Radiation Hard Optical Links for The ATLAS SCT and Pixel Detectors.

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Abstract

A full study of the optical readout package for the ATLAS SCT/Pixel detector data transmission is presented. Radiation hardness studies of VCSEL emitters, Epitaxial Silicon PIN diodes receivers and their associated chips have been carried out with fluences higher than 10^{15}n.cm^{-2} 1 MeV neutron equivalent and total ionising doses of 10 Mrad. The reliability was assessed by testing a large number of devices and accelerated ageing tests were also pursued over a period equivalent to more than the LHC operation time. Single Event Upset and magnetic field studies up to 6T have also been done on a new optical package design with positive results.

1 The Readout Architecture

The architecture and the overall performance of the optical readout to be used for reading out the ATLAS SCT/Pixel is described in [1, 2, 3]. For the SCT, a shematic view is represented in figure 1. Data will be readout by two fibres each transferring data at 40 Mbits/s. The Timing, Trigger and Control (TTC) data for each module will be distributed to the modules by optical fibre. Bi-phase Mark encoding will be used to encode the control data on top of the 40 MHZ bunch crossing clock. Similar architecture will be use for the Pixel detector but with a higher data rate of 80 Mbits/s.

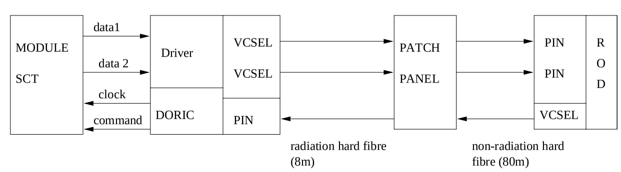

Figure 1: A schematic diagram of the ATLAS SCT links.

The links are based on radiation-hard VCSELs and PIN diodes. The radiation hardness of these components is discussed in the following sections. The VCSEL will be driven by a VCSEL Driver Chip (VDC) and the PIN diode output is processed by the Digital Optical Receiver Integrated Circuit (DORIC) chip. The chips have been designed in the AMS 0.8 μm BiCMOS process. This is not usually used as a radiation hard process but a radiation hard design has been obtained by:

- using bipolar npn transistors only;
- operating the transistors with relatively large currents such that the DC current gain β is large and less sensitive to radiation damage;
- using a design in which the circuits are very insensitive to changes in β.

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2 The opto-package

A radiation-hard, low mass, non-magnetic package containing two VCSELs and one PIN diode has been produced by Marconi. As seen on figure 2, the concept is based on a silicon baseplate on a ceramic tile where the PIN diode is mounted. The VCSELs are mounted on separate ceramic tile set on the silicon baseplate. An aluminised silicon mirror is used to turn the light from the vertical to the horizontal direction. The fibres are placed in v-grooves in a separate silicon lid which fits onto the silicon base. The use of a mirror gives some flexibility in the process of positioning the opto-components on the baseplate.

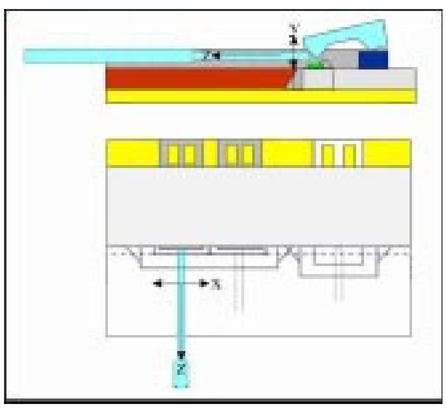

Figure 2: GEC Silicon Package for VCSEL/PIN.

The opto-package will be mounted on a flex rigid support which also contains the VDC and the DORIC chips. The support allows for electrical connection to the SCT module and to connect to the low mass aluminium tape carrying the DC voltage.

3 Radiation hardness of the Package components

The radiation hardness of the optical fibres have been already studied and their results presented in the previous workshop [4].

3.1 The DORIC/VDC chips

Twenty DORIC chips have been irradiated to a total ionised dose of 100 kGy with a Co^{60} source and a neutron beam to a total flux of 3×10^{14}n.cm^{-2}. No significant degradation was observed after irradiation. The chips were powered during the gamma irradiation. Nine VDC chips are under similar studies.

3.2 The MITEL VCSELs

Four VCSELs from MITEL[1] in ST packages have been irradiated up to 2.9×10^{15}n.cm^{-2}. The L-I curves before and after the irradiation are shown on figure 3. They were annealed during a short period of 3 weeks at the optimal 20 mA current. The low signal of one of them is due to a physical damage during the handling. A reasonable shift in the laser current threshold will not affect the performance of the VCSEL.

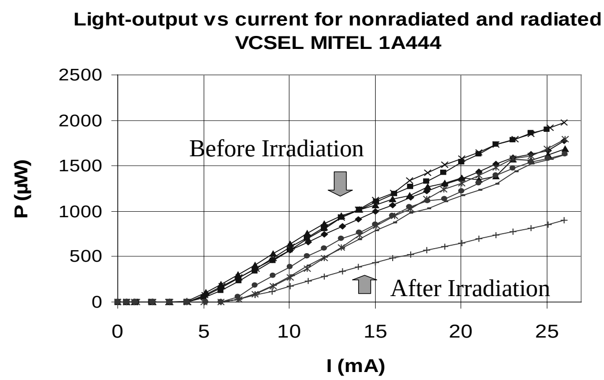

Figure 3: L-I curves before and after irradiation.

Important reliability plots from manufacturers exist on un-irradiated VCSELs . Reliability studies on irradiated devices have been done on a sample of 20 irradiated VCSELs to a fluence of 4×10^{14}n.cm^{-2}. Ageing tests have been performed at an elevated temperature of 43^{o}C. By considering an acceleration factor given by the Arrhenius law, and for an activation energy of 1 eV, an estimated accelerated period of 3768 ATLAS-years has been achieved. This result confirms the reliability of such an optical emitter even after irradiation.

3.3 The CENTRONIC epitaxial silicon PIN photodiodes

Ninety six epitaxial silicon PIN photodiodes [2], operating at the 850 nm wavelength of the VCSEL, have been irradiated with neutrons and protons during the last year. Previous study has shown that these photodiodes were sufficiently radiation hard [5]. Three different levels of irradiation have been carried out , some of them at the -8^{0}C SCT operational cold temperature, from 1.5×10^{14}n.cm^{2} to 1.05×10^{15} n.cm^{2} 1 MeV equivalent fluence. After a decrease of the responsivity at relative low fluence, there was no further degradation observed at higher levels as seen in figure 4. The final value of 0.3 A/W is adequate for

[1] MITEL VCSEL 1A444
[2] GEC-Marconi part no 520 /1/02603/001

the optical readout. For the highest integrated neutron dose, the dark current is 60 nA at room temperature, decreasing to a negligible value at the cold temperature of the Inner Detector.

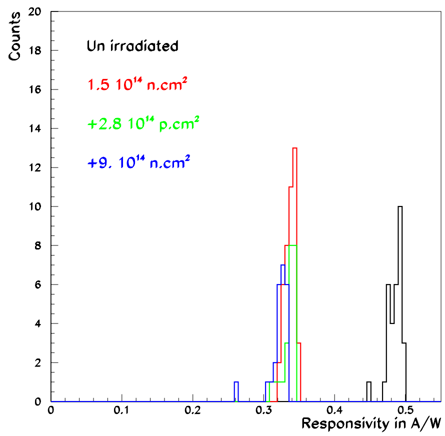

Figure 4: Distribution of the 96 PIN photodiodes responsivities at different irradiation level.

Figure 5 shows that the bias needed to obtain the full responsivity of the PIN diodes after an irradiation above 10^{15}n.cm^{-2} is about 8 V. The rise/fall time at 5V is less than 1 ns and does not change with different irradiation dose levels.

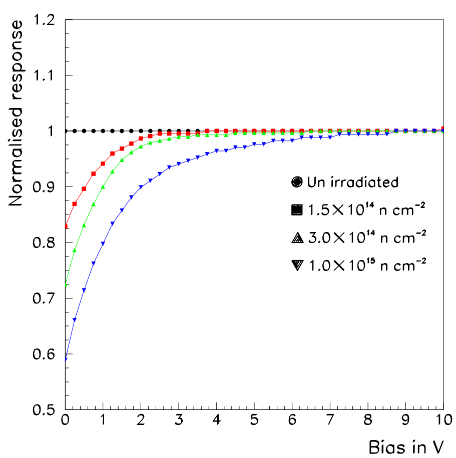

Figure 5: Normalised responsivities of the PIN photodiodes as a function of the bias at different neutron cumulative doses.

An accelerated aging test was performed on ninety six components by using an elevated temperature of 60^oC . The acceleration factor was calculated for an active energy of 0.6 eV as quoted in [6]. The estimation of a lower limit on the Mean Time To Failure after 3978h of ageing, with no failure recorded, is more than 2720 years at 90% Confidence Level. This means less than 8 failures among 2112 for the SCT barrel and less than 53 for the Forward, which has a higher temperature of 15^oC, for the 10 ATLAS-years.

4 Magnetic Field Study

Studies on the complete package itself placed in the equivalent 2T Inner Detector magnetic field have also been done . A superconducting magnet was used to create a magnetic field up to 6 T. Three different angles, between the package axis and the magnetic field steering, from 0 to 60^o have been tested. As seen in the figure 6, no degradation was observed.

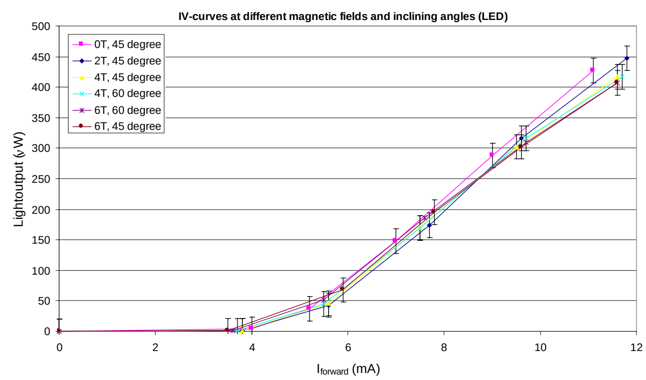

Figure 6: The package performance under different magnetic field value and positionning.

5 Single Event Upset

Single Event Upset (SEU) studies have been performed using an ionising source and neutron beams. By using a Sr^{90} source with β flux of 4.3×10^7 cm^{-2}s^{-1}, no increase of the Bit Error Rate (BER) was observed. One test with a 9 MeV neutron beam at the Birmingham cyclotron with a fluence of 2×10^6n.cm^{-2}s^{-1} caused no increase of the BER. With a 14.7 MeV neutron beam energy and a flux of 1.07×10^7 n.cm^{-2}s^{-1}, increase BER was observed as seen in the figure 7. The BER decreases as the optical power at the entrance of the package increases. We can deduce that the source of SEU is the PIN photodiode receiver which has the largest Si area. With the right optical power, an acceptable BER is obtained at the SCT level. But the problem need to be evaluated for the higher flux of 4.5×10^7 n.cm^{-2}s^{-1} expected in the Pixel detector. A test with pions beam have been scheduled for next year.

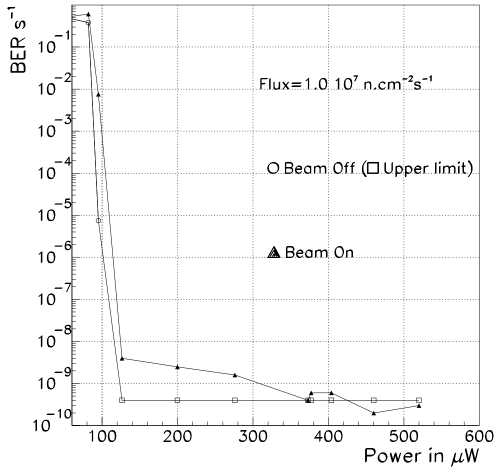

Figure 7: BER as a function of the power launched in the PIN photodiode.

6 Off-detector component

VCSELs and PIN arrays will be used in the off-detector electronics. A suitable candidat has been provided by MITEL[3] where the components are mounted in MT packages. A good uniformity of the VCSELs signal have been measured as shown on figure 8. The measurements of the PIN diode arrays show a responsivity greater than 0.5 A/W and rise and fall times less than 1 ns.

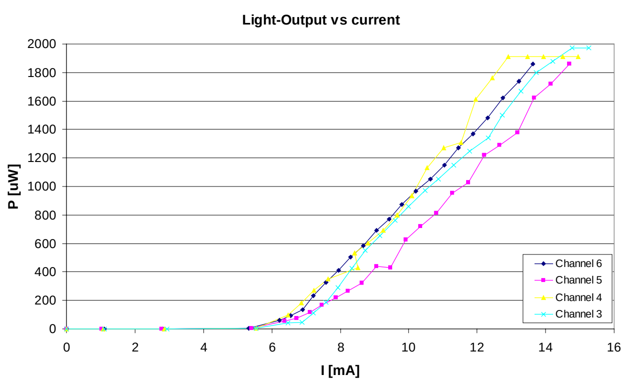

Figure 8: LI curves from 4 MITEL VCSELs array.

7 Conclusion

Radiation hardness tests of the individual components of the ATLAS SCT/Pixel opto-package have been performed, showing no major degradation for each of them. The global package is unaffected by the 2T magnetic field of the Inner Detector. Single Event Upsets were observed at high neutron flux and could be reduced to an acceptable level at the flux expected in the SCT. Sixty packages are in production. Once they are evaluated, they will be integrated in a complete system test of the SCT.

[3]MITEL 4 VCSEL array: 4D469, MITEL 4 PIN array: 4D468

8 Acknowledgment

We would like to thanks all the different technical staffs from all irradiation facilities: ISIS at Rutherford (UK), Ljubljana reactor (Slovenia), the National Physical Laboratory in London and the CERN PS accelerator (Switzerland).

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