Irradiation studies on InP-based Mach Zehnder modulator

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In this article, we discuss the results from the irradiation of InP-based Mach-Zehnder modulators (MZ) with a 24GeV/c proton beam at CERN up to various doses. The irradiated samples are characterized and compared against non-irradiated devices.

The modulators are investigated for use in the Large Hadron Collider at CERN where two high energetic proton beams collide to study particle physics. The smaller particles generated in these collisions are detected by huge particle detectors with tens of millions of readout channels. The particle detectors communicate to the control room on multiple Gbps links amounting to several Tbps for the whole detector. These data rates are growing as experiments progress to higher beam collision rates. Optical conversion of the electrical data is desired at the innermost parts of the detector, compared to the present scenario where it takes place after a few meters.

The detectors operate in a high radiation environment and particles passing through the circuits alter the properties of the circuits giving rise to performance issues. Optical data transmission by external modulation of a continuous wave laser is being explored as a possible solution.

Introduction

Particle Physics is going through exciting times after the discovery of the new boson in the Large Hadron Collider at CERN. The LHC collides two high energetic beams (protons or heavy ions) against each other and employ a wide range of detectors to detect particles that originate from these interactions. Particle detectors are made of various sensor elements and electronic circuits to read out the sensors. The data is read out on high speed serial links to a computer farm, located hundred meters away. The demand for data bandwidth is increasing as experiments progress to higher luminosities. Electronic sensor read out circuits need serial data rates of multiple Gbps per chip and several Tbps for the whole detector. Electrical read out of data using copper cables at data rates of 10 Gbps for a couple of meters of cable is already very challenging. Optical data transmission is a possible alternative, worth exploring.

The detector circuits have to operate in a high radiation environment [1]. Energetic particles that pass through the circuits cause damage to the crystal structure and trapping of charges at interfaces etc. giving rise to performance issues. The radiation levels are orders of magnitude lower already at a distance of a couple of meters. Presently, data is transmitted electrically for the first couple of meters and then electro-optic conversion is performed by directly modulating a laser diode. The photo-detectors are placed in the radiation-safe area, where also the computer farm resides, to read the optical data. With data rates going high, the electro-optical conversion is desired as close to the detector as possible. Current test results show that the performance of the lasers degrades significantly already at less severe radiation environments [2] and direct modulation of lasers is challenging in this extreme environment. Passive read out by external modulation of a continuous wave laser beam is an alternative solution worth exploring. The idea is to place such modulator devices in high radiation environments, with lasers and photo-detectors placed in the low radiation environment. For example, a Continuous Wave (CW) laser beam is injected in the optical fiber that arrives inside the particle detector area. The CW is modulated in an optical phase modulator circuit (MZM) by the digital read out chip. The modulated laser light is sent on a return optical fiber for data acquisition and processing. (Fig. 1)

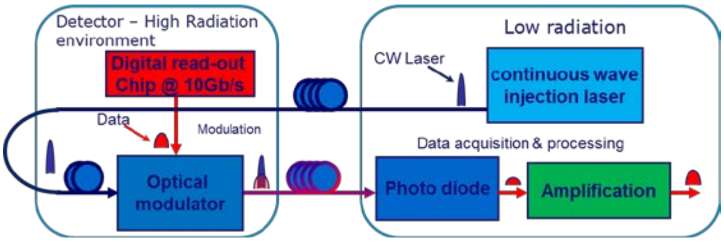

Fig. 1: Block diagram depicting external modulation and placement of optical devices in radiation zones.

However, relatively little is known about the performance of passive circuits under radiation and more research is needed on the subject. The steps taken in this direction include:

1. To investigate and understand the radiation hardness performance of existing modulator circuits.
2. To design Application Specific Photonic Integrated Circuits (ASPICs) with components like modulators, Arrayed Waveguide Gratings (AWG) etc. for irradiation tests.

Irradiation Tests

The first step was to irradiate already available modulator samples to investigate radiation hardness performance. Oclaro supplied a number of MZMs in bar form. Each bar consisted of 22 modulator structures, based on active-P Multiple Quantum Well (MQW) on N doped InP substrate technology. Four such bars were exposed to 10^{12}, 10^{13}, 10^{14} and 10^{15} protons/cm^2 fluence (1 MeV neutron$_{equivalent}$) respectively. These devices are compared in performance against a non-irradiated device. Moreover, circuits need to be biased under irradiation to mimic realistic operating conditions and therefore a PCB submount was designed for electrical and optical access of the sample [3]. The samples were irradiated in IRRAD-1 facility at CERN PS East Hall where samples can be exposed to 24 GeV/c proton beam (area ~ 2×2 cm^2). A shuttle, that can hold multiple samples, is used to move the samples in and out of the beam. Little is known about radiation hardness of InP based passive devices compared to bulk ($LiNbO_3$) devices [4]. Literature [5]-[8] suggests that MQW based devices perform better than bulk devices under irradiation.

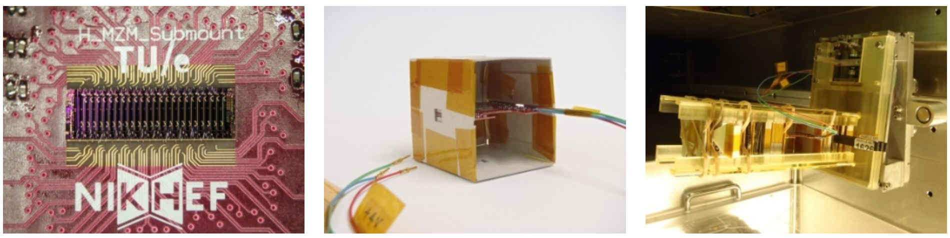

Fig. 2: (L to R) Modulator bar glued on the pedestal and bonded. Sub-mount PCB housed in a 5×5×5 cm^3 box for irradiation. Sub-mount PCB in the card-board box – loaded in the shuttle for irradiation.

Measurements

A simple schematic sketch of a MZ modulator is shown in Fig. 3. A 1550 nm laser with an output power of 6 dBm is coupled through a lensed fibre on the left facet of the chip. The light is collected with a lensed fibre on the right facet of the chip and coupled to an external power meter. The imbalance electrodes are used to correct any phase imbalance in the MZ interferometer and can be used for alignment of lensed fibre carrying the laser light. Once the laser is aligned, the lensed fibre on the right facet is aligned for maximum light output power under no bias condition. Typical measurements on the modulator include: measuring phase versus voltage characteristics and determining extinction ratio. The measurements on the non-irradiated sample are compared against the measurements on the 10^{15} protons/cm^2 irradiated sample. The non-irradiated sample had a V_π of 4 V and an extinction ratio of 18.5 dB. From the irradiated samples, the ones irradiated with 10^{12}, 10^{13} and 10^{14} protons/cm^2 fluence could not be evaluated because of improper handling after radiation, the experiments will be repeated. The modulation response of the sample irradiated with 10^{15} protons/cm^2 has almost disappeared, so this fluence is clearly too high.

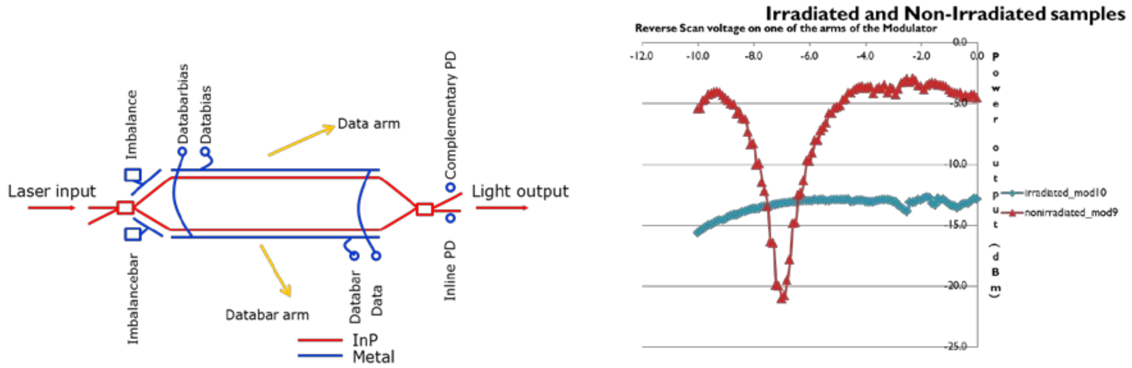

Fig. 3: (L) Simple schematic of the Oclaro MZ modulator. (R) Measurement results on one of the non-irradiated modulator in comparison with an irradiated sample.

Design of ASPIC

The ASPIC shown in Fig. 4 was designed in the COBRA generic integration platform [9], [10]. It includes passive structures like MZ modulators, Semiconductor Optical Amplifiers (SOAs) to act as modulators and AWGs for irradiation tests. The AWGs can (de-) multiplex 5 different wavelengths. 3 wavelengths are modulated using MZ interferometers and the remaining 2 are modulated using SOAs. The devices are expected soon, a submount will be designed and the samples will also be irradiated with protons. The total doses will remain as in the previous test cases.

Conclusions and Future

First irradiation tests were carried out at CERN. Due to the problems during transport of the sample, the experimental results are still limited. More detailed optical measurements on the 10^{15} protons/cm^2 irradiated modulators are being made at the time of writing this article. More research is needed to analyse the results of characterisation and understand the radiation hardness performance of the modulator. Based on the investigation, a modulator will be designed and tested for radiation hardness. The irradiation experiments will be repeated to see the influence of the 10^{12}, 10^{13} and 10^{14} protons/cm^2 fluence doses.

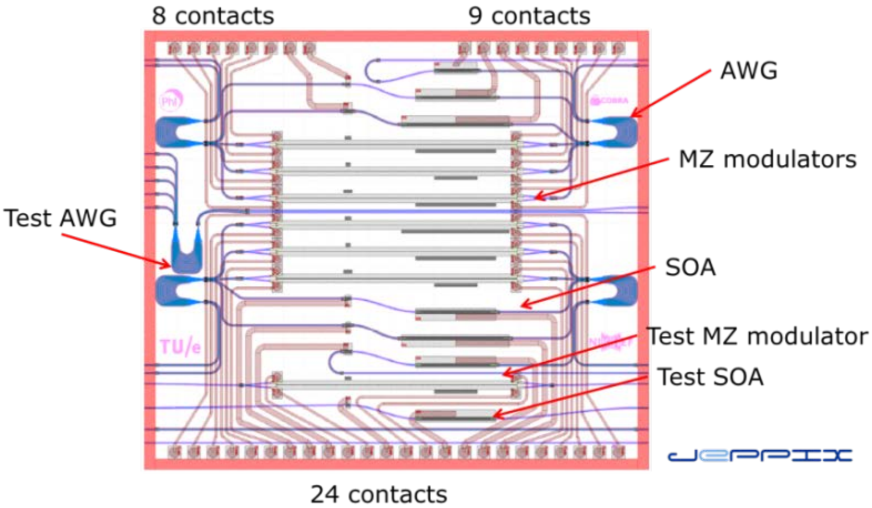

Fig. 4: ASPIC designed in the TU/e COBRA generic integration platform.

Acknowledgements

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