Ultra-Short Silicon-Organic Hybrid (SOH) Modulator for Bidirectional Polarization-Independent Operation

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Abstract: We propose a bidirectional, polarization-independent, recirculating IQ-modulator scheme based on the silicon-organic hybrid (SOH) platform. We demonstrate the viability of the concept by using an SOH Mach-Zehnder modulator, operated at 10 Gbd BPSK and 2ASK-2PSK.

Introduction

Future converged metro-access networks demand high capacity at low cost especially for the subscriber. In such WDM systems, lasers need a tight wavelength control even at each optical network unit (ONU). It could be more cost effective, if all lasers would be concentrated at the central office. To this end, remotely seeded schemes are proposed. However, at the ONU the polarization of the remotely supplied optical carrier is random, requiring polarization-insensitive device concepts. This renders the use of silicon photonic devices challenging, even though the technology would be ideally suited for low-cost mass production of transceivers for optical access networks. It has been demonstrated that the intrinsic polarization dependence of silicon photonic modulators can be overcome with bidirectional modulation schemes. However, conventional travelling-wave modulators are constructed for unidirectional operation with co-propagating (co) electrical and optical waves. For bidirectional operation, when electrical and optical waves are also counter-propagating (ctr), the bandwidth is limited to a few GHz.

In this paper we demonstrate a polarization-independent silicon-based bidirectional modulator relying on ultra-short phase shifters for a high e/o bandwidth. The phase shifters are based on the silicon-organic hybrid (SOH) platform which combines strongly guiding slot waveguides with electro-optic organic cladding materials. This allows us the fabrication of a MZM with 250 μm long phase modulator (PM) sections, and a 2ASK-2PSK (bipolar 4ASK) NRZ operation at 10 Gbd. Our results demonstrate that silicon-based broadband bidirectional IQ-modulators would be feasible for use in next-generation optical access networks.
The modulator requires short phase-shifters with identical modulation sensitivity for co-propagating and counter-propagating light. As mentioned before, this excludes travelling-wave modulators. For a simple separation of outgoing and incoming light with a PBS, matched optical path lengths are mandatory, which can be adjusted with proper phase align sections.

**Experimental Setup**

We demonstrate the feasibility of the concept by a series of experiments with devices fabricated by IMEC. In a first experiment, we measure the unidirectional performance of a 250 µm long MZM having a π-voltage of 2.5 V, and do the same for a 1.5 mm long IQ-modulator with a π-voltage 0.8 V. In a second experiment, we show bidirectional operation of the MZM.

The setup for bidirectional operation is depicted in Fig. 2. The intended PIC is schematically sketched in Fig. 1(a) and emulated by an assembly of discrete fiber-optic components and a silicon photonic chip (device under test, DUT). The aforementioned stable path length matching is not feasible with discrete components, primarily because of thermal drifts. The receiver operates differently, whether the data in both polarizations are correlated or uncorrelated. To avoid this change-over point of operation, we de-correlate the modulated signals and employ polarization demultiplexing at the receiver.

An external cavity laser (ECL) serves as optical source and local oscillator (LO) for homodyne coherent detection. To compensate the unduly high insertion loss of 25 dB of the DUT, the optical carrier was boosted to 18 dBm. An optical circulator separates the signals propagating and counter-propagating light. As mentioned before, this excludes travelling-wave modulators. For a simple separation of outgoing and incoming light with a PBS, matched optical path lengths are mandatory, which can be adjusted with proper phase align sections.

**Fig. 2:** Experimental setup for bidirectional measurement. The box displays the bidirectional modulator, which we envision to build on a photonic integrated circuit (PIC). Light of an external cavity laser (ECL) is boosted and passes a circulator, which separates input and output of the PIC. The output is split by a polarization beam splitter (PBS). Both outputs are aligned to the polarization of the grating coupler. The SOH modulator (device under test, DUT) modulates the signal with 10 Gbd data stored in an arbitrary waveform generator (AWG). The modulated signals travel back to the circulator, are amplified, filtered by a 2 nm optical bandpass filter, and coherently received with an optical modulation analyzer (OMA). The polarization controller between ECL and circulator tests the polarization sensitivity. For unidirectional operation the respective output of the DUT is directly connected the EDFA.

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This concept of a bidirectional modulator is transferable to IQ-modulators. However, the insertion loss of the PIC must be low enough so that unavoidable reflections at the fiber-chip coupling interfaces do not dominate. Unfortunately, with our present IQ-modulators, this requirement was not fulfilled. In the next-generation of the PIC, the PBS will be on-chip with matched lengths in the two arms, and even better results than those presented in Fig. 4 can be expected.

Conclusion
For laserless remotely seeded subscriber units, we propose a bidirectional, polarization-independent IQ-modulator scheme for future optical access networks. As a first step, we demonstrated QPSK modulation with a 1.5 mm long IQ-modulator at 5 GB in a counter-propagating configuration. We then performed polarization-independent bidirectional modulation with a 250 µ long SOH modulator using 10 Gbd BPSK and 2ASK-2PSK signals.

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