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Production of 500 pixel hybrid photon detectors for the RICH counters of LHCb

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Abstract

The pixel Hybrid Photon Detector (HPD) has been developed to detect the light produced by the two Ring Imaging Cherenkov (RICH) detectors of the LHCb experiment. The device is a vacuum photon detector equipped with cross-focussing electron optics and a custom anode for photoelectron detection. The production of the 500 such devices that are required to cover the photon detection surface of the LHCb RICH detectors is ongoing. A pre-series of HPDs has been manufactured and their performance assessed in the laboratory. Successful operation has also been confirmed in a test beam. Accelerated ageing tests performed on one pre-series tube show no degradation of performance.

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Keywords: Hybrid photon detectors; Electron optics; Cherenkov detectors; Microelectronics

1. Introduction

The LHCb experiment [1,2] will make high precision studies of CP violation and other rare phenomena in B meson decays. Particle identification in the momentum range from a few to ~100 GeV/c is essential for this physics programme, and will be delivered by two Ring Imaging Cherenkov (RICH) detectors [3]. The pixel Hybrid Photon Detector (HPD) has been developed to detect the Cherenkov light produced in these detectors in the wavelength range from 200 to 600 nm with a granularity of $2.5\,\text{mm} \times 2.5\,\text{mm}$. The HPD is a vacuum photon detector equipped with cross-focussing electron optics and a custom anode for photoelectron detection. The anode consists of a finely segmented silicon pixel detector bump-bonded to a binary readout chip with a time resolution better than 25 ns to cope with the LHC bunch-crossing rate [4]. This flip-chip assembly is packaged into a custom ceramic carrier to form the tube anode, and is consequently fully encapsulated in the tube vacuum. This concept results in a high-efficiency device with excellent spatial resolution and a large active area. Over the last 5 years, three generations of prototypes have been fabricated and have been shown to have good performance in both laboratory and beam tests [5–7].

The production of 500 such devices to cover the 2.6 m^2 photon detection surface required by the LHCb RICH detectors has recently started. In addition to the basic photon detection requirements, the HPDs must comply with the overall integration and environmental constraints of LHCb. These result in tight mechanical tolerances for optimal HPD close packing. The photo-detectors will be subjected to the fringe magnetic flux density of the LHCb dipole magnet. Iron magnetic shields housing the overall HPD arrays have been designed to reduce this fringe flux density to values between 10 and 25 G. Since unshielded HPDs have been shown to operate efficiently up to 10 G, each HPD will be placed inside a secondary magnetic shield made of a high-permeability material.

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2. Production aspects

The tube development and manufacturing are carried out in close collaboration with industry. The fabrication is divided into two distinct phases: the anode fabrication, followed by the fabrication of the HPD tube itself.

2.1. Anode fabrication

The binary readout chips are fabricated using the CMOS 0.25 μm process technology [8]. They are delivered as 8″ wafers, 750 μm thick that undergo thorough electrical testing at a probe station to identify the Known Good Dies (KGD). The typical yield is around 55–60%. The silicon pixel sensors are fabricated on 6″ wafers, 300 μm thick [9]. The solder bump deposition [10] is performed at the wafer level. It uses a high-temperature solder specially developed and optimized for this application [11]. After wafer dicing, KGD readout chips and pixel detector chips undergo flip-chip assembly. The resulting bump-bonded structure is submitted to thorough electrical testing, similar to that used for KGD identification, and is exposed to a radioactive source to check the quality of the bump-bonding process. Typical yields are around 90% good assemblies with >99% good bump connections. In parallel, Pin Grid Array (PGA) ceramic carriers are fabricated using the High-Density Ceramic Module technology [12]. These carriers are subsequently brazed [13] at high temperature to a Kovar ring that forms the mechanical interface to the rest of the HPD tube body. This is followed by a gold-plating step required for the subsequent flip-chip packaging process. The packaging [14] involves a die attach step using silver glass, and a gold ball bonding step. The completed anode (see Fig. 1) undergoes a test programme similar to that of the flip-chip assembly.

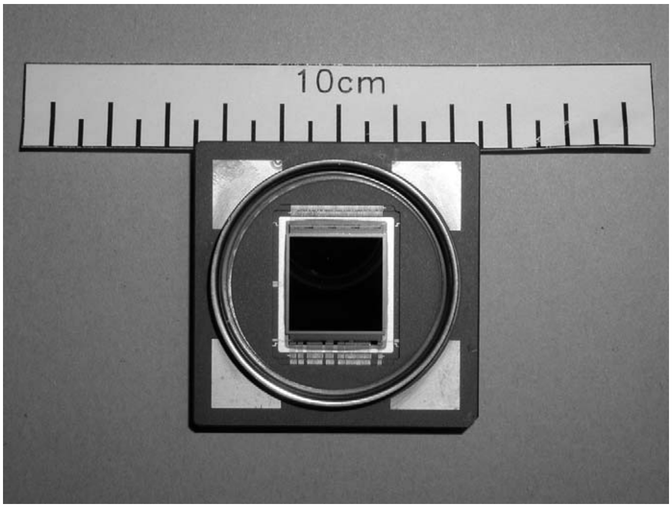

Fig. 1. Photograph of a tube anode, comprising the flip-chip assembly packaged into a PGA ceramic carrier.

2.2. Tube fabrication

The tube fabrication [13] involves tube body manufacturing and coupling to the anode, photo-cathode deposition and vacuum sealing process, tube cabling and potting. The completed tube (see Fig. 2) undergoes basic quality assurance at the factory. After shipment, thorough quality assurance is carried out by two "Photon Detector Test Facilities" within the LHCb–RICH group.

3. Summary of main results from the pre-series HPDs

3.1. Laboratory and beam tests

Nine pre-series tubes were fabricated during Autumn 2004. The requirements and their performance [15] are summarized in Table 1. The distribution of quantum efficiencies is shown in Fig. 3. All pre-series tubes performed very well. Six such tubes were installed in a prototype RICH 2 detector [16]. They were used to detect Cherenkov rings from 10 GeV/c negative electrons and pions traversing N_2 and C_4F_{10} gaseous radiators.

Fig. 2. Photograph of a pre-series tube.