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Modelling radiation-effects in semiconductor lasers for use in SLHC experiments

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Optical link components will typically be exposed to intense radiation fields during operation in the SLHC inner detectors and their qualification in terms of radiation tolerance is thus required. We have created a model that describes a semiconductor laser undergoing irradiation to enable the extrapolation to full lifetime total fluences from lower fluence radiation tests. This model uses a rate-equation approach with modified gain calculation that takes thermal rollover into account. The model is used to fit experimental data obtained during high-fluence (in excess of 10^15 n/cm^2) neutron irradiation testing in 2009 and its prediction capability is evaluated.

Summary

High-speed optical data transmission systems have been widely deployed in the readout and control of current particle physics detectors. These optoelectronic devices operate in a very harsh radiation environment and new experiments or upgrades will impose even more stringent demands on these systems. Their rigorous qualification in terms of performance and radiation hardness is crucial for the proper operation of the readout and control systems. The understanding of their performance during irradiation is essential in order to assure the proper operation during the whole lifetime of the experiment. Since the usual lifetime of current particle physics detectors is counted in tens of years, the device behaviour during irradiation has to be predicted.
The prediction of device behaviour during irradiation is not well established; hence an extensive testing programme for devices in question is usually required. The testing is mainly performed in irradiation facilities by an intense and well-characterised beam of particles or ions, which serve as proxy particles for the target environment. Such testing is rather expensive and time consuming. A complementary approach based on detailed modelling and prediction of semiconductor laser operating characteristics is presented. With such a model one could significantly reduce the time spent in irradiation facilities and predict the behaviour of semiconductor lasers from low-fluence data.
Single-mode steady-state operation rate-equations are often used to model semiconductor laser characteristics. They are also applicable to a multi-mode operation with a limited number of modes with relatively similar properties. The model describes the spontaneous- and stimulated-emission regions of laser operation and takes into account thermal rollover effects. In order to minimize the number of free parameters and to facilitate the numerical solving of the equations, these are normalized and new dimensionless quantities are introduced instead of real physical constant factors, which are unknown and differ of several tens of orders of magnitude.
In order to verify the applicability of the rate-equation model, the calculated operating characteristics of a semiconductor laser are confronted with experimental data obtained during high-fluence 20 MeV neutron irradiation campaign at Université Catholique de Louvain (UCL), Belgium in late summer 2009. This test aimed at evaluating the resistance of 19 prototype semiconductor lasers from six different manufacturers to fluences in excess of 10^15 n/cm^2.
The model parameters are obtained by fitting measured light-current (L-I) characteristics of a laser that underwent irradiation. The lasers were monitored in-situ during the irradiation in 15 minutes intervals thus a fluence-dependent set of model parameters can be calculated. Trends like laser threshold and quantum and slope efficiency are extracted and based on their behaviour device operation during irradiation can be predicted. Good agreement between the calculated and measured values was reached for different technology devices in both spontaneous and stimulated regions of operation.

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