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NEW PHOTOCATHODES FOR FAST GASEOUS DETECTORS

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Abstract

Semitransparent and reflective liquid and solid photocathodes were studied. The highest quantum efficiency and the best timing properties were obtained with reflective photocathodes made from substrates having a small working function (CsI, CuI, differrocenyl mercury) and covered by an adsorbed layer of ethyl ferrocene (EF) or tetrakis(dimethylamine)ethylene (TMAE).

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1. INTRODUCTION

During recent years an important tendency in the development of VUV gaseous detectors has been towards the enlargement of their spectral sensitivity range. Vapours with small ionization potentials E_i were found, and were adopted as photosensitive media for gaseous detectors: triethylamine (TEA) ($E_i = 7.2$ eV); ethyl ferrocene (EF) ($E_i = 6.1$ eV); tetrakis(dimethylamine)ethylene (TMAE) ($E_i = 5.36$ eV). The use of these vapours has led to a big increase in the field of application of gaseous detectors in high-energy physics (RICH and VUV scintillator calorimetry), as well as in other domains (astrophysics, plasma diagnostics, PET, and so on). Another way of increasing the range of the spectral sensitivity is to use solid or liquid photocathodes as the photosensitive media. They have two main advantages: i) the threshold of the photosensitivity is shifted in wavelengths longer than those for the vapour; iii) they make it possible to build fast detectors, because all the photoelectrons are created at a well-defined place in space and therefore the time jitter is small (< 1 ns). This direction was intensively developed during the last 10 years. An early attempt to combine a wire chamber with a photocathode (CuI) was made in 1978 [1]. However, the important contribution came from Anderson [2] who introduced liquid photocathodes for gaseous detectors; these are stable in time and achieve rather high quantum efficiencies [3]. They can be used either as very thin (adsorbed) or thick layers, and can work in both reflective and semitransparent modes [3]. Another step was done when photocathodes of pure CsI were shown to work in gaseous detectors [4]. The most important step was the discovery that CsI photocathodes are much more efficient than advocated before, if clean conditions are engineered, with an enhancement of efficiency by TMAE adsorbed layers, combined with a protection effect [5]. Our work confirmed this effect with EF adsorbed on CsI and we showed that even with these highly sensitive photocathodes, high multiplication can be achieved in gases without severe photon feedback problems [6].

In this work we try to go a step further towards understanding properties of the known photosensitive liquid layers, as well as finding new fast and efficient photocathodes. Two types of photocathodes were studied: reflective and semitransparent. The highest quantum efficiencies and the best timing properties were obtained with reflective photocathodes made with substrates having small working functions and covered by adsorbed layers of photosensitive vapours.

2. SEMITRANSSPARENT LIQUID PHOTOCATHODES

One of the main advantages of such photocathodes is that they can be directly deposited on the entrance window of the gaseous detector, which is convenient for some applications. For example, in the case of RICH detectors, this makes it possible to avoid having undesirable parallax errors. Semitransparent photocathodes deposited directly on BaF_2 crystals decrease the internal reflection and allow the scintillation light output to be increased by a factor of between about 2 and 5 [4].

The installation used in the investigation of an EF liquid photocathode is presented in Fig. 1. It consists of a pulsed VUV source (15 ns duration), a window that is transparent to VUV, a photodiode for the monitoring of the light, and a wire chamber with a drift region closed by a grid over the window. The TMAE, TEA, and EF were tested as photocathodes. The liquid photocathode was deposited on the window in two ways. Thin layers ($d < 100$ nm) were obtained by condensation when the warm photosensitive vapour was introduced into the chamber at room temperature. Thick layers (0.1 to 1 mm), were investigated for EF only. They were obtained by trickling the EF directly through pipettes. In all cases, the wire chamber was operated with CH_4 at 0.1^{-1} atm. In the latter case, the thickness of the layers was estimated by the volume of photosensitive liquid deposited on the surface of the window. At small thicknesses the layer was estimated by the absorption of VUV light in the layer deposited on the surface. For example, Fig. 2 shows the typical signals obtained simultaneously from the PM and from the wire chamber in the case of EF. It can be seen that between them there is a delay of about 0.2 μs , which is due to the electron drift in the chamber.

The efficiency of the EF liquid photocathode as a function of its thickness is given in Figs. 3a,b (the results obtained with thin layers of TEA and TMAE were similar). One can see that in the case of the thin layers, the efficiency increases according to the thickness. The time jitter was very small, less than 10 ns. In the case of thick layers, the jitter was much more than 10 ns.

We interpret these results in the following way. In the case of a very thin layer, $d < 100$ nm (Fig. 3a), the extraction of electrons is due to the excess kinetic energy E_k of the photoelectrons, because in the photoionization process $E_k = h\nu - E_{liq}$, where E_{liq} is the ionization threshold of the liquid and $h\nu$ the photon energy. If $E_k > V_0$, where V_0 is the energy of the electronic conduction level, then some fraction of the photoelectrons can escape from the layer into the gas phase. At small thicknesses (i.e. smaller than or equal to the photoelectron's mean free path in the layer), the efficiency increases with the thickness, simply because more VUV photons are absorbed. In the case of thick layers, $d > 100$ nm (Fig. 3b), the photoelectrons lose their kinetic energy quickly, but then drift, under the influence of the electric field E , to the liquid-gas boundary. They gain the kinetic energy $kT_e = eD/\mu$, where k is the Boltzmann constant, μ is the electron mobility, e is the electron charge, and D is the lateral diffusion coefficient. This kinetic energy depends on the strength of the applied electric field, but the maximum possible value kT_e is less than or equal to Ed . This is why the photoemission is high when the voltage in the layer drops by more than 10 V. At a thickness of more than 1 mm, the drop in efficiency is probably due to the electron trapping by impurities. Owing to the long drift in the liquid the time jitter is long. Some additional physical effects near the surface, which can deteriorate the jitter, are also possible (see, for example, Ref. [7]). The results indicate that good timing properties could be obtained more easily in the case of thin layers. However, the efficiency of thin semitransparent photocathodes is poor, simply because of the small amount of VUV light absorption. For this reason, we have concentrated our efforts on the investigation of thin reflective photocathodes. Such photocathodes enable us to obtain good timing properties, together with high quantum efficiency and high stability.

3. REFLECTIVE PHOTOCATHODES

In Ref. [3] we have described how photosensitive vapours adsorbed on metallic surfaces form a double electric layer, which decreases the working function of the metal. The quantum efficiency (QE) of such photocathodes should depend essentially on the substrate's working function and on the nature of the photosensitive adsorbed layer. In order to check this, we have made a systematic study of the QE of different substrates covered with photosensitive layers [5, 8]. The highest QE was obtained with CsI substrate,

covered with adsorbed layers of EF or TMAE [5, 6]. Such photocathodes can be combined with gaseous detectors working at high gain ($\sim 10^5$), without noticeable photon feedback [6]. The reasons for this were carefully studied, and the results of this investigation were presented by P. Fonte [9] at this conference. Preliminary tests of the stability in time of pure CsI photocathodes show that with a gain of about 10^5 and $p = 1$ atm, no noticeable degradation of the QE was observed up to a collected charge of about 10^{-2} C/cm². Without gain, no degradation was seen up to 1 C/cm². Other authors [10] have repeated these measurements at low pressure, and have found a weak degradation. In the next subsections we describe some photocathodes that are more stable than the ones mentioned above.

3.1 Stability of CsI + EF

The stability of CsI + EF photocathodes was investigated with the installation described in Ref. [3]. This installation contains a D₂ discharge tube, a monochromator, and a single-wire counter in which different photocathodes can be installed. The whole system was calibrated with respect to the QE of TMAE vapours and to the known QE of the phototube. This allowed us to measure the absolute QE of the photocathode being tested. A 500 nm thick CsI photocathode was evaporated onto stainless steel substrate (the diameter of the sample was ~ 3 cm), covered with a 100 nm layer of Al. The counter was flushed with Ar + CH₄ (10%) + EF or Ar + CH₄ (10%) + EF + tetramethyl pentane (TMP) gas mixtures. Under these conditions the CsI photocathode was covered with an adsorbed layer of EF [11]. The QE of the photocathode was measured 24 hours later. Then, by increasing the voltage applied to the counter, we initiated a corona discharge, with a current of about 10 μ A, that lasted for a few times 10 hours. Approximately at the end of each hour the corona discharge was stopped and the QE was measured. The results are presented in Fig. 4. As can be seen, no significant changes were observed up to a collected charge of about 10^{-2} C/cm². The stability obtained under our experimental conditions is much better than in the work carried out at low pressure [10]. The explanation is probably the following. In the presence of molecules with small ionization potential (EF), the positive ions of the main gas (Ar + CH₄ + TMP),

produced by the avalanches, travel to the cathode and exchange their positive charge with the EF molecules (the Penning process). At $p = 1$ atm, the small ratio of electric field/pressure causes the heavy positive ions of EF to have rather low kinetic energy (compared with that of the ions at low pressure). Therefore, there will be less damage to the CsI cathode.

3.2 Other photocathodes

We have tested also a few organometallic photocathodes as substrates [triferrocenyl phosphine, paraffin iron complex, 1,1'-trimethylene-ferrocene phosphine, (dimethylamino)ferrocene, diferrocenyl mercury] and metallo-iodines [(dimethylamino)methylferrocene iodine, CuI]. The advantages of such compounds are that they are solid, chemically stable, and do not interact with air. The QE of some of them has been studied, and the results are published in the Proceedings of this conference [12]. In the present work we have concentrated essentially on the investigation of the QE of these substrates, covered with EF or TMAE adsorbed layers. For these measurements we have used the installation described above. The best results were obtained with diferrocenyl mercury and CuI substrates.

3.2.1 Diferrocenyl mercury photocathodes

Diferrocenyl mercury (chemical formula: $C_{24}H_{18}Fe_2Hg$) is a very stable substance that is solid at room temperature, and is not reactive to air, water, and polar solvents. The photocathode was obtained using the following procedure. A few cubic millimetres of diferrocenyl mercury were introduced into 30 cm³ of xylene. The mixture was then heated to boiling point (~ 120 °C). Under these conditions, the diferrocenyl mercury dissolved. One drop of the solution was placed on the surface of a copper substrate. When viewed with an electron microscope it was seen that after evaporation, small crystals (10–50 μ m) were formed on the substrate surface. The results of the QE measurements of such a layer are presented in Fig. 5. It is remarkable that the QE of this photocathode remains virtually unchanged, even after exposure to air for 15 to 30 minutes. In the presence of EF or TMAE vapours the efficiency increases (see Fig. 5). The stability of the cathode is presented in Fig. 4.

3.2.2 CuI photocathodes

A CuI photocathode was obtained by treating a clean Cu surface with a solution of I_2 dissolved in absolute alcohol ($\sim 2\%$). Because such a photocathode interacts slightly with water vapour, its installation inside the detector was carried out in a dry-air atmosphere. Note that the reaction of the CuI with water is not irreversible, and in principle a cathode damaged by H_2O could be 'repaired' by heating it. The efficiency of a CuI photocathode measured with an Ar + alcohol mixture at $p = 1$ atm is shown in Fig. 6. If, in addition, TMAE vapour is introduced into the counter, then the efficiency of the photocathode is noticeably increased (Fig. 6). The ageing properties of this photocathode were measured for four different gas mixtures: Ar + CH_4 ; Ar + CH_4 + alcohol; Ar + CH_4 + alcohol + I_2 ; Ar + CH_4 + alcohol + I_2 + TMAE. The best results were obtained with the last mixture: no deterioration of the QE was measured up to a collected charge, of about 0.1 C/cm^2 (see Fig. 4). The high stability of the CuI photocathode in the presence of I_2 vapours is probably due to the continuous 'repair' of the damage caused to the surface by the iodine. But, in order to achieve this good stability, the materials used for building the detector must be chosen with great care, because the iodine vapours are rather corrosive. This can be the main limitation in the application of this photocathode.

4. CONCLUSION

As a result of this work, we have developed a few new, stable photocathodes. The best are CsI + EF and CuI + TMAE. Both of them can find applications in BaF_2 calorimetry, in RICH detectors, in plasma diagnostics, and in astrophysics.

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FIGURES CAPTIONS

Fig. 1 Experimental set-up for the study of the semitransparent liquid photocathodes.

Fig. 2 Typical signals from a) the photomultiplier, b) the wire chamber.

Fig. 3 Quantum efficiency of semitransparent liquid photocathodes as a function of the EF thickness for a) a thin layer (the thickness was measured by light absorption), b) a thick layer.

Fig. 4 Stability of the photocathodes versus collected charge measured under the conditions of corona discharge at one atmosphere (1) Pure CsI, (2) CsI + EF, (3) CuI + I_2 + TMAE, (4) diferrocenyl mercury + EF, (5) For comparison data for a CsI photocathode at low pressure are presented (from Ref. [10]).

Fig. 5 Quantum efficiency of pure Cu(1) and Cu substrate covered by diferrocenyl mercury (2) and diferrocenyl mercury + EF (3).

Fig. 6 Quantum efficiency of CuI (1) and CuI + TMAE (2) photocathodes.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6