RADIATION HARD OPTICAL LINKS FOR THE ATLAS SCT AND PIXEL DETECTORS

J. D. DOWELL, D. G. CHARLTON, R. J. HOMER, P. JOVANOVIC, I. R. KENYON, G. MAHOUT, H. R. SHAYLOR, J. A. WILSON

School of Physics and Astronomy, University of Birmingham, Birmingham, B15 2TT, UK
E-mail: jdd@hep.ph.bham.ac.uk

I. M. GREGOR, R. WASTIE, A. R. WEIDBERG

Physics Department, Oxford University, Keble Road, Oxford, OX1 3RH, UK

S. GALAGEDERA, M. C. MORRISSEY, J. TROSKA, D. J. WHITE

CLRC Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 OQX, UK

A. RUDGE

CERN, Geneva, Switzerland

M. L. CHU, S. C. LEE, P. K. TENG

Institute of Physics, Academia Sinica, Taipei, Taiwan 11529

A radiation hard optical readout system designed for the ATLAS Semiconductor Tracker (SCT) is described. Two independent versions of the front-end optical package housing two VCSEL emitters and an epitaxial Si PIN photodiode have been irradiated with neutron fluences over 10^{15} n cm^{-2}, the level encountered in the ATLAS pixel detector. Environmental tests have been performed down to -20 ^{o}C. Extensive radiation and lifetime tests have also been carried out on the opto-electronic components and the front-end VCSEL driver and timing/ control ASICs. Bit error rate, cross-talk and single event upset measurements using irradiated devices show that the system meets the performance specification.

1 Introduction

Optical links[1] will be used in the ATLAS Semiconductor Tracker (SCT) and pixel detector to transmit timing and control (TTC) information to the front-end electronics, and tracking data to the off-detector electronics some 90m away. The LHC beam crossing frequency is 40 MHz with approximately 20 collisions per crossing at the full luminosity of 10^{34} cm^{-2}s^{-1} producing a 1 MeV equivalent neutron fluence of 10^{15} n cm^{-2}(Si) and a total ionising dose of 500 kGy(Si) in the pixel detector over the nominal ten-year lifetime of the experiment. The corresponding figures for the SCT are 2×10^{14} n cm^{-2} and 100 kGy. For GaAs, the 1 MeV equivalent neutron fluences are six times higher. Radiation hard, low mass, non-magnetic packages have been developed to house the epitaxial Si PIN photodiode and two Vertical Cavity Surface Emitting Laser diodes (VCSELs) operating at 850 nm that are used to receive and transmit the data. The TTC link uses Bi-Phase Mark encoding to combine the 40 MHz clock with the control data on a single multimode fibre. SCT data links operate at 40 Mb/s and use NRZ coding of the binary readout data, with provision also to operate at 80 Mb/s for the pixel detector. Two data links are provided for each silicon strip detector module, one for each side. In the event of a link failure, the data can be rerouted through the other link. The control data may also be taken from a neighbouring module in the event of a TTC link failure. Several packaging schemes for the front end opto-electronic components have been studied and at present two alternative packages with similar characteristics have been successfully developed. Marconi (UK) use V-groove fibre mounting with a 45^o mirror to reflect the light into or from the opto-electronic components which are precision mounted. The Taiwan group use instead 45^o cleaving of the fibres which are glued into position after active alignment.

2 Radiation Hardness

Mitel VCSELs show good recovery after a short annealing period at 20 mA following irradiation with 2.9×10^{15} 1 Mev equivalent n cm^{-2}(GaAs), $\sim$ 1/2 pixel level. The total light output before irradiation is typically 1 mW at 10 mA. The main effect of the neutron irradiation is to shift the threshold current upwards by $\sim$2 mA. VCSELs from other manufacturers (Honeywell, Truelight) show similar behaviour. Enhanced ageing studies at 50^oC have given no failure, corresponding to a <0.2% failure rate (90% C.L.) over a 10 year running period in ATLAS. The epitaxial Si PIN photdiodes, made by Centronic, show a drop in responsivity of about 30% to 0.3 A/W after 10^{15} 1 MeV equivalent n cm^{-2}(Si). Ageing studies at 60^oC give similar results to the VCSELs. Pure silica core SIMM 50/60/125/250 fibre from Fujikura shows a total loss of <0.05 dB/m after 330 kGy ionising radiation.

The ASIC used to decode the TTC signals (DORIC) and the VCSEL driver chip use bipolar npn transistors in the AMS 0.8 micron BiCMOS technology. Samples have been exposed to 3×10^{14} n cm^{-2} and 500 kGy of gammas. All devices work correctly after irradiation. They are designed to be insensitive to changes in beta of the transistors, working with values as low as 10. Ageing studies at 100^oC show <0.3% failure (90% C.L.) over 10 years.

3 Environmental Tests

The optical packages will have to operate at temperatures as low as -15^oC. Irradiated VCSELs show an increase of 4 mA in laser threshold from room temperature to -18.3^o. Further work is needed to understand this. The irradiated PIN diode reponsivity falls at a rate of 0.25%/^{o}C with decreasing temperature which is an expected trend.

4 Cross-talk and Single Event Upset

Bit error rate and cross talk measurements have been carried out using packaged devices after irradiation. The performance is well within specification (BER $< 10^{-9}$) for an optical power of 200 μW into the photodiode. However, single event upset tests using pion beams between 300 and 465 MeV/c at PSI show that, at a flux of 3×10^7 cm^{-2}s^{-1} (pixel rate), up to 1 mW of optical power may be needed to meet the BER specification. While this is close to the limit, the lower fluxes expected in the SCT will allow more comfortable operation. The upsets are caused by particles interacting in the relatively large volume (15μm$\times550\mu$m^2) of the photodiode.

5 Conclusion

A successful optical readout scheme has been developed for the ATLAS SCT. The optical components and packaging are also expected to be sufficiently radiation hard for use in the pixel detector. Single event upsets due to particle interactions in the photodiode have been detected at rates which are acceptable for the SCT.

References

1. Further details may be found at http://atlas.web.cern.ch/Atlas/GROUPS/INNER_DETECTOR/sctnew/Electronics/links/