

10 Gbps and 2.5 Gbps error-free operation of a monolithically integrated widely-tunable all-optical wavelength converter with independent phase control and output 35nm tuning range

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Abstract: This paper reports on the first demonstration of 2.5 Gbps and 10 Gbps operation of a new InP MZI-SOA all-optical wavelength converter with independent interferometer phase control monolithically integrated with a widely-tunable SGDBR laser. We show a 35nm output tuning range with less than 0.8dB power penalty at -10 dBm input at 2.5Gbps NRZ and error-free operation with -5 dBm input power at 10Gbps NRZ.

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1. Introduction

The development of photonic integrated circuits (PICs) with increased functionality and monolithic integration on a single chip is a critical step for the deployment of optical networks. The tunable all-optical wavelength converter is a critical component for reconfigurable WDM systems that employ optical switching, wavelength routing and add/drop multiplexing. Integration of the tunable laser and all-optical wavelength converter on a single chip is necessary to meet performance, yield, cost and footprint requirements of these networks. This level of chip-scale integration has a number of benefits including reduced coupling loss between laser and converter, faster operating speed, improved converter noise figure and improved conversion efficiency. Tunable all-optical wavelength converters allow data to be transferred from an input wavelength to a tunable output wavelength without passing the signal through electronics. For wavelength conversion, the semiconductor optical amplifier based Mach-Zehnder Interferometer (SOA-MZI) wavelength converter is an important class of integrated wavelength converters that work for both RZ and NRZ data formats while also acting as a 2R signal regenerator due to their nonlinear transfer function. [1-3]. Previously, we have reported on the first widely tunable all-optical wavelength converter with 22nm tuning range working at 2.5 Gbps [4].

In this paper, we report for the first time a new tunable wavelength converter with independent interferometer phase control, which has a tuning range of 35nm with average converted output power of 0dBm. This device operates error free out to 10 Gbps with -5 dBm input power and shows very low power penalties (<0.8 dB) across the tuning range at 2.5 Gps with very low input signal power (-10 dBm).

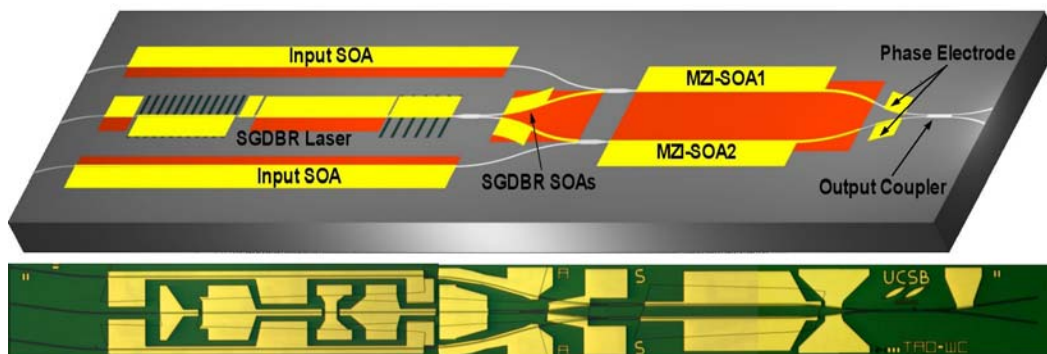


Fig. 1. Schematic and actual die shot of the widely tunable 10 Gbps all-optical wavelength converter with independent phase control using the phase electrodes in the interferometer arms.

2. Device Design and Fabrication

The new tunable wavelength converter design reported consists of a widely tunable sampled grating distributed Bragg reflector (SGDBR) laser monolithically integrated with a semiconductor optical amplifier based Mach-Zehnder Interferometer wavelength converter (MZI-WC) and is shown in Figure 1. The laser is 1.5mm long and has five sections: front mirror, gain section, phase section, back mirror and back facet detector and its operation is described in detail in [5]. The interferometer branches are defined by two S-bends and 1.5 mm long SOAs. The output light of the SGDBR laser is equally split using a 1x2 multimode interference (MMI) based light splitter, and then amplified by 2 in-line SOAs that also serve as part of the interferometer S bends. This amplified light is then coupled with light from the input waveguides using 2x1 MMI combiners into the SOAs in the branches of the MZI. 1.5 mm long MZI SOAs are used to achieve 10 Gbps operation. Each branch of the MZI has a 100 μ m long passive section contacted by a metal pad which is used to adjust the relative phase of the MZI independently of the SOA bias current. This separation of phase control provides for easier optimization of the operating bias point of the wavelength converter as well as better extinction for both inverting and non-inverting modes of operation.

The branches of the MZI are coupled by a MMI based 2x2 coupler at the output. Depending on the relative phase of the MZI branches, the output light will be split between the two output waveguides with two extreme cases: for the phase difference of -90 deg, all of the light will be coming out of one waveguide whereas for the phase difference of +90 deg, all of the light will be coming out of the other waveguide. The two outputs are used to constantly remove the light from the chip (this is different from our previous design [4]), which helps prevent light resonance buildup. Both of the output waveguides are curved and tapered before they reach the facet in order to minimize the back reflections.

The input signal is coupled onto the chip through a tapered, angled input waveguide, and then amplified by 2 SOAs running alongside the laser. In order to reduce the thermal crosstalk, the input SOAs are about 200 μ m away laterally from the SGDBR active regions. The total chip size is 0.5x5.3mm.

This device is fabricated using an MOCVD grown offset quantum well integration platform [4]. The layer structure consists of a 350nm thick 1.4Q quarternary waveguide followed by a 7 quantum well active region and a thin InP cap. The fabrication process requires only a single MOCVD regrowth and is similar to [4].

3. Results

The input signal at 1570nm was externally modulated with NRZ 2^{31} -1 PRBS data at both 2.5 and 10 Gbps. Light was coupled into and out of the device using conically-tapered lensed fiber. The converted output wavelength was filtered using a thin-film tunable filter and detected with an Agilent 83434A 10Gb/s lightwave receiver. For non-inverting mode of operation, both of the SOAs are biased by equal electrical currents, and the relative phase of the two branches is adjusted using the phase electrodes to cancel out the two signals. As can be seen in Fig. 2, it takes about 5 mA to turn the interferometer off completely; therefore, the new method of phase control is very efficient. For inverting mode of operation, the MZI-SOA bias needs to be adjusted in such a way that the powers of the CW signals in the MZI branches are equal for maximum input power of the data stream. Representative tuning of the device to 4 different output wavelengths over a 35nm tuning range is shown in Fig. 3 and these are the same wavelengths used in the BER measurements.

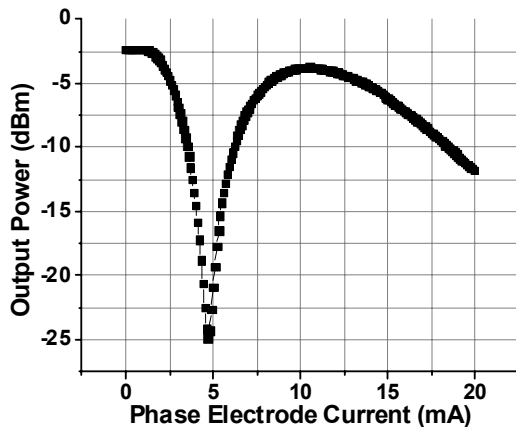


Fig. 2. Static extinction curve of the MZI

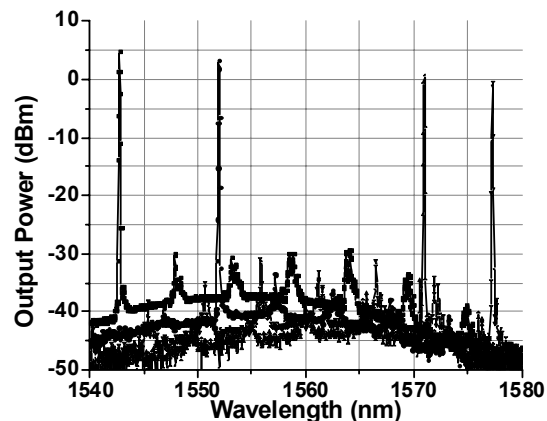


Fig. 3. Overlapped optical spectra of the on-chip tunable laser

The measured BER curves are shown in Fig. 4. The data input power was only -10dBm at 2.5Gbps and -5dBm at 10Gbps. The average output power of the wavelength converter was around 0dBm. At 2.5 Gbps the maximum power penalty measured was 0.8dB which can be attributed mainly to the ASE noise generated by on-chip SOAs. At 10Gbps, the power penalty was measured as low as 1.4dB for output wavelengths between 1542-1555nm. The penalty increased to around 3dB, and the BER slope decreased for longer wavelengths (above 1570nm), which can be attributed to SNR and extinction ratio degradation for wavelengths near the band edge. We expect that these numbers could improve with future device designs.

4. Conclusions

We have demonstrated for the first time error-free operation at 2.5 and 10 Gbps of a novel all-optical widely-tunable wavelength converter monolithically integrated in InP. The output tuning range of the device is 35nm (1542-1578nm), and less than 0.8dB power penalty is measured for 2.5Gbps NRZ operation at -10dBm input power. Error-free operation at 10Gbps NRZ with less than 3 dB is measured over the entire tuning range with input power of -5dBm. The average output power of the device is 0dBm. This work is supported by the DARPA/MTO CS-WDM Program under Grant No. N66001-02-C-8026

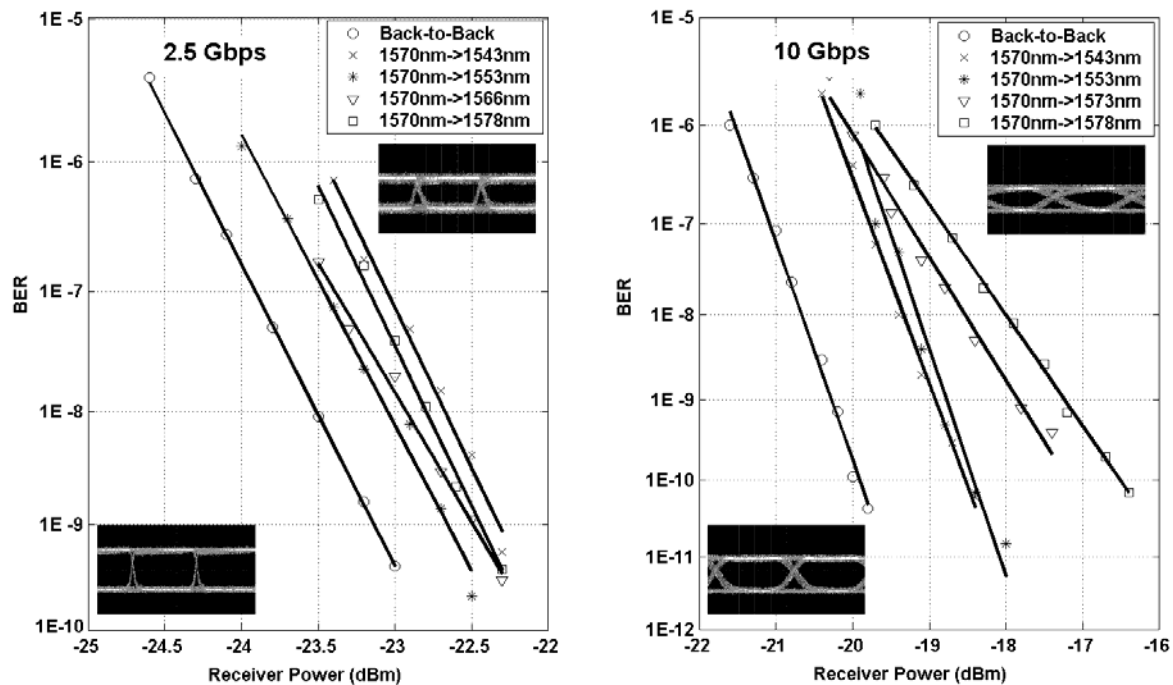


Fig. 4. BER plots for 2.5Gbps operation with -10dBm input power, and for 10Gbps operation with -5dBm input power. The insets also show the back-to-back received eye (bottom) and the converted eye from the device (Top) at the respective data rates

- [1] X. Pan, J.M. Wiesenfeld, J.S. Perino, T.L. Koch, G. Raybon, U. Koren, M. Chien, M. Young, B.I. Miller, C.A. Burrus, "Dynamic Operation of a Three-Port, Integrated Mach-Zehnder Wavelength Converter", *IEEE Photonics Technology Letters*, 7, IEEE, 995-97. (1995)
- [2] W. Idler, K. Daub, G. Laube, M. Schilling, P. Wiedemann, K. Dutting, M. Klenk, E. Lach, K. Wunstel, "10 Gb/s Wavelength Conversion with Integrated Multiquantum-Well 3-Port Mach-Zehnder Interferometer" *IEEE Photonics Technology Letters*, 8, IEEE, 1163-65. (1996)
- [3] C. Janz, F. Poingt, F. Pommereau, W. Grieshaber, F. Gaborit, D. Leclerc, I. Guillemot, M. Renaud, "New All Active Dual Order Mode (DOMO) Mach-Zehnder Wavelength Converter For 10 Gbit/s Operation", *ECOC 99, Nice, France*
- [4] "Monolithically Integrated Mach-Zehnder Interferometer Wavelength Converter and Widely-Tunable Laser in InP" M. L. Masanovic, V. Lal, J. S. Barton, E. J. Skogen, L. A. Coldren and D. J. Blumenthal, *IEEE Photonics Technology Letters*, 15 (8), August (2003).
- [5] V. Jayaraman, Z. Chuang, and L. Coldren, "Theory, Design, and Performance of Extended Tuning Range Semiconductor Lasers with Sampled Gratings," *IEEE J. Quantum Electron.*, vol. 29, pp. 1824-1834, 1993.