Thin-Film Lithium Niobate DP-IQ Modulator for Driverless 130 Gbaud 64 QAM Transmission

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Abstract: We report the first integrated LN DP-IQ modulator with 1-V V_π and electro-optic response with 1.7 dB roll-off at 67 GHz. We achieve 1.56 Tb/s line rate without electrical driver using 130 GBaud DP-64QAM.

1. Introduction

There is no end in sight for the exponential internet traffic growth from emerging applications such as 5G, video, cloud, data center interconnect and optical transmission systems need to constantly scale to higher and higher capacity. Digital coherent optical transmission technology, which is key to the capacity evolution of optical networks, requires high-performance dual-polarization in-phase and quadrature (DP-IQ) modulators supporting high baud rates and higher-order optical quadrature amplitude modulation (QAM). To date, DP-IQ modulators operating over 100 Gbaud rates have been demonstrated in various material platforms, such as indium phosphide (InP) [1], lithium niobate (LN) [2], and silicon on insulator (SOI) [3]. However, all of these material platforms have fundamental limitations that are difficult to address. For example, IQ modulators based on titanium-diffused LN waveguides, which used to be the mainstay device for long-haul optical links, are bulky in size and large in half-wave voltage (V_π), making them impractical for future coherent systems with large port density. Silicon and InP modulators feature compact footprints and large bandwidths. However, both technologies rely on carrier effect for optical modulation, which is intrinsically absorptive and nonlinear, and might lead to compromised signal integrity for high-order QAM.

Recently, thin-film LN (TFLN) has emerged as an appealing platform for next-generation electro-optic (EO) modulators [4-6]. This platform seamlessly merges Pockel's effect of the LN material with high-index-contrast waveguide structures, bringing a paradigm shift in the field of electro-optical (EO) modulators. Single polarization TFLN IQ modulators with large EO bandwidth, 2.4V V_π, low optical loss, and compact footprint have been demonstrated, supporting a 200 GBaud probabilistically shaped 64-QAM signal with polarization multiplexing emulation [7].

In this paper, we report a high-performance DP-IQ TFLN modulator that features a CMOS-compatible drive voltage. A polarization combiner and rotator (PCR) is integrated for low-loss and low cross-talk polarization combining. The V_π is measured to be 1 V and the EO response with only 1.7 dB roll-off up to 67 GHz. Using this device, we demonstrate 130 Gbaud DP-64QAM, corresponding to a line rate of 1.56 Tb/s on a single wavelength, with a pre- forward error correction (FEC) bit error rate (BER) of 1.29×10^{-2}.

2. TFLN Dual-polarization IQ Modulator

Fig. 2(a) shows a schematic illustration of the used integrated DP-IQ modulator on the TFLN platform. The TFLN DP-IQ is composed of the twin-IQ modulators, and each IQ modulator has two parallel sub-MZMs operating in single-drive push-pull mode. We employ thermo-optic (TO) phase shifters to control the DC bias points of the sub-MZMs and π/2 phase difference in twin-IQ modulators (X-IQ and Y-IQ). The outputs of the twin-IQ modulators are connected to the PCR, which maps the two fundamental TE0 waveguide modes of the twin-IQ modulators onto two mutually orthogonal polarization states in the optical fiber, as depicted in Fig. 2(b). The fabricated on-chip PCR exhibits polarization extinction ratios of ~20 dB, an operation bandwidth all over the whole C-band and an on-chip insertion loss of <0.3 dB. Edge couplers based on bi-layer inverse taper were used for polarization-insensitive off-chip coupling. The coupling efficiency between the edge coupler and a lensed fiber is less than 1.9-dB/facet for both polarizations. The total fiber-chip-fiber loss is 6.8 dB, including an on-chip loss of ~3 dB.

To achieve ultra-high bandwidth and ultra-low driving voltage, we adopt the optimized 2.3-cm-long capacitance-loaded traveling-wave electrodes (CL-TWEs) for the four sub-MZMs. In this configuration, we can achieve high modulation efficiency, i.e. low $V_\pi L$, without compromising the microwave losses from the TWE, thereby simultaneously enabling a large bandwidth and small V_π. [4, 9]. The CL-TWEs are optimally designed to achieve an impedance matching to 50 Ω and a velocity match between the light wave and microwave. As shown in Fig. 1, the device features a half-wave voltage (V_π) of 1 V and an EO response roll-off of less than 1.7 dB at 67 GHz. The electrical reflections are less than -18 dB for all modulator channels.

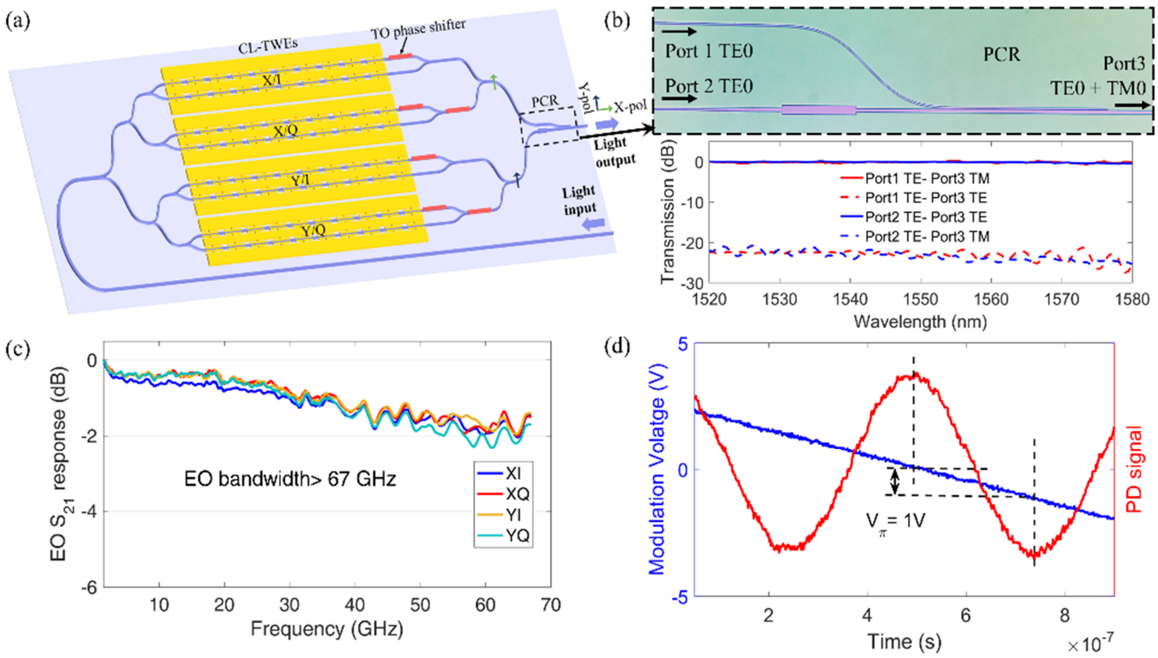

Fig. 1. (a) Schematic illustration of the LNOI-based DP-IQ modulator. (b) Microscope image and measured result for fabricated PSR. (c) Measured EO S_{21} response. (d) V_π measurement. CL-TWEs: Capacitively Loaded Traveling-Wave Electrodes; TO: thermal-optic.

3. Experimental Setup and Results

The schematic of the transmission setup is shown in Fig. 2. The data signal, consisting of four real components, is generated by four SiGe digital-to-analog converter (DAC) application-specific integrated circuits (ASICs) overclocked to operate at 130 GSa/s [8]. The electrical outputs are directly sent to the integrated DP-IQ TFLN modulator through 67-GHz cables and probes, Fig.1(a). The output optical signal of a tunable external cavity laser (ECL) with <100 kHz linewidth at 1550nm is amplified by an EDFA before aligning the polarization and feeding the modulator with ~18 dBm optical power. The DP signal is amplified by an EDFA before a configurable optical filter

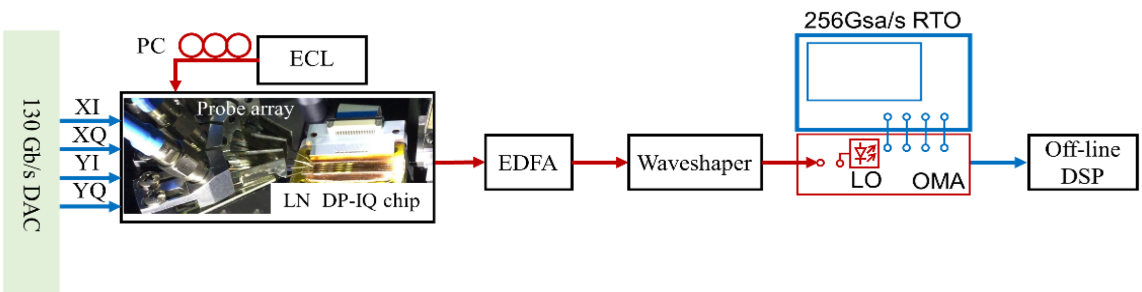

Fig. 2. Schematic of the experimental setup.

(Waveshaper) that, with 11 dB pre-emphasis, flattens the power spectral density of the modulated signal mainly compensating for the frequency response of the DAC and drivers.

The receiver consists of an EDFA used to keep the optical power at the input of the receiver around 9 dBm, a coherent mixer and four 100 GHz balanced photodetectors (BPDs) connected to a 256 GSa/s 80 GHz oscilloscope. Another ECL with linewidth <100 kHz is used as local oscillator.

The offline digital-signal processing (DPS) consists of classical algorithms for frequency offset compensation; frame synchronization, polarization de-multiplexing and equalization by means of a 4x4 real-valued least mean square (LMS) equalizer operating at 2 samples per symbol, carrier phase recovery and symbol decision. About one million symbols are used for bit error ratio (BER) calculation.

Fig. 3 shows the DP-64QAM constellation back-to-back configuration. For 130 Gbaud DP-64QAM, the measured BERs are 1.29×10^{-2} and 1.4×10^{-2}, which is below the threshold for soft-decision (SD) 20%-overhead (OH) forward error correction (FEC). The measured constellation signal-to-noise ratio (SNR) is 20 dB.

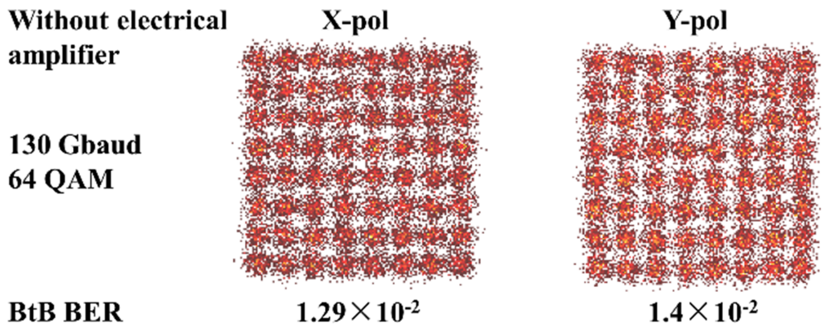

Fig. 3. 130 Gbaud DP-64QAM constellations. Device operation with 800-mV driving electronics without driving amplifier

4. Conclusions

We first report an integrated dual-polarization thin-film LN IQ modulator with ultra-high bandwidth and record low V_π of 1 V. We experimentally demonstrate dual-polarization 64QAM at 130 Gbaud with our device achieving a line rate of 1.56 Tb/s and a net data rate of 1.3 Tb/s. The modulator is effectively driverless modulated as no driver electronics are needed, owing to the ultra-low V_π and wide bandwidth.

5. References

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