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Radiation tolerance enhancement of silicon photonics for HEP applications

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Silicon photonics modulators are being investigated for use in optical links for High Energy Physics experiments. In order to withstand the harsh environment in experiments beyond the Large Hadron Collider at CERN, components will have to be resistant against extreme levels of radiation. We show that modulators, which lost their functionality after irradiation, can be fully recovered by applying a forward bias. Furthermore, it is presented that by applying a forward bias during irradiation, the irradiation-induced degradation can be compensated. The possibility of device recovery could lead to a tremendous increase of radiation resistance of the optical links.

Summary

Optical links have become vital components in the High Energy Physics Experiments (HEP) at CERN to transport data generated from the particle detectors and other control points along the Large Hadron Collider (LHC) in hostile radiation environments to the processing electronics. In order to withstand ever-higher radiation levels and to handle the increasing data volumes, alternatives to laser diode-based transmitters have to be investigated which can face these challenges.

In this work silicon photonics depletion type Mach-Zehnder Modulators (MZMs) are investigated and their applicability for use in optical links in future High Energy Physics experiments is discussed. Previous work has shown that silicon photonics modulators are relatively insensitive to neutron radiation, but show strong degradation with ionizing X-ray radiation. It was further presented, that with customized MZM designs the resistance against X-ray radiation can be improved. Recently, the influence of forward biasing on the radiation hardness was reported and a strong post-irradiation annealing effect was demonstrated.

Since then a deeper investigation of this injection enhanced annealing behavior after and during X-ray irradiation was carried out. We will show that a full recovery of the silicon photonics modulators is possible by applying a sufficiently high forward bias for a sufficient amount of time. Mach-Zehnder Modulators of different designs were irradiated up to a Total Ionizing Dose (TID) of 3 MGy while their static phase-shift was measured in situ. At this TID the devices did not show any functionality anymore. In other words, no static phase-shift was measured. After irradiation, the samples were annealed by applying a forward current of 10 mA for 24 hours and stored for another 24 hours with a reverse voltage of 3 V applied. After this annealing procedure the static phase shift reverted to its pre-irradiation value. Subsequently, the samples were re-irradiated under the same conditions and up to the same TID as during the first irradiation. We will demonstrate that the resistance to TID was the same in both irradiation runs, concluding that the device recovered fully after the performed forward bias annealing. Additionally, we will show measurement data indicating that by frequently applying a sufficiently high forward current during the irradiation the radiation effect leading to a degradation of the device performance can be compensated. It was presented that applying 2 mA for 1 minute results in a slight increase of radiation resistance. In further tests we applied 10 mA for 1 minute during an irradiation up to a TID of 3 MGy. In this case, no degradation during irradiation was observed in either of the investigated MZM designs.

Even though periods of forward biasing would add some complexity to the driving modulator circuit, the possibility of full device recovery by applying a forward bias in phases where the operation of the HEP experiments are paused, could lead to a tremendous increase of the effective radiation resistance or even eliminate the radiation sensitivity of the optical links.

Primary authors: KRAXNER, Andrea (CERN); DETRAZ, Stephane (CERN); OLANTERA, Lauri Juhani (CERN); SCARCELLA, Carmelo (CERN); SIGAUD, Christophe (CERN); SOOS, Csaba (CERN); Mr STILE, Carmine (CERN); TROSKA, Jan (CERN); VASEY, Francois (CERN)

Presenter: KRAXNER, Andrea (CERN)

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