Novel Photonic Integration Platform Based on Electro-Optic Polymers

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Abstract *We demonstrate for the first time monolithic and hybrid integration of complex passive and active InP elements on an electro-optic polymer platform. Using these elements we present a tunable laser and the optical part of a novel 100 Gb/s transmitter, revealing the potential of the material system to act as a multi-functional integration platform.*

Introduction

Optical polymers represent one of the most credible technologies for ultra-fast optical modulation. Thanks to the extremely high electro-optic (EO) coefficient they can possess[1], polymers can practically eliminate bandwidth limitations from the dielectric part of modulators and form the basis of transmitters for 100G telecom and datacom applications, and beyond.

Polymer modulators are commercially available today exhibiting EO bandwidth in excess of 65 GHz[2]. However, they come only as standalone, bulk devices, thus limiting the cost efficiency and the range of functionalities that EO polymer technology is able to provide. To overcome this limitation, the EO polymer technology should evolve into a highly functional platform for photonic integrated circuits (PICs), in the same way as InP or silicon-on-insulator (SOI) technologies have evolved in the past. This requires in turn the possibility for fabricating complex circuitry on the polymer boards through monolithic integration of passive structures, as well as the possibility for hybrid integration of active components with the passive part. Neither of these goals has been achieved to date.

In the present paper we make the step forward, and we demonstrate for the first time the fabrication of complex passive structures on EO polymer boards, including multi-mode interference (MMI) couplers, Bragg-gratings (BGs) and delay line interferometers (DLIs). Moreover, we report for the first time on the hybrid integration of InP gain chips and distributed-feedback (DFB) lasers with the EO polymer board, demonstrating a polymer BG-based tunable laser source and the optical subassembly for a novel 100 Gb/s transmitter.

Design and experimental characterization of passive structures on polymer platform

1. Structure of EO polymer platform

Fig.1 depicts the layout of the EO polymer waveguide used in this work. The height of the polymer stack is 6 μm including the top cladding the core and the bottom cladding layers. The core material exhibits a strong EO coefficient once poled, while the field of the propagating mode is strongly confined in the core region to further enhance the EO effect. The mode field diameter for the ridge waveguide is 2.8 μm in the vertical dimension and 4.6 μm in the lateral dimension. The bottom electrode is part of the platform structure, whereas the top electrode is present above the active region of the Mach-Zehnder modulators (MZMs) to selectively pole this region during material curing.

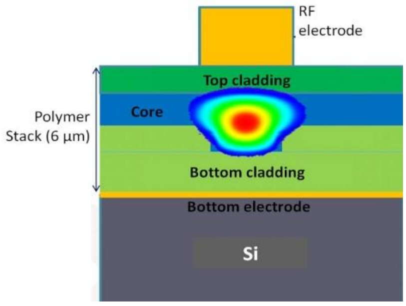

Fig. 1: Structure of EO polymer platform utilized.

2. MMI couplers

Y-splitters are commonly used in PICs as 3-dB splitters due to their simple design. However, to reduce scattering loss, avoid multi-mode behavior and suppress back-reflection, long device lengths in excess of 500 μm are often required. The use of compact 1x2 MMI structures in place of Y-splitters is thus highly desirable[3]. During the design phase, the width and the length of the multi-mode region and the output waveguide spacing were fine tuned. To compensate for material index uncertainties and fabrication imperfections, each optimal design was expanded to a structural parameter variation set on the mask. Fig. 2a presents an image of a fabricated 1x2 MMI coupler, whereas Fig. 2b shows measurement results of MMIs with 12 μm width and varying lengths.

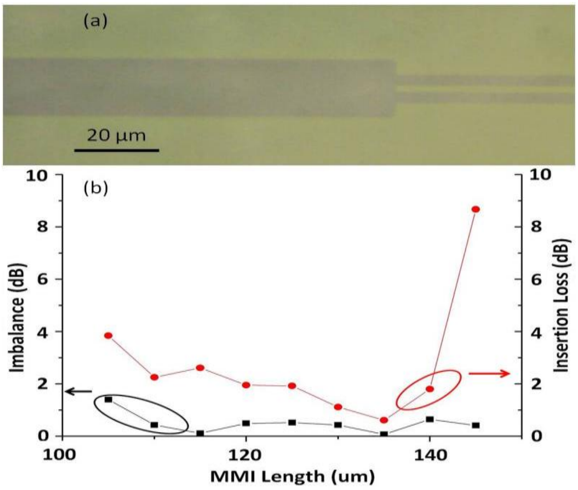

Fig. 2: (a) Microscope image of a 1x2 MMI coupler, (b) measurement results of MMIs with 12 µm width.

For 136 µm length the imbalance between the two outputs is below 0.1 dB, and the insertion loss of the coupler close to 0.6 dB. Good design to fabrication integrity was confirmed by the small variation between simulations and experimental results. Additional 1x4 MMI couplers were designed and fabricated. Their testing is ongoing and results will be reported elsewhere.

3. Bragg-gratings

The waveguide structure shown in Fig. 1 features a highly confined mode in the core region, which is thinned-down inside the top and bottom claddings. An efficient way to realize BGs in this structure involves the perturbation of the ridge width of the core layer and the generation of a "side grating" layout, as shown in Fig. 3a. As conventional i-line photo-lithography is used for wafer-scale production, the most promising 5th order grating designs were adopted with a period of 2.343 µm. The total length of the grating is 1874.4 µm. Fig. 3b presents a microscope image of the core layer during the fabrication process and before the addition of the tuning electrode on top. The rounded edges and the distorted duty-cycles of the grating indicate i-photolithography-related technology limitations. Nevertheless, using "hard" perturbation designs (e.g. w1 = 3.8 µm and w2 = 6.3 µm), clear dips could be observed in the experimental reflection spectrum. As shown in Fig. 3d the filter effect was measured to be 2.5 dB, which corresponds to ~40% reflectivity. Although lower than the predicted value, the recorded reflectivity is in principle more than sufficient to support lasing within cavities. Metal electrodes were also added on top (Fig. 3c) to heat the BGs and tune their reflection dips at different wavelengths by means of the thermo-optic effect on the polymer

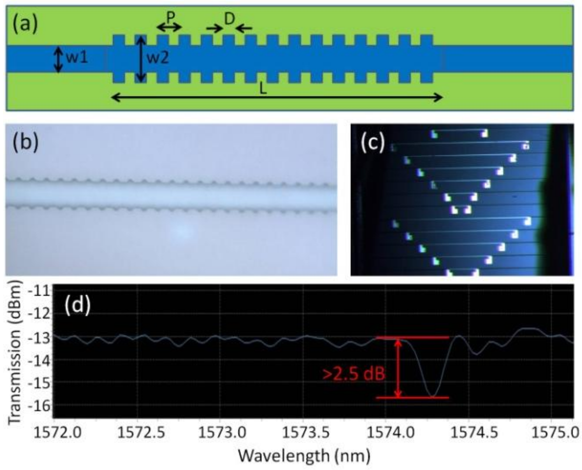

Fig. 3: (a) Design parameters of BG, (b) fabricated BG structure, (c) image of the polymer chip, and (d) transfer function of BG with a dip at ~1574.3 nm.

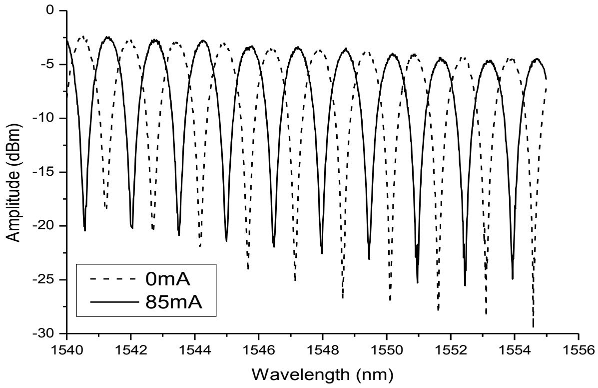

Fig. 4: TF of 160 GHz DI with full pi-shift capability by injecting current into the thermal phase shifters.

material. This functionality was used further for realizing a tunable external-cavity laser as described in the next section.

4. Delay line interferometers

DLIs are employed in PICs as unbalanced Mach-Zehnder interferometers to provide periodic filtering properties. Two DLI designs were made and fabricated on the EO polymer with 160 and 200 GHz periodicity, respectively. Metal electrodes were added on top to act as thermal phase-shifters. Fig. 4 illustrates the transmission spectra of the 160 GHz DLI in the case of 0 and 85 mA current through the phase-shifter, revealing that the complete π phase-shift could be achieved. The length of the 160 GHz device was 12.95 mm, the insertion loss below 6 dB, the polarization dependent loss below 0.3 dB and the extinction ratio higher than 17 dB.

Hybrid integration of active InP elements

An InP gain chip with a single reflector and an InP DFB laser were hybridly integrated with EO polymer boards to form a tunable laser source and a novel 100 Gb/s transmitter. In more detail:

1. Tunable external-cavity laser

An external cavity laser was developed by butt-coupling an InP gain chip to the board of the BG

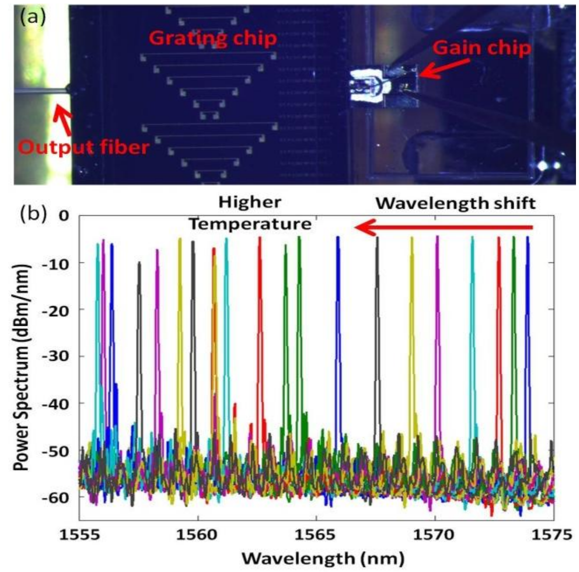

Fig. 5: (a) Photo of the BG-based laser assembly, (b) wavelength shift with increasing temperature.

Fig. 6: Optical subassambly for the 100 Gb/s transmitter.

described in the previous section. The gain chip has a single end-mirror, whereas the BG with ~40% reflectivity acts as the second (semi-transparent) mirror of the laser cavity. Fig. 5a illustrates the laser assembly. The coupling loss at the gain chip/polymer board interface was measured ~2 dB. However, the active chip is able to compensate for this loss and provide a net gain inside the cavity. Wide tunability of more than 17 nm was achieved with >40 dB side-mode suppression by thermally shifting the wavelength of the BG reflection peak[4]. The required power for covering this tuning range was ~800 mW. Optimization of the electrode (size, position, thickness, material) as a heating resistor will be made in order to reduce the required power by at least a factor of 2.

2. 100 Gb/s transmitter

The 100 Gb/s transmitter was designed and is being developed involving the hybrid integration of a DFB laser with an ultra-fast, polymer Mach-Zehnder modulator. Due to the molecular properties of the specific polymer system, the electro-optic effect is present only for light propagating at TM polarization. As most of the DFB lasers are designed to provide TE modes at their outputs, it is necessary to rotate the polarization either by adding a half-wave plate in-between the laser and the polymer board or by flipping the laser by 90^o and fine-tuning its

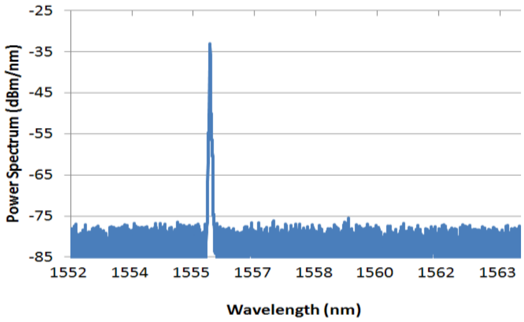

Fig. 7: Laser spectrum at the modulator output at 50 mA driving current.

position for optimal butt-coupling to the polymer waveguide. Fig. 6 illustrates the optical subassembly of the transmitter of the transmitter following the second way. The coupling loss at the laser/polymer interface was measured to be ~2.2 dB, and is very similar to the respective loss for TE modes, as the laser has a rather circular mode profile. The laser spectrum at the output of the transmitter subassembly is shown in Fig. 7. Integration with high-speed InP electronics[5] to drive the modulator will follow and will be reported in future work.

Next steps

Next steps involve further combination of passive and active structures on the polymer platform for developing complex transceiver modules including: the combination of MMI couplers with arrayed modulators for 200 and 400 Gb/s total connectivity, the combination of a BG-based laser with modulator chips for tunable 100 Gb/s transmitters, as well as the butt-coupling of InP photodiodes and laser chips on a single polymer board. For driving all these devices, InP electronic circuits will be integrated and co-packaged with the optoelectronic part.

Conclusions

We achieved monolithic integration of complex passives and hybrid integration of InP actives on EO polymer boards. Using these structures we demonstrated a tunable laser and the optical part of a 100 Gb/s transmitter, unveiling the potential of the EO polymer technology as an integration platform for ultra-fast transceivers.

Acknowledgements

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