Solution to the ion feedback problem in Hybrid Photon Detectors and Photo Multiplier Tubes[a]

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Abstract

A general solution to the positive ion feedback problem in Hybrid Photon Detectors (HPD), photo multipliers (PM) and other similar detectors was found in the insertion of a permanent electrostatic potential barrier which prevents drift of positive ions from the anode, or the first dynode, towards the photocathode. In this paper we present the method as applied to the Intevac HPD.

1. Introduction

This work has been motivated primarily by the recent developments in gamma ray astronomy. Air Cerenkov Telescopes (ACT) have been considered the ultimate instruments for the ground based detection of high energy cosmic gamma rays [1]. In order to lower the energy threshold for the detection of cosmic gamma rays down to 20 GeV – to explore the only unexplored window in cosmic electromagnetic spectrum (20 GeV to 300 GeV) – one should both increase the detector area, and achieve an unprecedented photon detection with single photon sensitivity and very high efficiency. Considering photon sensors, Hybrid Photon Detectors (HPD), possibly with high quantum efficiency photocathodes, currently present the most promising solution. However, commercial devices have still some serious drawbacks and need further improvement. In particular, it is very important to reduce the internal instrumental noise below the limits imposed by presently available technology, because other intrinsic sources of noise in imaging Cerenkov detectors (like the night sky background) are irreducible.

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The presence of positive ions in the vacuum tube is specially devastating because the acceleration and subsequent dumping of positive ions into the photocathode leads both to creation of noise through electrons released, and to a damage of the photocathode [2, 3]. In tubes with high vacuum the vast majority of positive ions do not originate from residual gas, but from the impact of accelerated photoelectrons in the surface of the anode (the photodiode and the surrounding material). Hydrogen or Oxygen ions from adsorbed water are the most abundant ions. Cesium ions are particularly abundant in devices with in situ photocathode activation procedure.

In this paper we demonstrate, using the Intevac HPD [3] as an example, how the insertion of an electrostatic potential barrier close to the anode solves the ion feedback problem. Apart from being complete, this solution is elegant and easy to implement.

The paper is structured as follows. The basic design of the Intevac HPD is described in Sect.1. Our modification of the Intevac design, which includes the potential barrier, is described in Sect.2.; two different actual designs with equivalent performance are presented and compared from a technological point of view, by carrying out 3-dimensional electron optics calculation. In Appendix 1. we discuss for reference an attempt of Intevac to solve the ion feedback problem by breaking the field symmetry in the HPD tube.

For all electron optics simulations presented in this paper we have used SIMION 3D software [4].

2. Intevac Hybrid Photon Detector

The basic design of the considered Intevac HPD [3] comprises a cylindrical vacuum tube, housing a 18 mm diameter photocathode, a set of focussing electrodes, and a photodiode (PD) (or an avalanche photodiode (APD)) placed at a distance of 39 mm away from the photocathode. Photoelectrons from the entire photocathode are focussed and accelerated towards a small photodiode, where each electron creates a large number of electron–hole pairs. The Intevac tube is envisaged to be operated at a potential difference ranging from 5 to 10 kV. The lower end is more suitable for ACT experiments due to possible harsh atmospheric conditions at the experimental sites. All simulations presented in this paper are therefore performed with 5 kV potential difference between the photocathode and the photodiode. The relatively low secondary electron yield in the PD[1] may be compensated using an APD with internal multiplication.

The ion feedback problem for the Intevac HPD is demonstrated in Fig. 1, where the HPD is shown with its photocathode on the left, and the anode complex on the right. Potentials are indicated for all electrodes, and a set of equipotential lines is presented (not

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[1] The number of secondary electrons is $N_e \simeq (U-U_0)/3.6V$, where U_0 is the voltage (in Volts) to accelerate an electron to an energy sufficient to penetrate the inert layer above the semiconductor pn structure.

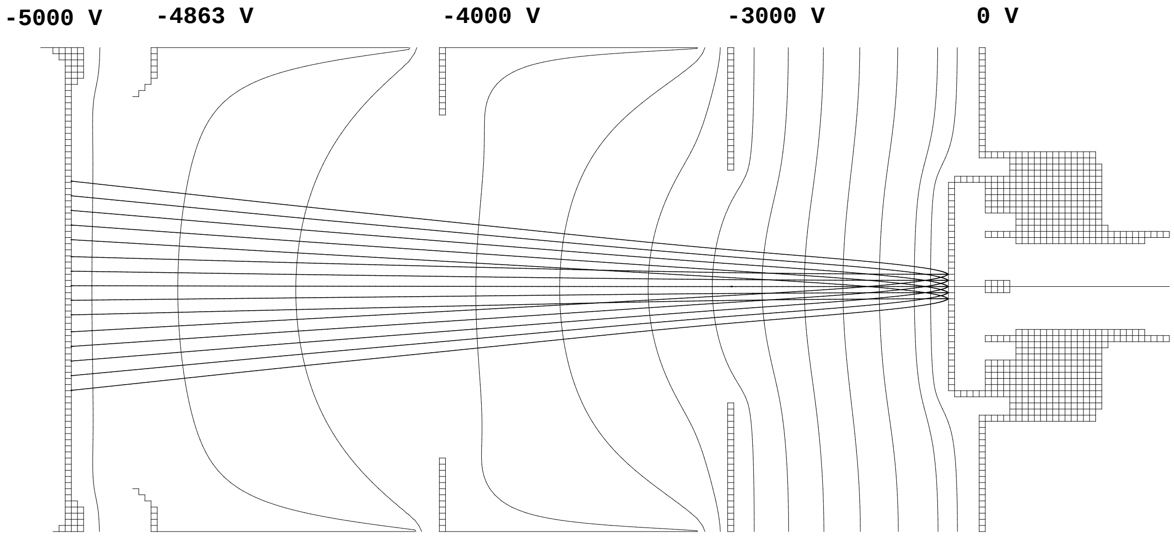

Figure 1. Positive ion trajectories in the Intevac HPD. Ions emerge from the surface of the anode (right) and accelerate towards the photocathode (left).

equidistant). Positive ions of energy E_{ion}=15 eV are launched from a set of points on the anode surface with emission angles +45°, -45° and 0°. After being accelerated, ions hit the photocathode, thus giving rise to the "ion feedback problem".

Note that the angular and energetic distributions of positive ions are, to our best knowledge, unknown. We have worked out a scheme how to perform a measurement of those quantities, using actually a tube designed according to our proposal in this paper, but since the results are not yet available, we are currently using a rough estimate that the ions could reach an energy of around 15 eV. Once the actual energy will be measured, it will be straightforward to repeat our simulations and find the optimal potential settings.

3. Potential barrier – solution to the ion feedback problem

The essential goal of the new electron optics is to prevent positive ions from leaving the region around the anode and heading towards the photocathode. That goal is accomplished by means of a permanent electrostatic potential barrier created in front of the anode by a cylindrically symmetric electrode – the so called "barrier–electrode" – kept at a potential somewhat higher than the anode potential. The method preserves cylindric symmetry of the entire device. Two different designs are presented in this paper: (i) with a flat barrier-electrode, see Fig. 2, and (ii) with a conically shaped barrier–electrode, see Fig. 3. In addition, the potential distribution around the anode plane for the conical design is shown in a magnified view in Fig. 4. Trajectories of singly charged positive ions are simulated with identical initial conditions like before.

The functionality of the barrier–electrode is simple: it creates a potential barrier in front of the anode which does not allow ions to penetrate further towards the photocathode, solving thus the ion feedback problem. The design with the conical barrier–electrode, Fig. 3, offers certain advantages. Since the conically shaped electrode more closely surrounds the anode area, the barrier–electrode potential needed to establish the potential barrier of a given height (for the examples presented we used $V_{Barrier}$=+15.5 V) is much lower (V_{BE}=+76 V) than needed for the flat electrode (V_{BE}=+350 V). In addition, the throughput connection to the voltage supply outside the tube appears for the conical barrier–electrode at a very safe distance from the throughput of the neighboring electrode of opposite polarity. Further, the conical electrode may better protect the anode area from cesium vapor deposition during (and after) the manufacturing of the photocathode, and also captures photoelectrons back-scattered from the PD. Both designs are optimised for electron focussing. Electron trajectories are shown in Fig. 5 and Fig. 6, for the flat and the conical barrier–electrode designs, respectively. Electron trajectories were simulated with the following initial conditions: emission angle normal to the photocathode surface, and initial energy $E_{electron}$=0.4 eV. An avalanche photodiode with 1 mm in diameter will eventually collect all the electrons, even if smearing in initial electron energy and emission angle is considered [5].

Let us also mention that some existing HPD and PM tubes do have already electrodes close to their anodes or first dynodes - originaly designed for other purposes - which may be used as our barrier electrodes with the application of an appropriate potential, and a redistribution of other potentials in the device in order to compensate for the likely change in electron focusing.

The stability of the potential on the barrier–electrode which is required for stable electron focussing is not a critical issue – variations of even 10% on the potential will leave the electron focussing essentially unchanged [5]. The most common voltage supply may be therefore used to bias the barrier–electrode.

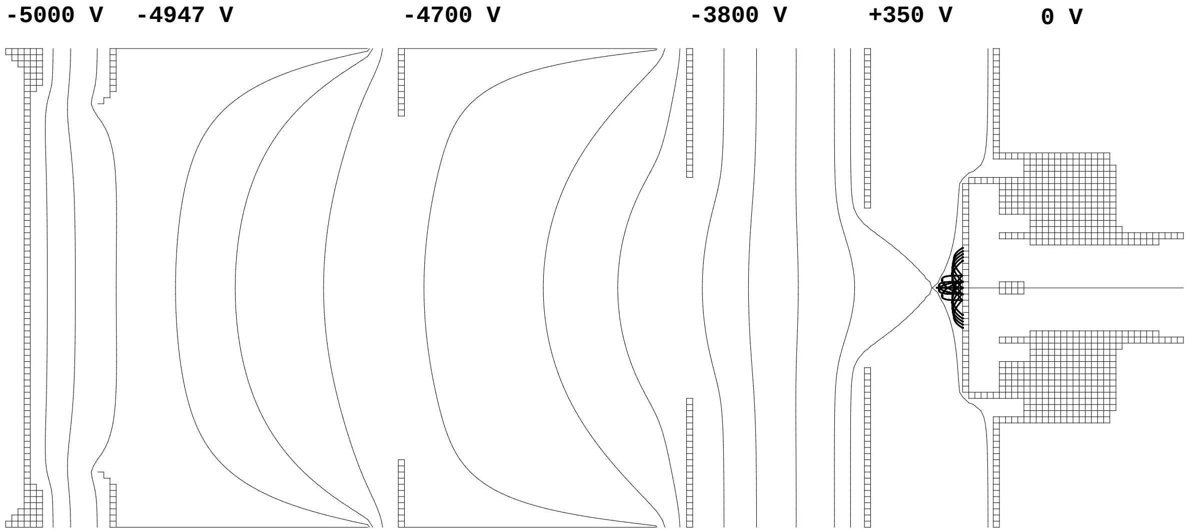

Figure 2. HPD design with a flat barrier–electrode at potential +350 V. Between the barrier–electrode and the anode a potential barrier is established, which repels positive ions emerging from the anode surface back towards the anode, see trajectories close to the anode surface.

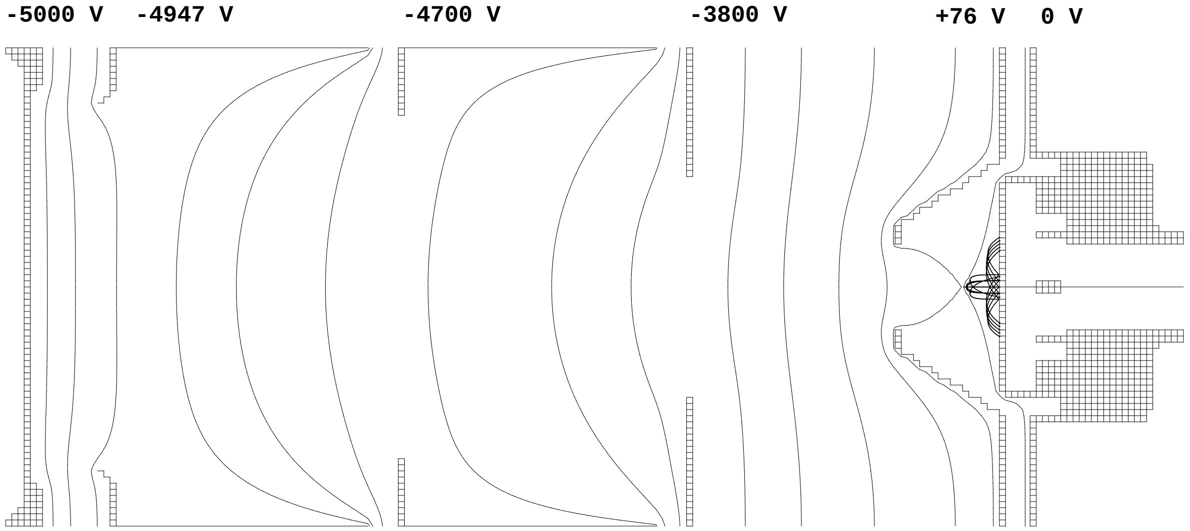

Figure 3. The same as in Fig. 2, but for the conical barrier–electrode design.

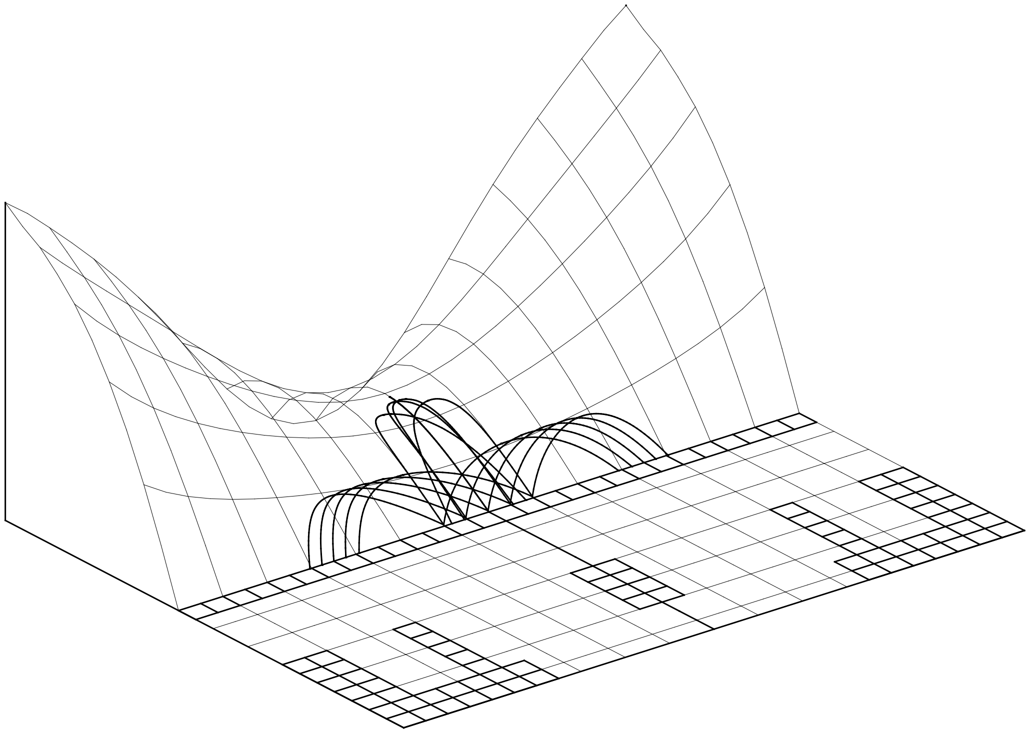

Figure 4. Potential distribution in front of the anode plane of the conical barrier–electrode HPD design (Fig. 3). Positive ions of energy E_{ion}=15 eV and emission angles +45°, -45° and 0° start "climbing" the potential barrier and get repelled back.

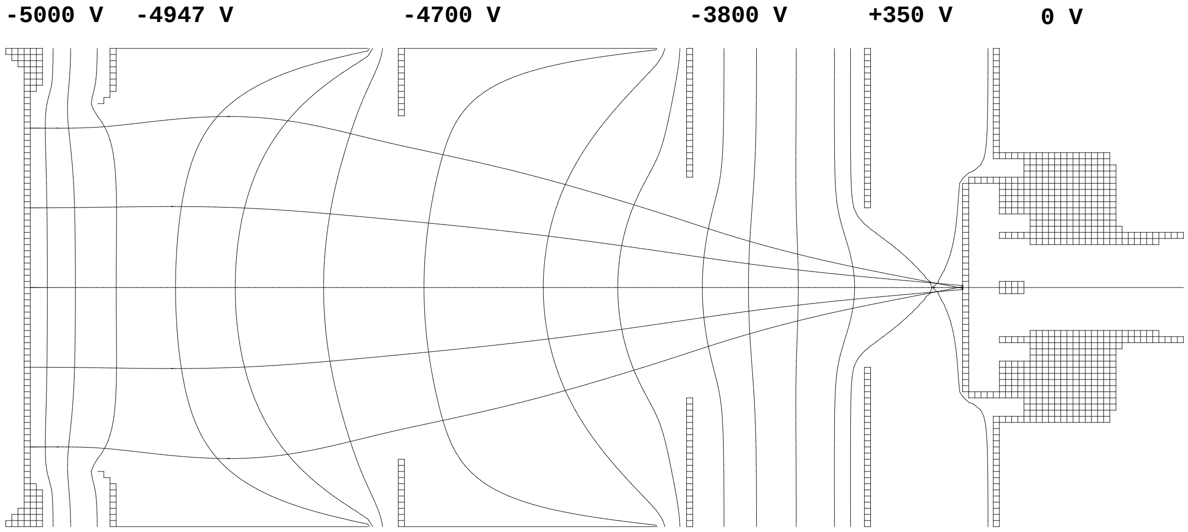

Figure 5. Electron focussing with a flat barrier–electrode HPD.

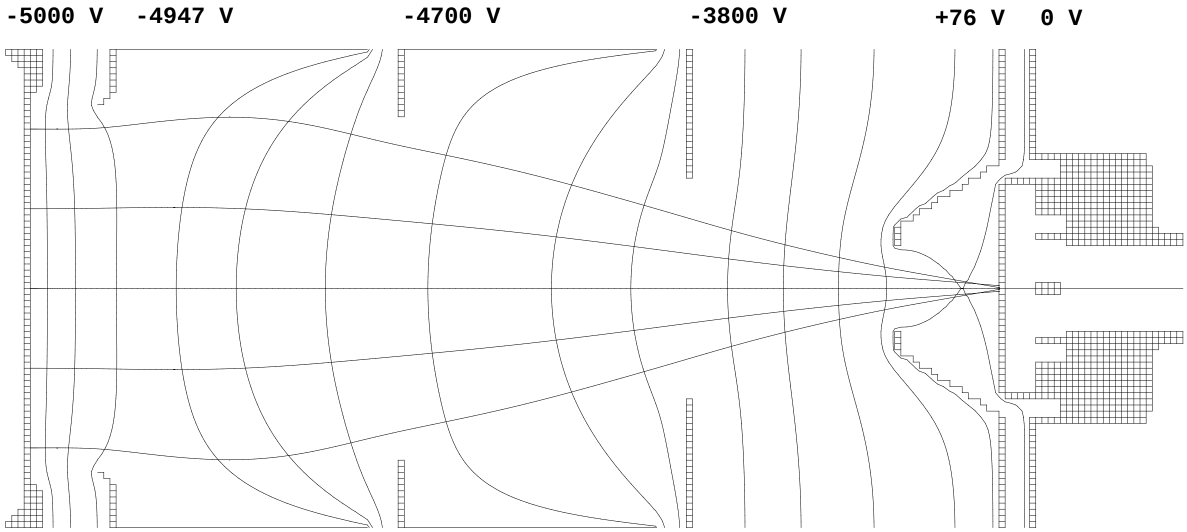

Figure 6. Electron focussing with a conical barrier–electrode HPD.

4. Summary

A general solution to the positive ion feedback problem in hybrid photon detectors, photomultipliers and other similar detectors was found in the creation of an electrostatic potential barrier in front of the anode in HPD's or the fitst dynode in PM's. By that means positive ions originating from the anode surface - released in impacts of photoelectrons - are not able to penetrate the potential barrier, and therefore cannot get accelerated towards the photocathode.

In this paper we presented the application of the potential barrier method to the Intevac HPD. The method is generally applicable, and we have applied it recently also in designs of some other devices [6].

5. Appendix 1. Intevac ion deflector

In an attempt to solve the ion feedback problem, Intevac introduced [3] a method based on broken cylindric symmetry of the field in the tube – an idea essentially different from ours, because there is no attempt to block the propagation of ions towards the photocathode, but only to deflect their trajectories to one side of the tube. The symmetry breaking is done by inserting an electrode on the anode potential, placed just on one side of the diode [3], the advantage being that no additional positive voltage source is needed. Note that the high energy photoelectrons are barely deflected by the deflector electrode. This deflection was compensated by displacing the pickup diode by small distance. A reproduction of the Intevac deflector solution is presented in Fig. 7. The same set of ions is simulated like above.

Although positive ions become deflected to the opposite side of the deflector electrode, a considerable fraction of ions still hit the photocathode and the remaining ones hit the electrodes or the tube walls, eventually releasing additional electrons and ions into the chamber vacuum – a result far from being satisfactory.

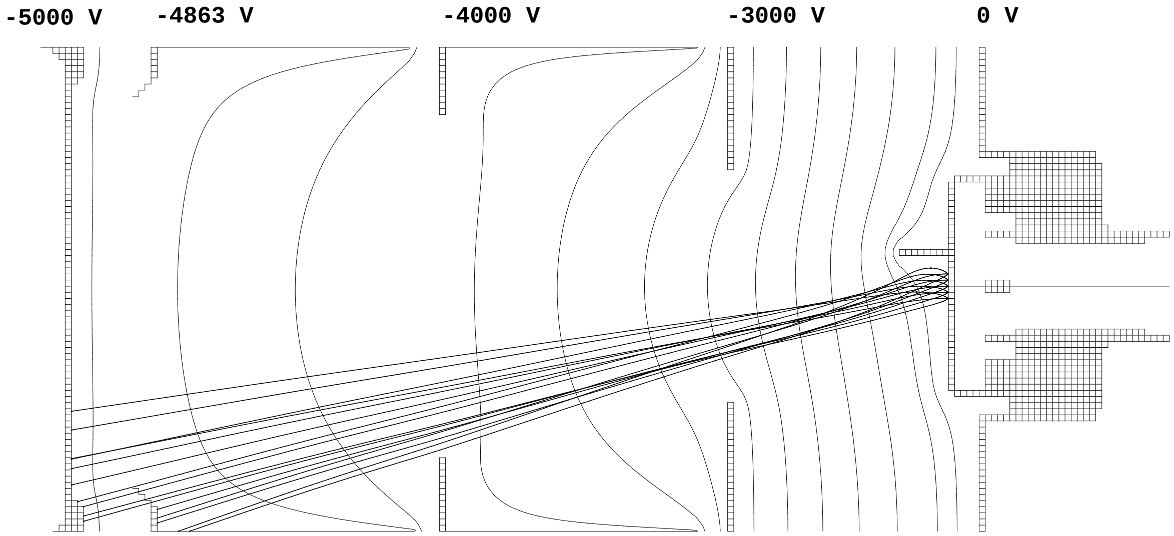

Figure 7. Intevac deflector modifies the potential distribution in such a way that positive ions find their way to the opposite side of the tube, but they all hit, with sizeable energies already, either the photocathode or other parts of the device.

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