40 Gb/s Widely Tunable Wavelength Converter with a Photocurrent-Driven High-Impedance TW-EAM and SGDBR Laser

Matthew M. Dummer, Jonathan Klamkin, Anna Tauke-Pedretti, and Larry A. Coldren
Univ. of California, ECE Department, Santa Barbara, CA 93106 USA
TEL:(805) 893-7163, FAX:(805) 893-4500, email:dummer@engr.ucsb.edu

Abstract— **We demonstrate a monolithic transceiver which integrates pre-amplified QW-pin receiver with a tunable SGDBR laser and high-impedance EAM. This device performs wavelength conversion at 40 Gb/s over 22 nm of optical bandwidth.**

I. Introduction

Widely-tunable lasers, like the sampled-grating (SG)DBR, have recently begun to dominate WDM systems. However, such systems still suffer from the cost, size, and power dissipation inherent within OEO approaches, which require discrete components such as receivers and modulators to be coupled to these lasers. Continued advancements in high-functionality photonic integration offer solutions to these shortfalls, delivering a level of performance that now rivals state-of-the-art discrete devices. In this work we present a fully-monolithic transceiver which integrates a high-power pre-amplified receiver and traveling-wave electroabsorption modulator with a widely tunable SGDBR laser. This single chip has been designed to perform wavelength conversion without any additional electronics at data rates up to 40 Gb/s.

II. Device Design and Fabrication

The schematic shown in Fig. 1 depicts the full wavelength converter device, designed for separate absorption and modulation (SAM) of optical signals [1], [2]. The receiver side consists of a two-stage SOA followed by a 35 μm long quantum well p-i-n (QW-pin) photodiode. The transmitter side is comprised of an SGDBR laser followed by an SOA and two parallel electroabsorption modulators (EAMs). One EAM is photocurrent driven by the QW-pin to perform wavelength conversion while the other can be electrically modulated with an external driver. The epitaxial layer structure for this device utilizes a dual quantum well platform for achieving the necessary high performance of each of the optical components [2]. Seven offset quantum wells (OQW) grown above the waveguide core provide gain for the laser and SOAs as well as absorption in QW-pin. Ten QWs centered in the waveguide core (CQW) provide high modulation efficiency but are detuned from the lasing wavelength in able to maintain low-loss passive waveguides.

The transmitter and receiver each employ very different geometries to optimize their individual performance (Fig. 2).

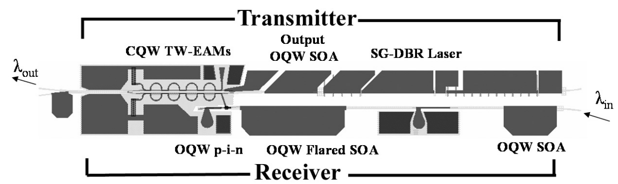

Fig. 1. Schematic of integrated wavelength converter device

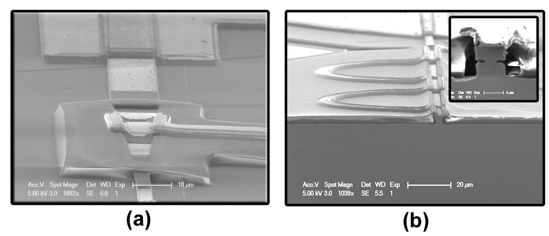

Fig. 2. SEM images of (a) the tapered-ridge photodiode and (b) the periodic TW-EAM electrode. Inset shows the undercut EAM waveguide cross section.

The SOA and QW-pin make use of laterally flared and tapered ridge waveguides, respectively, to improve the saturation power and linearity of the input optical signal [1]. The 250 μm long modulator was designed with a high-impedance traveling wave (TW) configuration to achieve very high bandwidth. The TW-EAM design incorporates a selective undercut etch [3] to reduce the core of the waveguide from 3.0 μm to 1.15 μm wide and is periodically distributed in five 50-μm sections along a high impedance microstrip line [4]. Together these two implementations significantly reduce the capacitance per length and improve velocity matching between the optical and electrical signals. The EAM transmission line is terminated with a 25 Ω NiCr resistor and DC blocking capacitor for low RF loss and simple biasing.

III. CW Characterization

The SGDBR laser achieves continuous tuning over the range of 1524 to 1564 nm. Figure 3 shows the overlayed supermode spectra demonstrating greater than 30 dB side mode suppression across the tuning range. The DC modulator extinction from 0 V to -5 V has been measured across the tuning range of the SGDBR (Fig. 4) with maximum slope efficiency ranging from 13 dB/V up to 19 dB/V. The extinction

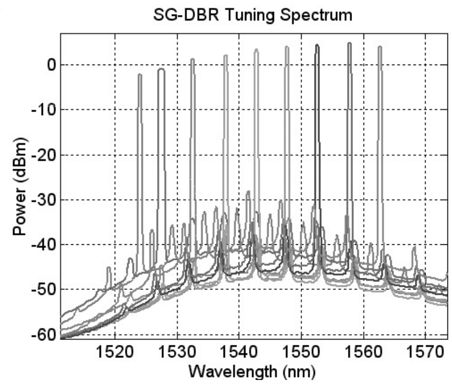

Fig. 3. Supermode tuning spectra of the SGDBR laser

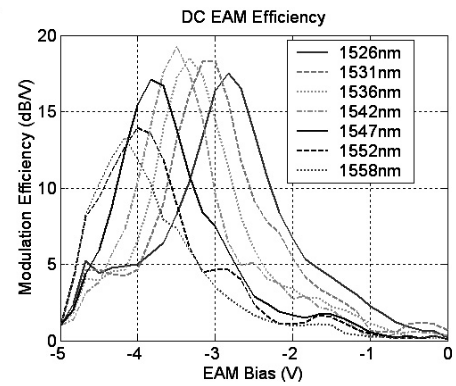

Fig. 4. Extinction efficiency of the 250 μm long EAM

variation observed is a consequence of the amount of detuning between the lasing wavelength and the modulator band edge. The CW response of the receiver is shown in Figure 5 for an input wavelength of 1550 nm. For DC biases of 70 mA and 310 mA on the two SOAs, and -3.0 V on the QW-pin, the unsaturated gain of the receiver was greater than 20 dB. Although over 60 mA of photocurrent is possible, the 1-dB gain compression of the receiver occurs at an input power of -5.4 dBm, corresponding to 32 mA of linear photocurrent for driving the EAM.

IV. High Speed Performance

Wavelength conversion at 40 Gb/s has been performed using $2^{31}-1$ PRBS data generated from an SHF bit error rate tester. For these experiments, the receiver SOAs were highly pumped (9.0 kA/cm^2) to maximize the saturation power, while the laser and output SOA were biased low (5.8 and 2.5 kA/cm^2) to limit the EAM photocurrent and reduce thermal crosstalk. The common-voltage configuration of the EAM and QW-pin creates a biasing tradeoff between input power and output wavelength. For each output wavelength, the bias voltage was chosen to maximize the output extinction while maintaining sufficient field in the photodiode to prevent bandwidth degradation from space charge effects. Figure 6 shows the clearly open eye diagrams converted from 1560 nm to 1537, 1548, and 1559 nm for both RZ and NRZ data formats with extinction

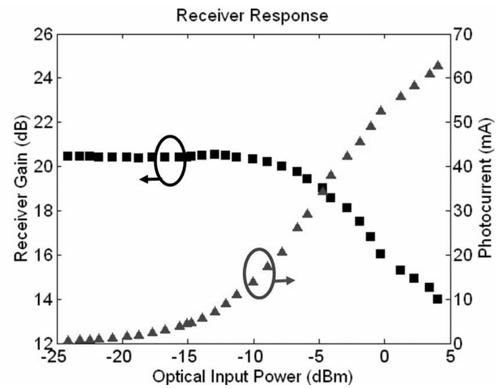

Fig. 5. CW response of the optically pre-amplified receiver

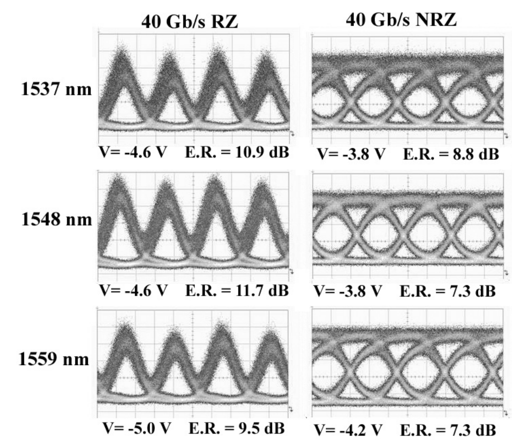

Fig. 6. 40 Gb/s RZ and NRZ wavelength converted eye diagrams with output extinction ratio for corresponding bias voltage

ratios ranging from 7.3 to 11.7 dB. The optical input power was -6.2 dBm and -5.5 dBm for the RZ and NRZ signals, respectively. In all cases, the output extinction is significantly higher for the RZ data format because the lower average power of the return-to-zero bit stream yields better receiver saturation characteristics and higher photocurrent swing.

V. Conclusion

We have presented a monolithic wavelength converter which utilizes a tunable SGDBR laser, a pre-amplified QW-pin photodiode, and high-impedance TW-EAM. This devices demonstrates 40 Gb/s wavelength conversion with greater than 7 dB output extinction over 22 nm of optical bandwidth.

Acknowledgment

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