Monolithic 40 Gbps Separate Absorption and Modulation Mach-Zehnder Wavelength Converter

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Abstract: The first 40 Gbps monolithic SAM Mach-Zehnder wavelength converter is demonstrated. The device exhibits a bandwidth is in excess of 20 GHz and power penalties less than 2.5 dB at 40 Gbps using NRZ data.

OCIS codes: (250.5300) Photonic integrated circuits; (250.7360) Waveguide modulators

1. Introduction

Wavelength converters are an important part of the next generation of optical networks to provide dynamic wavelength management within WDM systems. Monolithic approaches are able to reduce packaging costs and increase scalability. A popular approach to this problem is to utilize cross-gain or cross-phase modulation in semiconductor optical amplifiers (SOAs) [1, 2], however these devices are inherently limited by carrier lifetime. Recently, there has been success with the separate absorption and modulation region (SAM) approach to wavelength conversion in which input signal photocurrent generated by an on-chip photodiode is used to drive an optical modulator [3, 4]. This approach offers a number of advantages over SOA based approaches including conversion between identical input and output wavelengths, bit-rate transparency, and no optical filtering requirements.

In this paper we report the first monolithic Mach-Zehnder modulator (MZM) based SAM wavelength converter operating at 40 Gbps. The device implements a linear SOA, a quantum-well absorber, a widely tunable sampled-grating DBR (SGDBR) laser and a series-push-pull Mach-Zehnder modulator. Additionally, a capacitor and resistor are integrated on chip eliminating the need for bias tees, thus reducing microwave losses and simplifying biasing.

2. Device

A diagram of the Mach-Zehnder wavelength converter is shown in Fig. 1.

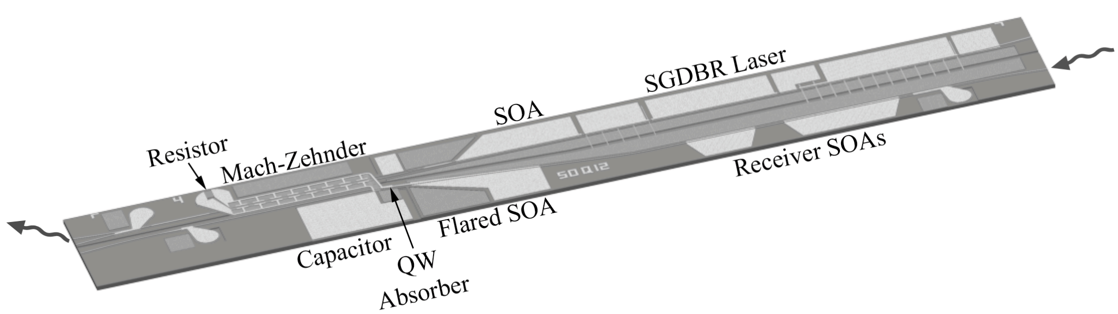


Fig. 1. Diagram of the wavelength converter

The SGDBR laser consists of five sections – an active absorber, a rear mirror, a phase section, a 500 μm long gain section, and a front mirror. A 500 μm SOA follows the SGDBR to increase the output power of the device and compensate for propagation losses. A phase section within the interferometer is implemented to allow for biasing to π-phase-shift. A flared and curved output waveguide combined with an AR coating was used to reduce optical reflections and to aid in fiber coupling.

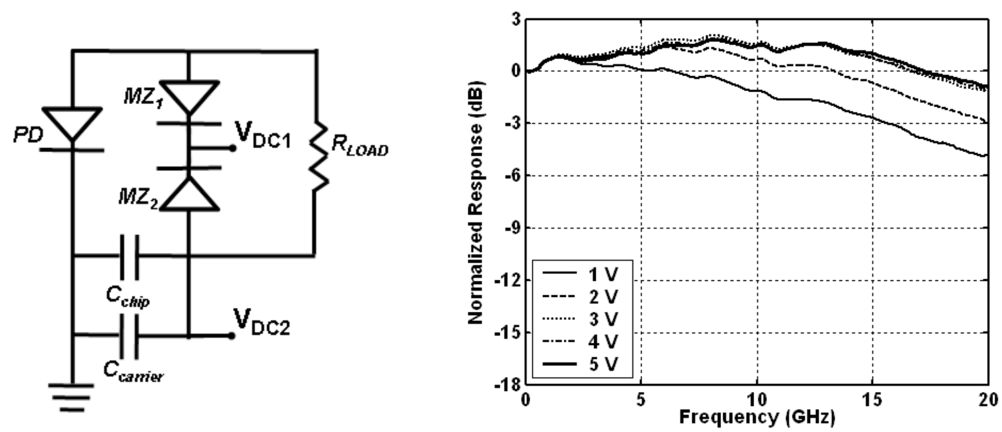
The modulator utilizes a traveling wave electrode segmented into 6-50 μm long T-sections to capacitively load the transmission line allowing for better impedance matching. To reduce the capacitance BCB is deposited under the modulator electrodes and the ridge width is reduced from 3 μm in the laser and SOA regions to 2 μm within the modulators. On chip termination is formed from an integrated 25 Ω semiconductor resistor fabricated out of the n-contact layer. The 300 μm long MZM is operated in a series-push-pull fashion with the photocurrent signal applied across the tops of the Mach-Zehnder arms. This configuration allows for improved bandwidth, reduced power consumption and small chirp values [5, 6].

The receiver section consists of a 500 μm long straight SOA, a 550 μm long linearly flared SOA and a 35 μm long tapered quantum well detector [7]. The flared pre-amplifier employs lateral flaring from 3 μm to 12 μm in order to increase the output saturation power. The absorber makes use of the offset quantum wells to obtain a high absorption coefficient. The detector is tapered from 9 μm to 2 μm to prevent saturation at the front end and uses BCB to reduce pad capacitance. A parallel-plate capacitor is formed by sandwiching SiN_x between the n-contact layer and p-metal is fabricated on-chip for biasing purposes.

The wavelength converter's dual-quantum-well epitaxial structure is comprised of two sets of quantum-wells as described in [8]. A set of offset quantum-wells (λ_{PL} = 1542 nm) are used in the gain section of the SGDBR and the SOAs. A separate set of seven quantum-wells (λ_{PL} = 1455 nm) centered in the InGaAsP waveguide are used for efficient modulation. Both sets of wells are used in the absorbing region. The fabrication of this device requires a single InP/InGaAs blanket regrowth following the selective removal of the offset quantum-wells from the passive sections and the etching of holographically defined gratings. Following fabrication, the devices were thinned, cleaved and mounted onto an aluminum nitride carrier for testing.

3. Experiments

All contacts were wirebonded to the carrier and contacted via a probe card. An on-carrier capacitor and 2 Ω damping resistor were wirebonded in parallel to the on-chip capacitor to provide a path for low frequency signal components. No bias tees were used, and all biases were applied with a DC probe card. The wavelength converter biasing configuration is shown in Fig. 2.



(a) Biasing Schematic

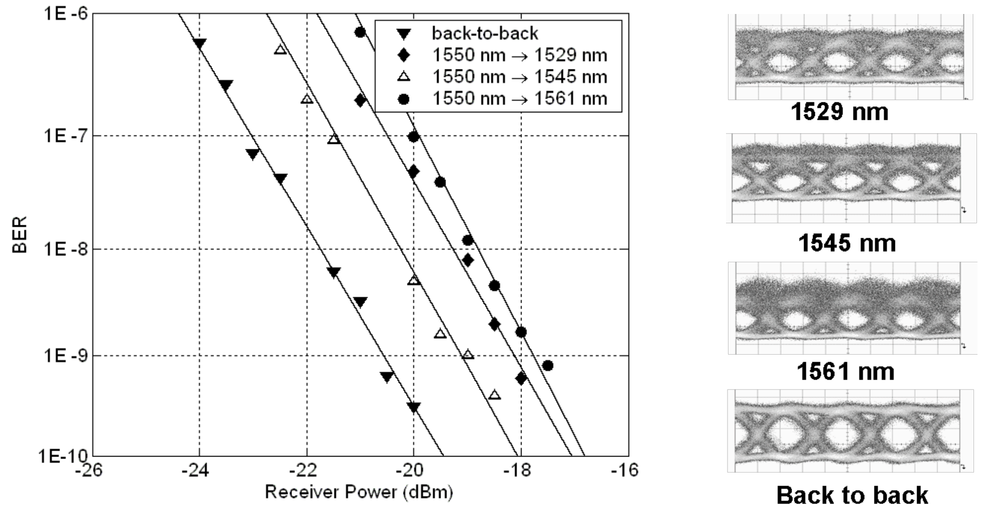
(b) Small signal response for R_{load} = 25 Ω, V_{DC2}-V_{DC1}=-2 V and varying bias for V_{DC2}.

Fig. 2.

The small signal response of the device was measured using a HP8703A network analyzer. The wavelength converter demonstrated greater then 20 GHz bandwidth as shown in Fig. 2. A slight bandwidth enhancement is seen due to the mismatched impedances of the termination (25 Ω) and the MZM coplanar stripline (53 Ω).

An SHF 40 Gbps Bit Error Rate Tester (BERT) was used to take bit error rate measurements at 40 Gb/s with a 2^7-1 pseudo-random bit sequence (the word length was limited by the BERT). The NRZ output signal from the SHF

BERT was amplified with a high power Erbium Doped Fiber Amplifier (EDFA). The signal traveled through a polarizer and optical filter before being coupled into the wavelength converter. The output of the wavelength converter was fed directly to the BERT's preamplified receiver. A high-speed probe with a 50 Ω load was placed in parallel to the on-chip termination to reduce the effective termination to 17 Ω to enhance the bandwidth. In future devices a smaller resistor can be fabricated on chip removing the need for the high-speed probe. Fiber coupled input power of 0.4 mW produced 28 mA of photocurrent used to drive the modulator. Data was converted from 1550 nm to output wavelengths of 1529 nm, 1545 nm and 1561 nm. The conversion range is limited by the tuning range of the SGDBR. Error free operation was observed for all wavelengths with power penalties of 1.5 dB – 2.5 dB.



(a) BER at 40 Gbps with a 2^7-1 pseudo-random bit sequence.

(b) Eye Diagrams

Fig. 3. 40 Gbps measurement results. (I_{gain} = 130 mA; I_{T_xSOA} = 110 mA; I_{R_xSOA1} = 185 mA; I_{R_xSOA2} = 250 mA; V_{DC2}-V_{DC1}=-2 V and V_{DC2} = -5.6 V)

4. Conclusion

For the first time a widely tunable SAM Mach-Zehnder based wavelength converter operating at 40 Gbps has been fabricated. The device exhibits greater then 20 GHz bandwidth and error free operation at 40 Gbps with power penalties less than 2.5 dB.

References

1. T. Hatta, T. Miyahara, Y. Miyazaki, K. Takagi, K. Matsumoto, T. Aoyagi, K. Motoshima, K. Mishina, A. Maruta, and K. Kitayama, "Polarization-Insensitive Monolithic 40-Gbps SOA MZI Wavelength Converter With Narrow Active Waveguides," *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 13, no. 1, pp. 32–39, 2007.
2. V. Lal, M. L. Masanovic, J. A. Summers, G. Fish, and D. J. Blumenthal, "Monolithic Wavelength Converters for High-Speed Packet-Switched Optical Networks," *Selected Topics in Quantum Electronics, IEEE Journal of*, vol. 13, no. 1, pp. 49–57, 2007.
3. M. Sysak, J. Raring, J. Barton, M. Dummer, A. Tauke-Pedretti, H. Poulsen, D. Blumenthal, and L. Coldren, "Single-chip, widely-tunable 10 Gbit/s photocurrent-driven wavelength converter incorporating a monolithically integrated laser transmitter and optical receiver," *Electronic Letters*, vol. 42, pp. 657–658, May 25 2006.
4. J. W. Raring and L. A. Coldren, "40Gb/s Widely-Tunable Transceivers," *Journal of Selected Topics in Quantum Electronics*, vol. 13, no. 2, 2007.
5. A. Tauke-Pedretti, M. Sysak, J. Barton, J. Raring, L. Johansson, and L. Coldren, "40-Gb/s Series-Push-Pull Mach–Zehnder Transmitter on a Dual-Quantum-Well Integration Platform," *IEEE Photonics Technology Letters*, vol. 18, pp. 1922–1924, September 15 2006.
6. R. G. Walker, "High-speed III-V semiconductor intensity modulators," *IEEE J. Quantum Electron.*, vol. 27, pp. 654–667, Mar. 1991.
7. A. Tauke-Pedretti, M. Dummer, J. S. Barton, M. N. Sysak, J. W. Raring, and L. A. Coldren, "High Saturation Power and High Gain Integrated Photoreceivers," *IEEE Photon. Technol. Lett.*, vol. 17, pp. 2167–2169, Oct. 2005.
8. M. Sysak, J. Raring, J. Barton, M. Dummer, D. Blumenthal, and L. Coldren, "A single regrowth integration platform for photonic circuits incorporating tunable SGDBR lasers and quantum-well EAMs," *IEEE Photonics Technology Letters*, vol. 18, pp. 1630–1632, August 2006.