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Section A

Recent results on the properties of CsI photocathodes

CERN RD26 collaboration

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Abstract

We report here on the results obtained by the CERN RD26 collaboration on the production and characterization of large area photocathodes, susceptible to equip fast UV-photon imaging devices. Such detectors are planned for some Ring Imaging Cherenkov (RICH) detector projects, in particular HADES at SIS Darmstadt, BABAR at the SLAC asymmetric B-factory, and ALICE at the LHC (CERN).

1. Introduction

The possibility to use solid photocathodes (PC) in RICH detectors has stimulated a large activity in the past few years. Systematic measurements of the quantum efficiency (QE) for the emission of electrons by UV photons in a reflective mode were performed [1]. The feasibility of the operation of a RICH, under realistic beam conditions, was proved using pad PCs, coated with a thin layer of evaporated CsI, incorporated into MWPCs of 10×10 cm^2 and 30×30 cm^2 [2]. The stability of operation, the satisfactory yield of detected photoelectrons and the absence of short term ageing effects (over a time scale of months) were demonstrated. At present the CERN RD26 collaboration devotes much effort to optimize the yield of CsI PCs in the specific environment of gas MWPCs, operated at atmospheric pressure. This particular task encompasses different aspects: optimization of the CsI surface preparation, its homogenization and study of the effects of the gas mixture and the electric field value at the CsI surface. Our aim is to achieve the maximum QE over pad PC surfaces ranging from several m^2 to hundreds of m^2. We present the first results of the studies enumerated above. Being preliminary, the results should be considered mostly as observations and indications of the way to proceed rather

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than as definitive procedures. We also report on the photon yields measured with UV light sources and the latest results on the photon yield obtained in beam tests with large size RICH prototypes.

2. Surface structure analysis

We want to establish on the PC a uniform surface with the least possible roughness, since the probability of losing photons by surface reflection depends on the local angle of incidence. It should be stressed that most of the reports on the QE do not account for the specularity of the surfaces.

To illustrate our point we show in Fig. 1 a comparison between the aspect of the CsI surface for two types of substrates: a quartz plate, coated with vacuum-deposited 100 nm of gold and 500 nm of CsI, and the standard RICH PC substrate – a printed circuit board with a chemically deposited gold layer, coated by an 800 nm thick CsI layer. The difference between the two surfaces is clear, and

Fig. 1. SEM micrographs of two CsI deposits: 500 nm of CsI deposited on gold coated quartz (a), and 800 nm of CsI deposited on a substrate for the RICH PCs used in the present tests.

indicates a clear advantage for the glass substrate. For other polished metallic surfaces, the aspect is similar to the glass one.

The optical quality of the surface however is not the only factor determining the photoemission qualities of the material. Alterations of the stoichiometry, of the crystalline structure (grain size, partial amorphism etc.), interaction with air during transfer, etc. were shown to influence the QE. To study some of these aspects we have used laterally resolved Electron Spectroscopy for Chemical Analysis (ESCA) and X-ray Secondary Electron Microscopy (XSEM) [3] on polished metallic samples. The main conclusions that can be drawn from these studies so far are:

– While Scanning Electron Microscopy (SEM) shows grains of submicrometer size, the photoemission spectroscopy with a lateral resolution of 27 μm indicates that the X-ray induced yield of secondary electrons emitted from the PC by Al K_α X-rays is widely varying across the surface. Taking adjacent areas of 40×40 μm^2 on the photocathode, one gets yield variations reaching a factor of three [3], indicating that, in spite of the apparent uniformity of the surface observed in Fig. 1a, there exist important non-uniformities in the photoemission level at a macroscopic scale. We plan to study the same spot on the PC by the ESCA and electron microscope to find the correlations.

– The heat treatment definitely alters the structure of the CsI layer. While heat treatment up to 50°C increases the secondary electron yield, heating above 70°C seems to deteriorate the surface and decreases photoemission [3,4].

3. Dependence of the QE on the angle of incidence

It has been speculated that the photon reflection at the surface of the CsI may be the reason for a diminished photo electron yield, in the case of the P-polarized Cherenkov photons, as well as in the case of unpolarized monochromatic light. To investigate the effects of slanted incidence on the QE in case of UV light sources, Miné et al. [5] measured the ratio of the QE at an angle of incidence of 45° to the one measured at normal incidence. The measurements were performed in two different ways, once tilting a planar PC and once shining UV light on a cone evaporated with CsI. The results are shown in Fig. 2. It is visible that the ratio departs from 1, especially at large wavelengths, where some noticeable decrease in the QE is observed. These results may indicate the importance of surface structure effects on the QE, since this is, offhand, the only effect one would attribute to the observed behavior. A word of caution is in order since from the SEM we know that the CsI is far from being a flat surface so that the meaning of "incidence angle" is a very relative one.

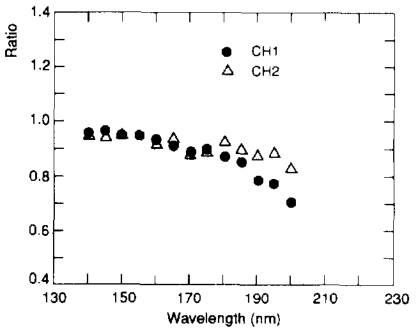

Fig. 2. Ratio of QEs measured by tilting the photocathode at 45° to the QE measured at normal incidence. The ratios obtained for two PCs are shown.

4. Gas mixture and electric field effects on the quantum efficiency

Most measurements of CsI QE were performed under vacuum with only a few in gas atmosphere. Gas counters using CsI PCs could be in principle affected in their electron yield by the gas and by the value of the "extracting" electric field at the PC surface.

Recently Breskin et al. [6] have studied the QE of CsI photocathodes as a function of the electric field strength on their surface, in gas media. Gas mixtures investigated were CH_4, C_2H_6, i-C_4H_{10}, He/CH_4 and He/i-C_4H_{10}, in the pressure range of 0.05–1 atm. It has been found that the relative QE of CsI has a universal character in all gases. In the charge collection mode, once the counting plateau is reached, the QE is independent of the field and is lower than in vacuum. The QE depends on the gas used and is 80% and 70% of the vacuum value for mixtures containing, respectively, C_2H_6 and i-C_4H_{10}. In the charge multiplication mode the QE increases with the field and reaches the vacuum value at high gas gains. A more pronounced behavior, leading to a very low QE in the collection mode (50% of the vacuum value) has been observed for the He-based gas mixtures. In pure CH_4 the QE is independent of the field both in charge collection and multiplication modes and is equal to that in vacuum even at atmospheric pressure. The QE value in a mixture of CH_4/i-C_4H_{10} (95/5), in the collection mode, is about 90% of that in vacuum.

These results are explained by the difference in the extraction probability of photoelectrons from CsI, which depends on the elastic backscattering probability from different gas molecules. At high gas gains elastic backscattering is taken over by inelastic collisions, resulting in a QE value equal to that in vacuum independently of the gas nature.

Consequently, one should avoid using noble gas mixtures in UV detectors using CsI PCs. Furthermore, except for the case of methane, multiplication geometries leading

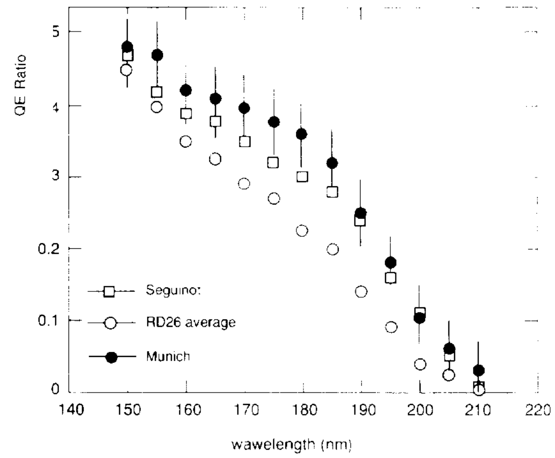

Fig. 3. QE as function of wavelength measured in vacuum, by RD26 (see text), Munich and Sequinot [8]

to the highest possible electric field at the CsI surface should be used.

5. Quantum efficiency of CsI photocathodes

Several groups have measured the quantum efficiency (QE) of CsI in vacuum and gas media using small samples, various substrates and different characterization techniques [1]. For a long time large discrepancies were observed. A considerable improvement has been achieved by the RD26 collaboration due to the detection of erroneous calibration curves, provided by the manufacturer, of the photomultipliers used to monitor the UV light [7].

In Fig. 3 we report the present status of the QE efficiency measured by the RD26, compared to the original data of Sequinot et al. [8]. The lower curve (RD26) is the result of several tens of PCs produced and measured at the Weizmann Institute and at Ecole Polytechnique, Palaiseau; the upper curve is the result of the QE measurements done at the Technical University Munich. The error bars in the measurements reflect the spread in the results obtained for a number of PCs. The large QE measured by Munich may be due to the use of electron gun heating of the pellets instead of evaporation by Joule effect used by other groups. Some early results of surface studies [9] seem to indicate that indeed one observes for PCs produced with an electron gun a different electrical behavior.

6. Measurement of the photon yield of CsI photocathodes with a RICH detector

The fundamental differences between the RICH operation and the measurement of quantum efficiencies of small samples with monochromator light are:

- a well defined polarization of the Cherenkov photons and a slanted angle of incidence;
- necessity for large area of PCs, implying "industrial" substrates (printed circuit boards of low cost, robust etc.) and short exposure to air during transfer to the detector.

Since 1992 we have tested ten PCs of different sizes installed in RICH detectors using a NaF radiator [10]. Also other RD26 groups have tested RICH prototypes using PCs prepared at different evaporation stations (Saclay and Giessen). The detector characteristics have been reported earlier [2] so that we recall here only the main features: the electron detection is made by a MWPC with a 2 mm gap and a 4 mm pitch between anode wires; the cathode is segmented with a pad size of 8×8 mm^2. The analog readout allows a spatial (rms) resolution of 1.2 mm for the photon impact and 600 μm for the charged particles; the single electron efficiency of the MWPC is 80–90%; the methane gas is flowing at atmospheric pressure; the distance radiator–photon detector is chosen such that rings of 10 cm radius are projected for $\beta \sim 1$ particles. The relatively long integration time of the frontend electronics (500 ns) allows operation at a low electron amplification of $\sim 10^5$. The electric field at the surface of the photocathode in the present geometry and with an anode voltage of 2100 V is ~2.6–3.7 kV/cm. The CsI layer thickness was ~ 700 nm. To circumvent the main disadvantage of the NaF radiators namely their optical anisotropy to polarized light due to constraints during crystal growth we have tested C_6F_{14} radiators.

We present here the new results obtained with a 30×30 cm^2 prototype using a C_6F_{14} radiator. The particularity of the present PCs is that they were produced in a different manner: the pad substrates have been heated for 24 hours in vacuum at 55°C before evaporation at the same temperature, followed by keeping them in vacuum at the same temperature for four hours. The prototype has been tested in a mixed 3 GeV/c proton and pion beam at the CERN PS accelerator. The particles were identified using time of flight. The results were analyzed using an offline routine which determines the single electron detection efficiency and the number of photoelectrons.

In total three large area PCs have been tested. The best result for pions is 7.3 detected photoelectrons/event using a 13 mm thick radiator and a normal beam incidence. The single photon Cherenkov angle resolution per event is ~ 8 mrad, in agreement with simulation. The Cherenkov angle resolution per event is 3.6 mrad, and 10 mrad for respective beam incidence of 0° and 10°.

To extract the integral quantum efficiency in the wavelength range 170–210 nm we have used the mean number of detected photoelectrons, and the following parameters and corrections: the window transmission, the measured C_6F_{14} transmission (inferior to the best achievable one in our case), a single electron detection efficiency of 80%, a cathode grid optical transmission of 70%, the methane transmission. The integrated QE, extracted in this way for two PCs out of the three treated at 55°C is 85% of the integrated RD26 curve, a markedly better result than the 50% value of the integrated RD26 curve (Fig. 3), achieved for earlier PCs. The third one exhibited a low QE similar to earlier prototypes made without heat treatment. Although apparently all three evaporations were done identically – in the same apparatus – with the same starting material (CsI crystal), the same evaporation rate etc., the reproducibilty is not yet satisfactory.

The stability of operation of all our prototypes has been remarkable, which is due largely to the low amplification used. No ageing effects were observed in beam or over a time scale of 6–8 weeks. Two other groups (Giessen and Saclay), that have tested similar prototypes within the RD26 collaboration, obtained results comparable to the ones presented here.

7. Conclusions

We have presented here the main results of the RD26 collaboration in the recent months, on the different aspects of the production of large size CsI photocathodes. The results obtained using MWPC prototypes operated at low gain with methane indicate that the detectable number of photoelectrons is sufficient at the present stage to separate 2 GeV/c pions from kaons in high particle density environment such as in ALICE for instance [11]. The beam tests indicate that the quantum efficiency of the large photocathodes integrated over the whole range of sensitivity is close to the average results measured on small samples. However, surface studies revealed large variations of the quantum yield even on polished metallic substrates. The surface state of the actual RICH PCs, points towards the necessity to have a much better control of the surface uniformity and crystallization conditions during evaporation, although an interesting conjecture would be that the stable behavior of the MWPC in the present prototypes is due in part to the disorderly surface of Fig. 1b, allowing for the evacuation of charges and hence for the stable operation observed. The investigations of the influence of the electric field at the PC surface demonstrated the importance of the effect and its dependence on the detector gas used. In the conditions of the RICH tests presented here no electric field effect is expected since methane at one atmosphere behaves, regarding the quantum yield, as vacuum.

Besides the quantum efficiency improvements, possible and probable, we stress that a judicious optimization of the detector design (optical transparency of the cathode) and increased single electron detection efficiency (frontend electronics) may easily increase the number of photoelectrons by ~ 25%.

Acknowledgements

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