Irradiation tests on InP based Mach Zehnder modulator

Citation for published version (APA):
Gajanana, D., Beuzekom, van, M. G., Smit, M. K., & Leijtens, X. J. M. (2013). Irradiation tests on InP based Mach Zehnder modulator. *Journal of Instrumentation*, *8*(2), C02025-1/7. Article C02025. https://doi.org/10.1088/1748-0221/8/02/C02025

DOI:
10.1088/1748-0221/8/02/C02025

Document status and date:
Published: 01/01/2013

Document Version:
Accepted manuscript including changes made at the peer-review stage

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 16. Nov. 2023

Irradiation tests on InP based Mach Zehnder modulator

2013 JINST 8 C02025

(http://iopscience.iop.org/1748-0221/8/02/C02025)

PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB

RECEIVED: *December 20, 2012*
ACCEPTED: *December 27, 2012*
PUBLISHED: *February 12, 2013*

TOPICAL WORKSHOP ON ELECTRONICS FOR PARTICLE PHYSICS 2012,
17–21 SEPTEMBER 2012,
OXFORD, U.K.

Irradiation tests on InP based Mach Zehnder modulator

D. Gajanana,[a,b,1] **M. van Beuzekom,**[a] **M. Smit**[b] **and X. Leijtens**[b]

[a] *Nikhef,*
Science Park 105, 1098 XG, Amsterdam, The Netherlands
[b] *Eindhoven University of Technology,*
Den Dolech 2, 5612 AZ, Eindhoven, The Netherlands

E-mail: deepakg@nikhef.nl

ABSTRACT: Particle detectors in High Energy Physics experiments contain various types of mixed-signal integrated circuits and demand data rates of multiple Gigabits per second per chip and several Terabits per second for the whole detector. Optical transmission by external modulation of a continuous wave laser is a possible solution to solve the problem of high data rates. The detectors have to operate in a high radiation environment and particles passing through the circuits alter the properties of the circuits giving rise to performance issues. In this paper, we investigate the radiation hardness performance of Indium Phosphide (InP) based Mach-Zehnder modulators (MZM). The modulator circuit has been irradiated with a 24 GeV/c proton beam at CERN up to various fluences. The irradiated samples have been characterized and compared against measurements of non-irradiated devices. Also, a design of an optical integrated circuit using the Generic Integration philosophy is presented.

KEYWORDS: Optical detector readout concepts; Radiation-hard electronics; Electronic detector readout concepts (solid-state); Front-end electronics for detector readout

---

[1] Corresponding author.

doi:10.1088/1748-0221/8/02/C02025

Contents

1 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 highly 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. 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]. For example, at a few mm from the beam, we can quantify the dose to be: several 10^{15} particles / cm^2 (1 MeV neutron equivalent), and a total ionizing dose of several hundred MRad (or several MGy) [2]. Energetic particles that pass through the circuits cause damage to the crystal structure and cause trapping of charges at interfaces etc. giving rise to performance issues. Presently, data is transmitted electrically for the first couple of meters and then electro-optic conversion is performed by directly modulating a laser diode. At this distance, the radiation levels are already orders of magnitude lower. The photo-detectors are placed in the radiation-safe area, where also the computer farm resides. With data rates going high, the electro-optical conversion is desired as close to the interaction point as possible. Current test results show that the performance of the lasers degrades significantly already at less severe radiation environments [3] and direct modulation of lasers is challenging in this extreme environment. Data readout by external modulation (using passive elements) 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

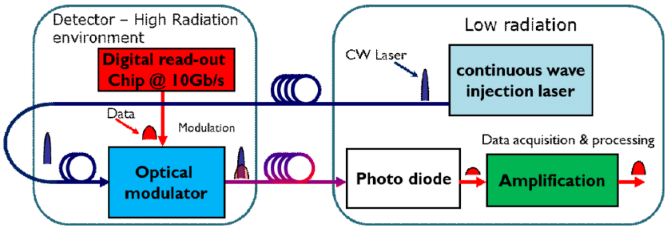

Figure 1. Block diagram depicting external modulation and placement of optical devices in radiation zones.

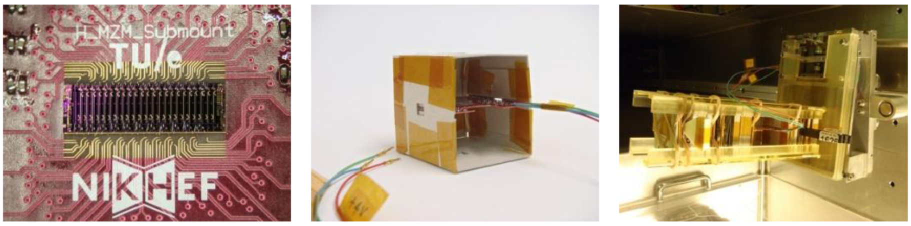

Figure 2. (Left to Right) Modulator bar glued on the pedestal and bonded. Sub-mount PCB housed in a 5×5×5 cm^3 box for irradiation. Sub-mount PCB in the card-board box — loaded in the shuttle for irradiation.

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 (figure 1).

However, relatively little is known about the performance of modulator 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.

2 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 a 24 GeV/c proton beam with intensities of 10^{12}, 10^{13} and 10^{14} and 10^{15} protons/cm^2, respectively. These devices are compared in performance to a non-irradiated device. Circuits were biased under irradiation to mimic realistic operating conditions. The samples were irradiated in the IRRAD-1 facility at the CERN PS East Hall where samples can be exposed to a 24 GeV/c proton beam (area $\sim$ 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 (LiNbO3) devices [4]. Literature suggests that MQW based devices perform better than bulk devices under irradiation [5–8].

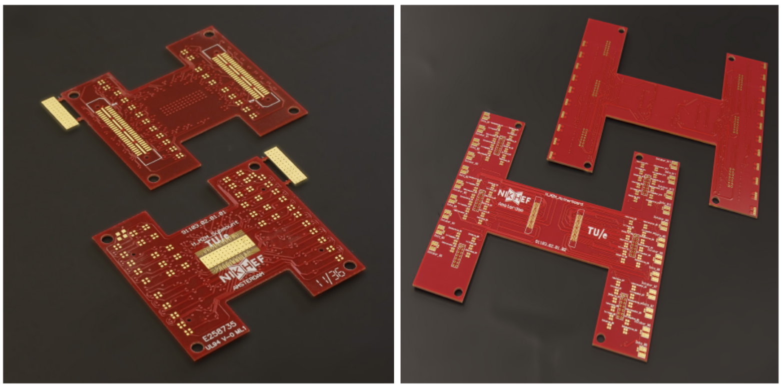

Figure 3. (L) Unassembled Sub-mount with break-away pedestal. (R) Unassembled Mother-board to house RF connections and also the sub-mount.

2013 JINST 8 C02025

2.1 Design of submount

The shuttle used for irradiation can hold samples of size 5×5 cm^2 only. Materials might get radioactive when exposed to irradiation, so, it is preferred to minimize the amount of material. Hence, a very small and thin PCB sub-mount is required [9] (figure 2). Since the coupling of a fiber to the waveguide on the device demands some clearance, a pedestal was first glued on the PCB using conductive glue. The modulator bar was then glued on the pedestal. Gold wires of 17 microns were then used to connect to the bond-pads on the PCB (figure 3). The dimensions of the sub-mount are 4.8×4.2 cm^2 and it is 0.77 mm thick. In order to minimize the amount of metal, care was taken to use copper only where necessary. The traces are impedance matched and differential in nature. High speed mated 52-pin SAMTEC connectors were used to connect the sub-mount board to the mother-board. The mother board is 18×15 cm^2 in dimensions and 1.6 mm thick. The mother-board houses all the RF connections (figure 3). The traces carrying the RF signals were impedance matched and routed differentially. The dielectrics of PCBs are made of normal FR4 material. Due to space constraints, only 11 out of 22 modulators in each bar have been bonded. The cardboard box housing the sub-mount PCB with mounted MZMs is shown in figure 2 ready to be irradiated. Finally, the whole set-up is loaded in the shuttle as shown in figure 2.

2.2 Measurements and results

A simple schematic sketch of a MZ modulator is shown in figure 4. 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. Once the laser is aligned, the lensed fibre on the right facet is aligned for maximum light output power under no bias condition. This requires precision XYZ fibre alignment stages. Typical measurements on the modulator include: measuring phase versus voltage characteristics and determining extinction ratio. The voltage required to bring a phase change of π, which gives maximum extinction, is called V_π (the Half wave voltage). Applying a reverse voltage on one of the arms of the MZM can bring phase change and in turn amplitude modulation (constructive and destructive interference) at the output. Extinction ratio

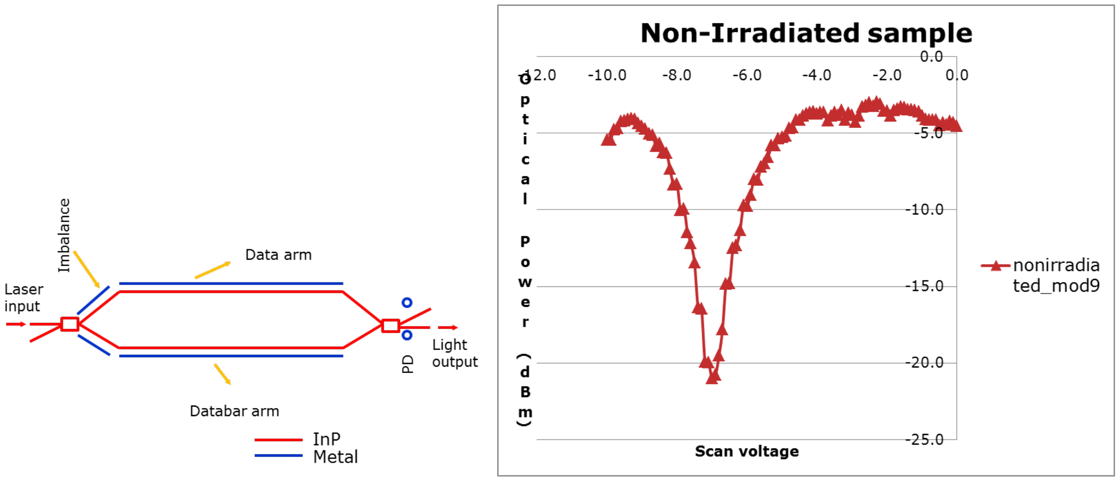

Figure 4. (L) Simple schematic of the Oclaro MZ modulator. (R) Measurement results on one of the non-irradiated modulator in comparison with an irradiated sample.

is the ratio of the optical powers corresponding to constructive (equivalent to a digital ‘1’) and destructive interference (equivalent to a digital ‘0’) of light at the end of the modulator. In the case of InP MZM, a reverse voltage on one of the arms of the MZM brings the phase change. The other arm of the modulator is held at ground potential. 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 irradiation to these fluences will be repeated. The modulation response of the sample irradiated with 10^{15} protons/cm^2 has almost disappeared as shown in figure 5, so this fluence is clearly too high.

3 Design of ASPIC using generic integration platform

Steady increase of demand for integrating more functionality in photonic chips is pushing photonic integration. Photonic integration is following the generic integration philosophy, wherein an ASPIC is designed from a library of standard building blocks. This is similar to the microelectronics industry, where it is a reliable and successful formula. More design automation tools are being developed for photonic integration. Libraries consisting of simple building blocks, from different technology platforms, are also being researched. Multi-project wafer runs are getting popular in InP based photonics. This significantly lowers the cost and the accessibility for ASPICs. The ASPIC shown in figure 6 was designed in the COBRA Research Institute of TU Eindhoven using the generic integration platform [10, 11]. 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. MZMs modulate the 3 wavelengths 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 with similar fluences as in the previous test case.

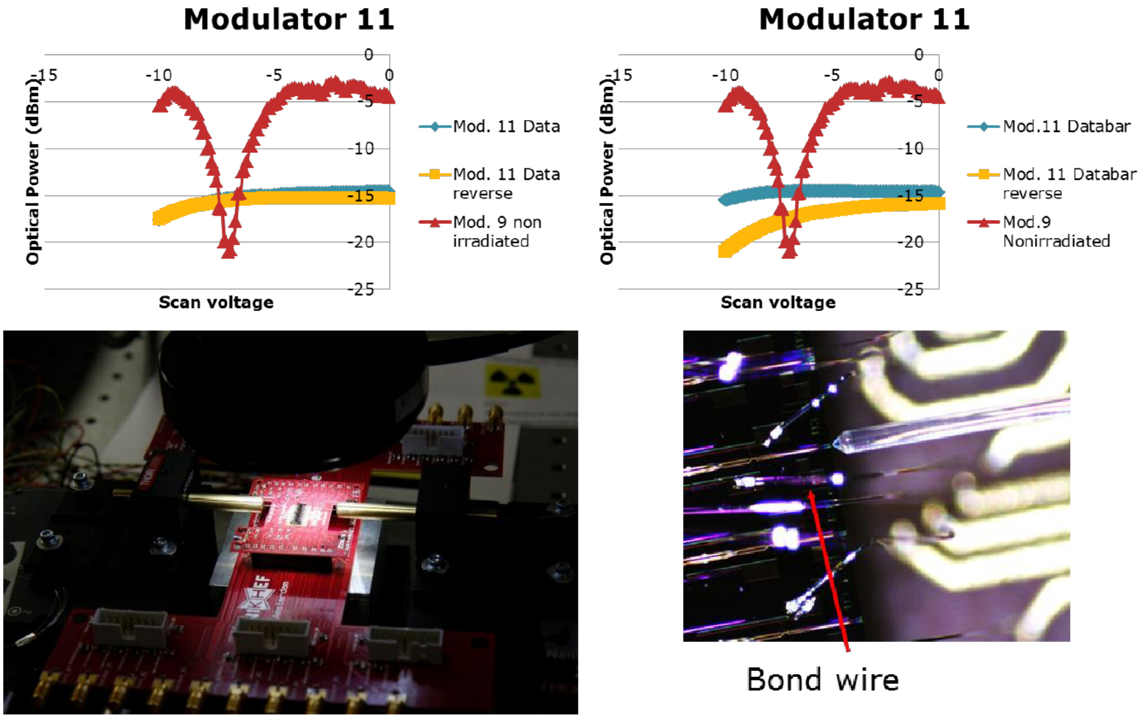

Figure 5. (Top Left) Irradiated modulator with data arm scanned; (Top Right) databar arm scanned; all graphs have non-irradiated sample measurement in red for comparison; reverse means that the laser was coupled on the output facet and light collected at the input facet. (Bottom Left) shows measurement setup with submount and alignment stages. (Bottom Right) A lensed fiber aligned in between the bond wires, on one of the facets of the modulator.

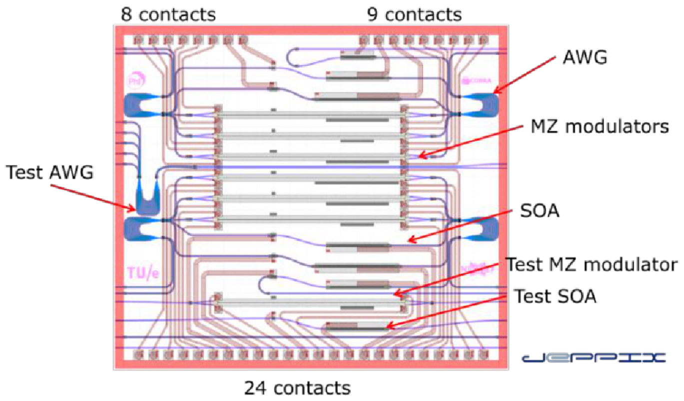

Figure 6. ASPIC designed in the TU/e COBRA generic integration platform.

4 Discussion

First irradiation tests on the Oclaro MZMs were carried out at CERN. Due to the problems during transport of the sample, the experimental results are limited. Modulation response is almost absent for the 10^{15} protons/cm^2 irradiated sample. 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

2013 JINST 8 C02025

is needed to analyse the results of the 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 fluences.

Acknowledgments

This work is part of the research program of the “Stichting voor Fundamenteel Onderzoek der Materie (FOM)”, which is financially supported by the “Nederlandse organisatie voor Wetenschappelijke Onderzoek (NWO)”.

2013 JINST 8 C02025

References

[1] F. Faccio, *COTS for the LHC radiation environment: the rules of the game*, in proceedings of *LHC Electronics Workshop*, 2000.

[2] C. Claeys and E. Simoen, *Radiation effects in Advanced Semiconductor Materials and Devices*, Springer, Germany (2002).

[3] P. Le Metayer et al., *Proton damage effects on GaAs/GaAlAs vertical cavity surface emitting lasers*, *J. Appl. Phys.* **94** (2003) 7757.

[4] C. D’hose et al., *Electrical and Optical Response of a Mach-Zehnder Electrooptical Modulator to Pulsed Irradiation*, *IEEE Trans. Nuc. Sci.* **45** (1998) 1524.

[5] R. Leon et al., *Effects of Proton Irradiation on Luminescence Emission and Carrier Dynamics of Self- Assembled III-V Quantum Dots*, *IEEE Trans. Nuc. Sci.* **49** (2002) 2844.

[6] F. Guffarth et al., *Radiation hardness of InGaAs/GaAs quantum dots*, *Appl. Phys. Lett.* **82** (2003) 1941.

[7] M. Boutillier et al., *First Evaluation of Proton Irradiation Effects on InAs/InP Quantum Dash Laser Diodes Emitting at 1.55* μ*m*, *IEEE Trans. Nuc. Sci.* **55** (2008) 2243.

[8] S. F. Tang et al., *Investigations for InAs/GaAs multilayered quantum-dot structure treated by high energy proton irradiation*, *J. Thin Solid Films* **518** (2010) 7425.

[9] D. Gajanana, M.G. van Beuzekom, M.K. Smit and X.J.M. Leijtens, *Test of InP- based Mach Zehnder modulator for radiation hardness*, in proceedings of the *2011 Annual Symposium of the IEEE Photonics Benelux Chapter* (2011) 285.

[10] M. Smit et al., *Generic foundry model for InP-based photonics*, *IET Optoel.* **5** (2011) 187.

[11] M. Smit et al., *A Generic Foundry Model for InP-based Photonic ICs*, OFC, Los Angeles (2012).