A multi-wavelength photonic integrated transceiver for free space optical communication systems

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In this work we propose a multi-wavelength transceiver dedicated to applications in free space optical communication systems. The device is realized as an application specific photonic integrated circuit, designed and manufactured in a generic technology. The transmitter uses an array of lasers as light sources. Digital signals are generated either by direct modulation of the lasers or external modulation of the carriers by Mach-Zehnder modulators. All the signals are multiplexed into a single output by a six-channel arrayed waveguide grating. The receiver uses an AWG for WDM signal demultiplexing and an array of PIN photodiodes for detecting the incoming signals.

Introduction

Free space optical communication is a technique, which may provide efficient point-to-point wireless communication in all applications, where the physical connection is impossible or just impractical due to high costs, technical limitations etc. The good examples are aerial and space applications, as well as high-speed links between points in highly urbanized area (e.g. between two skyscrapers in a city center) [1,2]. The basic operating principles, apart from the transmitting medium, are similar as for the fiber-optic systems. So is the spectral range of operation - the wavelengths from so called IIIrd telecommunication window may be effectively used as they are not absorbed by the atmosphere and considered as eye-safe, which is an additional advantage. Therefore – free space communication systems can benefit directly from solutions developed for fiber-optic links. Among these, one of the most attractive and innovative approaches seems to be the photonic generic integration technology based on InP platform, significantly developed over the past few years [3]. The most significant advantages of photonic integrated devices are their compact size and weight, energetic efficiency and confirmed potential for low-cost production and assembly in medium and large scale.
In this work we propose a multi-wavelength transceiver dedicated to free-space communication systems, which was designed as an application specific photonic integrated circuit (ASPIC) and fabricated in a multi-project wafer (MPW) run using the generic foundry approach [4].

Chip design

Figure 1. presents the schemes of the transceiver circuits. The transmitter part uses an array of lasers (DFB or DBR) as light sources. Digital signals are generated either by direct modulation of the lasers or external modulation of the CW carriers by interferometric Mach-Zehnder amplitude modulators that use carrier injection phase shifters. All of the signals are multiplexed into a single output by a 6-channel arrayed waveguide grating (AWG). The channel spacing of the AWG is set to $\Delta\lambda$ = 1.6 nm, the

central wavelength λ_c = 1550 nm and the free spectral range FSR = 9.6 nm. The nominal wavelengths of the lasers are set to comply with the AWG passbands.
The receiver part uses another AWG, designed to have the same spectral performance as in the transmitter part, for WDM signal demultiplexing and an array of PIN photodiodes to detect the digital signals.

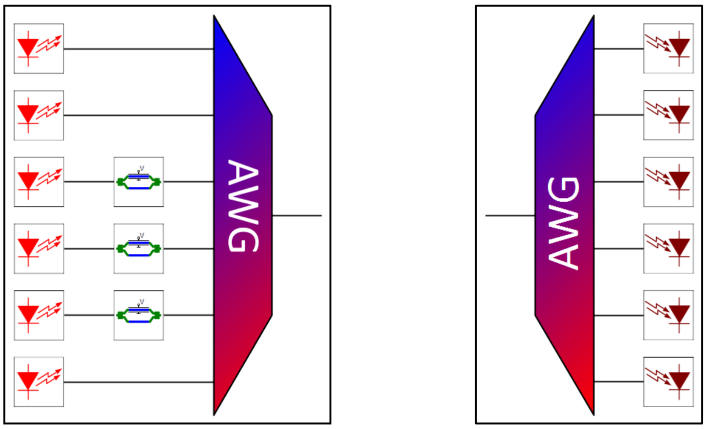

Figure 1. Circuit schemes of the transmitter (left) and the receiver (right) of the multi-channel transceiver for free space communication systems.

Figure 2. presents the designed mask layout of the photonic chip. It comprises two independent optical circuits, the transmitter and the receiver, positioned in a 4 mm × 6 mm chip cell. The circuit design uses available foundry building blocks such as DBR and DFB lasers, carrier injection phase modulators, 1×2 multi-mode interference (MMI) couplers, DBR gratings, PIN photodiodes, deeply and shallowly etched passive waveguides and spot size converters. The metal tracks are used to connect lasers, phase modulators and PIN diodes to DC and RF electrical ports.
The AWG of the transmitter part has a slightly different layout, since shallow waveguides are used for connecting the arrayed waveguides to the free propagation region, which results in lower insertion loss. However, due to the larger size of such a multiplexer, it was impossible to fit the same layout for the receiver in the 4 mm × 6 mm cell.
The ASPIC was designed in compliance with a newly developed generic packaging template. The electrical tracks are used to connect PIN diodes, phase modulators and lasers to DC and RF ports, positions of which are defined by the template. Several DC pads are placed on the chip cell regardless of the packaging regime and are connected to structures designed for testing purposes. Optical interface is provided on one side of the chip by means of two angled spot-size converters.

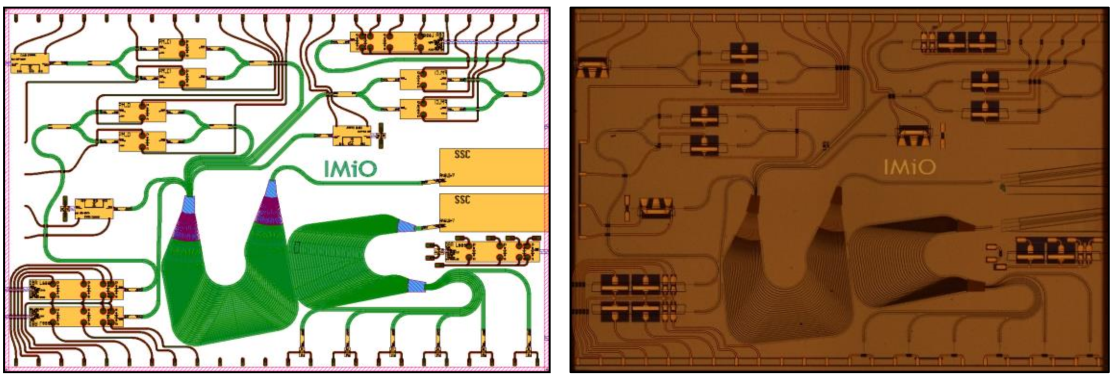

Figure 2. The mask layout and a microscope photograph of the multichannel transceiver.

Characterization

Schemes of the setups used for characterization of the developed ASPIC are depicted in Figure 3. The tested chip was mounted on a copper block that was thermally stabilized at 20°C. A cleaved SMF fiber was used for coupling the optical signal in and out of the chip. DC current sources were used to drive the laser components – amplifiers, Bragg gratings, phases shifters and heaters, while source meters were used for biasing the photodiodes and recording the photocurrent. An optical spectrum analyzer or a power meter was used to record the output signal generated by the lasers. For characterization of the receiver a CW signal from a tunable laser operating around λ_c = 1550 nm was used. Experiment with a 10 Gb/s digital signal required additionally a PRBS generator connected to a DFB lasers through a bias-tee and an RF electrical probe in G-S-G configuration. The output signal was then monitored on a high-speed sampling oscilloscope.

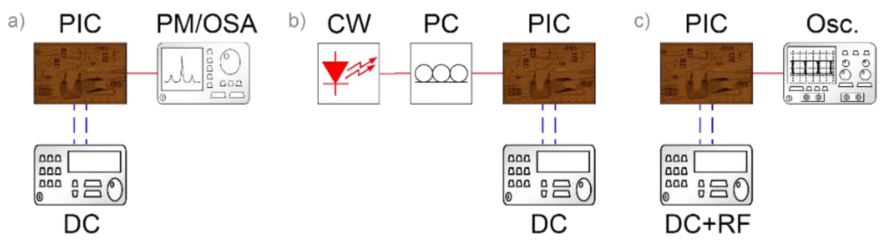

Figure 3. Schemes of the setups used for characterization of the transmitter (a) and receiver (b) part of the circuit; the setup used for an experiment with a 10 Gb/s digital signal (c)

Figure 4. presents measured characteristics of the optical power versus laser driving current, measured for on-chip test structures of the DBR and DFB lasers. The threshold current was measured to be 20 mA and 10 mA for the DBR and the DFB lasers, respectively. The maximal output power (at 100 mA) is approximately 3 dB higher for the DBR laser and reaches 0 dBm. For both lasers the measured side mode suppression ratio is better than 40 dB. The DBR laser can be tuned by $\Delta\lambda_1$ = 2 nm towards shorter wavelengths while injecting current into the rear DBR grating. Tuning of the DFB lasers is provided by a heater, which allows tuning of the output wavelength by up to $\Delta\lambda_2$ = 5 nm towards longer wavelengths.

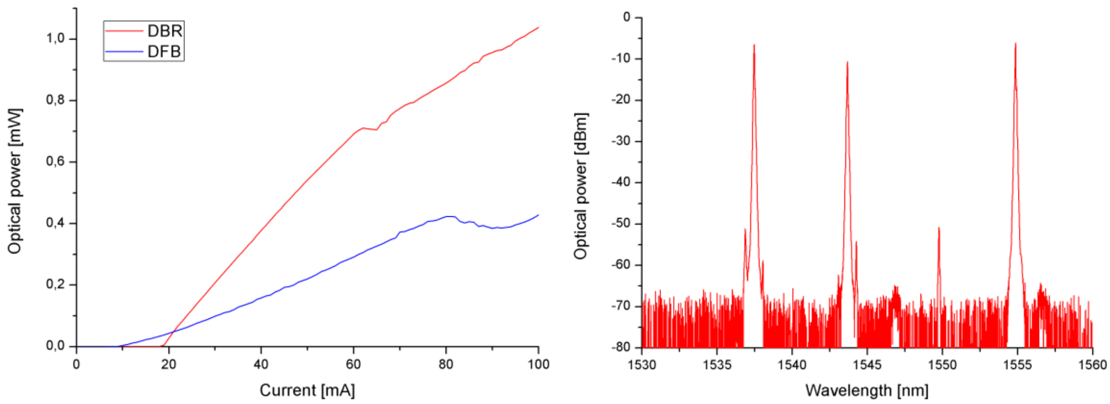

Figure 4. LI characteristics of the DBR and DFB lasers (left) and spectrum of a multichannel signal while supplying DBR1, DBR5 and DFB2 (right)

Figure 4. visualizes also a spectrum measured at the output of the device while two DBR lasers and one DFB laser are activated simultaneously. Smaller amount of power, in

comparison to the test structures, is caused by the waveguide attenuation, insertion loss of the AWG multiplexer and other circuit components.

High-speed measurements were performed for the test DFB laser, as this type of laser can be connected directly to a RF G-S-G probe. The laser was driven by a PRBS generator, using a 10 Gb/s (NRZ) signal. Figure 5. shows an eye-diagram recorded at the output of the chip on a sampling oscilloscope. For such a direct connection the measured dynamic extinction ratio is 7 dB. The quality of the eye-diagram will be further improved when the chip is connected to an electrical submount circuit with proper impedance matching.

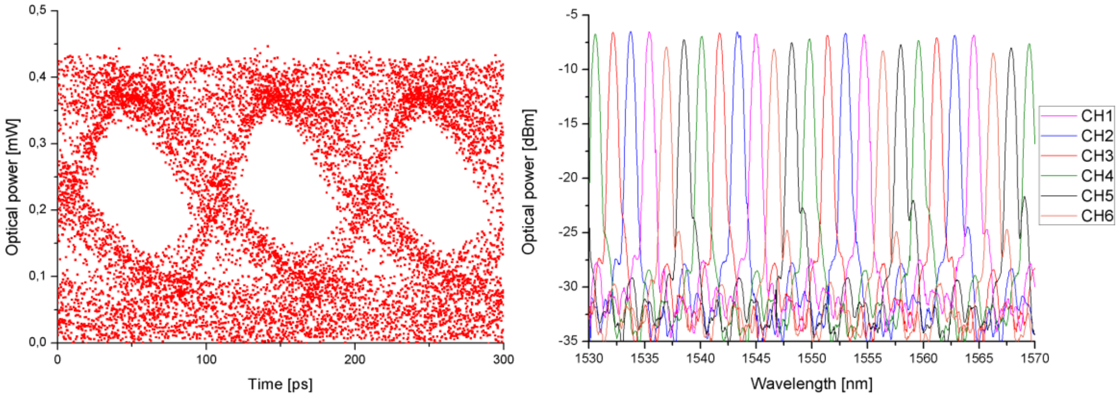

Figure 5. Recorded 10 Gb/s digital signal after direct modulation of a DFB laser (left) and measured transmission characteristic of the AWG demultiplexer of the receiver circuit (right)

Figure 5. presents also the measured transmission characteristic of the AWG demultiplexer of the receiver circuit. The properties of the AWG transmission are consistent with the design values in terms of the channel spacing $\Delta\lambda = 1.6$ nm and FSR = 9.6 nm. The power non-uniformity is 1.5 dB, while the crosstalk level is above 17.0 dB for all six channels (within the FSR from 1535.4 nm to 1545.0 nm).

Summary

In this work a multi-wavelength photonic integrated transceiver was demonstrated and discussed. The chip was realized in a generic foundry approach, designed using available building blocks and fabricated on a multi-project wafer. Characterization results achieved so far confirm multi-wavelength operation with CW signals. High-speed modulation with a 10 Gb/s NRZ signal was successfully tested with a dynamic extinction ratio of 7 dB. The performance of the AWG demultiplexer of the receiver circuit is good in terms of a flat response $\Delta P = 1.5$ dB and crosstalk better than 17.0 dB. The measurement results prove suitability of the developed multi-channel transceiver for application in free-space optical communication systems.

Acknowledgement

The research leading to these results has received funding from the EC Seventh Framework Program FP7/2007-2013 under grant agreement ICT 257210 PARADIGM.

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