A novel monolithically integrated widely-tunable wavelength converter based on a SGDBR-SOA-MZ transmitter and integrated photodetector

Jonathon S. Barton[1], Milan L. Mašanović [2], Matthew N. Sysak[2], Erik J. Skogen[2],
John M. Hutchinson[3], Daniel J. Blumenthal[2], Larry A. Coldren[2]

1: University of California, Santa Barbara, Materials Dept.
2: University of California, Santa Barbara, ECE Dept.
3: Intel Corporation

Abstract: The first monolithically integrated MZ-OEIC tunable wavelength converter is presented. Error free operation at 2.5 Gbit/s with a 2^{31}-1 PRBS is demonstrated. A power penalty of 1-2dB is measured across the 37nm wavelength range of the SGDBR.

Keywords: Wavelength conversion, Mach-Zehnder, Monolithic integration, Tunable laser

1. Introduction

Tunable wavelength converters represent a novel class of highly sophisticated photonic integrated circuits that are crucial in the function of future optical networks. They allow for the manipulation of wavelengths in WDM optical switches, routers and add/drop multiplexers. Many different implementation of non-tunable wavelength converters have been proposed using cross phase modulation(XPM) in SOAs and fiber[2,3], and cross absorption modulation(XAM) of SOAs [1], Many of these architectures have been demonstrated to perform the significant feature of digital signal regeneration – including improvements in extinction ratio, signal to noise ratio, pulse width etc. More recently, monolithically-integrated tunable all-optical wavelength converters (TAO-WC)[4] have been demonstrated and have shown promise to allow for the conversion of one wavelength to another without requiring the signal to pass through electronics.

To the best of our knowledge, a monolithically-integrated widely-tunable wavelength converter based on a SGDBR-SOA-MZ transmitter and integrated photo-detector has never been reported. The Mach-Zehnder design has high extinction with a very low drive voltage making it suitable as a driving modulator for the device. The modulation efficiency is high due to the large change in index and absorption in the branches of the waveguide (band-gap energy corresponds to λ=1.4μm). The integrated device also allows wavelength monitoring, transmits at high speed, and removes the requirements for filtering the input wavelength at the output[4]. Integrating the SGDBR gives a compact wavelength agile source that requires only two fiber connections – with low loss coupling between the SGDBR and the modulator. This design ultimately yields a small footprint and low cost. The device can operate in both inverting and non-inverting modes. A typical interferometric WC generates negative chirp in non-inverting mode and positive chirp in inverting mode[2].

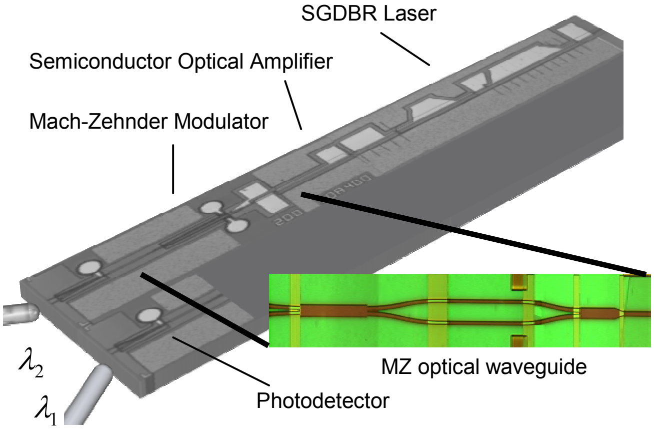

Figure 1 : Mach-Zenhder modulator / Detector OEIC wavelength converter

2. Wavelength Converter Design

The device uses a ridge-based SGDBR with laser design similar to the one described in [7]. An absorber section is on the back-end of the device for measurement of power, and to decrease the requirements of the backside Anti-Reflective coating. The Mach-Zehnder modulator utilizes one 1x2 Multimode interference (MMI) coupler (97 um long) at the input of the interferometer with curved waveguides extending to a separation of 20μm in between the two branches and a 172μm 2x2 MMI at the output of the MZ modulator section (inset of fig.1). The outputs are angled to reduce the AR coating requirements. The total device chip size is 1mm x 3.5mm. For the MZ-OEIC, the pads on both the bulk (Franz-Kelydsh) detector and the MZ are both 200μm long. This bulk detector drives one of the branches of a SGDBR-SOA-MZ transmitter at the output wavelength λ_2.

This design uses a common waveguide structure in which the passive sections are formed by etching off the QWs down to the 10nm InP stop-etch layer. The process is similar to that described in [4,5,7]. The epi-layer structure consists of an offset quantum well structure (QW) as shown in table 1.

TABLE I
EPILAYER STRUCTURE

Layer	Thickness (nm)	Composition – Doping
InGaAs	100	Lattice Matched 1e19 cm^{-3} Zn
p-InP	1800	1e18 cm^{-3} Zn
1.226LM	25	
7QWs		Nid 8nm barriers 6.5nm wells
nid InP	10	
Waveguide	350	1.4Q
n-InP Buffer	1800	1e18 Si InP
S Doped Substrate	10000000	5e18 Sulfur doped

3. Photo-detector characteristics

The bulk Franz-Kelydsh detector in this wavelength converter offers high photocurrent generation without saturation at high optical input powers. Fig. 2. demonstrates the photocurrent characteristics as a function of reverse bias and optical input power.

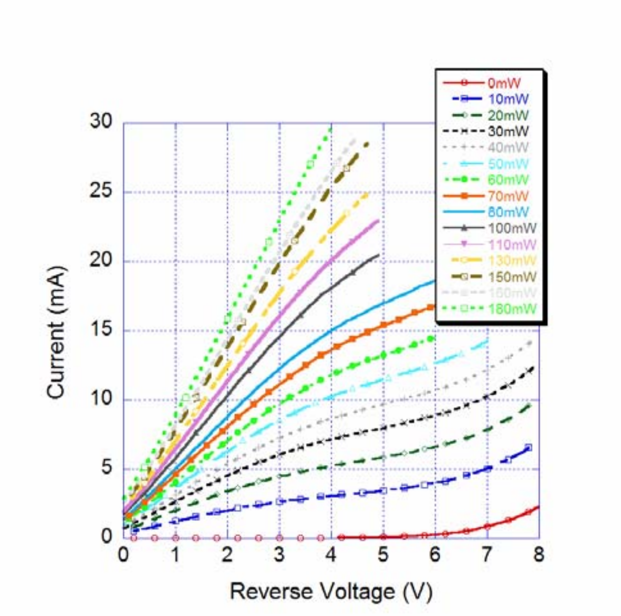

Figure 2 Photodetector IV Characteristics as a function of incident optical power at 1548.1nm

Determination of the bias point of the detector is based on concerns of excessive device heating with high bias(-6V) and optical facet damage with high optical power (>200mW). For these reasons, the detector was biased at -4V to generate 30mA photocurrent using 180mW of optical power. Due to the flaring and angling of the waveguide and the use of lensed fiber – we experience approximately 5dB of coupling losses at the facet.

4. Bias Configuration

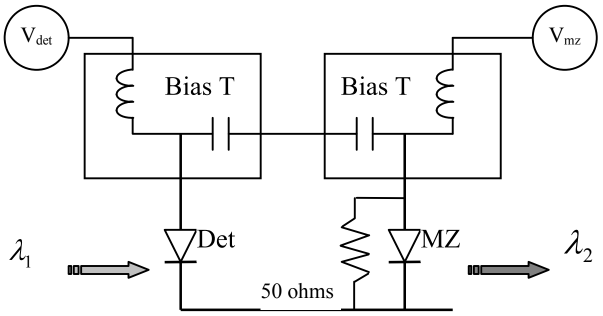

Figure 3. Bias configuration Picosecond 5542 Bias Ts

Conceivably the two devices could be directly connected together with proper design. In this device configuration, one would like to reverse bias the detector highly (-4V) to achieve sufficient photocurrent and resulting voltage swing, but leave the MZ at a lower bias(-1V) where there isn't excessive absorption. This requires a capacitor between the two devices and for the purposes of this paper, two Picosecond labs model 5542 bias Ts were used on the respective devices to provide this bias configuration (fig. 3). For improvement of the lumped bandwidth, a 50 ohm parallel resistor is connected to these diodes.

5. Experiment

BER curves as a function of receiver power were generated using an experimental setup as shown in fig. 4. NRZ 2^{31}-1 PRBS 2.5Gbit/s data was generated at an input wavelength of 1548.1nm using a 3 Gbit/s BERT and Agilent 83433A transmitter. An EFDA was used to boost the power to 180mW and generate 30mA of photocurrent in the detector at a bias of -4V on the detector which provides adequate drive voltage on the modulator – and ultimately high extinction ratio output. The converted signal from the integrated transmitter at λ_2 was fed into an attenuator and a filtered amplified PIN receiver as shown in fig. 4 (Agilent 11982A). Separate filters were tuned for each wavelength in the C and L bands.

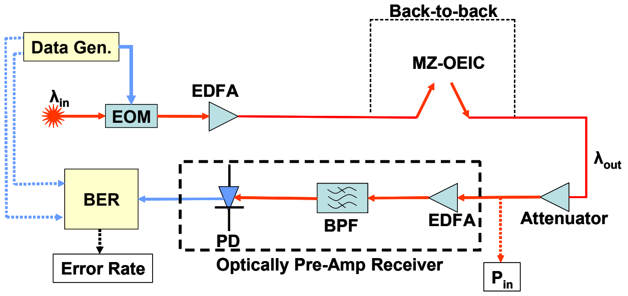

Figure 4. Schematic of test setup

6. Results

Typical BER measurements are shown in fig. 5. The PBRS 2.5 Gbit/s output waveforms corresponded to 7.5-8.3 dB extinction across the wavelength range. Error free wavelength conversion was achieved over a wide range (37nm output) corresponding to a 1-2dB power penalty over this range.

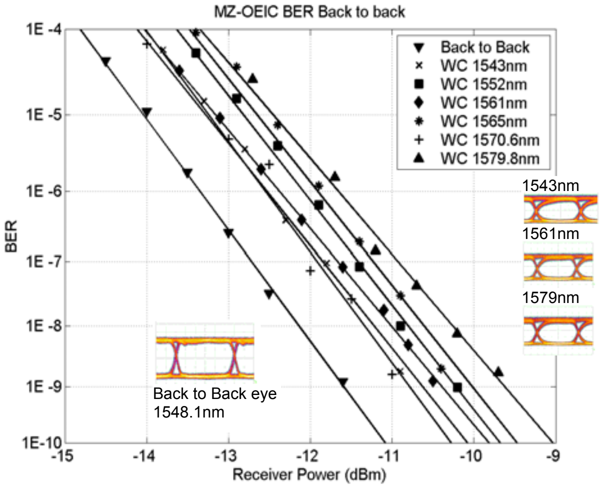

Figure 5 : BER data for different wavelengths with original wavelength at 1548.1nm [1-2dB power penalty]

The device was biased with the following currents. Gain section = 120mA, SOA = 70mA, MZ branch1(modulated) = -1V, MZ branch2 = -3.6V. The tuning was performed by current injection into the rear mirror.

7. Conclusion

We have demonstrated error free wavelength conversion over 37nm with <2dB power penalty using a novel MZ-OEIC wavelength converter. We see great promise in this monolithically integrated approach to wavelength conversion. These devices should become practical for implementation with improvement of on-chip coupling losses and with the eventual integration of a preamplifier before the photo-detector, we will provide significant optical gain which will provide sufficient photocurrent to drive the Mach-Zehnder modulator with much lower optical power requirements. Potentially, either a capacitor can be integrated on chip so that bias-T’s are not required or an active detector employed that can absorb more of the light with lower bias.

8. Acknowledgment

The authors acknowledge Agility Communications for the regrowth of the material. This work was funded by Intel Corporation and DARPA MTO – CS-WDM grant number N66001-02-C-8026.

9. References

[1] N. Edagawa, M. Suzuki, S. Yamamoto, “Novel wavelength converter using an elecroabsorption modulator,” IEICE Trans. Electron., E81-C, 1251-1257 (1998).

[2] C. Janz, F. Poingt, F. Pommereau, W. Grieshaber, F. Gaborit, D. Leclerc, I. Guillermot, M. Renaud, ‘’ New All Active Dual Order Mode (DOMO) Mach-Zehnder Wavelength converter with monolithically integrated DFB Probe source ‘’, IEEE Photonics Technology Letters, 9, IEEE, 1349-51. (1997)

[3] L. Rau, R. Doshi, S. Rangarajan, Y. Chiu, D. J. Blumenthal, J. E. Bowers, ‘’Analog performance of an ultrafast sampled-time all-optical fiber XPM wavelength converter ‘’, IEEE Photonics Technology Letters, Volume : 15 Issue : 4, April 2003, pp. 560-562.

[4] M. L. Masanovic, V. Lal, J. S. Barton, E. J. Skogen, D. J. Blumenthal, L.A. Coldren, Monolithically Integrated Mach-Zehnder Interferometer wavelength converter and widely-tunable laser in InP ”, IEEE Photonics Technology Letters, August 2003.

[5] B. Mason, G. A. Fish, S.P. DenBaars, and L.A. Coldren, "Widely Tunable Sampled Grating DBR Laser with Integrated Electroabsorption Modulator*," IEEE. Photon. Tech. Letts,*. vol. 11, No. 6. pp. 638-640, June. 1999.

[6] L. H. Spiekman, J. M. Wiesenfeld, U. Koren, B. I. Miller, M. D. Chien, “All-Optical Mach-Zehnder Wavelength Converter with Monolithically Integrated Preamplifiers” IEEE Photon. Tech. Letts., Vol. 10, No. 8, Aug. 1998.

[7] J.S. Barton, E.J. Skogen, M.L. Masanovic, SP DenBaars, L.A. Coldren. “Tailorable chirp using integrated Mach-Zehnder modulators with tunable sampled grating distributed Bragg reflector lasers.” *2002 IEEE 18th International Semiconductor Laser Conference. IEEE. 2002, pp.49-50. Piscataway, NJ, USA.*

6. Glossary

SGDBR: Sampled Grating Distributed Bragg Reflector

OEIC: Opto Electronic Integrated Circuit

SOA: Semiconductor Optical Amplifier

BER: Bit error rate

MZ: Mach-Zehnder

NRZ: Non return to zero

PRBS: Pseudorandom bit stream

WDM: Wavelength division multiplexing