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Modelling radiation-effects and annealing in semiconductor lasers for use in future particle physics experiments

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Optical link components used in future particle physics experiments will typically be exposed to intense radiation fields during the lifetime of the experiment and the qualification of these components in terms of radiation tolerance is thus required. We have created a model that describes the degradation of the L-I characteristic of a semiconductor LASER undergoing irradiation with the annealing processes taken into account. This model can be used to predict the behaviour of a laser being irradiated with the different particle fluxes at different locations inside a particle physics experiment. The robustness of the model has been checked against the experimental data obtained during high-fluence (in excess of 10ˆ15 particles/cmˆ2) neutron and pion irradiation testing in 2009 and 2010.

Summary 500 words

Radiation tolerant, high-speed optoelectronic data-transmission links have been widely deployed in the read-out and control in today's large scale particle physics detectors, as exemplified by the experiments at the Large Hadron Collider (LHC). Their component optoelectronic devices, such as semiconductor lasers, operate in a very harsh radiation environment. New experiments or upgrades will impose even more stringent demands on these devices from the point of view of performance and radiation tolerance. In highly exposed areas, less margin may be available before irradiated lasers reach their end-of-life conditions, thus requiring more detailed modelling of the device performance degradation under various operational conditions. Rigorous qualification and understanding of these devices in terms of performance and radiation hardness is crucial for the proper operation of the readout and control systems during the lifetime of the future experiments.

The modelling of semiconductor laser behaviour during operation in radiation environment is not well established; hence, an expensive and time-consuming testing programme for devices in question is usually required, a trend which would increase with higher fluence constraints in the future. Alternatively, this testing effort can by significantly reduced by modelling radiation-effects and annealing in devices in question from low fluence data and by extrapolation to fluences required.

A rate-equation based model has been developed to describe semiconductor laser L-I characteristics during irradiation. This model is fitted to real laser characteristics measured during irradiation and a fluence-dependent set of fitting parameters is obtained. Using the model, laser characteristics can be extrapolated to both higher fluences as well as higher driving currents.

The radiation-induced damage observed in lasers is flux dependent since they anneal and can thus recover a significant part of the radiation-induced damage. To consider the annealing process, the annealing phase was carefully studied and an annealing model was devised based on Hill equations. The model considers the saturation of annealing which was indeed observed.

Due to the fact that laser L-I characteristics preserve their shape during annealing period, it is sufficient to flux-scale only one fitting parameter –typically the laser threshold. By combining the rate-equation model with the annealing model, one can predict device behaviour for different fluxes and total fluences, which allows the simulation of device degradation at various positions inside a real detector.

In order to verify the applicability of the combined laser model, the predicted operating characteristics of a semiconductor laser are compared to experimental data of 56 prototype lasers from 9 different manufacturers obtained during high-fluence neutron and pion irradiation campaigns at Université Catholique de Louvain (UCL), Belgium and at Paul Scherrer Institut (PSI), Switzerland in 2009 and 2010. Good agreement between the predicted and measured values was reached for different laser types.

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