Performance of High Pixel Density Multi-anode Microchannel Plate Photomultiplier tubes

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Company overview

Specialist manufacturers of photon detectors and camera systems. Photek manufacture Image Intensifiers, PMTs, Streak Tubes, open faced detectors and a range of associated electronics and camera systems.

- Founded in 1991
- St Leonards-on-sea, East Sussex
- 60 employees
- Approximately ¼ of employees educated to PHD or degree level
  - Research & Development
  - Design & Engineering
  - Production
  - Test & Quality Control
  - Sales & Administration
Company Overview: What we make

Photek design and manufacture vacuum based sensors and camera systems for photon and particle detection such as:

• Gen II MCP image intensifiers
• Ultra fast MCP photomultiplier tubes
• UV detectors
• Streak Tubes
Company Overview: What we make

- Advanced photon counting/imaging camera systems
- Ultra high vacuum imaging detectors (VIDS)
- Electronic products

All our products are *bespoke*
Covered detectors

• New range of Multi-anode MCP PMTs
  – Auratek MAPMT-253
  – Auratek MAPMT-228

• Plus integrated readout solutions
  – Auratek PCS-256 multi-channel photon counting system
MAPMT Applications

- Cerenkov radiation detection (e.g. DIRC/RICH detectors)
- Time resolved spectroscopy
- Fluorescent Lifetime Imaging
- LIDAR
- Scintillating fibre readout
- Beam monitoring
- Sampling Calorimeter Readout
MCP OPERATING PRINCIPLE
MCP Photon Detection
Vacuum MCP detector advantages

- Low-noise gain from $10^3$ up to $10^7$
- Single photon imaging devices, i.e. preserves photon’s position
- High bandwidth signal (~6GHz for single channel)
- High time resolution
  - <50ps single photon jitter
  - <10ps multi-photon jitter
A tileable, high density, multi-anode MCP-PMT

PMT253
PMT253 Readout Format

- Direct couple anodes
- 64 x 64 array
- 0.73 mm pad width on a 0.83 mm pitch
- Outer dimensions of 60×60 mm², with 53×53 mm² active area

Vacuum side

Air side
Challenges and Solutions

• Only 3.5 mm available for HV insulation, vacuum wall and MCP fixing around outside
  – 40 mm circular image intensifier has 16.5 mm for the same task!

• Our novel MCP fixing method allows tight gap between photocathode, and MCP input
  – In the range 1.5 – 2 mm
  – Leads to improved timing performance

• Predicted MCP – anode gap is 2.5 – 3 mm

• 15 µm MCP pore size
Signal Interface

- We have adopted Anisotropic Conductive Film (ACF) as an interconnect solution
- Uses temperature/pressure to permanently bond PCB to detector output
- Allows connectors etc… to be mounted on PCB
  - significant per application customisation

ACF is insulating in $x$ and $y$ but conducting in $z$
Interface Options

• Currently a challenge to connect all 4096 connections in 64 x 64 array to front-end electronics
• However, this format gives flexibility to gang pads together:
  • Gang 8 x 8 pads together
  • 8 x 8 array
  • e.g. MCX co-ax
  • Gang 4 x 4 pads together
  • 16 x 16 array
  • e.g. SSMCX co-ax
  • Gang 8 x 1 pads together
  • 8 x 64 array
  • e.g. Samtec 140-pin multi-way
The TORCH detector format – Cerenkov PID

The TORCH project is funded by an ERC Advanced Grant under the Seventh Framework Programme (FP7), code ERC-2011-ADG 299175.
Spectral Response

- Broad range of photocathodes available
  - visible (S20, S25, Bialkali)
  - near-UV (solar blind)
  - deep-UV (CsI)
Single Photon Pulse Height Distribution

Example PHD
Dark counts subtracted
MCP-PMT Lifetime

- ALD has allowed Photek to achieve drastic improvements in detector lifetime
- Two PMTs produced: Double-MCP 10 mm diameter working area
  - One with ALD coated MCPs, One control with standard MCPs
  - Accelerated test: ~ 800 nA / cm\(^2\) for ~ 14 weeks over small area

- Work presented by Conneely et al at VCI 2013
MCP-PMT Lifetime

- Photek have licensed Arradiance ALD technology for in-house coating of MCP substrates
- We have started a KTP project in collaboration with the University of Liverpool ALD research group
  - Embed ALD process knowledge in Photek
  - Optimise process to improve MCP collection efficiency
  - Use ALD for improving other aspects of detector performance
Round format, multi-anode MCP-PMT

MAPMT228
Multi-Anode

- PMT228 has a 40 mm round format
- Allows a tight photocathode gap for timing performance
  - 0.2mm nominal gap
- Active area
  - 28x28mm area
  - 32x32 pads
  - 0.75 mm width on a 0.88 mm pitch
Input Windows

• Broad range of photocathodes available
• Fibre optic and fused silica input windows
• ALD available for enhanced lifetime
PCB Interface

• Currently using “cold” ACF for interface PCBs
  – Does not produce permanent bond
  – Requires constant pressure applied to rear of detector during operation
  – However, PCBs can be changed after purchasing detector

• Possibility of customising anode layout grouping pads together
Gain

PMT240MA 31140520
PHD
Dark Counts Subtracted
Detector Crosstalk

- Measured using single photon illumination at a gain of $5.5 \times 10^6$, 0.2 mm FWHM laser spot
Single anode signal

Average of 50 single photon pulses measured on 5 GHz, 20 GS/s scope, using a Photek LPG-405 pulsed laser.

<430ps FWHM
256 Multi-Anode detector with integrated timing electronics

PCS-256
Detector Specification

- Uses the PMT228 MCP detector as a baseline
- Instrumented to provide an $8 \times 8$ array of independent pixels
  - 1.5mm pad width, 1.76mm pitch
Multi-Anode / TOFPET Camera System

- Using TOFPET ASIC developed by PETsys Electronics SA (Booth 316)
- Demo available at Photek’s Booth no. 318
TOFPET ASIC

- Combined analogue frontend and time-to-digital convertor in a single ASIC
- 64 channels per chip (PCS-256 uses 4 ASICs in total)
- Ethernet connection to data acquisition PC
- Time over threshold technique used to correct for amplitude walk
- 160,000 c/s per channel rate limit

- TOFPET2 ASIC now available
  - Improved dynamic range
  - Higher per channel rate capability

- Plan to integrate new ASIC with system
- Further work to miniaturise the system
Multi-Anode / TOFPET Camera System

Results of TOFPET chip with MCP-PMT

Logarithmic plots of time-over-threshold vs arrival time

Single photon time resolution (black) with Gaussian fit (red)
Uncorrected $\sigma = 225$ ps
Corrected $\sigma = 96$ ps

Thanks to Steve Leach & Jon Lapington (University of Leicester) for this data
Multi-Anode / TOFPET Camera System

Screenshot of provisional GUI:
Thank you for listening
BACKUP SLIDES
MCP-PMT Lifetime

- We have also looked at different MCP manufacturers with same ALD coating
  - Differing outcomes for gain enhancement
  - Also some different lifetime results, currently being explored
  - May need different surface preparation or modification of ALD process
FUTURE DIRECTION
High granularity multi-anode

- Use a AC coupled anode to induce charge spreading
- TOFPET time-over-threshold measures charge collected by each anode
- Multiple pads readout in clusters, then centroiding algorithm used to reconstruct photon position
- Having A.C. coupled anodes allows the photocathode to be operated at 0 V
- Removes issues with charge-up on the input window

High granularity multi-anode

- Concept has been demonstrated by the TORCH project in one dimension using alternative electronics (NINO + HPTDC)

\[ y_c = \frac{\sum_i y_i \times q_i}{\sum_i q_i} \]

- We plan to extend concept to 2D, using TOFPET ASIC

See L. Castillo García et al JINST 11 C05022 (2016)