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Photonic integrated transceivers for data read-out systems

S. Stopinski1,2, M. Malinowski1, R. Piramidowicz1, D. Gajanana2,3, M. J. van der Hoek3, M. K. Smit2, X. J. M. Leijtens3

1 Institute of Microelectronics and Optoelectronics, Warsaw University of Technology, Koszykowa 75, 00-662 Warsaw, Poland; S.Stopinski@imio.pw.edu.pl
2 COBRA Research Institute, Eindhoven University of Technology, 5600 MB Eindhoven, the Netherlands
3 Nikhef, Science Park 105, 1098 XG Amsterdam, the Netherlands

Abstract: In this work design and characterization results of integrated optical transceivers are presented. The devices were realized as photonic integrated circuits in a generic InP-based technology. The application is a data read-out unit for a sensor network. The circuits utilize PIN photodiodes for detection of a slow speed signal and amplitude modulators, either in a Michelson or a Mach-Zehnder interferometer configuration, for data encoding. Modulation bandwidth of 16.1 GHz was measured, eye-diagrams with 11.6 dB dynamic extinction ratio were recorded and transmission of a 10 Gb/s signal over 25 km of SMF fiber with BER below 10^{-10} was achieved.

Introduction

In a distributed sensor network, the read-out system is responsible for collecting all signals generated by a large number of sensors. The system we consider here has a star topology and comprises microelectronic and optoelectronic devices located next to the sensors, and is connected with optical fibers to a central station (CS). The upstream signal, towards the CS, provides information about the monitored physical parameters, while the downstream from the CS may be used for sending a control signal to the sensor units. Figure 1 presents a scheme of an optical link between the central station and a single sensor, where the downstream is a 1.25 Gb/s digital signal, modulated with low extinction ratio (ER = 0.4 dB). At the sensor unit a fraction of the input power is tapped and the downstream signal is detected. The remaining signal is used as a carrier for modulation with high extinction ratio in order to generate the upstream signal. It is assumed that the read-out from the sensor as well as driving the modulators is performed by electronic circuitry deployed at the sensor unit.

![Fig. 1. Optical fiber link between the central station (CS) and a single sensor (left) transceiver circuit schemes in transmitting (a) and reflecting (b) configurations (right)](image)

This concept, based on discrete photonic components, has been proposed and investigated by the Dutch institute for subatomic physics (Nikhef) for the data read-out system of the KM3NeT neutrino telescope experiment. It utilized a 5%-95% fiber-optic power coupler, a PIN photodiode and a reflective electro-absorption modulator. In this work we demonstrate photonic integrated circuits that combine all of the functionality in a single semiconductor chip. We utilized an InP-based generic integration technology platform. It supports building blocks such as passive waveguides, electro-optic phase modulators exploiting the quantum confined Stark effect, PIN photodiodes and semiconductor optical amplifiers.

Chip design

Figure 1 presents the block diagrams of the designed circuits. Two possible arrangements are presented. Both of them utilize a power tap, which is either a symmetric 50%-50% 1x2 MMI power splitter or a 15%-85% 2x2 MMI power coupler, and a PIN photodiode for monitoring the downstream signal. The data from the sensor is encoded onto the carrier using amplitude modulators in either
transmissive Mach-Zehnder (MZM) or reflective Michelson (MM) configuration, constructed from MMI couplers and phase modulators. Additionally, the transmitting circuits utilize a semiconductor optical amplifier in order to boost the power of the output signal. Figure 2 presents the mask layout of the transmitting circuits with two additional test circuits and a picture of a fabricated device mounted on a ceramic block for RF characterization. The chip dimensions are 6x2 mm².

Characterization results

For the RF measurements the chips were mounted on ceramic submounts and the circuit components were wire-bonded to the gold DC pads and RF ground-signal-ground (G-S-G) coplanar transmission lines. The RF-response of the modulators was measured with a 67 GHz lightwave component analyzer (LCA, Agilent N4373C) by injecting CW laser light at 1550 nm and analyzing the modulated signal by the LCA. Figure 3 presents the characteristics of the S₂₁ magnitude, normalized at 0 GHz, for the Mach-Zehnder and Michelson type modulators. The measured 3 dB bandwidth is 11.5 GHz and 16.1 GHz, respectively.

The measured static extinction ratio of the Mach-Zehnder modulators is 18 dB at λ = 1550 nm and the driving voltage Vₚ = -3.9 V. For the Michelson arrangement the ER is 25 dB and Vₚ = -3.0 V. Dynamic measurements were performed with the injected CW carrier at λ = 1550 nm and a pseudo random bit sequence generator which was driving the modulators. The recorded eye-diagrams for the back-to-back configuration are presented in Figure 3 for both types of modulators. In both cases the eye is wide open with the dynamic extinction ratio 11.6 dB and 11.2 dB, respectively. For the Mach-Zehnder circuits transmission of the modulated signal for back-to-back and over 25 km of SMF fiber was achieved with a bit error rate smaller than 10⁻¹⁰ (measured with Anritsu MP1764C error detector).

Conclusions

The integrated optical transceivers were designed and fabricated in a standardized generic InP technology. Their overall performance is good in terms of dynamic extinction ratio higher than 10 dB and available RF bandwidth up to 16 GHz.

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