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Preliminary results of the study of gaseous detectors with solid photocathodes sensitive in the spectral region from 105 to 300 nm

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Abstract

We describe the development of several types of solid photocathodes that can be used in gaseous devices (multiwire and parallel plate chambers) for the detection of photons in the wavelength region between 105 and 300 nm. Feedback problems at high gains have been studied in various operating conditions.

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1. Introduction

Recently developed fast position-sensitive gaseous detectors with CsI [1] and other solid photocathodes [2, 3], sensitive in the spectral region around 230 nm may find applications in Cherenkov Ring Imaging [4], readout of VUV scintillators [5-7], Positron Emission Tomography [8]. During the last year we found and tested several other solid photocathodes, sensitive to longer wavelengths up to 300 nm; some can be shortly exposed to air without deterioration. The practical importance of these photocathodes becomes evident if they can be combined with gaseous detectors, working at high gain. In this work we present some progress in this direction.

2. New photocathodes and experimental setup

Our experience in developing photocathodes shows that some substrata, covered by adsorbed or condensed layers of ethyl-ferrocene (EF) or tetrakis(dimethylamine) ethylene (TMAE) gain new properties: their quantum efficiency increases and they become more stable in air [7, 9]. A possible explanation for this observation can be a chemi-sorption process, when the adsorbed molecules give one electron to the substratum and form a double electric layer on the surface. This changes the chemical properties of adsorbed molecules and decreases the work function of the substratum. Starting from this observation, we tried to test a wide range of solid photocathodes with small work function (metals of lanthanide group, metallo-organic compounds as well as some conventional photocathodes used in vacuum tubes and photo-multipliers), treated by adsorbed or condensed layers of EF and TMAE.

Two set-ups were used: one for the study of photocathodes, the other for studying the gases in which this photocathodes could work at high gain. The setup for the study of the photocathodes consists of the test chambers and a monochromator with a photon beam calibrated with respect of TMAE gas and various phototubes. For the study of the metals of lanthanide group and metallo-organic compounds we used a single wire chamber and a parallel plate avalanche chamber (PPAC) similar to the one described in [7].

For the study of conventional air stable photocathodes (CsTe, SbCs etc.) we used the set-up shown in Fig. 1: it consists of a glass tube with a quartz window and two metallic flanges, equipped with stainless steel tubes for the gas flow and a special device, allowing to make some manipulation inside the tube. The test tube was flushed through Oxysorb by CH_4 , Ar or He with or without EF vapors; a specially cleaned EF was used. The complete system could be heated up to 70 °C. In the case of He, a zeolite trap cooled to liquid nitrogen temperature was used to clean additionally the gas. Before each set of measurements the system was cleaned by warming and flushing during 5 to 7 days. Such a method allows to reduce the level of impurities to less than 0.01 ppb. The vacuum photodiodes with the photocathode chosen for the test (for example with CsTe) could be placed inside the test

tube; the test chamber was equipped with a knife, which could be manipulated from outside to break the glass envelope of the photodiodes. The gas from the test tube penetrated then inside the photodiodes. High voltage up to few KV was applied to the anode; the cathode signal was readout then using a charge sensitive amplifier or a pico-amperometer. A mercury or hydrogen lamp with filters or a light beam from the monochromator were used to measure and monitor the changes with time of the quantum efficiency of the photocathodes.

3. Experimental results

The quantum efficiency of different metal substrata, covered by a TMAE adsorbed layer or treated by a solution of iodine in alcohol (for details see ref. [2]) are presented in Fig. 2. Results are shown for zinc (Zn) and holmium (Ho) and for the same covered with TMAE and a metallo-organic layer (MO) (Fig. 2a), and for copper and cadmium treated with a solution of iodine in alcohol (Fig. 2b). One can see that a considerable improvement at long wavelengths (> 200 nm) is achieved, as compared to the results obtained with metal and TMAE photocathodes [9]. In Fig. 3 we show the changes in time of the quantum efficiency of CsTe photocathodes exposed to various gases at atmospheric pressure. Very similar results were obtained for the SbCs photocathodes. The time zero corresponds to the moment when the glass envelope of the vacuum photodiodes was broken. One can see that the quantum efficiency degrades rather quickly in all cases, except for the cleanest gas used, He. This is not astonishing, because the photodiodes filled with ultra clean gases are known to be stable. The important fact is that one can reach some stability of operation by flushing with clean gas in rather simple laboratory conditions.

Although small impurities in the gas cause degradation the quantum efficiency, one can considerably reduce this effect condensing a clean EF layer on the photocathode surface. The rate of diffusion of gaseous impurities through this layer appears to be rather slow, and this allows to expose the photocathode to air for a short time (a few seconds). We found that by flushing afterward with clean He and by warming the photocathode it is possible to evaporate in short times the liquid layer and the quantum efficiency at 260 nm restores to about 10 % of the initial value. Even better results were obtained when metallo-organic compound were condensed on the photocathode surface. A systematic study of this protection effect is in progress.

4. Photon emission in the avalanches and feedback

As soon as photocathodes sensitive at long wavelength were found the next task was to search for gases in which such photocathodes can be used at high proportional gains. A search of gas mixtures suitable for the CsI photocathode was done before [10]; the new photocathodes have however a different spectral response (smaller quantum efficiency at short and higher at long wavelengths), so the results obtained with the CsI photocathode are not directly applicable. Two set-ups were used for this study: one for

measurements at atmospheric pressure and another for low pressures. The first setup was similar to the one described in ref. [10], with however the PPAC replaced by a wire chamber. The anode plane of the wire chamber was 1,5 mm from the cathode grid, in contact with the CaF_2 window and 3 mm apart from the other cathode plane facing the drift region. This was done in order to reduce the adsorption of VUV light emitted by the avalanches on their way between the anode wires and the CaF_2 window. To make the field lines near the anode wires symmetrical, the high voltages applied to the cathode planes were different. A schematic drawing of the second set-up is shown in Fig 4: it consists in a PPAC inside a vacuum tight box with a CaF_2 window touching the anode mesh. The light emission from the avalanches was recorded by different photo-multipliers through narrow band filters.

Fig. 5 shows the measured VUV emission (140 to 175 nm) of the avalanches from the wire chamber at atmospheric pressure for mixtures with TEA (Fig. 5a) and methane (Fig. 5b), as a function of quencher partial pressure; the intensity of the emission is given in photoelectrons per electron as in ref. [10]. For comparison, the results obtained with a PPAC for the same gas mixtures and pressure published earlier are also given. One can clearly see that the intensity of the VUV emission from the wire chamber is 3 to 30 times higher than for a PPAC in the same conditions.

In Fig. 6a and b typical results obtained with the low pressure PPAC are presented, and compared with the measurements obtained at atmospheric pressure; one can see that the VUV light emission at low pressure is more intense than at atmospheric pressure. We should also note that in presence of EF vapors the intensity of VUV emission usually drops by an order of magnitude.

The emission in the region above 200 nm was also measured. In the case of the PPAC at 1 atm and mixtures of CH_4 and C_2H_6 with noble gases this emission is practically independent from the concentration of the quencher, as shown already in ref. [10]. In the case of other gas mixtures however, and especially at low pressure and with the wire chamber we found a more complicated behavior confirming the results obtained by other authors [11]. We do not present here these results because in presence of EF vapors, especially at temperature above 40 °C, the intensity of this emission is strongly suppressed.

5. Operation at high gas gain

The photocathodes that we have tested can be mounted in gas detectors and allow operation with gas gain, the limit being set by feedback processes leading to discharge. As was expected from our study, the highest stable gas gain was achieved with PPAC filled with a helium-EF mixture (at temperatures above 40°C) or with $\text{He-C}_4\text{H}_6$. In the case of metallic and metallo-organic photocathodes this maximum gain was about 10^5 , and around 10^4 for the CsTe photocathode, allowing in both cases to detect single photoelectrons. No evidence of aging of the photocathode was observed up to integral collected charges of 1 mC/cm².

6. Conclusion and summary

The preliminary results obtained with various kinds of photocathodes are encouraging. They indicate that it is possible to build gaseous detectors with solid photocathodes sensitive up to 300 nm. Such detectors can operate at gas gain up and above 10^4 , high enough to detect single electrons. They may find a wide range of applications. The protection provided by thick adsorbed layer of EF allows the mounting of the photocathodes in large devices and should be studied in more details.

References

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Figure captions

Fig. 1: Schematic view of the glass test chamber used to measure quantum efficiency of commercial photocathodes in a gas.

Fig. 2a: Quantum efficiency measured with holmium pure and covered by an adsorbed layer of TMAE vapors. For comparison we show the quantum efficiency of a Zn photocathode [9] known to have the highest quantum efficiency amongst the metals.

Fig. 2b: Quantum efficiency measured on metals treated by a solution of iodine in alcohol.

Fig. 3: Changes in time of the quantum efficiency for a CsTe photocathode exposed to different gases.

Fig 4: The experimental setup used for the study VUV emission from a PPAC at low pressures.

Fig 5a and b: Light yield (in photons per electron) measured in a wire chamber flushed with different gas mixtures at atmospheric pressure, as a function of the partial pressure of the quencher. For a comparison, data obtained with a PPAC are also shown [10].

Fig 6a and b: Light yield (in photons per electron) of a PPAC filled with TEA added to helium at 20 Torr as a function of the partial pressure of the addition. For comparison similar data obtained at atmospheric pressure are also shown [10].

Fig. 1

Fig. 2 a

Fig. 2 b

Fig. 3

Fig. 4

Fig. 5 a

Fig. 5 b

Fig. 6 a

Fig. 6 b