Performance of 80 Gb/s MMI-Based DQPSK Demodulator on SOI

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***Abstract*—A Silicon-on-Insulator (SOI) Differential Quadrature Phase Shift Keying (DQPSK) demodulator based on a novel Multimode Interference (MMI) design is characterized for a number of operating wavelengths, with results indicating good uniformity and low wavelength dependency.**

Keywords- silicon integrated devices; DQPSK demodulator; MMI; characterization

I. INTRODUCTION

The introduction of multilevel modulation formats in optical communication systems has allowed the efficient scaling of system bit rates, without requiring electronics and photonics operating at very high bandwidths. Of special interest is Differential Quadrature Phase Shift Keying (DQPSK) modulation, which encodes two bits in the phase difference between two consecutive symbols, as it can be very robust against Chromatic Dispersion (CD) and non-linearities [1]. For the demodulation of DQSPK signals, a delay line equal to the symbol duration and phase shifters are required, which means that fiber-based receivers are bulky. On that respect, photonic integration can offer substantial improvement, leading to smaller, more stable and potentially low-cost receivers.

Silicon-based integration platforms are especially suitable for such applications, since they exhibit low losses and photodiodes can be easily accommodated, through hybrid or heterogeneous integration. For that reason, a number of silicon-based demodulators have already been presented [2-4]. The device characterized in this paper uses a MMI design based on a combination of shallowly and deeply etched regions, which results in very low phase errors and maintains compact design [5]. The Continuous Wave (CW) measurements of this 90^0 hybrid have been undertaken and results confirm the very good phase properties of the MMI coupler [5]. In this paper, the integrated demodulator was evaluated in a 40 Gb/s DPSK test bed, in order to determine the system performance of the device.

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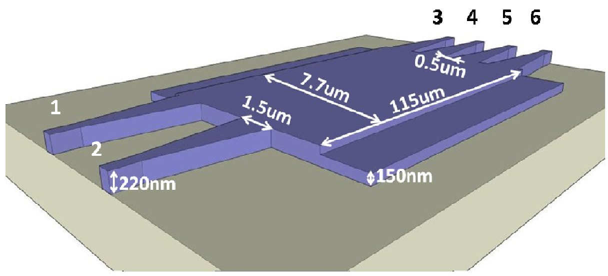

Figure 1 Schematic of the 2x4 MMI

II. DEVICE DESIGN

The device consists of grating couplers for fiber-to-chip coupling, a splitter, a 25 ps delay line (40 GHz Free Spectral Range) and the 90^0 hybrid, implemented in SOI technology. The hybrid is the most critical structure of the design and is based on a 2x4 MMI coupler. The schematic of the MMI is shown in Fig. 1, with the inputs (1 and 2) and outputs (3, 4, 5 and 6) of the structure labeled. The novelty of the MMI is the direct coupling of a shallowly etched multimode region to deeply etched waveguides. The shallowly etched region reduces the index contrast, keeping the phase errors very low. On the other hand, the rest of the waveguides are deeply etched, allowing for small curvature radii. With this approach, good imaging quality and a small footprint for the 90^0 hybrid are achieved.

III. EXPERIMENTAL SET-UP AND RESULTS

The experimental set-up built to test the device is shown in Fig. 2. The demodulator is capable of decoding DQPSK signals at 80 Gb/s, however, the DQPSK transmitter available was limited to 56 Gb/s. For that reason, the device was tested with a binary DPSK signal at 40 Gb/s. A tunable laser source creates the CW signal which enters, after polarization control, the DPSK transmitter subsystem, where it is modulated in order to create the 40 Gb/s Non-Return to Zero (NRZ) DPSK signal.

The output power of the transmitter is fixed at -3 dBm. Then, the signal is inserted to a variable optical attenuator (VOA), where the received power is set. Afterwards, the attenuated signal passes through two amplification stages (EDFAs) and is launched into the chip with a fixed power of +17 dBm. High input power was necessary, in order to compensate for the coupling and on-chip losses, which were around 20-23 dB (approximately 6.5 dB from each of the grating coupler, 6.5 dB insertion loss from the MMI and 1 dB propagation losses). The demodulated signal is coupled out of the device and is amplified by an EDFA to +7 dBm and filtered (to remove the excess ASE noise). The demodulated signal is detected by a balanced photo-detector pair, which lacks an integrated Trans-Impedance Amplifier (TIA). The lack of electrical post-amplification meant that optical amplification after the chip had to be employed, to ensure that the detected electrical signal had a voltage level above the sensitivity of the Error Analyzer (EA).

To verify the performance of the device, BER measurements as a function of the received power for every output of the device, with single-ended detection, for a number

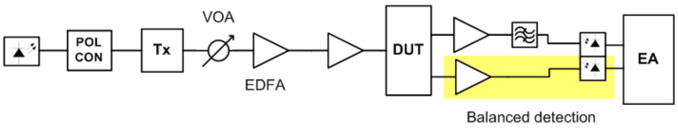

Figure 2 Experimental set-up

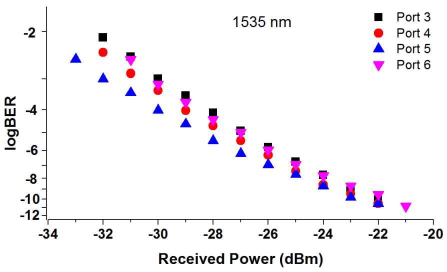

Figure 3a BER vs. received power, λ=1535 nm

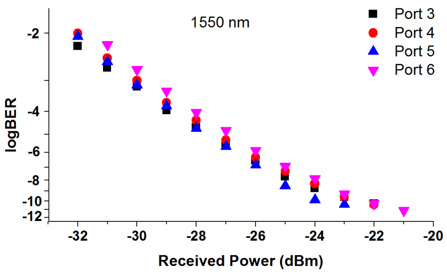

Figure 3b BER vs. received power, λ =1550 nm

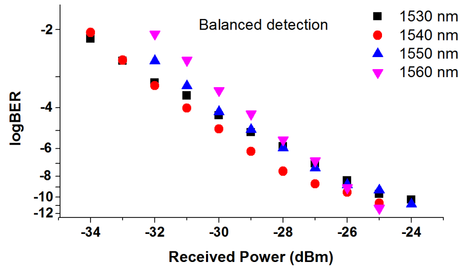

Figure 4 BER vs. received power, balanced detection

of wavelengths were performed. The BER curves for the 1535 and 1550 nm are shown in Figs. 3a-b, obtained using a pattern length of 2^{31}-1 in the experiments. From the results it can be seen that there is good uniformity between all the outputs of the device. As far as wavelength dependency is concerned, optimal performance is observed for the 1535-1550 nm range, with a small penalty for higher wavelengths (not shown here). This is in agreement with the CW measurements, which indicated optimum performance up to a wavelength of 1560 nm [5]. After validating every individual 90^0 hybrid output, experiments involving balanced detection of a pair of outputs were performed. Due to the fact that both outputs needed to be amplified and that the pulse length is quite short, there was a misalignment between the two bit streams that had to be corrected by inserting fiber patch cords and tunable optical delays. That approach required a short pattern length, 2^7-1, to enable the aligning of the bit stream through a scope. The results of balanced detection for outputs 3 and 6 for a number of wavelengths can be seen in Fig. 4. An improvement over the single-ended case, as expected, can be clearly seen. A small wavelength dependency, around 1 dB, can also be observed.

IV. CONCLUSIONS

The system performance of a MMI-based SOI DQPSK demodulator was validated at 40 Gb/s in this paper. The results prove the very good phase error properties of the novel MMI design and demonstrate low wavelength dependency. Combined with integrated photo-detectors, very high-speed, compact and potentially low-cost integrated receivers for advanced modulation formats can be realized.

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