Integrated optical serializer designed and fabricated in a generic InP-based technology

S. Stopiński[1,2], M. Malinowski[2], R. Piramidowicz[2], M. K. Smit[1], X. J. M. Leijtens[1]
1) COBRA Research Institute, Technische Universiteit Eindhoven, Eindhoven, the Netherlands,
2) Institute of Microelectronics and Optoelectronics of Warsaw University of Technology, Warsaw, Poland
S.Stopinski@tue.nl

***Abstract*—This work presents design and characterization results of an optical pulse serializer, realized as an Application Specific Photonic Integrated Circuit (ASPIC) in a novel, generic InP-based technology and fabricated in a multi-project wafer run. The measurement results show high-speed (32 Gbit/s) output signal as a result of optical time domain multiplexing of parallel input signals. The on-off modulation of independent data channels is provided by means of electro-optical amplitude modulators with extinction ratio better than 20 dB.**

Keywords- photonic integrated circuit, indium phosphide (InP), generic integration technology, serialization, OTDM, data read-out

I. Introduction

Generic photonic integration technology will cause a breakthrough in the field of design, fabrication and application of photonic integrated circuits (PICs). During the last years a major research effort has been conducted in order to develop and establish generic integration technology platforms both for Si and InP-based PICs [1].

The EU NMP EuroPIC project, a collaboration of European key players in InP-based photonics, aims to establish a standard production chain based on the generic technology approach [2]. One of the objectives is to prove that the same process can be used to fabricate photonic devices for various fields of application and covering a wide range of functionalities. In order to achieve this, ten pilot application specific photonic integrated circuits (ASPICs) have been designed in a novel way and fabricated in multi-project wafer runs [3-5].

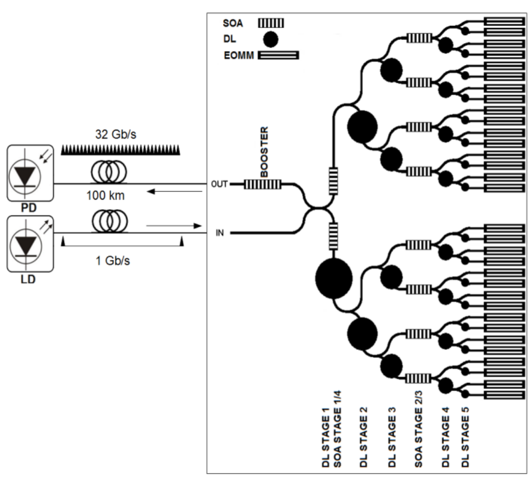

Figure 1. Schematic of the read-out system

II. System specifications and ASPIC design

One of the pilot applications of the EuroPIC project is a read-out unit for the KM3NeT project [6]. KM3NeT (an acronym for Cubic Kilometer Size Neutrino Telescope) is a European project aiming to develop a large volume neutrino detector, consisting of thousands of photomultipliers deployed at the bottom of the Mediterranean Sea. The basic module of the telescope is a glass sphere with 31 photomultipliers assembled inside. A 3D array of such spheres will form the detector. The read-out system has to transmit the digitized output data of the photomultipliers to the central analysis station. The required sampling frequency is 1 GHz, the BER coefficient 10^{-9}, and the total power consumption inside a single module should be kept below 7W.

The schematic of the proposed read-out system is shown in Fig. 1. It makes use of a fiber link between the central station and an application specific photonic integrated circuit (ASPIC) mounted inside the glass sphere. The operation principle is based on time-domain multiplexing of optical signals by means of optical delay lines [7]. The input signal, a 1 GHz optical pulse-train with very narrow pulses is distributed among 32 waveguides by five stages of 3dB MMI (multi-mode interference) power splitters, after which the 32 different signals are modulated by a reflective Michelson Interferometer array and coupled through the five stages back to the input port. The pulses are on-off modulated. In the five-stage network a number of delay lines has been included as indicated by the black circles in Fig. 1. The delay lines have been designed such that after being coupled back to the input port each pulse has got a delay such that the 32 pulses are serialized, what results in a 32 Gb/s optical signal. The SOAs (semiconductor optical amplifiers) are used to compensate the losses introduced by the circuit components.

As a proof-of-concept an 8:1 serializer has been designed using the Oclaro Ltd. (UK) foundry platform. Fig. 2 shows the mask layout of the photonic circuit with dimensions 2x6 mm^2. The circuit is built with using three basic structures – deeply-etched waveguides, phase modulator sections (utilizing

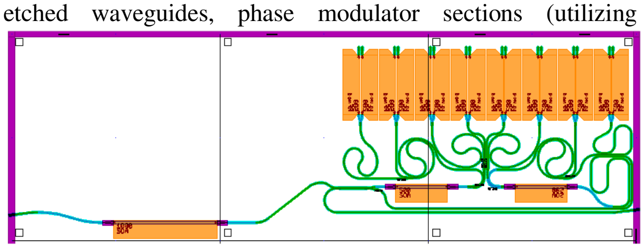

Figure 2. Mask layout of the 8:1 integrated optical serializer

quantum-confined Stark effect for enhanced electro-optic effect) and shallowly-etched SOAs. By combining the abovementioned building blocks more complex components can be formed, such as spiral delay lines, 1x2 and 2x2 MMI power splitters/couplers and MMI reflectors. Coupling between deeply- and shallowly etched structures is provided by low-loss transition elements. The whole circuit operates in a reflecting regime, so that the total area required is two times smaller as compared to a transmission configuration.

Michelson modulators are built by using a 1x2 MMI power splitter at the input, phase modulator sections and MMI reflectors. Biasing of one of the phase modulator sections with a proper voltage introduces a phase shift, which results in destructive interference at the output of the modulator. For this type of modulator the measured driving voltage is $V_\pi = 3$ V and the extinction ratio exceeds 20 dB [8].

III. MEASUREMENT RESULTS

The chip has been fabricated, together with other EuroPIC ASPICs, in a multi-project wafer run at Oclaro Ltd in the UK. The characterization took place at the Optical Measurement Laboratory of the COBRA Research Institute.

Fig. 3 shows the time-domain response of the 8:1 serializer circuit. It has been measured by launching a pulse laser signal ($\lambda_c = 1550$ nm, 150 ps time duration of a pulse, 80 MHz repetition rate) into the chip and measuring the output signal with a digital communication analyzer (DCA). During the measurement all three SOAs have been biased so that all of the channels are activated. As a result, 8 serialized pulses are observed at the output of the chip. The measured delay between adjacent channels, 32-33 ps (accurate determination is limited by the broadening of the pulses due to the 30 GHz bandwidth of the DCA) is slightly larger than the design value of 31.25 ps.

The SOA gain has been optimized by tuning the injection current so that the pulses of the first and fifth channels have the same power. However, the power of the pulses depends as well on the transmission of the Michelson modulators, so that the determination of the propagation losses in the delay lines is not possible. There is a slight asymmetry in the transmission characteristics of the modulators [8]. The asymmetry is most likely the effect of unwanted excitation of higher order waveguide modes, which results in an asymmetric power splitting by the MMI power splitter.

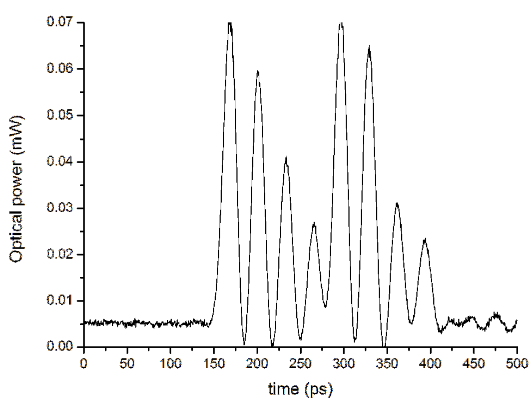

Figure 3. Pulse response of the 8:1 serializer circuit

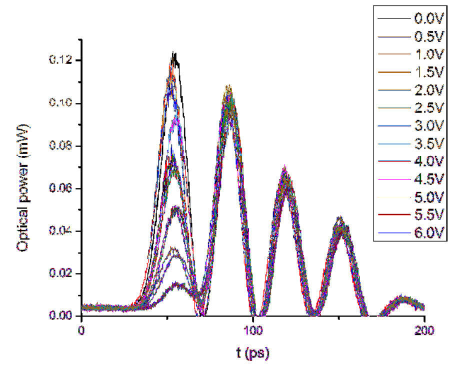

Figure 4. Independent modulation of the first channel

To observe the performance of the circuit when one of the channels is modulated, light from the pulse laser has been launched to the circuit and one of the modulator arms has been driven. Fig. 4 shows the result, when only the booster and one of the inline amplifiers are activated and the second inline amplifier is off. The measurement has been performed for a reverse bias voltage applied to the modulators ranging from 0 V up to 6 V with a 0.5 V step. The figure presents the output signal when the first channel is modulated. The results prove that it is possible to modulate one of the channels while not affecting the others. The extinction of the pulses is not complete, due to the broad wavelength spectrum of the input femtosecond laser signal. The value of the phase shift in the electro-optical modulators is wavelength dependent so it is different for each wavelength component. This results in non-complete destructive interference at the output of the modulator.

IV. SUMMARY AND CONCLUSIONS

An 8:1 integrated optical serializer has been designed and fabricated in a generic InP-based technology. The device works as intended and time domain multiplexing of the optical signals has been observed. Possibility of modulation of independent data channels has been shown as well. The circuit makes use of modulators with good optical properties, i.e. extinction ratio exceeding 20 dB and low driving voltage (3 V). First characterization results demonstrate the potential of the novel generic way of production.

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