Breakthrough in the Lifetime of Microchannel Plate Photomultipliers

F.Uhlig[a,*], A. Britting[a], W. Eyrich[a], A. Lehmann[a], R. Dzhygadlo[b], A. Gerhardt[b], K. Götzen[b], G. Kalicy[b], M. Krebs[b], H. Kumawat[b], D. Lehmann[b], M. Patsyuk[b], K. Peters[b], G. Schepers[b], L. Schmitt[b], C. Schwarz[b], J. Schwiening[b], M. Traxler[b], M. Zühlsdorf[b], V. Kh. Dodokhov[c], M. Düren[d], E. Etzelmüller[d], K. Föhl[d], A. Hayrapetyan[d], B. Kröck[d], O. Merle[d], J. Rieke[d], E. Cowie[e], T. Keri[e], R. Montgomery[e], P. Achenbach[f], M. Cardinali[f], M. Hoek[f], W. Lauth[f], S. Schlimme[f], C. Sfienti[f], M. Thiel[f], P. Bühler[g], L. Gruber[g], J. Marton[g], K. Suzuki[g]

[a] *Friedrich Alexander-University of Erlangen-Nuremberg, Erlangen, Germany*
[b] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany*
[c] *Joint Institute for Nuclear Research, Dubna, Russia*
[d] *II. Physikalisches Institut, Justus Liebig-University of Giessen, Giessen, Germany*
[e] *University of Glasgow, Glasgow, United Kingdom*
[f] *Institut für Kernphysik, Johannes Gutenberg-University of Mainz, Mainz, Germany*
[g] *Stefan Meyer Institut für subatomare Physik, Austrian Academy of Sciences, Vienna, Austria*

Abstract

Cherenkov detectors using the DIRC (Detection of Internally Reflected Cherenkov Light) principle are foreseen for particle identification in the $\overline{\text{P}}$ANDA experiment at FAIR. Promising sensors for the detection of the Cherenkov light are so called micro-channel plate (MCP) photomultipliers (PMT). They have an excellent time resolution, can be operated at high gain for single photon detection and have a high resistivity against magnetic fields. The disadvantage of these devices was their limited lifetime, due to damage by feedback ions on the photocathode.

The lifetime of various types of MCP-PMTs from different manufactures have been tested under conditions similar to that in the $\overline{\text{P}}$ANDA experiment. The sensors are assembled in one setup, to ensure the same illumination conditions. The measurement procedure requires permanent monitoring of the illumination and interruptions after about 2-3 weeks to measure dark count rate, gain and spectral quantum efficiency of all sensors. Furthermore surface scans of the whole photocathode are done every 2-4 months to determine faster aging areas.

The latest results show very good lifetime performance for MCP-PMTs, where the MCPs have been treated with the atomic layer deposition (ALD) technique.

Keywords: PANDA experiment, MCP-PMT, Photon detector, DIRC, lifetime, ALD-coating

1. Introduction

In the $\overline{\text{P}}$ANDA [1] experiment, which will be installed at the new FAIR accelerator facility [2], a barrel DIRC [3] [4] detector and a disc DIRC [5] detector will be used for particle identification. The aim is to provide pion/kaon separation of up to 4 GeV/c.

Since both focal planes of the DIRC detectors will be placed inside a magnetic field of up to 2 tesla, standard dynode PMTs can not be used. Also Silicon Photomultipliers are not suitable, due to high darkcounts and radiation damage. From an average interaction rate of 20 MHz $p\overline{p}$ collisions, simulations predict a detected photon rate of 200$\frac{kHz}{cm^2}$ at the focal planes of the barrel DIRC and even more ($\approx 1\frac{MHz}{cm^2}$) at the disc DIRC.

This leads to an integrated anode charge of $5\frac{C}{cm^2}$ for the barrel DIRC, assuming a 50% operation of $\overline{\text{P}}$ANDA over 10 years and a MCP-PMT gain of $1 \cdot 10^6$. At the disc DIRC the integrated anode charge will be even higher, if no optical wavelength filters are used.

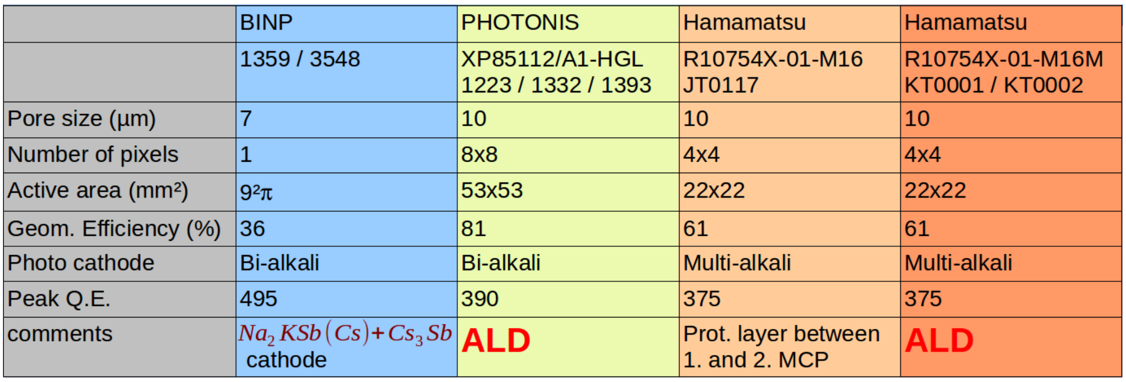
2. Lifetime

2.1. Methods to increase lifetime

Aging of an MCP-PMT usually means a reduction of its gain, its dark count rate and in particular its quantum efficiency (QE) when the integrated anode charge accumulates. A reduced gain can usually be compensated by

---

[*] Corresponding author
Email address: `fred.uhlig@physik.uni-erlangen.de` (F.Uhlig)



	BINP	PHOTONIS	Hamamatsu	Hamamatsu
	1359 / 3548	XP85112/A1-HGL 1223 / 1332 / 1393	R10754X-01-M16 JT0117	R10754X-01-M16M KT0001 / KT0002
Pore size (µm)	7	10	10	10
Number of pixels	1	8x8	4x4	4x4
Active area (mm²)	$9^2\pi$	53x53	22x22	22x22
Geom. Efficiency (%)	36	81	61	61
Photo cathode	Bi-alkali	Bi-alkali	Multi-alkali	Multi-alkali
Peak Q.E.	495	390	375	375
comments	$Na_2KSb(Cs)+Cs_3Sb$ cathode	**ALD**	Prot. layer between 1. and 2. MCP	**ALD**

Figure 1: Properties of the investigated lifetime-enhanced MCP-PMTs.

a higher PMT voltage, and a lower dark count rate is a positive effect of aging. The reduction of the QE may lead to an unusable tube. The main cause of the QE drop appears to be back-flowing ions from the MCPs, especially hydrogen and heavier ions (lead), which impinge at the photo cathode (PC) and damage it.
The manufacturers often apply electron scrubbing to clean and polish the MCP surfaces and also try to improve the vacuum. Besides these approaches the three main manufacturers of MCP-PMTs apply the following techniques to extend the QE lifetime:

1. In their latest MCP-PMT models the Budker Institute of Nuclear Physics (BINP) in Novosibirsk applies a special treatment to the bi-alkali PC which is baked in a vapor of cesium and antimony. This seems to increase the PC's hardness against feedback ions, but significantly increases the dark count rate of the tube [6].
2. A new approach is pursued by PHOTONIS. The surfaces and pores of the MCPs are coated with a very thin layer of secondary electron emissive material by applying an atomic layer deposition (ALD) technique [7]. This layer is expected to significantly reduce the outgassing of the MCP material and also increases the gain.
3. Hamamatsu first tried to eliminate the ion backflow from the rear part of the MCP-PMT by putting a thin protection layer of aluminum between the two MCPs. In addition, potential gaps between the MCPs and the metal walls of the tube frame were sealed with ceramic elements to prevent neutral atoms and molecules from the back part of the MCP-PMT in reaching the PC [8]. In their most recent MCP-PMTs Hamamatsu also applies the ALD technique.

The properties of the investigated lifetime-enhanced MCP-PMTs are listed in figure 1.

2.2. *Setup*

The setup of our lifetime measurements was described several times in other papers [9][10]. The MCP-PMTs are permanently and simultaneously illuminated with a blue LED (460 nm) at a single photon rate comparable to that expected for $\overline{\text{P}}$ANDA. The LED stability was controlled by measuring the current of a photo diode placed close to the PMTs. The light was broadened to a homogeneous spot that covered the photocathodes of all MCP-PMTs and attenuated to the single photon level. At a highly prescaled rate the signal charges are permanently monitored and recorded using a VME DAQ. Every 2-3 weeks gain and dark count rate of each MCP-PMT are measured and a wavelength scan (250-700nm) of the QE is performed using an in-house monochromator with a reference diode of type S6337-01 from Hamamatsu [11]. The uniformity of the photo sensitivity of the reference diode fluctuates 0.5% at maximum [12]. In intervals of a few months the photo current across the whole PC surface is measured in small steps of 0.5 mm with a Pilas[1] laser at a wavelength of 372 nm to identify regions with a degraded QE for each MCP-PMT. The laser is kept temperature stable at 20° Celsius to ensure a variance of less then 2% in light yield. The active area of all sensors is fully illuminated, except for the PHOTONIS XP85112/A1 #1223 and #1332, where one half of the area is covered to see if there is any aging in the covered area by for instance neutral gas.

---

[1] Advanced Laser Diode Systems GmbH, D-12489 Berlin, Germany

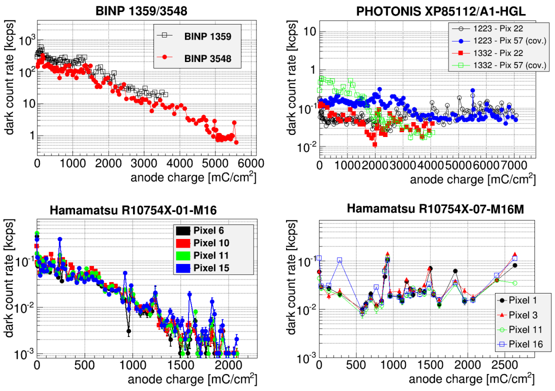


Figure 2: dark count rate vs integrated anode charge of different MCP-PMTs

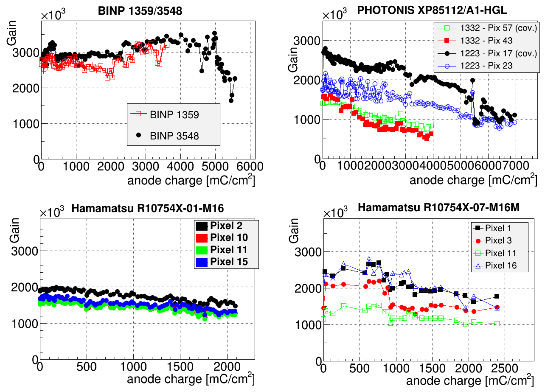


Figure 3: gain vs integrated anode charge of different MCP-PMTs

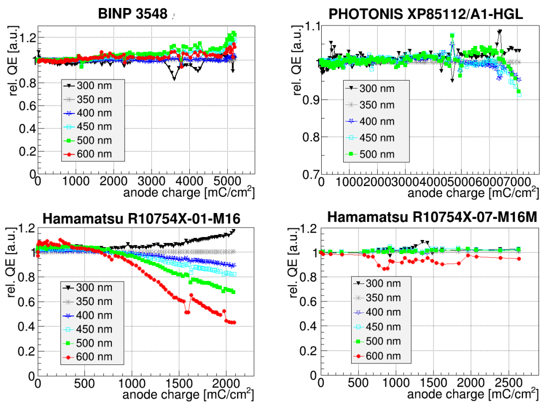


Figure 4: relative QE as a function of the integrated anode charge for different wavelengths.

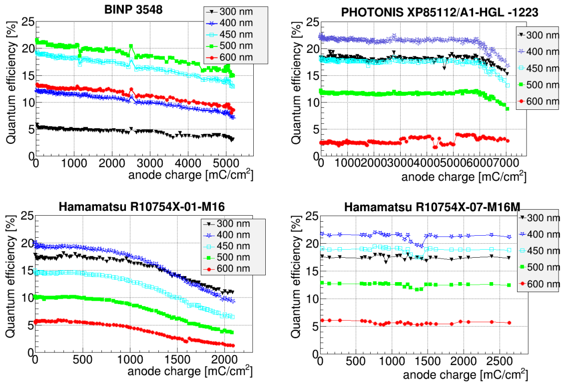


Figure 5: absolute QE as a function of the integrated anode charge for different wavelengths.

2.3. Results

The gain and dark count rate of photosensors are important properties for Cherenkov detectors. Figures 2 and 3 show the dark count rate and the gain as function of the integrated anode charge per cm^2 for the sensors with improved photo cathode (BINP) and protection layer between both MCPs (Ham. R10754X-01-M16) compared to MCP-PMTs with ALD-coating (Phot. XP85112 and Ham. R10754X-07-M16M). The dark count rate of the ALD-coated devices stays more or less the same, whereas for the other two devices it drops more then two orders of magnitude. This effect indicates a change of the PC work function during the illumination of the sensors.

For the gain we measure only moderate or no decrease for all displayed sensors. This can be compensated by increasing the tube voltage.

The Figures 4 and 5 show the QE (relative to 350 nm and absolute) as a function of the integrated anode charge. The QE has dropped continously since the start of the illumination for the BINP 3548, whereas for the R10754X-01-M16 the degradation has started at about 800 mC/cm^2 and then dropped more rapidly towards the end. The QE of the PHOTONIS XP85112/A1-HGL 9001223 starts to drop after $\approx$ 6 C/cm^2. The ALD-coated Ham. R10754X-07-M16M shows no aging after about 2.6 C/cm^2. For the Hamamatsu without ALD-coating (-01-M16) the QE drops faster at higher wavelengths, which indicates also a changing work function.

The surface scans reveal faster aging areas on the photocathode (see fig. 6). One can observe, that for all sensors the aging starts at the corners/rim. The right side of the PHOTONIS XP85112/A1-HGL is covered (marked by red rectangle) and therefore not illuminated. The non illuminated area clearly is not damaged, while on the left side the QE has dropped. This also indicates, that

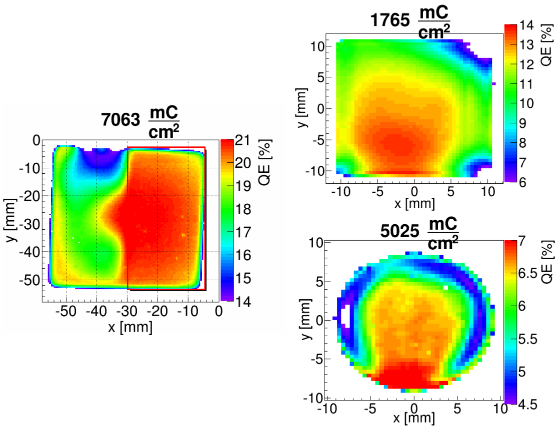


Figure 6: spatial QE of the photocathode for the PHOTONIS XP85112/A1-HGL (left), Hamamatsu R10754X-01-M16 (top right) and BINP 3548 (bottom right)

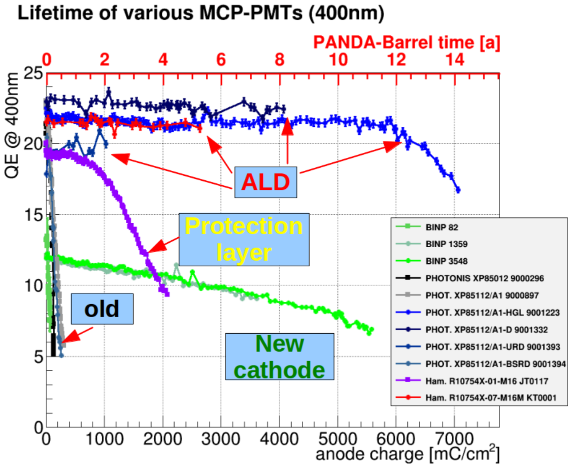


Figure 7: Comparison of the lifetime for different MCP-PMTs

neutral gas does no or only minor damage to the photocathode.

The overall comparsion in figure 7 shows that MCP-PMTs with ALD-coating have superior lifetime. The lifetime of the PHOTONIS XP85112/A1-HGL 9001223 was stable until ≈ 6 C/cm^2. The QE of the other ALD-coated devices is not decreasing yet. But also the treatment of the photocathode as done in the BINP 3548 enhanced the lifetime considerably. The former MCP-PMTs (labeled “old”) are shown at the very left of the plot.

3. Conclusions

The lifetime measurements presented in this paper show a significant improvement of recent MCP-PMTs. All approaches against aging led to an increase of the lifetime of at least one order of magnitude. The best performance is achieved by ALD coated devices, but the complementary approach of a different photo cathode of BINP is also interesting.

A further improvement, which is under investigation, is to change the MCP material from lead- to borosilicate-glass. Then one would get rid of the heavy lead ions, which damage the photocathode more then lighter ions. And also borosilicateglass can be heated up more and therefore one can achieve a better outgassing.

Acknowledgments

We thank our Erlangen colleagues of ECAP (especially O.Kalekin and B.Herold) for granting use of the spectral QE setup. Further thanks goes to PHOTONIS (in particular J.Defazio and E.Schyns) for useful conversations and M.Barnykov from the Budker Institute of Nuclear Physics for providing us with the two lifetime enhanced BINP MCP-PMTs. This work is supported by GSI Darmstadt and German BMBF.

[1] PANDA collaboration, *Technical progress report for PANDA. Strong interaction studies with anti-protons*, http://www-panda.gsi.de/archive/public/panda_tpr.pdf

[2] Walter F. Henning, *FAIR - recent developments and status*, *Nucl. Phys.* **A 805** (2008), 369c-376c

[3] J.Schwiening et al., *The barrel DIRC detector for the $\overline{\text{P}}$ANDA experiment at FAIR* *Nucl. Instrum. Meth.* **A 639** (2011), 315-318

[4] M.Hoek et al., *The PANDA Barrel DIRC Detector* *Nucl. Instrum. Meth.*, RICH 2013, Japan

[5] O.Merle et al., *Development of an Endcap DIRC for PANDA*, *Nucl. Inst. and Meth.*, RICH 2013, Japan

[6] M. Yu. Barnyakov and A. V. Mironov, *Photocathode aging in MCP PMT*, *J. Instr. 6* (2011), C12026

[7] O.H.W. Siegmund et al., *Atomic layer deposited borosilicate glass microchannel plates for large area event counting detectors*, *Nucl. Inst. and Meth.* **A 695** (2012), 168

[8] T. Jinno et al., *Lifetime-extended MCP-PMT*, *Nucl. Inst. and Meth.* **A 639** (2011), 111

[9] A. Britting et al., *Lifetime-issues of MCP-PMTs*, *JINST 6* C10001 (2011)

[10] A. Lehmann et al., *Significantly improved lifetime of micro-channel plate PMTs*, *Nucl. Instrum. Meth.* **A 718, 535** (2013)

[11] B. Herold and O. Kalekin, *PMT characterization for the KM3NET project*, *Nucl. Instrum. Meth.* **A 626-627** (2011), 151-153

[12] Datasheet of Hamamatsu S6337-01 photodiode, *http://pdf1.alldatasheet.com/datasheet-pdf/view/212393/HAMAMATSU/S6337-01.html*