Novel position-sensitive gaseous detectors with solid photo-cathodes

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Abstract— **Currently a revolution is happening in the development of gaseous detectors of photons and particles. Recently developed gaseous detectors with solid photocathodes are now replacing photosensitive wire chambers, which dominated for years in high energy and space flight experiments. We will review the main developments in this field as well as their applications in high-energy physics, medicine, industry and plasma diagnostics. New results on solid photocathodes coupled with gaseous micropattern/wire detectors will also be presented.**

I. Introduction

PHOTOSENSITIVE wire chambers introduced by J. Seguinot et al [1] and independently by G. Bogomolov et al [2] opened new avenues in applications such as RICH detectors [3], readout of VUV scintillators [4], plasma diagnostics [5] and others. Although such detectors have given important results in many experiments, they have two major drawbacks:

1. Bad time resolution ($> 1\ \mu s$) due to the big spatial jitter in creating the photoelectrons in the detector volume,
2. The spectral sensitivity is restricted by the ionization potential of the gases (vapors).

Vapors with the lowest ionization potential found so far are ethylferrocene (EF) [5] and TMAE (see [6] and references therein). Both of them have a low vapor pressure at room temperature ($< 0.5\ Torr$). To improve the efficiency and time resolution one needs to heat the detector up to $60 - 80\ °C$. In this case the vapor density increases and all photons are adsorbed near the entrance window of the detector. This reduces the spatial jitter in creating the photoelectrons and improves time resolution.

Yet, another approach is using solid photocathodes instead of vapors [5]. Gaseous detectors with such photocathodes should have: high time resolution as the photoelectrons are produced at a fixed place in the detector volume, and lower threshold of spectral sensitivity, which is determined by the work function of the cathode material (usually less than a few eV).

There were early attempts to develop wire chambers with solid photocathodes. For example, a wire chamber with a CuI photocathode was built and successfully used for plasma diagnostics [5]. A single wire counter with a Cs photocathode was also tested [7]. However real success came from Charpak's group where the first parallel-plate chamber with a CsI photocathode was tested [8]. CsI was deposited on a metallic plate by vacuum deposition. Surprising was that the quantum efficiency (QE) of the CsI photocathode remains high enough after transfer in air from the evaporation system into the gaseous detector. This simple technology suggested a wide range of application for CsI photocathodes in gaseous detectors. Shortly after that Dangendorf et al [9] developed a wire chamber with the CsI photocathode and Seguinot et al [10] did work on the systematic study of the CsI photocathode and the ways of getting a high QE.

Further there are attempts to develop photocathodes that are sensitive to longer wavelength than CsI and compatible with gaseous detectors. The potential advantage of such detectors, compared to traditional vacuum ones, is their insensitivity to magnetic fields and possibility to use large area photocathodes at low cost.

In addition, during these developments, it was found that the most efficient photocathodes are also good secondary electron emitters, which allows them to be used for detection of x-ray photons and charged particles [11]. This may open new fields of application for gaseous detectors with solid photocathodes.

In this paper we will review the main problems and achievements in these promising directions. New, unpublished yet results will be presented as well.

II. PROBLEMS AND SOME POSSIBLE DIRECTIONS FOR THEIR SOLUTIONS

The experience of several groups shows that it is not an easy task to combine solid photocathodes with an ordinary gas amplification structure such as wire chambers or parallel -plate chambers (PPAC) [12],[13]. There are two main problems:

1. Even tiny tracks of impurities (for example oxygen or water) cause degradation of the photocathode quantum efficiency,
2. With highly efficient photocathodes it is almost impossible to reach gains more than 10^2 due to photon and ion feedback.

Both problems actually arise due to the low work function of the photocathode and therefore in the case of the photocathodes being sensitive to visible light, they become very serious.

What are some ways to overcome these problems? The first problem has been solved by using a properly clean gas system [14]. An alternative approach could be to protect the photocathode by a thin layer of CsI or other material evaporated on the top of the photocathode [15]. Such a

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layer should be thin enough to be transparent for both the photons and photoelectrons created by the photocathode, but slow down the gas diffusion. Preliminary results indicate that the photocathodes with the protective layers have a lower QE, but are more robust and have better aging properties. This allows the use of less clean gases and even exposure of photocathodes to air [15].

This work on photocathode protection is continued by Breskin's group [16]. They confirm that the best protective layer is the CsI, however their other results are difficult to evaluate since they did not expose photocathodes directly to air (as was done in our earlier work). The second problem (photon and ion feedback which spoils the performance and also causes discharges) is more complicated.

Discharges due to feedback appear when one of the following conditions are fulfilled first: $A\gamma_{ph} = 1$ or $A\gamma_{+} = 1$, where A is a gas gain,γ_{ph} and γ_{+} are probabilities to create a secondary electron from the cathode due to photoeffect or ion interactions respectively.

In ordinary gaseous detectors γ_{ph},$\gamma_{+} < 10^{-6}$. However, in the case of highly efficient photocathodes, sensitive to visible light $\gamma \sim 10^{-2}$. Therefore the maximum achievable gains cannot be more than 10^2. In order to reach higher gains, special designs allowing to suppress photon and ion feedbacks should be developed.

Recently it was suggested the use of GEM [17] or capillary tube as an amplification structure for gaseous PM (see the next paragraph and [13]). Due to their geometry the GEM and capillary tubes allow to suppress photon feedback very efficiently (10^{-2}).

Below we will discuses the main achievements as well as another approach to use photocathodes which are less sensitive to impurities and less affected by feedback effects.

III. NEW APPROACHES

A. GEM

The use of GEM for gaseous PM with CsI photocathode (see Fig. 1a and 1b) allowed to efficiently suppress photon and ion feedback [16]. Unfortunately, attempts to combine GEM with photocathodes sensitive to visible light have not been successful so far. There are two main problems:

1. outgassing of GEM does not allow to achieve good photcathode stability,
2. Cs vapors (if the photcathodes are manufactured in the same chamber where GEM was placed) reacting with GEM.

This is why we suggested using glass capillary plates instead of GEM [13]. Glass is a material compatible to vacuum and photocathode technology.

B. Capillary plates

A. Del Guerra, V. Perez Mendes and collaborators introduced lead glass capillary detectors operating in gas atmosphere quite a long time ago as a high granularity converter of gammas to primary electrons (see for example [18]). They demonstrated that due to favorable capillary geometry (thin walls) gammas could be efficiently converted to primary electrons [19]. These primary electrons can then drift through capillaries and be detected in the adjusted MWPC.

To reduce the charging up effect the inner parts of capillaries were treated by H_2 that allows to reduce their surface resistivity on a controllable way.

The authors also succeeded to get gas multiplication in capillaries [20]. Thus, it was the first demonstration that a avalanche multiplication may occur not only in electric field concentrated near anode wires, but also inside holes, which act as an electrostatic lens. Based on this approach a high granularity gamma detector was build and used for medical imaging applications.

The other important application was to use capillary as a light attenuator in RICH detectors, filled with TMAE vapors. In this case photoelectrons created by UV radiation in a rather thick drift region, before entering a MWPC, were drifted through rather thin capillary plate and then were multiplied in the MWPC. The light, emitted by avalanches, was strongly attenuated by the capillaries (due to the small ratio of their diameter to the length) and this reduces the probability to create secondary electrons in the absorbed region (see Fig. 2). As a results undesirable photon feedback was strongly suppressed and this allowed to reach the highest possible gains.

A new interest to this type of detectors appeared recently after Japanese group [21] started to use commercially available glass capillary plates (GCP): a bi -product of MCP production (see Fig. 3). Typically, such plates have diameter of 20 mm, thickness of 0.8 mm and halls diameter of 100 μ. Samples of 10x10 cm^2 are currently available too from Hammatsu Inc. The authors demonstrated that gas gains up to 10^4 could be achieved with capillary plates operating at 1 atm or lower pressure. They also suggested to use light, emitted by avalanches inside capillary, for high precision position measurements. For example, tracks of primary electrons produced by soft x-rays were recorded [22]. This gives a powerful method for measuring x-rays polarization .

The other application developed by Japanese group was to use GCP as a preamplifier for MSGC [23].

One of the most promising applications of capillaries could be to use them as amplification or a light attenuation element in position sensitive gaseous photo multipliers with solid photocathodes sensitive to visible light, for example SbCs or bi alkaline [13],[24]. Such photocathodes are very sensitive to tiny impurities in the system and therefore only limited number materials can be used, the glass from which capillary plates are manufactured is one of ideal choices. Several prototypes of gaseous photomultipliers, based on capillary plates were build and successfully tested [13],[24] allowing to detect visible light with efficiency of a few %.

The developments in this direction are very fast; for example, recently a new device based on capillary plate was developed- hybrid gaseous photomultiplier.

C. Hybrid Gaseous photomultipliers

In an attempt to overcome these problems described above, we have developed a hybrid gaseous photomulti-

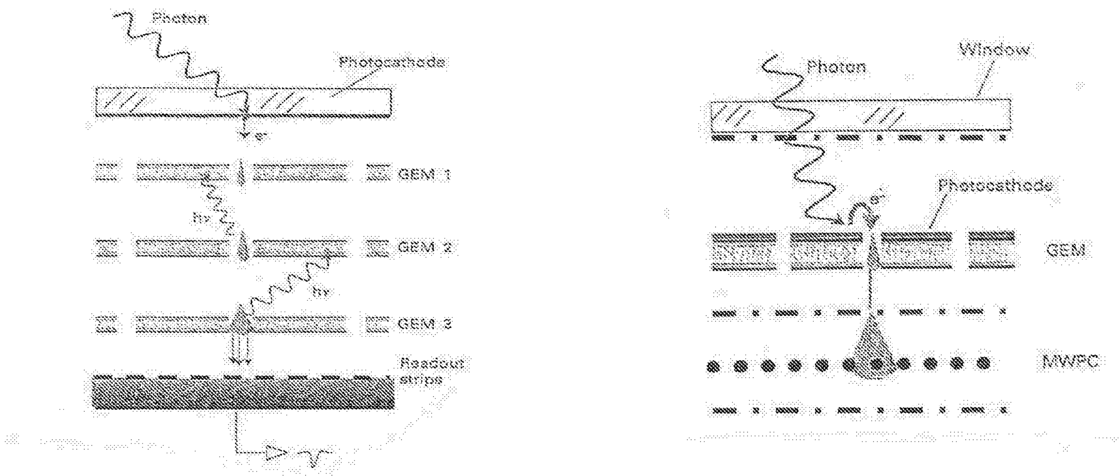

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Fig. 1. GEM- based gaseous photomultipliers (a and b)

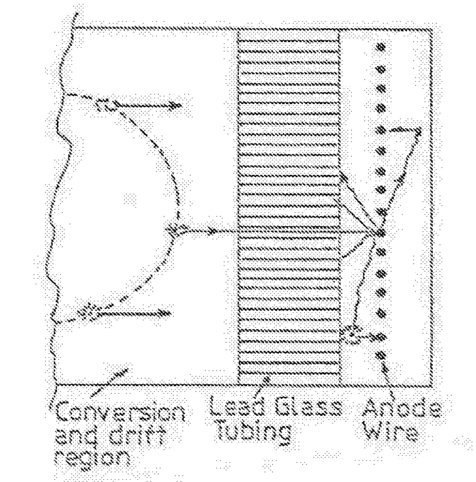


Fig. 2. A design of RICH detector with a capillary plate for suppression of the photon feedback.

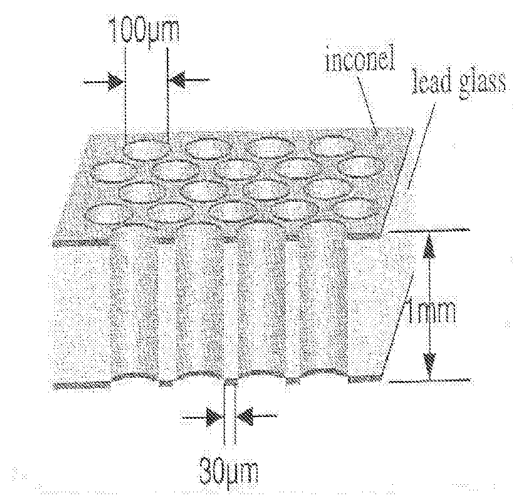


Fig. 3. A schematic drawing of the capillary plate.

plier (see Fig. 4). It consists of two planar parts: a sealed chamber with a semitransparent photocathode sensitive up to visible light ("scintillation chamber") and coupled to it a position-sensitive gaseous detector with a CsI photocathode (" readout detector").

The scintillation chamber operates in pure Xe at 1 atm of pressure. Electrons created by visible light from the photocathode (two types of photocathodes were tested: bi-alkali and SbCs; the best results were obtained with the SbCs photocathode) moved through the capillary plate (which acts as a light attenuator) and produced weak scintillation light in the gap between the capillary plate and collecting mesh. This light is detected by the readout gaseous detector operating at 1 atm (see Fig. 5a and 5b).

A practical quantum efficiency of 5% was achieved at a wavelength of 400 nm, (see Fig. 6) and position resolution better than 1 mm (Fig. 7). The rate capability of 10^5 Hz over the sensitive area (the diameter of the capillary plate was 20mm) and was only limited by the electronics used.

The main advantage of hybrid photomultipliers is that the photocathode is kept in a sealed chamber, which has only a few (2-4) feedthroughs and does not contain any outgassing materials. This ensures high degree of cleanliness. As a result photocathodes have a high quantum efficiency, are stable in time and do not show any sign of aging. The device, especially with the gas scintillation chamber, may have large sensitive area because there are no mechanical constrains on the window size and it is also practically insensitive to magnetic fields. Note that multi-pin feedthroughs for position measurements are located only in the readout chamber (flushed with the gas) and this simplifies the design and reduces cost.

The other practical consequence linked to this is that one

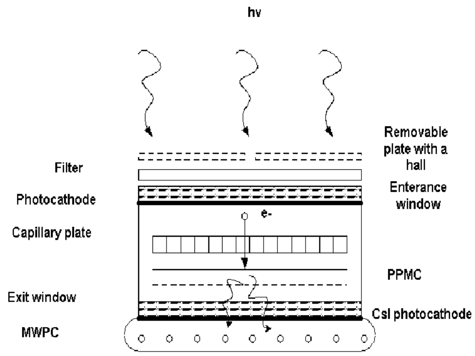


Fig. 4. A schematic drawing of hybrid gasseous photomultiplier.

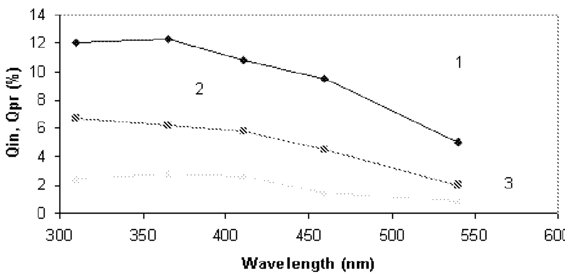


Fig. 6. The quantum efficiency of the SbCs photocathode measured in vacuum (1), in Xe at 1 atm without a capillary plate (2) and in Xe at 1 atm with the capillary plate (3).

may only purchase the scintillation chamber at low costs and combine them with standard photosensitive gaseous detectors. As was described above, such photosensitive detectors (with gaseous or with CsI photocathodes) are routinely used in many experiments, they are simple, reliable and can be easily manufactured in the Lab.

D. CsTe photocathodes

As was discussed above, photocathodes sensitive up to visible light are very unstable in the presence of tiny impurities. This is why we used a sealed chamber (see III-C). However, there exist some photocathodes, sensitive to ultraviolet, which are robust enough. Recently we have tested CsTe photocathode, operating in gas atmosphere (fig. 8). This allows making a very simple detector with a

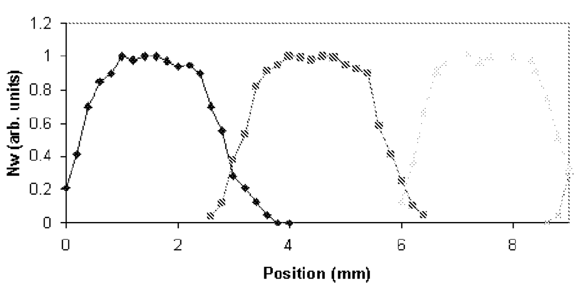


Fig. 7. Signals from wires of the MWPC obtained with a moving slit of 0.2 mm width.

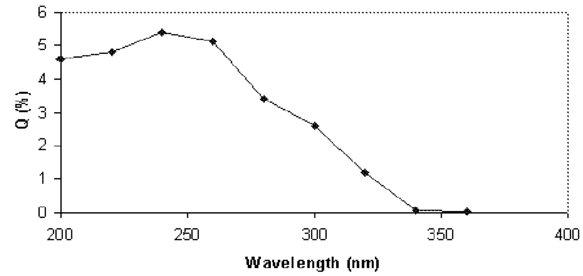


Fig. 8. The QE efficiency of the SbCs photocathode.

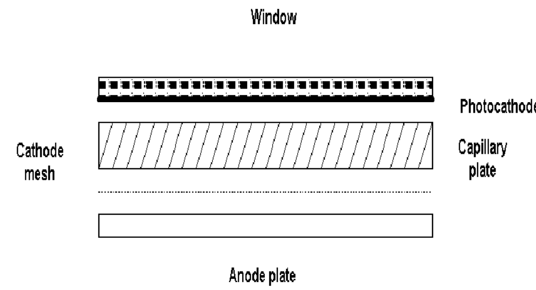


Fig. 9. A schematic drawing of the gaseous detector with the SbCs photcathode and the capillary light attenuator.

single capillary attenuator only (see fig. 9). A first prototype of such detect was build and tested recently.

E. Solid photocathodes as an efficient secondary electron emitters

Glass capillary plates were also successfully combined with secondary electron converters (for example porous CsI), which allowed to detected charge particles with high efficiency and position resolution [11].

Of course they can be combine with any micropattern detectors. For example we have combined successfully CsI emitters with small gap RPC (see fig 10). An excellent position resolution, better than 50 μ was achieved in a simple counting mode, without applying any treatment method, like center of gravity.

F. New fields of applications

As was mentioned in the Introduction, gaseous detectors with CsI photocathodes found a lot of applications, for example in RICH [25], hadron-blind Cherenkov counters, detection of scintillation lights from crystals [4].

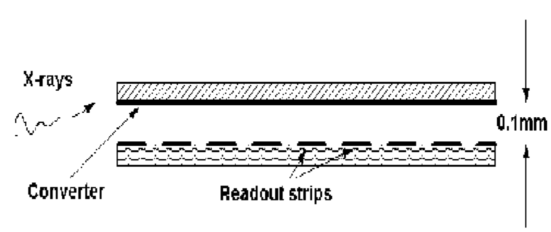
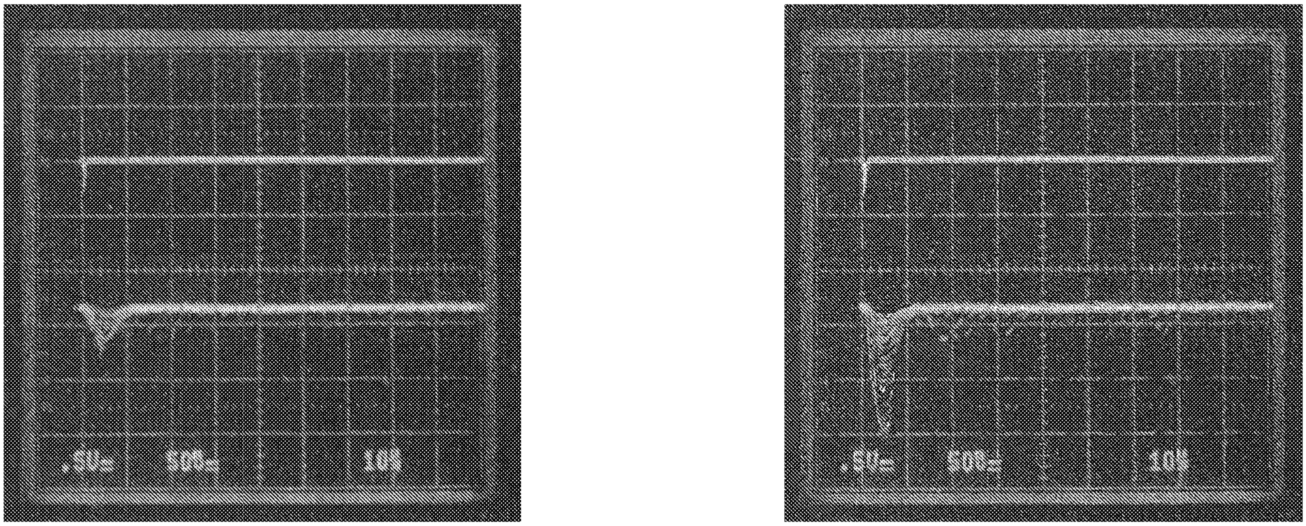


Fig. 10. A microgap RPC with a CsI X-ray convertor



a b

Fig. 5. Signals from the wire chamber (lower traces) detecting the visible light (the upper traces) through the scintillation. The visible light produces electrons from the SbCs photcathodes and these electrons cause the scintillation light in the chamber which is further detected by the photosensitive wire chamber. The Voltage between meshes was VM=700 V (a) and VM=800 V (b). Voltage on the multiwire chamber was 1530 V.

We would like to mention some new recent applications: detection of primary scintillation light noble liquid [26] and also to use these detectors as a cheap and efficient open flame detectors. There is no doubt that the new field of application for gaseous detectors with solid photcathodes will be continuously explored.

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