A Bit-Rate-Transparent Monolithically Integrated Wavelength Converter

Matthew M. Dummer, Jonathan Klamkin, Anna Tauke-Pedretti and Larry A. Coldren
Univ. of California, ECE Department, Santa Barbara, CA 93106 USA
dummer@engr.ucsb.edu

Abstract

We demonstrate monolithic wavelength converters based on a PD-EAM optical gate and tunable SG-DBR laser operating at any bit rate up to 40 Gb/s in both NRZ and RZ formats.

.

Introduction:

Monolithic wavelength converters (WCs) are important devices for future WDM networks as they enable dynamic wavelength management and all-optical signal routing while reducing optical loss, power consumption, and packaging complexity. A common implementation of monolithic WC is based on non-linear SOAs to achieve cross-gain or cross-phase modulation between an input data signal and CW signal from an on-chip tunable light source. However, due to the slow gain recovery time of the integrated amplifiers, these devices typically rely on delayed interferometry to achieve high data rates and are therefore limited to single a bit rate and data format [1,2].

In this work we demonstrate the first broadband, widely-tunable monolithic wavelength converter that operates at any data rate up to 40 Gb/s in both return-to-zero (RZ) and non-return-to-zero (NRZ) data formats. The bit-rate transparency of this device, which is based on a separate absorption and modulation (SAM) architecture, makes it very well suited for future use in highly flexible WDM networks.

Device Design:

The SAM device is based on an integrated transceiver design with separate transmitter and receiver waveguides similar to [3]. A photograph of the device is shown in Fig. 1. The transmitter consists of a widely tunable sampled grating (SG)-DBR laser followed by an output SOA and two parallel high-impedance traveling-wave electro-absorption modulators (TW-EAM) [4]. One of the EAMs can be electrically driven to function as a transmitter while the other is used to perform wavelength conversion. The receiver is designed

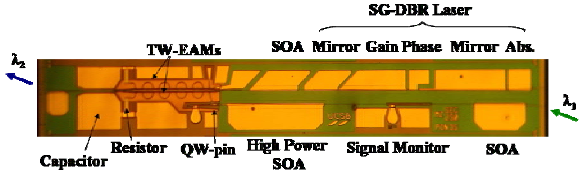

Figure 1: Photograph of integrated wavelength converter. The total footprint of the device is 4.0 mm x 0.45 mm.

with two SOAs followed by a quantum-well p-i-n (QW-pin) photodiode (PD). A microstrip transmission line connects the QW-pin to one of the TW-EAM electrodes such that the photocurrent generated in the receiver directly modulates the output of the SG-DBR laser to produce wavelength conversion. This type of traveling-wave optical gate enables very high bandwidths, as similar configurations have demonstrated switching times as fast as 2 ps [5]. The TW-EAM electrode is followed by a thin-film resistor (25 Ω) and capacitor which serve to terminate the photocurrent signal and allow for DC biasing.

Receiver and Transmitter Measurements:

The performance of the wavelength converter is entirely determined by the efficiency of both the receiver and the EAM. For the receiver, achieving high saturation power in both the SOAs and the photodiode is important for maintaining high extinction ratios and limiting pattern dependence. To characterize the receiver linearity we have measured the CW response as shown in Figure 2. The optical input and output powers were obtained by reverse biasing the first SOA to measure the input photocurrent and then forward biasing both SOAs to measure the photocurrent in the QW-pin. For these measurements, the biases were 70 mA, 310 mA, and -3 V for the 400 μm and 800 μm SOAs, and 35 μm photodiode, respectively. The gain of the receiver is greater than 20 dB and it is capable of generating up to 30 mA of linear DC photocurrent before saturation begins to occur.

The SG-DBR laser is tunable from 1524 nm to 1564 nm with fiber-coupled output powers from -2 to 4 dBm over the wavelength range. Figure 3 shows the DC extinction characteristics of the 250 μm EAM over the laser tuning range, demonstrating 20-30 dB extinction from 0 to 5 volts. The observed wavelength dependence is typical of QW EAMs, which require greater amount of Stark shift as the lasing wavelength becomes further detuned from the QW band edge.

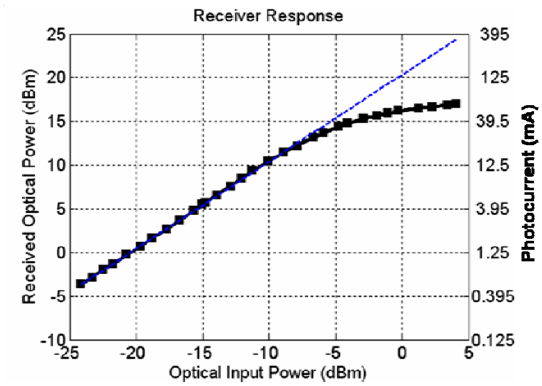

Figure 2: Response of the SOA pre-amplified QW-pin receiver

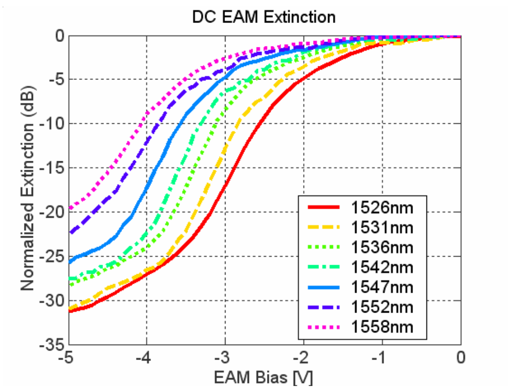

Figure 3: Extinction characteristics of the TW-EAM over the tuning range of the SG-DBR laser

Wavelength Conversion:

To demonstrate the high bandwidth and bit-rate transparency of the device, wavelength conversion has been performed at various bit rates for both RZ and NRZ formats. Using an SHF bit error rate tester, optical PRBS data (2^{31}-1) was generated and coupled to and from the WC with lensed fibers. The bias conditions for the two receiver SOAs were 110 mA and 310 mA, and the laser gain section and the transmitter SOA, were biased at 95 mA and 30 mA, respectively. The SG-DBR mirrors were tuned by current injection to the desired output wavelength. The bias across the photodiode and EAM was adjusted to achieve the maximum amplitude of the output signal. Figure 4(a) shows the wavelength converted eye diagrams (1560 nm to 1548 nm) for NRZ input data signals at 5, 10, 20 and 40 Gb/s. The input power in all cases was -5.5 dBm and the output power was -12 dBm accounting for 4 dB fiber coupling losses. With a bias of -3.8 V, the output extinction ratio was 8.9, 9.4, 9.5 and 8.1 for the four data rates respectively.

To evaluate the return-to-zero performance, input RZ signals were generated at both 20 Gb/s and 40

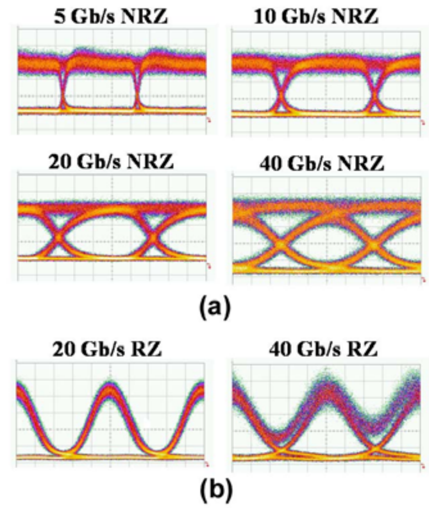

Figure 4: Wavelength converted (1560 nm to 1548 nm) eye diagrams in both (a) non-return-to-zero and (b) return-to-zero format

Gb/s using a 20 GHz clock signal and $LiNbO_3$ modulator with a V_π or $2V_\pi$ drive to carve the NRZ data. Figure 4(b) shows the wavelength converted output eye diagrams for both data rates. The lower average power of the RZ data format allows for greater signal swing and therefore greater output extinction. For an input power of -6.2 dBm and PD-EAM bias of -4.5, the output extinction ratios were 11.5 dB and 10.8 dB for 20 Gb/s and 40 Gb/s.

Conclusion:

We have demonstrated a monolithically integrated, widely tunable SAM wavelength converter for highly flexible WDM applications. This device demonstrates efficient wavelength conversion for data rates ranging from 5 Gb/s up to 40 Gb/s in both RZ and NRZ data formats with output extinction ratios exceeding 8 dB.

Acknowledgment

The authors acknowledge the support of DARPA under the MTO-LASOR Grant W911NF-04-9-0001.

References

[1] V. Lal et al. *Photon. Tech Lett.* vol. 18, no. 4 pp. 577-59 (2006)

[2] P. Bernasconi et al. *Electron. Lett.* Vol. 18, no 4 pp 701-702 (2005)

[3] M. Dummer et al. *J. Lightwave Tech.*. Vol. 26, no. 8 pp. 938-944 (2008)

[4] M. Dummer et al. *OFC 2008* OThC6 (2008)

[5] S. Kodama et al. *Electron Lett* vol. 40 no. 9 pp 555-556 (2004)