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VCSEL Reliability Studies and Development of Robust VCSEL Arrays

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Severe problems with VCSEL reliability have been observed in ATLAS operation. ATLAS has developed the use of Optical Spectrum Analysers as a sensitive indication of VCSEL damage. These studies and detailed microscopic investigations have shown that the observed VCSEL reliability issues have been caused by moderate levels of humidity combined with the use of non-hermetic packages. Long term damp heat tests of VCSEL arrays produced by AOC and ULM which have been optimised for humidity resistance will be presented. The ULM arrays were packaged in a very compact semi-hermetic package which could be interesting for future HEP experiments.

Summary 500 words

Radiation testing of Vertical Cavity Surface Emitting Lasers (VCSELs) to the fluences expected for an inner detector at the HL-LHC have shown excellent results. A comparison of similar results with EELs shows a clear advantage in the use of VCSELs. However ATLAS has suffered from very severe reliability problems with VCSELs and this paper will present a summary of the understanding that has emerged from these studies. While being very radiation tolerant VCSELs are sensitive to other environmental factors. VCSELs have a very low ESD threshold of around 400V so excellent ESD precautions are mandatory. VCSELs are also known to be sensitive to very high levels of humidity and the ATLAS investigations have shown that VCSEL lifetimes can be greatly reduced by operation in moderate humidity levels. This is not an issue for single channel VCSELs packaged in hermetic TO cans but is a major issue for array VCSELs as there is no suitable fully hermetic package available.

The first indication that VCSEL reliability in ATLAS was affected by moderate levels of humidity was the observed correlation between death rates and relative humidity (RH). This observation was surprising as the variation in RH was not large. One very sensitive technique for monitoring VCSEL degradation before death has been developed by ATLAS; this involves using an Optical Spectrum Analyser to measure the spectral width. Channels that were operated continuously but still alive were found to have significantly narrower spectral widths than channels on the same array which has not been operated.

A series of controlled experiments have been performed which have confirmed the humidity hypothesis. Firstly damp heat tests with 85% RH and a temperature of 85C have shown that the Truelight VCSELs used in ATLAS have very short lifetimes. Dry heat tests of the same type of arrays have shown excellent results as expected from the manufacturer's data.

Secondly long term controlled tests at different RH values have been performed with periodic OSA measurements of the spectral widths. Arrays operated in a dry Nitrogen atmosphere showed no significant changes over months of operation. However arrays operated in typical laboratory RH have shown significant spectral narrowing over the same time period. Detailed microscopic investigations of dead channels have been performed using Electroluminescence (EL), Electron Beam Induced Current (EBIC), Focussed Ion Beam (FIB) slicing and Scanning Transmission Electron Microscopy (STEM). The damage mechanisms discussed in the literature will be reviewed and compared with the results from ATLAS investigations.

Manufacturers have been developing more humidity tolerant VCSELs using alternating dielectric layers on top of the top DBR layer to prevent humidity penetrating the DBR. Results of long term damp heat tests will be presented for AOC arrays. Although a fully hermetic array package is not practical, a semi-hermetic package (iFlame) has been developed by Xloom. This compact array design would be an attractive option for some applications in particle physics experiments. Results of long term damp heat tests of ULM VCSELs in the iFlame package will be presented.

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