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Quality evaluation of CsI photocathodes for the ALICE/HMPID detector

H. Hoedlmoser[a,*], A. Braem[a], G. De Cataldo[a,b], M. Davenport[a], A. Di Mauro[a], A. Franco[b], A. Gallas[a], P. Martinengo[a], E. Nappi[b], F. Piuz[a], E. Schyns[a]

[a]*CERN, Switzerland*
[b]*INFN-Sez. di Bari, Bari, Italy*

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Abstract

The facility for the production of the large area ($64\times 42\,\mathrm{cm}^2$) CsI photocathodes for the ALICE/HMPID detector has been equipped with a photo-current scanner system for the in situ measurement of the CsI response over the full photosensitive area before transfer to the detector. The photo-current measured on a first batch of 17 PCs, out of the 42 needed to fully equip the seven HMPID modules, has been correlated with test beam measurements in order to define acceptance criteria. Furthermore the system's sensitivity to variations in quantum efficiency allows us to study various effects such as post-deposition heat enhancement or decreased quality due to ageing.
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1. Introduction

The ALICE High Momentum Particle Identification (HMPID) detector [1,2] consists of seven RICH detector modules covering a total sensitive area of $11\,\mathrm{m}^2$. The current status of the ALICE HMPID project is described in Ref. [3]. This paper focuses on the Cesium Iodide photocathodes (PCs) for the detector, the status of their production and the measurement of their quality by means of a Vacuum Ultra Violet (VUV) scanner system, which has been integrated into the production plant. Results from the production and from investigations of CsI properties are given. The substrate for the $64\times 42\,\mathrm{cm}^2$ CsI pad PCs is double layer Cu clad PCB coated with Ni and Au. A 300 nm layer of CsI is deposited onto the substrate by evaporation of CsI from four crucibles under vacuum (10^{-6} mbar). The substrate temperature during evaporation is 60 °C.

*Corresponding author. Tel.: +41 76 487 3465.
E-mail address: herbert.hoedlmoser@cern.ch (H. Hoedlmoser).

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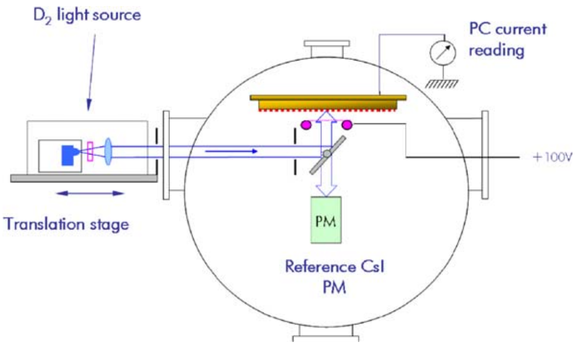

Fig. 1. VUV-scanner measurement layout.

PCs are kept at this temperature for a minimum of 12 h. Details about the production procedures can be found in Refs. [4–6]. So far the PCs have been tested in charged particle beams. Comparison of the test beam data with Monte Carlo predictions allows the extraction of quantum efficiency (QE) data and the assessment of the PC quality [7]. As this procedure is time consuming and depending on beam availability,[1] an alternative method to measure the quality of the CsI PCs during the series production had to be developed.

2. VUV-scanner system

2.1. Experimental setup

The VUV-scanner system allows to scan the PC with a UV beam and read the resulting photo-current from a given location on the PC. Fig. 1 shows the basic layout of the measurement system. The system outside the main chamber contains the UV source[2] under Ar flow and UV optics (CaF_2 lens, pinholes, diaphragm, optional quartz filter under vacuum). This optical system is connected to the main chamber by a flexible bellow, which allows to move the optics in and out of the chamber. The volumes are separated by a CaF_2 window. In the main chamber the UV beam (2–16 mm diameter) is directed onto the PC via a revolving mirror. The PC is fixed to two rails at the top of the chamber. The photoelectrons produced by the UV beam are extracted from the PC by means of a bias voltage of +100 V on an anode ring approximately 5 mm in front of the PC. The PC is connected to a pico-amperemeter for the measurement of the photo-current (Fig. 1). By means of the mirror the beam can be directed onto a CsI photo-multiplier[3] (PM) to obtain a reference measurement. The software controlled movements of the optical system and of the PC itself, allow a fully automated scan of the photo-current over the PC surface. The scans are performed according to a set of pre-defined coordinates, with a positioning accuracy of 1 mm.

2.2. Measurement method

For each point in a VUV-scan the photo-current I_{CsI} from the PC is recorded as well as the reference signal I_{PM} from the PM (read from the first dynode) and the background levels $I_{CsInoise}$ and $I_{PMnoise}$. The reference current on the PM is used to normalize the photo-current from the PC (Eq. (1)). The currents are measured without amplification in the range of approximately 100–500 pA, whereas the background currents are <1 pA. I_{norm} (Eq. (1)) has a value around 3–3.5. A repeated measurement on a single spot on a PC including repositioning of the spot shows a non-reproducibility of 2%:

$$I_{norm} = \frac{I_{CsI} - I_{CsInoise}}{I_{PM} - I_{PMnoise}}. \quad (1)$$

3. Series production of PCs

3.1. Production summary

Immediately after CsI deposition the photo-current from the PC is monitored to check the development of the QE during the heat conditioning phase (see Section 4.1). Before the PC is extracted from the plant, a scan covering 280

[1] There is no test beam available at CERN in the mass production phase in 2005.

[2] Hamamatsu L7292 with a MgF_2 window (http://www.sales.hamamatsu.com/).

[3] Electron Tubes 9403B (http://www.electrontubes.com/).

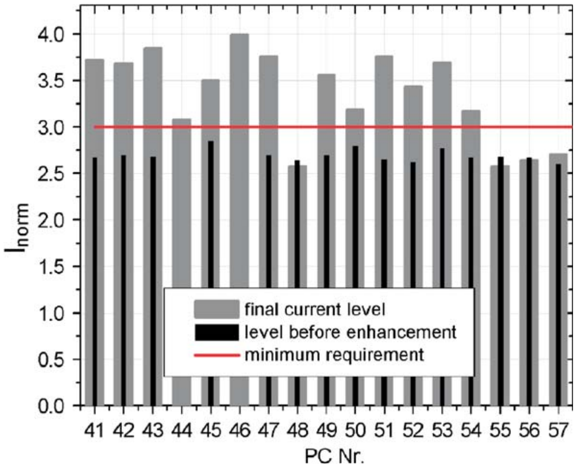

Fig. 2. $\langle I_{\text{norm}} \rangle$ for each PC produced since May 2004.

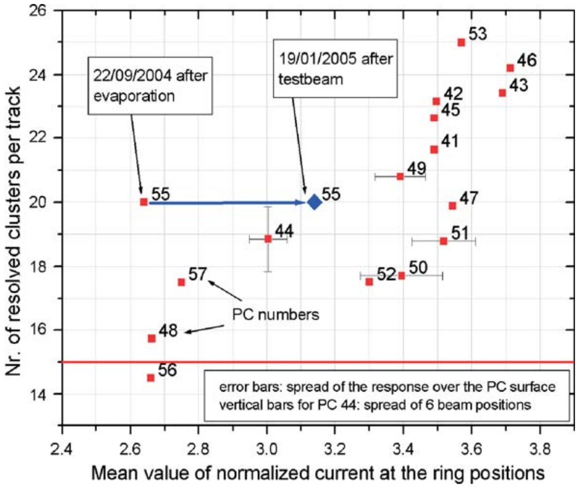

Fig. 3. N_{CL} in the beam plotted against $\langle I_{\text{norm}} \rangle$ at the position of the Cherenkov ring.

points equally spread over the PC is performed. Minimum to maximum variation of 6–12% of the normalized current across the PC surface can be measured. Since May 17, 2004 PCs have been produced and measured. Fig. 2 shows the average normalized current $\langle I_{\text{norm}} \rangle$ for each of the PCs obtained from the 280 points scan. The variation from PC to PC is substantial, with values from 2.7 up to 3.8 of $\langle I_{\text{norm}} \rangle$ corresponding to a spread of almost 33%. The plot also shows a level of acceptance of $\langle I_{\text{norm}} \rangle = 3$ derived from a preliminary comparison with test beam results—see Section 3.2. During the production of PC 54 an accident damaged both primary and secondary pumps of the plant. Afterwards we had to work under questionable vacuum conditions, and we obtained three PCs with a low current level in the scanner.

3.2. Comparison of scanner and test beam results

The PCs were mounted onto modules 3–5 of the detector, which were tested with a 120 GeV/c pion beam [3]. The most important quantity to be measured is the number of resolved clusters per particle track, N_{CL}. This number depends not only on the PCs QE, but also on several detector parameters, e.g. radiator transmittance or chamber gain. Therefore this number can only be used as a first approximation in a direct comparison between test beam and VUV-scanner. Also the differences in photon-flux, spectral composition, and photo-emission have to be kept in mind: in the detector photoelectrons created by single photons are emitted into gas as opposed to a high photon-flux (10^{10} photons s^{-1} cm^{-2}) and photo-emission under vacuum in the scanner. Fig. 3 shows the correlation between N_{CL} and $\langle I_{\text{norm}} \rangle$ at the position of the Cherenkov rings. The plot also shows the minimum value of $N_{\text{CL}} = 15$, which is required to achieve the necessary Cherenkov angle resolution of 3 mrad. From the first results from the scanner a value of 3 for $\langle I_{\text{norm}} \rangle$ was chosen as the minimum requirement for the PCs, as all the PCs with currents higher than 3 are clearly above the limit for N_{CL}. Despite the general trend visible in Fig. 3 there are some PCs, which performed differently in the test beam than expected from the scanner results, e.g. PC 55 which will be discussed in Section 4.1.

4. CsI properties: post-treatment and ageing

The use of the VUV scanner system is not limited to quality control during the series production. It was used to measure properties of the CsI PCs like the post-deposition heat enhancement effect, which

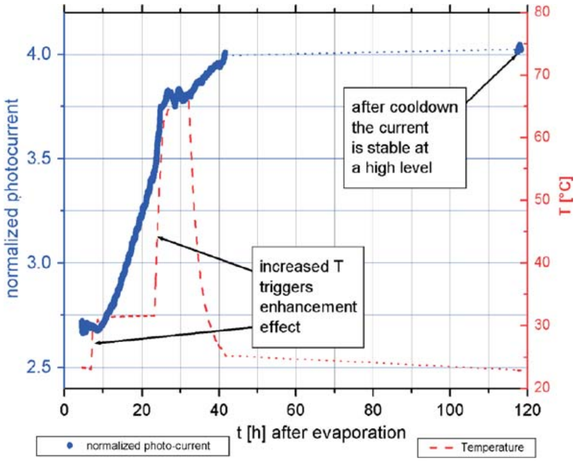

Fig. 4. Time development of $\langle I_{norm} \rangle$ and T during heat enhancement phase.

has been reported for small cathode samples [2,8–10] and to perform tests concerning ageing of CsI PCs due to exposure to humid air and to ion bombardment. In the case of humidity aged PCs a recovery effect was observed caused by heating the PCs.

4.1. Post-deposition heat enhancement

A series of CsI depositions onto a test substrate[4] was performed and the heat enhancement was measured both for depositions on cold (20–25 °C) and hot (65 °C) substrates. The scanner was used to continuously record the development of the photo-current immediately after CsI deposition.

Fig. 4 shows a measurement of the time development of the temperature on the PC backside and of the photo-current averaged over several points on the PC. The CsI deposition was carried out at room temperature and the initial photo-currents were low. The PC was heated first to 30 °C and afterwards to 65 °C, which caused a 50% increase of the photo-current compared to the initial level.[5] Afterwards the PC was cooled down to 25 °C and the photo-current stayed at a high level. When the measurement was repeated 3 days afterwards, the current was still high. Several other tests showed a similar behaviour both for evaporations at 25 °C and at 65 °C. Usually the enhancement phase is shorter for evaporations at 65 °C with equal final results. Sometimes the initial enhancement phase is followed by a very slow increase of the photo-current in the first few days or even weeks after evaporation. This can explain the behaviour of some PCs of the series production, which showed a discrepancy between the performance in the scanner and later in test beam. In the PC production the development of the quality during the enhancement phase is recorded. Fig. 2 shows both the levels of the photo-current before the enhancement phase and the final level before extraction. Before the enhancement, all the PCs show approximately the same level of $\langle I_{norm} \rangle$ and the large variation from PC to PC is only due to a difference in the enhancement process. The bad PCs, e.g. PC 48 or PC 55 did not show any enhancement at all. However, in the case of PC 55 the beam tests showed a good performance later and a new scan 119 days after CsI deposition confirmed an improved response. Therefore we assume, it took a much longer time to complete the enhancement phase for PC 55 than for other PCs. So far these differences could not be clearly correlated with any other production parameters, like pressure in the vacuum chamber ($0.5–1.3 \times 10^{-6}$ mbar), residual gas composition, CsI powder, or substrate quality.

4.2. Exposure to humidity

As indicated in Fig. 5 the test PC described in Section 4.1 was exposed to air 145 h after CsI deposition inside the clean room facility and consequently to humidity, which is known to destroy the hygroscopic CsI film, e.g. Ref. [8] and references therein. The exposure lasted for 4 h (15% RH at 22 °C). Subsequently the vacuum chamber was closed, pumped again and the measurement restarted. The photo-current was decreased by 31% compared to the level before exposure. One day later the PC was heated to 65 °C, which caused a recovery effect, as previously reported in Refs. [8,10]. The photo-current

[4] A $27 \times 39\,cm^2$ test substrate was identical to the standard PC substrates, except that it was not segmented into pads.

[5] The increase depends on the spectrum used in the measurement.

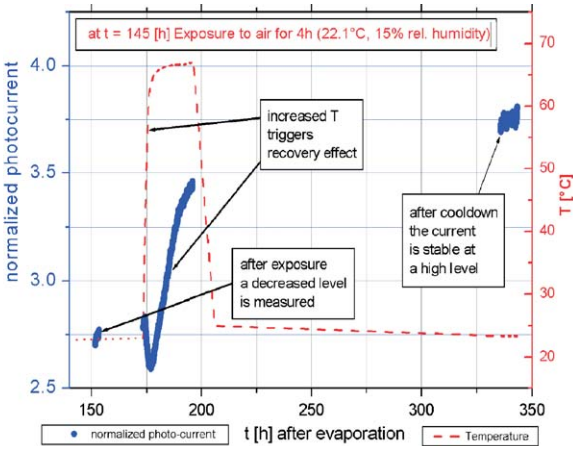

Fig. 5. Time development of $\langle I_{norm} \rangle$ and T after exposure to humid air (extension of Fig. 4).

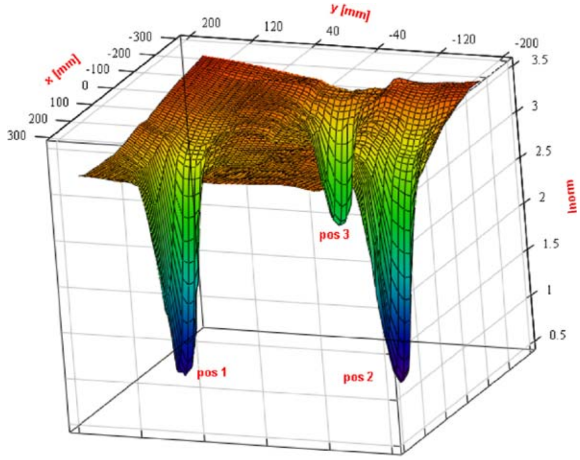

Fig. 6. Scan of the irradiated PC.

stayed at a high level when the temperature was lowered again (Fig. 5). The measurement was repeated after 6 days and the photo-current had reached more than 93% of the level before exposure. Other test cathodes showed a recovery of up to 100% of the level before exposure in similar tests. The decrease of QE of the PCs is due to the hydration of the CsI by the adsorbed water molecules and the recovery could be a consequence of the increased desorption of water molecules at higher temperatures.

4.3. Ageing due to ion bombardment

The radiation environment of a HEP experiment continuously causes avalanche processes inside the detector and consequently avalanche ions hitting the CsI layer. This process can decrease the quality of a CsI PC [11,12]. To determine the damage to the detector, a standard PC was irradiated with a colliminated Sr^{90} beta source inside a detector prototype. The specifications of the experimental procedures used in this ageing test, as well as a discussion of the results are given in a separate article in these proceedings [13]. The VUV-scanner can be used to investigate the aged PCs. In a first test three positions of approximately 4 cm diameter were irradiated with rather high accumulated charge densities and rates in order to produce a measurable effect, as it was also one of the first tests of the sensitivity of the VUV-scanner. The accumulated charge densities for positions 1, 2, and 3 were of 6.31, 6.79 and 1.54 mC cm^{-2}, respectively,[6] administered within 2–9 days. After the irradiation, the PC was remeasured in the scanner. The photo-current scans across the irradiated zones revealed a decreased QE in these zones, as can be seen in Fig. 6. The QE decreases shown in Fig. 6 are close to 80% for positions 1 and 2 and 40% for position 3. In repeated measurements we found that this was not stable in time due to a possible self-ageing mechanism [13].

5. Conclusions

The VUV scanner measurements during the first phase of the series production of PCs for the ALICE RICH show that the device is able to provide useful information about the quality of the PCs and the photo-current measurements agree with the test beam results. With the exception of only one in 17 PCs, all of them meet the minimum requirement for the number of resolved clusters in order to achieve the necessary Cherenkov angle resolution for the detector. Furthermore the device

[6]Ten years inside ALICE correspond to 0.5 mC cm^{-2}, however, other experiments are reaching much higher doses, e.g. COMPASS.

proved to be very efficient in the study of CsI properties. However, the measurements also show that certain properties are still not sufficiently understood: variations were found in post-deposition enhancement and long term behaviour of PCs, although there were no major differences in the monitored production parameters e.g. pressure, temperature or residual gas composition. These phenomena are currently being investigated.

Acknowledgements

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