WDM Modulator Circuit for High Energy Physics Applications

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Particle detectors in High Energy Physics experiments provide huge amounts of data which needs to be transported to the data center. Fiber-optic links provide a high-capacity low-mass solution. However, the performance of semiconductor lasers used in such links is shown to degrade by the amount of radiation that is generated when particles with high energy collide. We investigate a wavelength-division multiplexing (WDM) scheme in which only the semiconductor modulators are in the high radiation environment, and test the modulators for radiation hardness. The InP-based WDM modulator circuits are designed for fabrication on generic integration platforms. The samples will be irradiated with a 23 MeV proton beam at Karlsruhe Institute of Technology (KIT) up to various doses. Here we discuss the system concept and preliminary measurements of non-irradiated samples that will later be compared with the irradiated samples.

Introduction

The large hadron collider (LHC) at CERN in Geneva collides two highly energetic particle beams against each other 40 million times per second, producing billions of interactions. The subatomic particles that are created in such interactions are detected by so called particle detectors. Particle detectors are made of sensors elements and electronic chips are attached to the sensors to read out the data. Particle detectors produce enormous amounts of data and are read out on high speed links to a computer farm, located hundred meters away. As experiments progress to higher luminosities, future detectors will be designed to read all data to the computer farm, unlike the present selective readout. Each read out chip needs serial data rates of multiple Gbps making it several Tbps for the whole detector. Presently, the data rate is low enough to be transmitted electrically for the first couple of meters and then perform electro-optic conversion by direct modulation of a laser. 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. With higher data rates, the electro-optic conversion is preferred as close to the detector as possible.

Particle beams colliding against each other produce high amounts of radiation close to the interaction point. The detector circuits have to withstand high radiation levels [1]. High energy subatomic particles created in the collisions fly through the circuits, causing damage to the crystal structure and giving rise to trapping of charges at interfaces etc. These phenomena affect the performance of the circuits. Direct modulation of lasers in such a harsh environment is challenging as literature suggest that the lasers degrade significantly already at less severe radiation environments [2]. Modulation of a continuous wave laser using external modulators is another interesting option. However, relatively little is known about the performance of such modulators under radiation and more research is needed on the subject. Consider the following configuration: The laser is placed in a low radiation environment and the Continuous

Wave (CW) laser beam is brought inside the particle detector area on an optical fiber. This CW is then modulated by the read out chip using an optical modulator circuit. The modulated light is sent back to the data acquisition and processing part at the computer farm on a return optical fiber (Fig. 1).

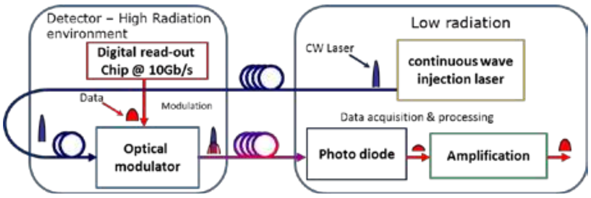

Fig. 1: Block diagram depicting external modulation and placement of optical devices in radiation zones.

The steps taken in the direction of indirect modulation technique include:

- To investigate and understand how existing modulators behave in the radiation environment.
- To design Wavelength Division Multiplexed (WDM) modulators for irradiation tests.

Design of ASPIC and sub-mount

The Application Specific Photonic Integrated Circuit (ASPIC) shown in Fig. 2 was designed in the COBRA generic integration platform [3]. It includes two WDM modulator circuits with a possibility of pre-amplification or post-amplification. In addition, there are a number of test structures to test the individual components. The circuits are built using standard building blocks like modulators, Semiconductor Optical Amplifiers (SOAs) and Arrayed Waveguide Gratings (AWG). Phase modulator sections of ~2 mm length are designed in Mach-Zehnder (MZ) interferometer configuration. Alternatively, small SOA sections can be used as modulators. Larger SOA sections provide optical gain. The AWGs have 2 inputs and 5 outputs, with a channel spacing of 400 GHz and Free Spectral Range (FSR) of 2400 GHz. A SOA is included in one of the inputs of the AWG giving the circuit the capability of pre or post amplification of signals. The 3 wavelengths are modulated using MZ interferometers and the remaining 2 are modulated using the smaller SOAs. The building blocks are also separately placed as test structures.

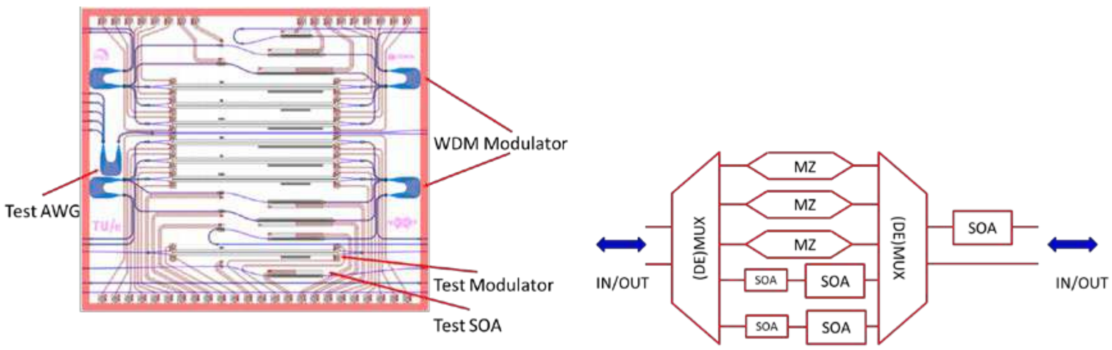

Fig. 2: (L) ASPIC designed in the TU/e COBRA generic integration platform. (R) Circuit schematic.

Little is known about radiation hardness of InP based passive devices compared to $LiNbO_3$ devices [4]. Literature [5]-[8] suggests that Multiple Quantum Well (MQW) based devices perform better than bulk devices under irradiation. All passive circuits in the COBRA platform are bulk devices and the active circuits are devices with multiple quantum wells. The modulators supplied by Oclaro in bar form consist of 22 MZ modulators per bar and are based on multiple quantum wells. Four samples from COBRA and four modulator bars from Oclaro will be 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 for different exposure levels and between technologies. During irradiation, the circuits need to be electrically biased to imitate actual operating conditions. Therefore a PCB sub-mount was designed for electrical and optical access to the sample as shown in Fig.3.

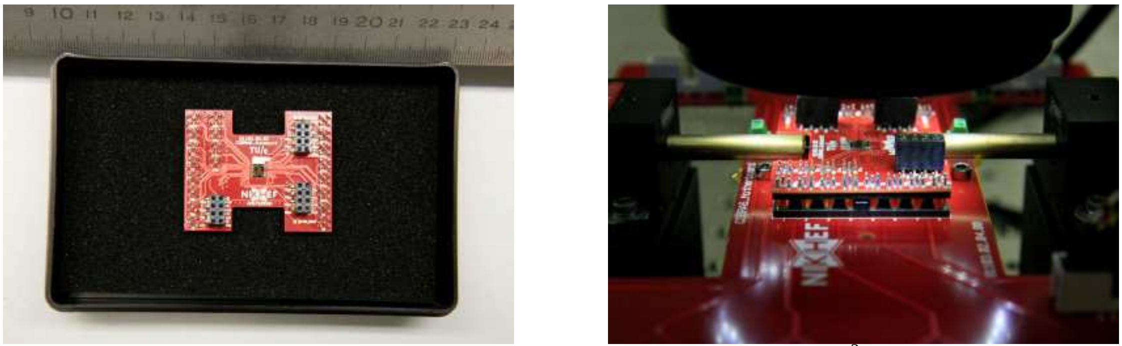

Fig. 3: (L to R) ASPIC glued and bonded on the sub-mount measuring 5×5 cm^2. Sub-mount mounted on the motherboard for measurements.

Measurement results for non-irradiated samples

All measurement results reported here are on the non-irradiated test structures in the COBRA circuit. A simple schematic sketch of a MZ modulator is shown in Fig. 4. Light from a 1550 nm laser is coupled through a fiber-based polarization controller to a lensed fiber on the left facet of the chip. After transmission through the chip, the light is collected with a second lensed fiber on the right facet of the chip and coupled to an external power meter. Typical measurements on the modulator included: phase versus voltage characteristics and determining the extinction ratio. The non-irradiated sample had a V_π of 6.5 V and an extinction ratio of 14 dB as shown in Fig. 4. The SOA was tested using a current source and recording the light output power by an optical power meter. The light output power and the Amplified Spontaneous Emission (ASE) spectrum measurements are in agreement with expected values. Further, light from a tunable laser source with an output power of 0.7 dBm at 1550 nm was injected into an SOA and the output spectrum was recorded. The peak output power is +4 dBm. From this we estimate a SOA gain around 13.4 dB, as the SOA has compensated the coupling loss (2× 4.5 dB) and waveguide propagation loss (1.1 dB). The AWG response was measured using an Erbium-Doped Fiber Amplifier (EDFA) source with a broad optical spectrum. The output spectrum was recorded using an Optical Spectrum Analyser (OSA). Measurements of the AWG show a channel spacing of 400 GHz, FSR of 2400 GHz and a crosstalk of 16 dB.

Conclusions and Future

The individual building blocks of the WDM modulator circuit have been characterized and show proper functionality. Detailed optical measurements on the ASPIC are being carried out now. Irradiation tests of the WDM circuits and the Oclaro modulators [9] in the 23 MeV proton beam at KIT are planned. The irradiated samples will be measured and the performance will be compared with non-irradiated samples. Thorough investigation is needed to analyse the results of characterisation and understand the radiation hardness performance of the modulator.

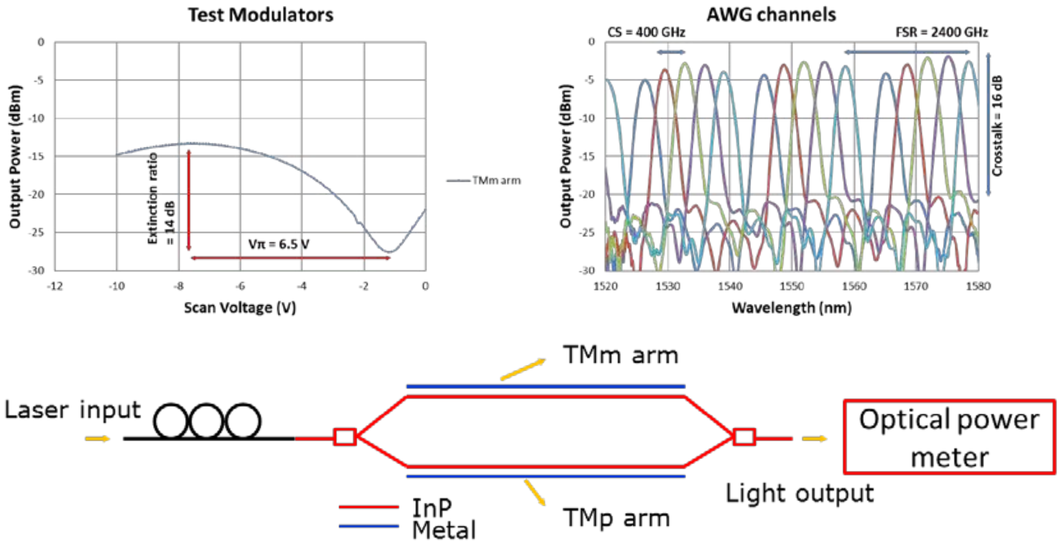

Fig. 4: (Clockwise) Measurements on the non-irradiated test MZ modulator; Measurements on the AWG; Schematic of the MZ measurements.

Acknowledgements

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