Development of a 10-inch HPD with Integrated Readout Electronics

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A round 10-inch diameter Hybrid Photodiode with spherical entrance window is under development for Cherenkov imaging applications in cosmic ray astronomy. The HPD adopts the fountain focusing electron optics, which, as already demonstrated in the 5" Pad HPD, allows for a linear demagnification of the image over practically the full tube diameter. Self-triggering front-end electronics providing also sparse readout capability, has been tested. High efficiency Rb_2Te cathodes have been produced on a UV extended borosilicate glass windows with very thin conductive underlayers of Indium Tin Oxide (ITO). We report on the design of the 10-inch HPD, the fabrication procedure and first tests of a 5-inch HPD with Rb_2Te photocathode and 2048 channels.

Keywords: Photodetector; Hybrid Photodiode; HPD; Photocathode; Rubidium Telluride;

1. Introduction

The imaging air Cherenkov telecope CLUE (Cherenkov Light Ultraviolet Experiment) is situated on the Canarian island La Palma. It consists of 9 identical mirror telescopes of 1.8 m diameter[1,2]. The focal planes of the telescopes are equipped with MWPC detectors, operating with a TMAE loaded gas mixture. Recent calculations and a measurement with a small commercial HPD have demonstrated an increase of the light yield by a factor 20 [3], if these chambers were replaced by large HPD tubes with Rb_2Te photocathode. This solar-blind type of cathode has the advantage of a practically negligible quantum efficiency for wavelengths at which the night sky background is not fully suppressed by the atmospheric ozone layer ($\lambda > 300$nm) while it provides high sensitivity below this value down to the cut-off of the quartz entrance window of the HPD. In a joint effort of groups from CERN and INFN, which is called TOM project in memory of our former collaborator and pioneer of the Ring Imaging Cherenkov (RICH) technique, Tom Ypsilantis[2], the development of a round 10-inch HPD with integrated readout electronics has been launched. The design and fabrication technology is based on the 5-inch Pad HPD, developed and fabricated at CERN and reported in a previous Beaune conference [4]. Since then the performance of the 5-inch HPD has been optimised to design values [5] and was recently demonstrated in an aerogel radiator RICH set-up [6]. While the final performance figures will be published in a forthcoming paper, we summarize some essential results below.

1.1. The 5-inch Pad HPD

The Pad HPD is a round HPD of 127 mm diameter, of which 114 mm are active. The fountain-shaped electron optics provides a linear demagnification of ca. 2.6 over the full tube diameter. This allows to project the cathode image onto the round silicon sensor of 50 mm diameter, seg-

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[2]Tom Ypsilantis, 1928 - 2000.

mented into 2048 pads of 1×1 mm size. The Pad HPD is equipped with a bialkali (K_2CsSb) photocathode, evaporated on the entrance window made of UV extended borosilicate glass. Quantum efficiency peak values in the range of $25 \pm 3\%$ are routinely reached. The Pad HPD features analogue readout electronics of the IDEAS[3] VA family (VA2, VA3 and VA-prime) with shaping times from $0.35\mu s$ to $3\mu s$, encapsulated in the vacuum tube. The HPD operates at cathode voltages up to -20 kV with random noise levels of about 1 permille per pad and a photoelectron detection efficiency of ca. 93%.

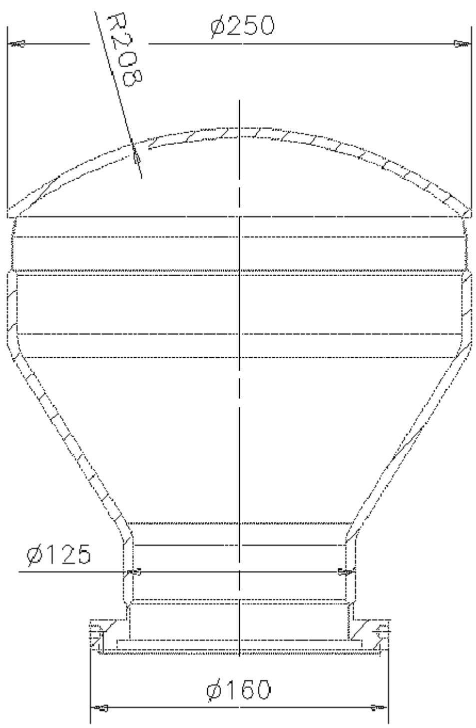

Figure 1. Longitudinal-sectional view of the 10-inch envelope.

2. The design of the 10-inch HPD

2.1. Geometry and materials

The design and the electron optics of the 10-inch HPD (see figure 1) resemble the one of the 5-inch device. The tube, manufactured in glass blowing technique, has an outer diameter of 250 mm and a height of ca. 275 mm. While for the final CLUE detectors quartz entrance windows are required, the first 10-inch prototype HPD will be built with envelopes with standard glass entrance window developed for the AQUARICH project [7]. A baseplate of 160 mm diameter, which carries the silicon sensor and the readout electronics is sealed to the tube body (cold indium press seal).

2.2. Electron optics

The fountain shaped electrical field is defined by a set of 4 concentric ring electrodes, including the so-called bleeder electrode, close to the

[3] http://www.ideas.no

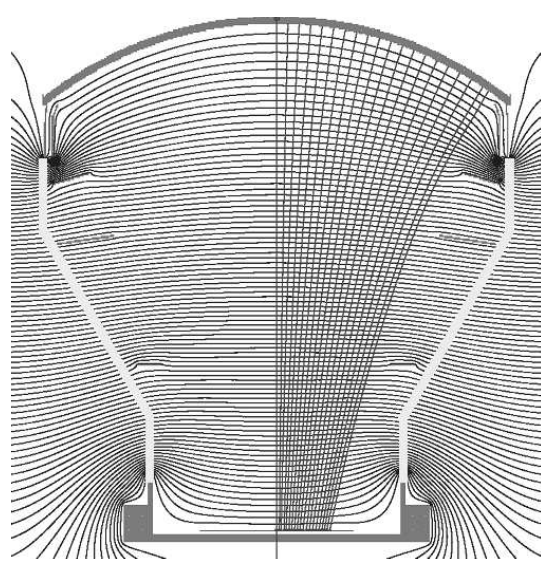

Figure 2. Simulated potential distribution and electron trajectories. The voltage settings of the electrodes are (in kV, from cathode to anode): -20, -19.6 (bleeder), -16, -13.5, -7, 0.

cathode. The 10-inch HPD is planned to be operated at -20 kV (-30 kV as option). Simulations with the code SIMION 7.0 predict a practically linear demagnification of about 4 over a diameter of almost 240 mm. The point spread function, simulated on the level of the silicon sensor, is expected to be 1.3 mm (at -20 kV). Figure 2 shows the simulated potential distribution and electron trajectories.

3. The silicon sensor and the readout electronics

The final 10-inch tubes will be equipped with a p^+n silicon sensor of about 65 mm diameter, produced in double metal layer technology, very similar to the one in the 5" Pad HPD. Square pads of about 3 mm size are matched to the point spread function and will result in a granularity on the photocathode surface of about 12 mm. The number of readout channels will be of the order 400.

3.1. The autotriggering front-end chip

For cosmic ray physics applications a self-triggering readout is required. We plan to use the recently developed front-end chip VATA-GP3 from IDEAS. This chip provides in parallel to the normal amplification and shaping chain (τ_{peak} = 3μs) a second fast gain and shaping line (τ_{peak} = 200 ns) which is used to generate a trigger signal. The functionality of the chip has been demonstrated and detailed studies of its performance (noise, gain) are currently under way. A faster version with $\tau_{peak}(slow) = 1\mu$s and $\tau_{peak}(fast) =$ 35 ns is under development. The sparse readout option, another feature of this chip, is expected to allow data taking rates in the 100 kHz range.

4. The Rubidium Telluride photocathode

Semitransparent solar blind photocathodes, like Cs_2Te or Rb_2Te, have the disadvantage of a high surface resisitivity (in excess of 10^{10} Ω/square). For cathodes of a certain diameter usually very thin metallic underlayers, e.g. Cr, are pre-deposited on the substrate to allow for sizeable photocurrent values and a uniform electric field distribution over the full cathode surface. A drawback of this method is the transmission loss associated with the metallic underlayer.

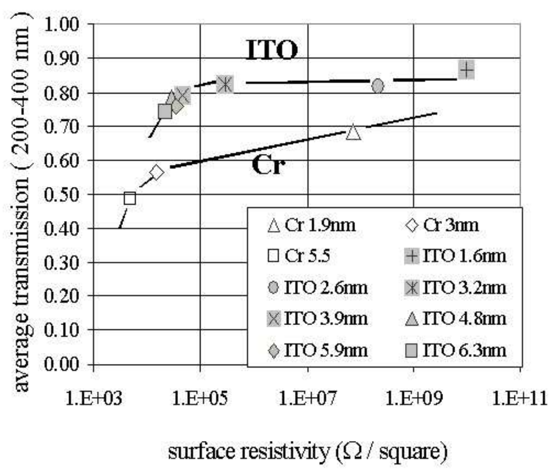

Figure 3. Optical transmission versus resistivity for thin Cr and ITO films on a quartz substrate.

4.1. ITO as transparent conductive underlayer

We have systematically studied thin conductive layers of ITO, a mixture of indium oxide and tin oxide, in comparison with chromium. Compressed pellets of ITO powder are evaporated by means of an electron gun. A post-treatment in an oven at 300°C in air for 8 hours re-oxidizes the partially reduced compounds, decreases the resistivity and increases the transparency of the film. Figure 3 shows the transmission, averaged between $\lambda = 200$ and 400 nm versus the surface resistivity of thin (1.6 - 6.3 nm) ITO and Cr films. At the same resistvity ITO films exhibit a significantly higher transparency. Resistivity values around 1 MΩ/square, which are considered as sufficient for our application, can be obtained with ITO at a transmission loss of only 15%, compared to 35% for Cr.

4.2. The Rb_2Te process

A simple co-evaporation process for the Rb_2Te cathode has been developed. Following an extended vacuum baking of the process chamber at 160°C and of the envelope at 300°C, vacuum levels in the 10^{-7} Pa range are obtained. The partial pressure of water and other reactive gases is below 1×10^{-7} Pa. During the evaporation the process chamber and the substrate are kept at a temperature of 70°C. The photocurrent for illumination with white or monochromatic light and all other essential process parameters are permanently monitored and logged. A calibrated UV photodiode allows to calculate the quantum efficiency. First Rb is evaporated from a commercial dispenser. A Rb film, covering the complete substrate, manifests itself in a small but stable photocurrent. Then Te is co-evaporated from a source, which consists of a small Ta boat, on which a Te bead has been pre-melted under vacuum. The simultaneous evaporation of Rb and Te is continued until a peak of the quantum efficiency at $\lambda = 250$ nm is observed.

4.3. Results

Several Rb_2Te test photocathodes and finally two sealed 5-inch HPD tubes have been produced following the above process. The transparency characteristics of the UV extended borosilicate entrance windows permits to measure the quantum efficiency down to about 220 nm. The transparency of the windows has been measured before the processing in order to allow an extrapolation of the results for a HPD with quartz window. The ITO layer has been found to be essential for the cathode growth on the glass substrate. Two tests without ITO resulted in very poor and with time degrading quantum efficiency, while all cathodes on ITO coated substrates gave consistently high and stable values: Q.E. $\approx 15-18\%$ at $\lambda \leq 250$ nm (see figure 4). At 300 nm the efficiency falls below 1% and at 400 nm below 0.01% were measured. The peak Q.E. significantly exceeds values quoted by commercial phototube suppliers.

The impact of ITO on the growth and sensitivity of bialkali (K_2CsSb) cathodes has been studied in another series of evaporations. Our preliminary conclusion is that, contrary to Rb_2Te, the efficiency of the bialkali cathodes suffers from the presence of ITO.

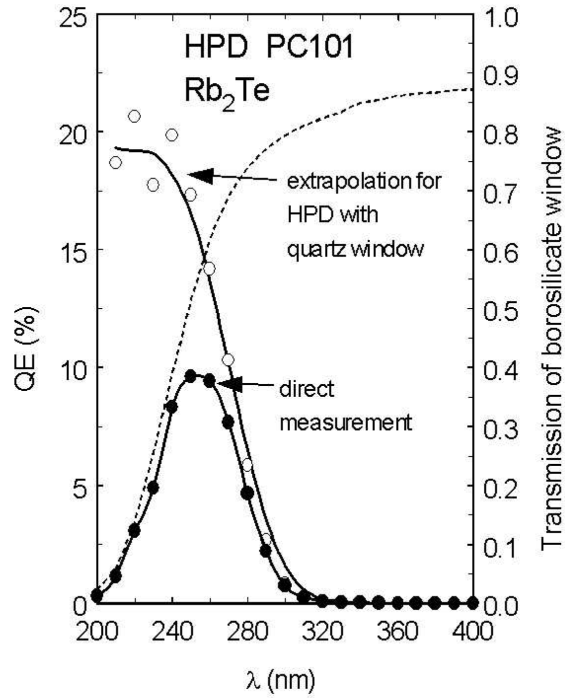

Figure 4. Quantum efficiency of a 5-inch HPD (PC101) with Rb_2Te photocathode. The knowledge of the transmission chracteristics of the borosilicate window (dashed line, related to the right axis) allows to extrapolate the measured Q.E. for an HPD with quartz entrance window.

Both sealed 5-inch HPD tubes with Rb_2Te cathodes have been tested in our laboratrory set-up with a collimated D_2 flash lamp. The operational parameters and electron optical behaviour of the detectors are identical to the standard bialkali Pad HPD discussed in the introduction. On a time scale of several months all tube characteristics have been found stable.

5. Status and outlook

We have developed the technological ingredients to fabricate 10-inch HPD tubes with high efficiency Rb_2Te photocathdes. The ITO underlayer represents a very interesting alternative to conventional thin metal layers. The processing plant, which is set up for 5-inch tubes, will now be modified for the production of 10-inch tubes. The mechanical components have been designed and fabricated. A first sealed 10-inch prototype HPD is planned for the end of 2002. It will be equipped with a silicon sensor and VA2 electronics of the 5-inch HPD and a bialkali photocathode compatible with the standard glass entrance window. Envelopes with quartz windows as well as a new silicon sensor with adapted geometry and VATA-GP3 readout is expected to become available in 2003.

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