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A Novel Optical Package for ATLAS Pixel Detector

K.K. Gan

Department of Physics, The Ohio State University, Columbus, OH 43210, U.S.A.

An optical package of novel design has been developed for the ATLAS pixel detector. The package contains two VCSELs and one PIN diode to transmit and receive optical signals. The design is based on a simple connector-type concept and is made of radiation-hard material. Several packages have been fabricated and show promising results.

1. Introduction

The ATLAS pixel detector[1] consists of three barrel layers and three forward and backward disks. The detector covers the pseudo-rapidity region $|\eta| < 2.5$ and provides at least three space point measurements. The signal from the digitalization electronics of the pixel detector is converted into an optical signal using a Vertical Cavity Surface Emitting Laser (VCSEL)[2] and is transmitted to the counting room via a fibre. The 40-MHz beam crossing clock, encoded with the command signal, from the counting room, is transmitted to a PIN diode[3] via a fibre. The VSCEL and PIN couple to the two fibres inside an optical package located in close proximity to the pixel detector. In this paper, we describe the performance of a more complicated package which contains two VSCELs and one PIN diode. The simpler version with no redundancy is adopted by the ATLAS pixel collaboration due to the severe space constraints around the pixel detector region.

2. Optical Package Design

The main technical challenge in the fabrication of the package is the tight alignment tolerance of the VCSEL with respect to the fibre:

- 50 μm in z (along the fibre)
- 25 μm in r (transverse to the fibre)

The requirements can be satisfied either by passive or active alignment. For the former, parts must be fabricated or placed with high precision (≤ 10 μm) so that total precision is still within the tolerance.

There are currently three designs for the optical package: Marconi, Ohio State University (OSU), and Academia Sinica (Taiwan). Both Marconi and OSU use passive alignment while Taiwan uses active alignment. The Marconi design consists of several pieces and uses aluminized mirrors to reflect the light by 45^0. The Taiwan design consists of three pieces and replaces the mirrors by cleaving the fibers at 45^0. Each fiber is actively aligned and glued permanently to the package. The package is of low cost but the permanent attachment of the fibers to the package presents a technical challenge to the assembly of the pixel detector.

The OSU design uses a connector concept: a cap with three holes for the fibres and a base with deposited wire bonding traces and pads for PIN and VCSEL placement. The design is shown in Fig. 1. The package is of low cost and the cap with the fibers attached can be mounted to the base near the end of the pixel detector assembly.

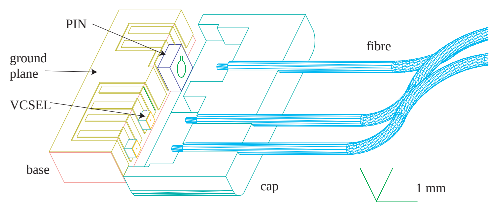

Fig. 1. A cut out view of the optical package showing the two VCSELs and one PIN diode mounted on gold pads which are connected to the gold traces.

In the OSU design, precise alignment of the fibres to the VCSELs is achieved by fabricating the bases and caps with high precision and by the accurate placement of the VCSELs and fibres relative to the base and cap, respectively. The precision dice placement is realized using a jig with precisely machined pockets for the base, VCSELs and PIN. The accurate placement of the fibres in the cap is achieved by precise machining of the holes in the injection mold used to fabricate the cap (see below).

3. Prototype Results

We have investigated several kinds of material for the fabrication of the package. The first material tested was aluminum silicate, a machinable ceramic. We then decided to switch to macor because of its smaller grain size, which was better in reproducing some of the fine features in the design. Unfortunately, the adhesion of the tiny VCSEL to the gold trace was not good because the gold surface was not smooth enough due to the roughness of the machined macor surface. We now use aluminia to fabricate the base because of its much smoother surface. To fabricate the bases, aluminia sheet is ground to the precise thickness of the bases and then cut into strips for deposition of three-dimensional traces.[4] Most of the deposited traces have good connectivity across the corner of the bases. Strips with a large number of traces of good connectivity were then precisely diced into individual bases.[5]

We have also attempted to fabricate the cap using the same materials, aluminum silicate and macor. However, it is difficult to consistently machine the cap to the desired tolerances. We now use Ultem (polyetherimide), a mold-injectable plastic with a radiation tolerance[6] of 10 GRad. Due to the high cost and long lead time in developing the mold injection technique for fabricating small parts with high precision, we decided to use “manual mold injection”. Here a small spring-loaded mold of 5 cm $\times$ 5 cm $\times$ 10 cm is used in a small oven as opposed to a standard mold of 30 cm $\times$ 30 cm $\times$ 30 cm placed inside an automatic mold injection machine of 1 m $\times$ 1 m $\times$ 2 m. The critical part in the mold fabrication is the precisely machined mold for the interior of the cap that goes over the base and the three precisely located holes for the placement of the three pins which produce the holes for the fibers. We have proven the principle of this precise micro-mold injection technique and can fabricate several quality caps per hour.

We have fabricated twelve optical packages. The coupled power of ten of the packages are above the specification of 300 μW minium power for an average current of 10 mA in the VCSEL. The caps are interchangeable, an important test of the feasibility of the connector-type design. The waveforms[7] in both VCSELs have fast rise time, $<$ 1ns. The PIN diode also has good responsivity, 0.5 A/W. The bit error rate (BER) meets the specification, $< 10^{-9}$ at 90% confidence level, for PIN current $>$ 60 μA. The cross talk between the PIN diode and the inner VCSEL can produce a data bit error and this can be measured by sending the signal from the outer VCSEL to the PIN diode while running the inner VCSEL with an asynchronous 40 MHz clock at an average current of 10 mA. There is no measured cross talk (BER $< 10^{-9}$ at 90% C.L.) between the inner VCSEL and the PIN diode for PIN current above $\sim$ 20 μA. The ground plane around the traces is critical in achieving this low cross talk.

4. Summary

In conclusion, we have demonstrated the principle of the connector-type optical package. The package can be fabricated at low cost and satisfies the minimum coupled power and low cross talk requirements.

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