CEA/SACLAY
DSM

DAPNIA/99-07

October 1999

**FASTS SIGNALS AND SINGLE ELECTRON DETECTION
WITH MICROMEAS PHOTODETECTOR**

**J. Derré, Y. Giomataris, Ph. Rebourgeard, H. Zaccane,
J.P. Perroud, and G. Charpak**

DAPNIA

Submitted to Nuclear Instruments & Methods in Physics Research A

Fast signals and single electron detection with a MICROMEGAS photodetector

J. Derré^a, Y. Giomataris^a, Ph. Rebourgeard^a, H. Zacccone^a,
J.P. Perroud^b, and G. Charpak^c

^a*CEA/DSM/DAPNIA/C.E.-Saclay, 91191 Gif-sur-Yvette, France*

^b*IPHE, University of Lausanne*

^c*CERN/LHC-EET, Geneva*

The performance of a new gaseous photodetector was investigated. It consists of a solid photocathode and a gas amplification structure of the MICROMEGAS type. Using a mixture of helium and isobutane at atmospheric pressure, a stable and high amplification gain close to 10^7 was achieved. Such a high gain and small fluctuations allowed the detection of single photoelectrons with a time resolution better than 700 ps. These performances are comparable with those obtained with the best photomultipliers.

1 Introduction

Large-area single photoelectron detection with good time resolution and accurate localization is a challenge in particle physics, astronomy, and nuclear medicine. Combined with a photocathode, a gaseous amplification structure which could operate at high gain ($> 10^6$) with small fluctuations and good stability would be an excellent candidate for fulfilling these requirements. Furthermore, in contrast to phototubes, such a detector can operate in a high magnetic field without changes in performance. Photoelectron extraction in gas at atmospheric pressure is feasible with CsI photocathodes [1]. It has a high quantum efficiency in the UV region, for wavelengths lower than 250 nm. In the past ten years intensive research has been devoted to the development of gaseous detectors based on CsI photocathodes [2,3,4,5,6] for ring imaging (RICH) or other Cherenkov detectors [7,8,9]. A drawback is the instability generated by photoelectric effects on the photocathode of the UV photons produced during the avalanche development (photon feedback effect).

Operation in the visible region is more difficult; many attempts to develop photocathodes (SbCs, GaAs/Cs, Si/Cs) compatible with gaseous detectors have

been undertaken [10,11]. Two major difficulties have been reported. Firstly, it requires an extremely clean gas environment because of the damage to the photocathode caused by exposure to very small quantities of air. Secondly, the photon feedback effect is greatly enhanced because of the abundant emission of visible photons during the amplification process.

In this paper we present a new gaseous UV photodetector based on a MICROMEGAS [12,13,14] amplification structure. Its main characteristic is the suppression of the photon-feedback problem by a suitable choice of configuration of the photocathode which allows very high gains to be achieved with the amplification structure of the detector.

2 Principle of the photodetector

The main idea is to deposit a solid photocathode on the metallic mesh on the side which does not face the amplification gap (Fig. 1a), in such a way that the avalanche is not seen by the photocathode. In this configuration, the divergent process induced by the photon-feedback effect, which limits the maximum achievable gain, is clearly suppressed. Another advantage is the operation of the photodetector in the reflective mode which is twice as efficient as in the semi-transparent mode.

The UV light produces photoelectrons in the photocathode by photoelectric effects. Then the electrons are guided along the electric field lines to the amplification gap where they are amplified. This is illustrated in Fig. 1b, which shows a simulation of electric field lines originating from the upper side of the micromesh carrying the photocathode. We must point out that the electric field lines cover the whole surface of the photocathode and all of them reach the amplification region. One can therefore expect a good photoelectron extraction and collection efficiency.

3 Experimental set-up

A self-triggered hydrogen lamp gives UV photons with a spectrum peaking at 160 nm. However, because of light absorption in the gas quencher, only photons around 190 nm reach the photocathode. The lamp produces flashes at a repetition rate of about 2.5 kHz with a duration in the sub-nanosecond range. A bipolar electrical pulse is available for triggering.

A sketch of the apparatus used in our measurements is shown in Fig. 2. The light enters the gas vessel through a thin SiO₂ window followed by a colli-

mator 2 mm in diameter and 10 mm long. Inside the gas a thin Ni mesh (3–5 μm in thickness) separates a 5 mm gas space from a 100 μm amplification gap. To achieve a constant amplification gap, polyamide cylindrical spacers, 200 μm in diameter and 100 μm in thickness are disposed every millimetre. The 500 LPI (Lines Per Inch) mesh is a regular array of square holes $39 \times 39 \mu\text{m}^2$ with a 50 μm pitch. The drift electrode is a standard grid with high optical transparency. The anode electrodes are made of 8 μm thick copper glued onto 1.6 mm epoxy plate. A central disk 8 mm in diameter (capacity of 5 pF with respect to the mesh) is surrounded by an 80 mm ring with 1 mm insulator separation. The small disk is connected to a fast (300 ps rise time) current preamplifier allowing a precise determination of the current pulse response of the detector. The cathode grid signal was amplified by a charge-sensitive electronic chain (ORTEC 142C preamplifier and ORTEC 472 spectroscopy amplifier) and used to measure the gain. The light spot in the middle of the central disk was about 3 mm in diameter.

4 Results with a Ni photocathode

In a first test, we used the nickel grid itself as an UV photocathode. The low quantum efficiency of Ni, of the order of 10^{-4} within the operating wavelength bandwidth, and the lamp power limit the yield to a few photoelectrons per flash.

A very high gain was observed with a mixture of helium and a common quencher. In Fig. 3 the gain variation with the voltage applied to the micromesh is shown for two gas mixtures: He + 6% and 10% isobutane; the maximum achievable gain is 6×10^6 .

In order to produce single photoelectrons, the UV light from the hydrogen lamp was attenuated such that only a few per cent of the flashes produce a detected signal at high operating gain. The charge preamplifier was fed to a discriminator with a threshold set at 3×10^4 electrons. The counting probability per flash as a function of the voltage applied to the mesh is shown in Fig. 4. The probability rises and saturates to 11.5% above a voltage of 450 V. This ensures that the observed signal is mainly due to a single photoelectron, since the probability of counting two photoelectrons is only 0.6%. Single photoelectron pulses from the charge preamplifier were fed to an ADC. The spectrum for two mesh potentials is shown in Fig. 5a (560 V) and Fig. 5b (580 V). An excellent separation between the single electron signal and the pedestal is observed. In particular, the second spectrum (Fig. 5b) gives a peak to valley ratio of four. Such a performance is difficult to achieve with photomultipliers. In contrast with most of the other gaseous detectors where the pulse height distribution of single electrons exhibits an exponential Furry distribution [15] our spectrum is in good agreement with a Polya distribution (solid line in

Fig. 5).

The pulse height distribution of the signal output from the current preamplifier signal of the small anode disk also gives a good Polya-type distribution, but with a less pronounced single electron peak, as it has already been observed [16]. The single photoelectron signal caught by the fast preamplifier is shown in Fig. 6. The first peak with a steep rise (2 ns) corresponds to the fast electron current. The tail of about 40 ns is mainly associated with the current of the positive isobutane ions that are collected in the cathode mesh. The superposed second peak could be attributed to a small fraction of positive helium ions (about 15% of the total charge) that are collected within 20 ns, and gives a mobility of $10 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ (twice the isobutane mobility) in good agreement with the expected value. The fast preamplifier signal was fed to a discriminator to investigate the time resolution of our detector. Figure 7 shows the distribution of the time difference between the hydrogen lamp trigger signal and the single electron response of the detector for a gas filling of helium and 10% isobutane. The width of the distribution is 1.8 ns FWHM and a gaussian fit to the data gives a standard deviation of 770 ps. This excellent time resolution is an upper limit of the true resolution of the detector since neither the time fluctuation contribution of the hydrogen lamp nor the time-slewing effect were taken into account. With helium and only 6% isobutane the time resolution slightly worsens to 1.2 ns. This might be attributed to the change of diffusion and the electron mobility.

5 Results with a CsI photocathode

For the second test, a thin 300 nm CsI layer photocathode was deposited by vacuum evaporation in the CERN workshop onto the top face of the Ni metallic grid. The mesh was transported to our laboratory in a glass vessel under vacuum in order to prevent degradation of the photocathode in air. The transfer of the mesh to the detector volume was performed in a glove box under nitrogen atmosphere. It is worth mentioning here that previous investigations have shown the compatibility of the CsI photocathode with most of the gas mixtures used in gaseous detectors. They are, however, moisture sensitive, and any exposure to air has to be avoided. The loss of quantum efficiency can be recovered by heating-up the photocathode, but in some extreme cases of strong humidity exposure, the loss of efficiency is irreversible, and the CsI photocathode is permanently damaged. Pure noble gases are compatible with CsI, but the quantum efficiency is about a factor of two lower than in vacuum because of the inefficient extraction of the electrons due to the backscattering process. However, the addition of a few per cent of a molecular gas is sufficient to recover the whole quantum efficiency.

Under the same light illumination, the number of photoelectrons detected with CsI is 3000 times higher than with Ni, confirming a significant quantum efficiency of the CsI photocathode. Although we are not able to determine the absolute quantum efficiency of CsI, our CsI/Ni ratio is in agreement with known values. The high increase of the detected signal was very beneficial: it was possible to observe a signal when operating the detector in the ionization mode and therefore obtain a precise measurement of the absolute gain. Figure 8 shows the amplitude of the signal as a function of the mesh voltage. One can observe a fast rise then a plateau (ionization mode), and then an exponential rise indicating that multiplication occurs. The gain measured is shown in Fig. 9 for the He + 6% isobutane mixture. The maximum gain obtained, 2×10^6 , is an important result showing that the photon feedback was greatly suppressed. Moreover, there is no significant deterioration of the quality of the single photoelectron response. Figures 10a and 10b show the pulse height distribution of single photoelectrons at 520 V and 540 V, respectively. One can observe a clear Polya distribution, comparable to the Ni photocathode. Furthermore, the time accuracy is not affected (a standard deviation of 680 ps was measured), as shown in Fig. 11. These results with the CsI photocathode are quite promising and open up new ways of using the same configuration for visible light detection.

6 Collection efficiency and discussion

It is clear that the light transmitted through the holes of the photocathode grid is lost, so we have to use grids with low optical transparency. The previous results presented were obtained with a cathode electrode which consisted of a 500 LPI Nickel mesh with an optical transparency of 60% for normal light incidence. Only this mesh was covered by the CsI photosensitive layer. Other models with lower transparency gave about the same performance in terms of gas gain and single electron response. The most attractive mesh commercially available is the 2000 LPI model (12 micron pitch), which has an optical transparency of 36%. Our simulation program predicts full electron extraction and collection efficiency.

A study to evaluate the collection efficiency was undertaken with the CsI photocathode operating the detector in the ionization mode. The amplitude of the signal collected in the anode was measured as a function of the mesh voltage (HV2) with the drift electrode potential at the same value (HV1 = HV2). The signal rises, reaches saturation, and then amplification takes over, as shown in Fig. 12 for the two He mixtures, 6% isobutane and 89% CF4. The latter mixture allows us to reach large electric field before amplification. Therefore the observed plateau, which indicates a good extraction efficiency, is longer and better pronounced in the CF4 mixture. It should be noted that the signal

is about 50% higher in the CF₄ mixture due to its higher light transmission in the UV region. The good collection efficiency does not exclude local dead space on the surface of the photocathode. To evaluate such a possible loss we measured, under the same conditions, the photoelectron flux leaving the surface of the photocathode. For this the mesh potential was set at the ground ($HV_2 = 0$) and the polarity of the drift electrode was reversed. In this case photoelectrons extracted are collected on the drift electrode in the ionization mode. As is shown in Fig. 13 the amplitude of the signal reaches a saturation value at about $HV_1 = +800$ V (electric field 1.6 kV/cm), which means a full collection efficiency. The amplitude at the saturation value is about equal to the one measured in the previous study (Fig. 12). This demonstrates a full extraction and collection efficiency of our photodetector, in agreement with our simulation.

The detector response is rather insensitive to the drift electric field. Variation of the drift potential, at a fixed mesh voltage (500 V), produces a small effect on the amplitude of the signal (Fig. 14) and on the quality of the single photoelectron spectrum. The conclusion is that one can keep a drift electric field slightly positive or suppress the drift electrode in order to avoid electrons created outside the amplification region being detected. Therefore the signal produced by charged particles traversing the device is greatly suppressed. This is an ideal situation for most of the applications, in particular for the new generation Cherenkov counter called the Hadron Blind Detector (HBD) [17]. Moreover, such a configuration will permit stable operation in hard radiation environments where gaseous detectors suffer from discharges induced by large energy deposits.

Another configuration of the photodetector is the semi-transparent mode where the photocathode is deposited on the drift electrode. In this configuration the photodetector operates in the standard MICROMEGAS mode with a drift and an amplification gap. The drawback of this particular operation could be a limitation of the gain due to the photon feedback effect, since the photocathode is in view of the avalanche. This configuration is attractive for reading out scintillation light produced by ionizing particles in a crystal (i.e. BaF₂).

7 Conclusions

We have studied the performance of a MICROMEGAS-type photodetector coupled to UV photosensitive materials, and in particular the CsI photocathode. The result with this type of photon-counting detector is extremely encouraging. Its performance, in some respects, challenges the best available photomultiplier. High gains close to 10^7 , excellent single electron distribution with a counting efficiency close to 100%, fast signals (rise time < 2 ns) and low

time jitter (< 680 ps) were measured. The good localization properties and the relatively low cost of the detector make this instrument an excellent tool for UV light detection over a broad field of applications in basic and applied research. The study could be extended to other types of photocathodes with sensitivity in the visible region.

Acknowledgements

We would like to thank A. Braem and C. David for the deposition of the CsI photocathode.

References

- [1] J. Seguinot et al., Nucl. Instrum. Methods **A297** (1990) 133.
- [2] V. Dangendorf, Nucl. Instrum. Methods **A289** (1990) 322.
- [3] F. Piuz et al., Nucl. Instrum. Methods **A333** (1993) 404.
- [4] C. Lu, K.T. McDonald, Nucl. Instrum. Methods **A343** (1994) 135.
- [5] D. Anderson et al., Nucl. Instrum. Methods **A323** (1992) 626.
- [6] R. Aleksan et al., Nucl. Instrum. Methods **A343** (1994) 173.
- [7] J. Seguinot, T. Ypsilantis, Nucl. Instrum. Methods **A142** (1977) 377.
- [8] G. Charpak, Y. Giomataris, A. Gougas, Nucl. Instrum. Methods **A343** (1994) 300.
- [9] M. Chen et al., Nucl. Instrum. Methods **A346** (1994) 120.
- [10] D.F Anderson, S. Kwan, V. Peskov, Nucl. Instrum. Methods **A343** (1994) 109.
- [11] A. Breskin et al., Nucl. Instrum. Methods **A387** (1997) 1.
- [12] Y. Giomataris, Ph. Rebourgeard, J.P. Robert, G. Charpak, Nucl. Instrum. Methods **A376** (1996) 29.
- [13] G. Charpak et al., Nucl. Instrum. Methods **A412** (1998) 47.
- [14] G. Barouch et al., Nucl. Instrum. Methods **A423** (1999) 32.
- [15] W. Blum, L. Rolandi, Particle Detection with Drift Chambers, Springer Study Edition, p. 144.
- [16] Ph. Gorodewski et al., How to detect individually each ionisation electron of a track in HELLAZ TPC', submitted to Nuclear Instruments and Methods.
- [17] I. Giomataris, G. Charpak, Nucl. Instrum. Methods **A310** (1991) 589.

8 Figure captions

Figure 1: a) Principle of the photodetector in the reflective mode; b) simulation of the electric field lines relevant for photoelectron collection.

Figure 2: Schematic view of the experimental set-up.

Figure 3: Amplification gain as a function of the mesh voltage (HV2) in a helium mixture with 6% and 10% isobutane, with the Ni photoconverter.

Figure 4: Counting probability per flash as a function of the mesh voltage (HV2) for the Ni photoconverter.

Figure 5: Pulse height distribution of single photoelectron signal with the Ni photoconverter for a mesh voltage of a) 560 V, b) 580 V in He + 10% isobutane. The solid line is the Polya fit (between arrows); the dashed line is its extrapolation.

Figure 6: Fast electron signal from the current preamplifier for the He + 10% isobutane. The electron signal and the ion tail develop within 5 ns and 40 ns, respectively.

Figure 7: Time distribution of the anode discriminated current signal of single photoelectrons for the Ni photoconverter.

Figure 8: The amplitude of the mesh signal as a function of the mesh potential (HV2) for the CsI photocathode in two gas fillings He + 6% and 50% isobutane.

Figure 9: Amplification gain as a function of the mesh voltage (HV2) in helium + 6% isobutane mixture for the CsI photocathode.

Figure 10: Pulse height distribution of the single photoelectron signal with the CsI photocathode for mesh voltage of a) 520 V, b) 540 V in He + 6% isobutane. The solid line is the Polya fit (between arrows); the dashed line is its extrapolation.

Figure 11: Time distribution of the anode discriminated current signal of single photoelectrons for the CsI photocathode.

Figure 12: Amplitude of the cathode signal (CsI photocathode) versus the

mesh voltage (HV2) with the drift electrode at the same potential (HV1 = HV2) for two He mixtures, 6% isobutane and 89% CF₄.

Figure 13: Amplitude of the cathode signal (CsI photocathode) versus the positive drift potential (HV1) with the mesh electrode at ground (HV2 = 0) for two He mixtures, 6% isobutane and 89% CF₄.

Figure 14: Amplitude of the cathode signal (CsI photocathode) versus the drift potential (HV1) and the mesh electrode at a fixed potential (HV2 = 500 V).

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14