10Gbit/s wavelength conversion using a widely-tunable series push-pull photocurrent-driven transmitter

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Abstract— Error-free operation at 10 Gbit/s was demonstrated for a hybrid connected photocurrent-driven series push-pull Mach-Zehnder based wavelength converter (TPDMZ-WC). Back-to-back power penalties of <1dB were measured across the 37nm wavelength tuning range of the SGDBR.

***Index Terms*— Quantum well lasers, photodiodes, optical receivers, optical transmitters, optical planar waveguide components, tunable lasers, optical modulation, wavelength conversion, photocurrent driven wavelength conversion**

I. INTRODUCTION

Widely-tunable wavelength converters are widely regarded as critical to the scalability, flexibility, and cost of future optical networks. These devices have opportunities for deployment in optical switches, routers and add/drop multiplexers. Essentially, they enable Wavelength Division Multiplexed (WDM) signals to be transferred from one wavelength channel to another wavelength channel without requiring off-chip electronic circuitry. Differing approaches have been pursued with devices using cross phase modulation (XPM)[3], differential phase modulation (DPM)[4], and/or cross absorption modulation (XAM) of SOAs. High performance has been obtained with both discrete and monolithically-integrated tunable all-optical wavelength converters (TAO-WC)[6].

Photocurrent-driven (PD-WC) devices have been demonstrated [1,8,9] using either the direct modulation of a laser[9], or external modulation using either an Electro-absorption (EA)[1,9], or Mach- Zehnder modulator.[8] PD-WCs do not require an optical filter to reject the input signal at the output which is desirable particularly with wavelength tunable applications where the response time of a filter could limit system performance. 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, low cost, and transmits at high speed.

II. WAVELENGTH CONVERTER DESIGN

This particular implementation uses a hybrid-integrated widely-tunable wavelength converter based on a series push-pull SGDBR-SOA-MZ transmitter[10] and offset QW based photo-detector receiver (fig.1&2)[11].

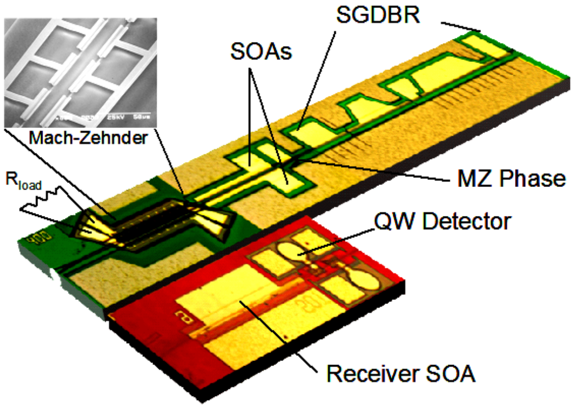

Fig. 1 Device Layout

A tunable transmitter using a 400µm long series push-pull driven Mach-Zehnder modulator electrode structure was fabricated similar to the structure shown in [7]. This structure can improve the bandwidth of the modulator by roughly a factor of two compared with a single-side drive configuration. The receiver for this device consisted of a 600µm long tapered semiconductor optical amplifier (SOA) (from 3µm to 9µm) with a 50µm long offset-QW detector that was tapered down from 9µm to 6µm and nominally reverse-biased to -4.5V[11]. Both devices were fabricated using the same offset-QW base structure[6,8,9] with compatible processing steps and regrowth. The total footprint of the chips is less than 1mm x 3.8mm. The bias configuration is shown in Fig. 2 and uses a load resistor termination at the end of the

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electrode as shown in Fig 1. The detector and the front end of the modulator were both probed with separate bias Ts. This allows the Mach-Zehnder modulator to operate at low bias (-0.5V), favoring reduced insertion losses and the detector to be reverse-biased higher (-4.5V) for improved efficiency.

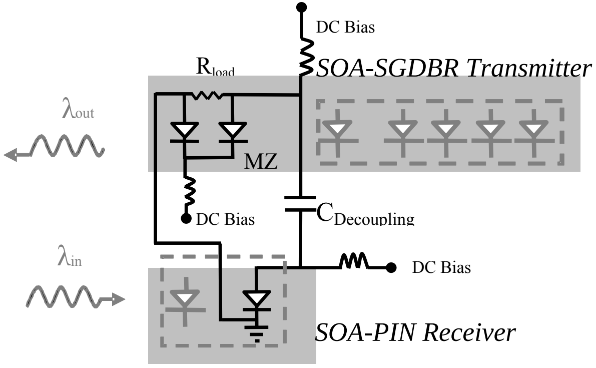

Fig.2. Series Push-pull MZ photocurrent-driven wavelength converter configuration

Despite some additional bias circuitry, this configuration has the added benefit that the device may be biased to achieve zero chirp for inverting and non-inverting operation, and DC power does not dissipate across the resistive load for identical MZ branch biases.

III. RECEIVER CHARACTERISTICS

Integrating the SOA with a detector allows the fabrication of a high-gain, high-saturation power receiver. Figure 3 shows the optical gain at 1548nm for various input optical powers as a function of bias current.

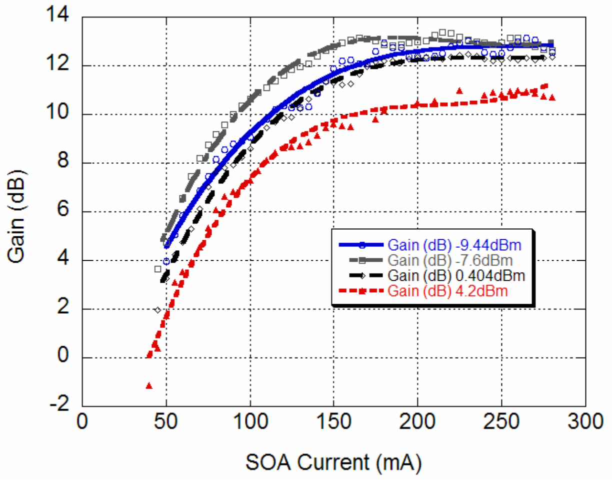

Fig. 3 Optical gain of the SOA in receiver as a function of optical input power at 1548nm. (A current density of 8.33kA/cm corresponds to 250mA bias)

This added gain improves the operation sensitivity of a photocurrent driven wavelength converter significantly as compared with previous work[8,9] allowing successful operation with only 1.3mW coupled input power.

IV. WAVELENGTH CONVERSION RESULTS

As an optical input signal is fed into the receiver, photocurrent is generated resulting in a voltage swing applied to the transmitter. This voltage swing was measured at 10Gbit/s as a function of the coupled input power. Due to the bias T's used in the hybrid scheme, approximately 2dB of electrical loss at 10GHz was present.

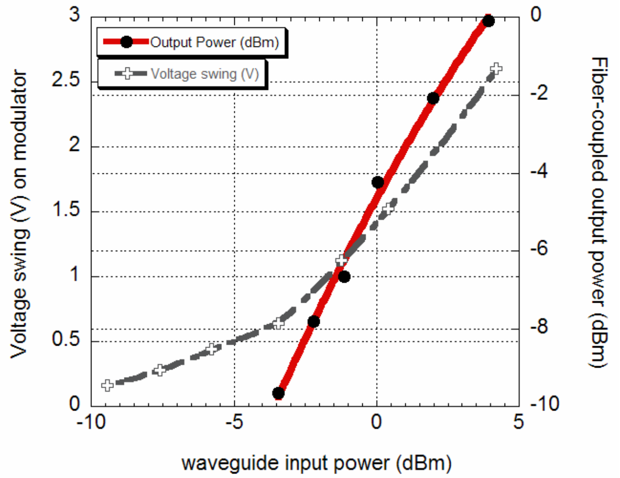

Fig. 4. Voltage swing applied to the modulator and the fiber coupled output power. Input wavelength 1548nm Output 1555nm. Coupling loss for input ~6dB and output ~4dB

The fiber-to-fiber insertion loss of the device is approximately 10dB, however, is only 0dB without input and output fiber coupling loss.

The small-signal optical-to-optical bandwidth (S_{21}) was measured for the wavelength converter with an input signal at 1548nm and converted signal at 1555nm for various biases on each branch of the Mach-Zehnder modulator. The 50ohm terminated 3dB bandwidth corresponding to the modulator and detector independently were ~30GHz and ~20GHz respectively. The optical-to-optical wavelength converter bandwidth is given in fig. 5. As can be seen in fig. 5, an optical bandwidth suitable for 10Gbit/s operation is obtained with a 50ohm termination on the detector and modulator. Modest voltage dependence of the bandwidth is due to the depletion of the PN junction in the waveguide of the MZ structure.

Transmission though the wavelength converter was measured for NRZ 2^7-1 PRBS 10Gbit/s data generated at an input wavelength of 1548.1nm using a 12 Gbit/s BERT and Agilent 83433A transmitter. An EFDA was used to boost the power to 8dBm fiber power, in which the signal was optically filtered and the polarization controlled to achieve 1.3mW of coupled optical power in the receiver waveguide.

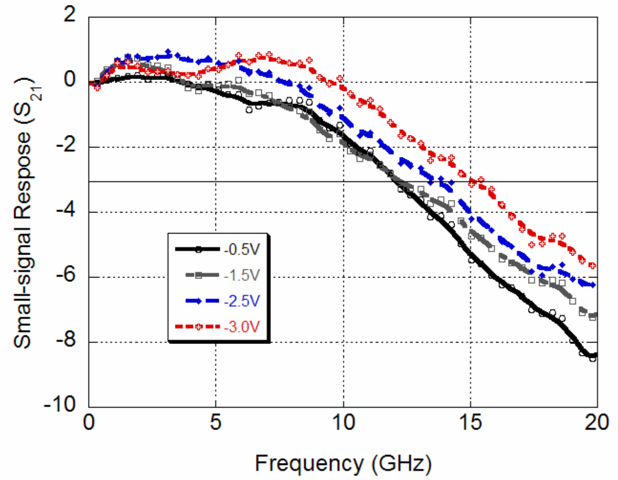

Fig 5. Optical-to optical small-signal response of WC with 50ohm termination. Detector biased at -4.5, MZ bias varied as shown in figure with the same bias on each branch.

The converted signal from the integrated transmitter at λ_2 was measured using an Agilent 11982A receiver without preamplification. Typical back-to-back bit error rate (BER) measurements are shown in fig. 6. The PRBS 10 Gbit/s output waveforms corresponded to 12-13 dB extinction across the wavelength range.

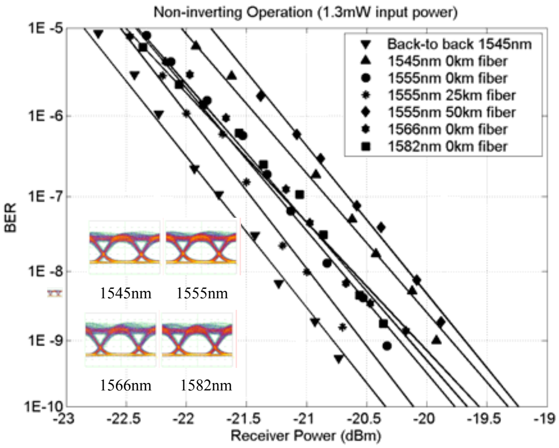

Fig. 6 BER for 10 Gbit/s NRZ 2^7-1 PRBS for different output wavelengths and fiber transmission. Input wavelength = 1548nm >12dB RF extinction for all wavelengths. Gain = 150mA SOA#1 70mA, SOA#2 80mA, FM = 0.5mA, Rear Mirror = 0.5mA, phase = 0mA

Error-free wavelength conversion was achieved over a wide range (37nm output) with less than 1dB power penalty. Transmission through Corning SMF-28 fiber was also measured for 25km and 50km distances at 1555nm yielding <1.2dB power penalty.

V. CONCLUSION

We demonstrate a hybrid wavelength converter that achieves 10Gbit/s operation. The use of high-gain, high saturation power receivers coupled with high bandwidth efficient modulators have been shown to allow the realization of viable wavelength conversion at high bit rates. We have demonstrated error-free wavelength conversion over 37nm with <1dB power penalty, and low input power (1.3mW) using a novel series push-pull photocurrent driven wavelength converter. Both chips utilize the same epitaxial platform and processing steps leading to simple integration.

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