Imaging Hybrid Photon Detectors with a Reflective Photocathode

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Abstract

Modern epitaxially grown photocathodes, like GaAsP, bring a very high inherent quantum efficiency, but are rather expensive due to the complicated manufacturing and mounting process. We argue that such photocathodes could be used in reflective mode, in order to avoid the risky and expensive removal of the epitaxial growth substrate. Besides that, the quantum efficiency should increase considerably. In this paper we present results of the development of large imaging Hybrid Photon Detectors (HPDs), particularly designed for such reflective photocathodes.

Key words: Photon detectors, Photocathodes, HPD

1 Introduction

With the onset of new technologies, Hybrid Photon Detectors (HPDs) became one of the most favorable options for the detection of photons in many applications, as e.g. in large area Ring Imaging CHerenkov (RICH) detectors. In contrast to ordinary Photo Multiplier Tubes (PMT), where a photoelectron initiates a multi-step amplification process in a dynode system, in HPDs (1) a photoelectron undergoes a single-step acceleration from the photocathode towards the silicon sensor. Due to its relatively high energy (5-20 keV) a photoelectron releases a large number of electron-hole pairs upon its impact in the semiconductor sensor.

Recent HPD developments have focused on the following goals: (i) improvement of imaging performance, (ii) reduction of dead area, (iii) improvement of time characteristics and (iv) positive ion feedback protection (2; 3; 4; 5). In this paper we focus on yet another important topic, the possibility to increase the photon conversion efficiency. In order to be effective in converting the incoming photons into the photoelectrons, a photocathode has to be opaque for light and at the same time transparent to the released photoelectrons.

In general, these objectives are hard to meet simultaneously, in particular in the usual transparent-mode photocathodes, where the photons enter from one side of the layer, and the released electrons leave on the other. In addition, the traditional manufacturing process of the highest inherent quantum efficiency photocathodes in visible range, like the GaAsP photocathodes, requires a costly and risky removal (chemical etching!) of the crystal wafer used to grow the GaAsP structure in the Molecular Beam Epitaxy (MBE) process.

We propose to use the photocathode in the reflective mode, first of all to avoid the removal of the MBE growth substrate, but also in order to increase the overall quantum efficiency. A large area imaging HPD has been particularly designed for such a reflective photocathode.

2 Imaging HPD with a Reflective Photocathode

A possible reflective HPD configuration is presented in figure (1). For all electron optics simulations presented, SIMION 3D software (6) has been used. In all the figures presented, only elements important for electron optics (focusing electrodes) are shown, while the supporting structures are left out. It is assumed that the medium in the tubes is vacuum.

Figure (1) presents a cross section through a 5-inch diameter cylindrical reflective HPD tube (or alternatively, through a device arbitrarily elongated along the normal to the image surface). The photocathode is mounted onto the upper surface of the blends, which are in turn attached to the hemispherical input window and kept at the same potential (here -20 kV). It is important that the photocathode may be mounted on the blends without a need to remove the MBE growth substrate. After passing through the window, photons hit a photocathode layer on one of the blends. Released photoelectrons undergo complicated trajectories in the electrostatic field, finally hitting the position-sensitive silicon sensor, shown on the right side of the figure. Given the complicated way the photoelectrons reach the detector, the image mapping from the entrance window to the silicon sensor seems to be surprisingly regular.

The presented HPD may be operated in two resolution modes, depending on the position of the silicon sensor along the electron trajectories. Since all photoelectrons originating from a given blend meet in a single point along their trajectories, placing the silicon sensor in the focal plane leads to the low-resolution mode (one blend corresponds to one point, in fact circle or line, depending on the detector geometry). This HPD was carefully optimized in order to bring all the focal points corresponding to different blends into the same plane. Alternatively, when the detection surface is placed still further away from the photocathode, trajectories start to split, which results in a finer, sub-blend resolution. In both cases focal regions corresponding to different blends got rather well separated, which may be of some advantage, since there is no need for the silicon sensor to cover the entire surface continuously.

This HPD has two major drawbacks. First, the angular acceptance for the incoming light is very narrow, since the blends are not always in overlap. Second, the time of flight of the photoelectrons depends strongly on their origin on the blend surface - those electrons originating close to the window feel a low potential gradient and accelerate slower than the ones emitted from the edges of the blends.

A possible solution to the acceptance problem may be a double-blend structure, as e.g. in figure (2), but the spread in the time of flight will increase even more due to the increased depth of the blend regions.

In general, the width of the time of flight distribution could be considerably improved by optical means, by focusing the incoming light onto a very small region on a blend. This would also lead to savings in the photocathode surface, but on the expense of spatial resolution. However, such a solution is possible only when the initial light beam has a very narrow angular dispersion, like e.g. in gas RICH detectors. Unfortunately, any attempt to reduce the cross section of a light beam and to reduce (or keep) the angular spread simultaneously must fail due to the Liouville phase space arguments (7).

3 Summary

We have presented a development of Hybrid Photon Detectors (HPDs) particularly based on the reflective photocathode concept. In spite of the complicated blend structure which houses the photocathode, surprisingly good imaging properties have been achieved. Modern epitaxially grown photocathodes may be mounted in our HPDs without the need to remove the epitaxial growth substrate, which leads to a considerable cost reduction, and to a further increase in the quantum efficiency.

4 Acknowledgements

The concept of HPD with a blend was initiated in discussions with Guy Paić. Many thanks to Eugenio Nappi who started production of a prototype of the presented HPD in Bari.

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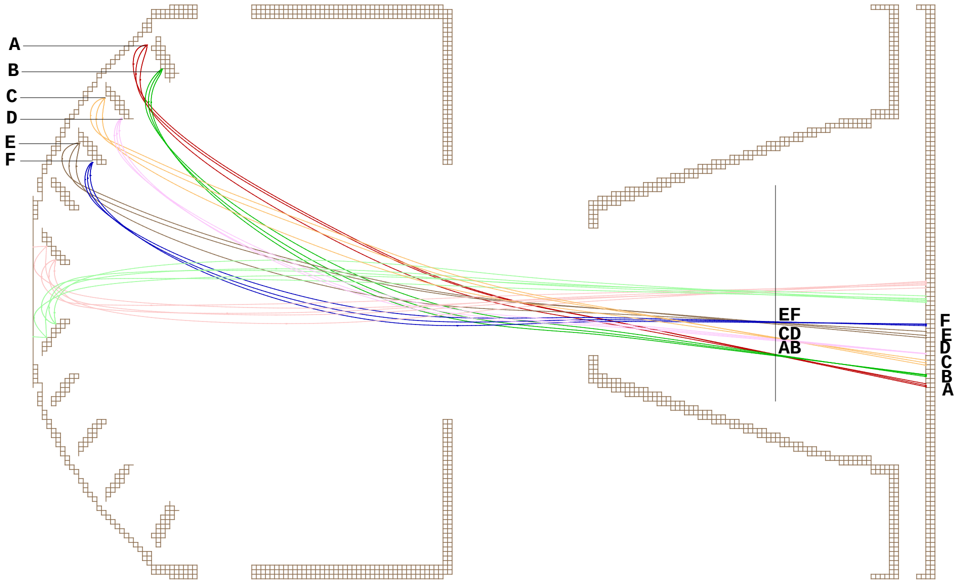

Fig. 1. HPD with a reflective photocathode. Electrostatic focusing provides correct imaging. Labels indicate groups of trajectories.

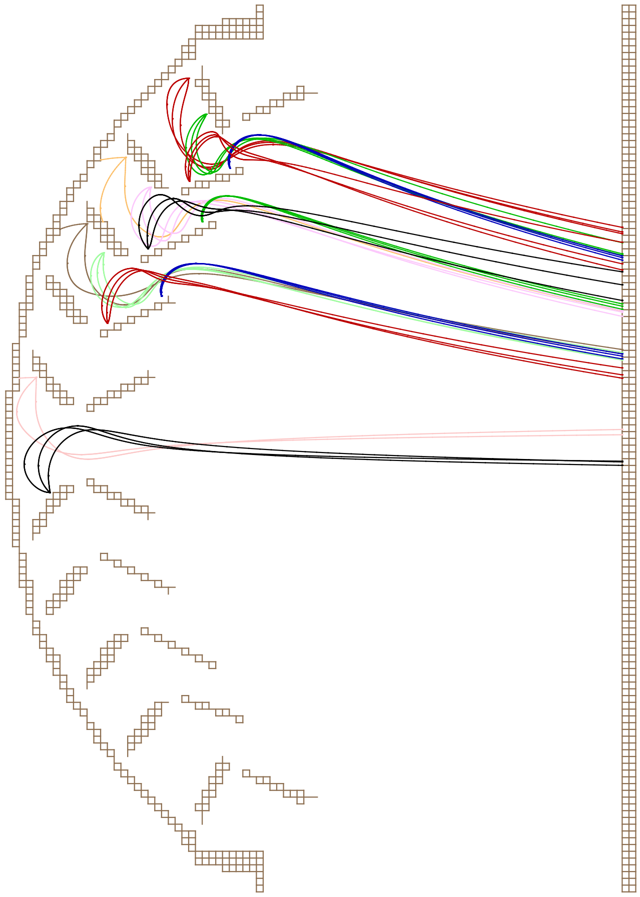

Fig. 2. Double-blend reflective photocathode HPD may improve the angular acceptance.