 0.75 × 0.75 mm square on a 0.88 mm pitch, which is ~ 50% of the target granularity. The design requires a PCB readout through an Anisotropic Conductive Film (ACF) contact which, when under compression, conducts in one axis only, as shown in Figure 6.

Due to the high number of channels and the timing accuracy required we plan to use the NINO ASIC [8] as our front end, a 32-channel differential amplifier / discriminator developed at CERN with 10 ps RMS jitter on the leading edge (using the time-over-threshold technique) and a maximum rate of greater than 10 MHz.

The NINO will directly interface with the High Performance Time-to-Digital Convertor (HPTDC), a programmable TDC developed for ALICE at the LHC. It has two modes of operation: 100 ps LSB resolution with 32 channels or 24.4 ps LSB resolution with 8 channels. The default maximum rate is 2.5 MHz per channel, but this can be increased beyond 10 MHz using a higher logic clock.



ACF is insulating in *x* and *y* but conducting in *z*

Figure 6. Diagram showing the contact between the detector and the PCB through the Anisotropic Conductive Film

Using a method of charge sharing between pads, we can reduce the channel count by a factor of 2, and therefore also the required granularity of the multi-anode structure. The method will produce 128 virtual pixels from 64 real, charge sharing pixels. The plot on Figure 7 shows the simulated position resolution of a parallel readout, charge sharing detector in the “y” (fine) direction. The simulation includes the noise in the charge measurement of the NINO and the digitisation of HPTDC.

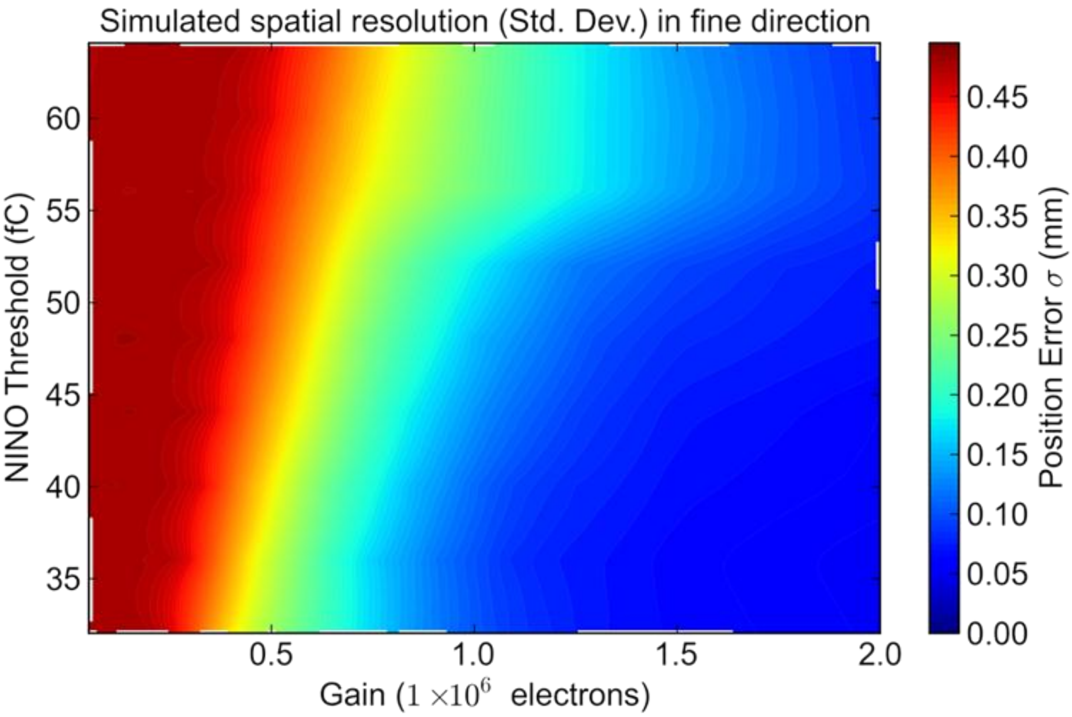


Figure 7. Simulated position resolution of a multi-anode MCP-PMT using charge sharing

The position resolution strongly depends on the NINO threshold and detector gain, and to achieve an accuracy of 0.4 mm we need an RMS of 0.2 mm. Furthermore we would like a confidence factor of at least a factor of 2, leading to a revised RMS target of 0.1 mm. Figure 7 shows a gain of greater than 1×10^6 being required to achieve the desired resolution. The expected maximum magnetic field in the TORCH environment of 10 mT is not expected to have an impact on the charge sharing performance.

4. Close Packing

The technical challenge for Photek is to produce a tube envelope that has a fill factor of > 88% working area over the total detector size (including housing) in the “x” direction of 60 mm, with a less restrictive limit in the “y” direction. To achieve the close packing requirement the detector has to be square or rectangular.

The traditional method of anode sealing – welding – is unusable due to the close packing requirements. We are experimenting with indium seal, brazing and fritting and are currently producing leak-tight square test cells.

5. Conclusion

We have established that ALD coated MCPs bring a major improvement to the operating lifetime of MCP-PMTs, along with an improved gain and collection efficiency. We have demonstrated our technique to derive a high granularity multi-anode readout to provide an equivalent of 128 pixels across a 53 mm working width inside a 60 mm detector envelop.

Acknowledgments

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