Design, Fabrication and Performance of the 10-inch TOM HPD

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The first sealed TOM HPD with 10-inch diameter has been fabricated and successfully tested at CERN. This Hybrid Photon Detector has a spherical entrance window and a bialkali photocathode. The fountain focusing optics produces a demagnified image (D = 4) on the round segmented silicon sensor. The signals of the 2048 cells are read out through analog front-end electronics encapsulated in the vacuum envelope. We report on the design, fabrication technique and the experimental results obtained with laboratory test benches. The large TOM HPD is a prototype tube developed for the CLUE cosmic ray experiment. The final tubes, now under development, will be equipped with a solar-blind Rb_2Te photocathode and self triggering front-end electronics.

Keywords: Photodetector; Hybrid Photodiode; Hybrid Photon Detector; HPD; Photocathode; Bialkali; Rubidium Telluride;

1. Introduction

Hybrid Photon Detectors (HPD) [1], also called Hybrid Photodiodes, are attractive devices when detection or imaging of low light levels is required. Combining the sensitivity known from conventional photomultiplier tubes with the superb spatial and energy resolution of silicon sensors, a number of appealing features is obtained: sensitivity to single photons with excellent signal definition, real photon counting, sub-millimeter spatial resolution. Proximity focused HPD tubes allow in addition for operation in magnetic fields. In high energy physics only few experiments have made use of the HPD technology, however, some large scale applications are in the prototype or construction phase. Over the last five years a CERN based team has built up dedicated facilities and infrastructure to design, fabricate and test HPDs. While the first development, the 5-inch Pad HPD [2,3], was designed for the readout of the LHCb RICH counters, the current developments open up applications in astrophysics and medical imaging.

The 10-inch TOM HPD is the largest HPD ever built and is named after our former collaborator and pioneer of the Ring Imaging Cherenkov (RICH) technique, Tom Ypsilantis[2]. TOM HPDs are planned to be used as focal plane detectors of the nine imaging air Cherenkov telescopes of CLUE (Cherenkov Light Ultraviolet Experiment) [4], situated on the Canarian island La Palma. The glass envelopes used for these developments were originally designed and fabricated as prototypes for the AQUARICH experiment [5]. They are therefore equipped with a standard glass entrance window. The operational conditions at CLUE require however a solar-blind photocathode, deposited on a quartz entrance window. The excellent sensitivity of Rb_2Te cathodes on ITO undercoating, which we developed for this pur-

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[2] Tom Ypsilantis, 1928 - 2000.

pose, have been described in a recent paper [6]. In the current article we describe the design, the fabrication technique and the performance of the first sealed and fully operational 10-inch HPD. This first TOM HPD is equipped with a standard glass entrance window and bialkali photocathode. The purpose of this intermediate development step is the validation of the electron optical concept, photocathode evaporation and sealing technology.

2. Design of the 10-inch TOM HPD

The TOM HPD makes use of the fountain shaped electron optics (see Figure 1), already applied in the 5-inch Pad HPD. The tube body with a height of about 275 mm, joint to a spherical (R_{curv} = 200 mm) entrance window of 250 mm diameter, is manufactured in glass blowing technique[3]. The electric field is defined by 4 concentric ring electrodes (incl. a bleeder electrode very close to the entrance window). A baseplate of 160 mm diameter carries the silicon sensor and the readout electronics. The first TOM HPD is equipped with a silicon sensor of 50 mm diameter, segmented in 2048 pads and read out by 16 VA-prime[4] front-end chips with 350 ns shaping time, encapsulated in the vacuum envelope. In the final version the auto-triggering VATA chip will be used, which in recent tests demonstrated its design performance.

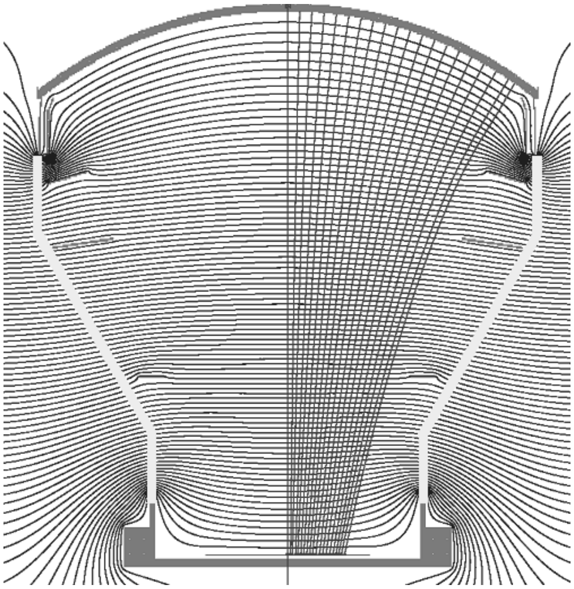

Figure 1. Equipotentials and electron trajectories simulated with the SIMION code. The voltage settings of the electrodes are (in kV, from cathode to anode): -20, -19.6 (bleeder), -16, -13.5, -7, 0.

Figure 2. Photo of the 10-inch TOM HPD and the 5-inch Pad HPD.

The electron optical performance of the TOM tube has been studied with the SIMION 7.0 code[5]. A linear demagnification over the full active diameter (ca. 228 mm) of about 4 is expected. The point spread function was predicted to be 1.3 mm for a cathode voltage of -20 kV [6].

3. Fabrication

The TOM HPD is fabricated by an external process in the CERN plant, which was originally built for the 5-inch Pad HPD [2,7]. Comprehensive modifications were required to mount the

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[3] SVT, France, www.svt-vacuum.com

[4] IDE AS, Norway, http://www.ideas.no

[5] ISS, USA, www.srv.net/∼klack/simion.htm

large tube inside the vacuum tank. Three special heating elements, fully enclosing the glass envelope, provide the temperature levels required for bake-out (300°C) and cathode processing (150°C). The evaporation sources (Sb, K, Cs) are mounted on a movable platform. A ring mask screens the tube body from Sb vapors. During the cathode processing the platform is positioned close to the center of curvature of the tube entrance window. This is essential for the uniformity of the cathode thickness.

The bialkali photocathode is produced in our standard co-evaporation process [2]. As the tube is expected to operate at very low intensity illumination (i.e. very small photocurrent), no conductive undercoating is deposited. After the cathode processing, the plant is cooled down to room temperature, the non evaporable getter is activated, and the tube body is in-situ sealed with the base plate by means of cold indium press seal.

4. Performance

The tube performance was assessed on two test benches. The first, comprising a Xe-lamp and a monochromator, allows to determine the quantum efficiency of the HPD in the wavelength range 200 - 800 nm. A calibrated UV photodiode (±3 % relative precision) serves as reference. The monochromatic light spot of about 3 mm diameter can be scanned over the tube surface to measure the uniformity of the response. In the second test bench the HPD is illuminated with a collimated spot ($\sigma = 0.7$ mm) from a H_2 flash lamp, which can be precisely scanned across the tube diameter. The pick-up signal from the flash lamp triggers the DAQ system to read the signals stored in the VA-prime chips. The average pedestal noise and its spread (σ_{noise}) of all 2048 electronic channels is measured and subtracted for all subsequent measurements (typically a $5\sigma_{noise}$ cut is applied).

The quantum efficiency of the TOM HPD is shown in figure 3. A peak value of 24% is achieved at 350 nm. The surface scan reveals a uniform response to a radius of 60 mm radius. A significant drop is observed at larger radii: R = 80 mm: -20%, R = 100 mm: -50%. This unexpected behaviour is caused by the mask of the Sb source which was accidentally set too tight.

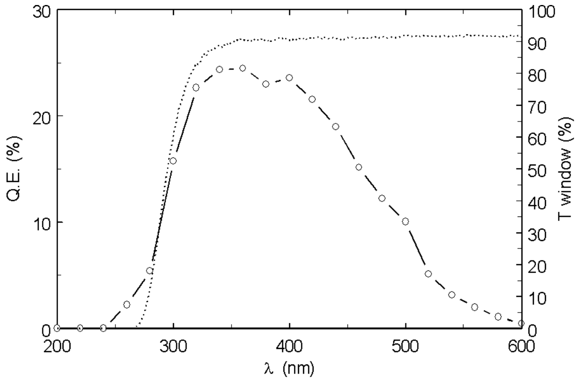

Figure 3. Quantum efficiency of the 10-inch TOM HPD. The drop below 300 nm is is due to the cut-off of the standard glass window (dotted line).

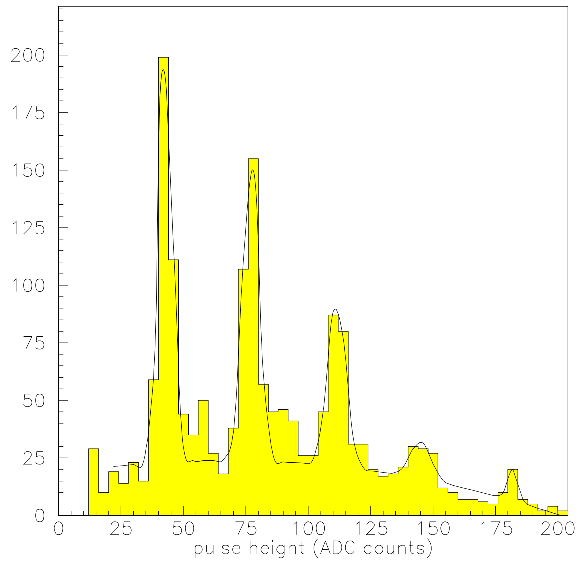

Figure 4. Pulse height spectrum of a single channel at a cathode voltage of -30kV.

The TOM HPD can be operated with very low noise count rates at cathode voltages up to -30 kV (currently limited by the available power supplies). A pulse height spectrum of a single Si pad at this value is shown in figure 4. The single photoelectron peak is separated by more than $20\sigma_{noise}$ from the pedestal noise. For all measurements presented below the light intensity was reduced to single photon level.

Figure 5 demonstrates the HPD typical perfect linearity between signal amplitude (1^{st} photoelectron) and the applied cathode voltage. The linear fit intersects the abscissa at 0.96 kV, corresponding to an energy loss of the photoelectron of about 1 keV in the dead layers of the Si sensor (Al metalization and n^+ implant).

In figure 6 the variation of the average charge (i.e. the integral under the 1^{st} photoelectron peak) and the random noise are plotted versus the level of the applied pedestal noise cut. Below 5 sigmas the influence of the electronics noise becomes dominant. A cut above 10 sigmas diminishes the signal charge and also the noise, as it consists mainly of diffuse background light and real dark counts from the photocathode, i.e. single photo electrons in both cases. The slight decrease of the signal charge between 3 and 10 sigmas is due to the suppression of so-called back scattered photoelectrons. At U_C = -25 kV noise values in the range of $1-2\times10^{-4}$ per trigger and pad are obtained. Part of this is attributed to the halo of the light spot. The pure dark count rate of the total tube is of the order of 150 kHz (ca. 450 Hz/cm^2). At U$_C$ = -25 kV and a 5 sigma noise cut the photoelectron detection efficiency is estimated to be 95%.

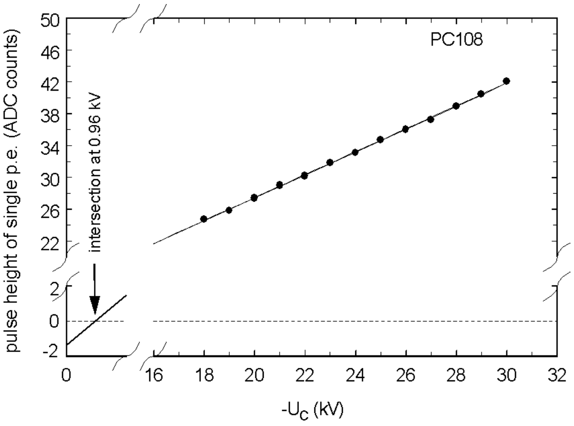

Figure 5. Pulse height of the 1^{st} photoelectron peak versus cathode voltage. The intersection with the abscissa corresponds to the energy loss in the non-active back layer of the Si sensor.

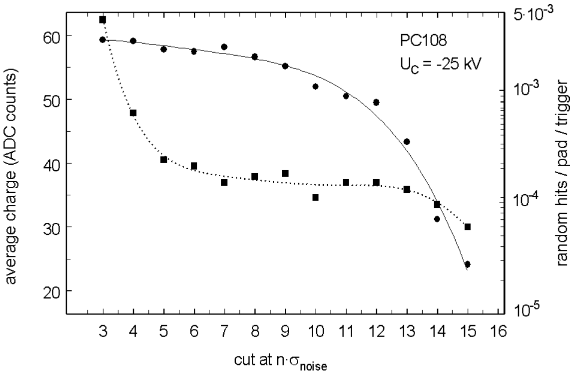

Figure 6. The average charge (integral under the 1^{st} photoelectron peak) and noise counts are shown as a function of the pedestal noise cut. The noise counts (dotted line, right scale) are measured per pad and per trigger.

The imaging properties of the TOM HPD are characterized by Figures 7 and 8. A radial scan of the light spot over the HPD reveals a linear demagnification of D = 4.02, constant up to a radius of about 100 mm and fully in agreement with the SIMION simulation. With the exception of the bleeder electrode ($V_{bl} = V_{bl}^{sim.} - 240V$) all voltages are set to the values optimized in the simulation. The diameter of the Si sensor (R$_{Si}$= 25 mm) prevents a measurement beyond R$_{cath}$ = 100 mm. The point spread function, defined as the Gaussian width of the charge distribution on the Si sensor measured with a pointlike light source, shows the expected $1/\sqrt{U_{cath}}$ behaviour. The measured values are slightly higher than the simulated ones, e.g. at 20 kV 1.5 mm (measured) compared to 1.3 mm (simulated).

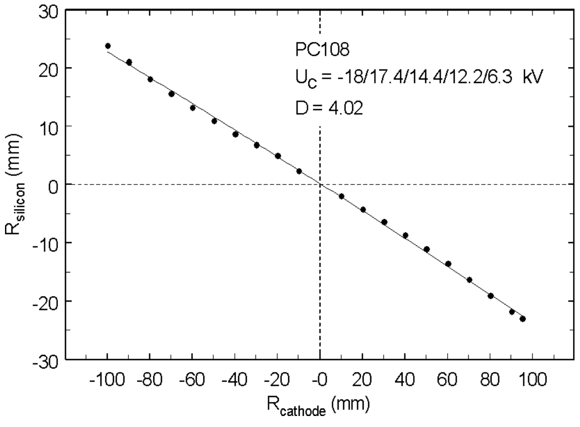

Figure 7. Relation between the radial coordinates, measured from the tube center, on the photocathode and the silicon sensor. The demagnification obtained from a linear fit is $D = 4.02$.

5. Outlook

The final photodetector for the CLUE telescopes requires a Rb_2Te cathode and a quartz entrance window. The significant mismatch of the thermal expansion coefficients of the quartz window and kovar metal excludes the fabrication of a tube of this size in the classical technique. We are currently pursuing two alternative strategies: (1) Fabrication of the whole tube in quartz[6], and (2) joining the quartz entrance window to the glass body by means of an Indium seal[7]. We expect prototype tubes to be available by the end of 2003. In parallel a larger Si sensor (ca. 65 mm diameter) with a segmentation of about 4 × 4 mm (ca. 256 pads) needs to be designed and fabricated. It will be read out by 2 VATA chips. 10-inch TOM HPDs matching the complete CLUE specifications can then be built in 2004.

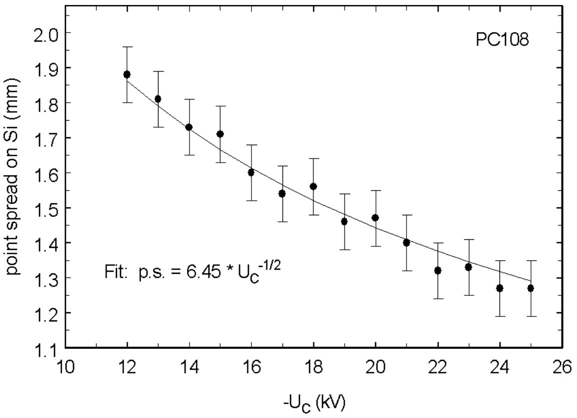

Figure 8. Point spread function, measured at the level of the silicon sensor, as a function of the applied cathode voltage.

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[7] Collaboration with PHOTEK LTD, www.photek.co.uk