

10 Gb/s Photocurrent Driven, Widely Tunable Electroabsorption Modulator Based Wavelength Converter

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Abstract: An electroabsorption modulator based photocurrent driven wavelength converter has been fabricated and characterized. Bit Error Rate measurements at 10Gb/s show less than 2.5dB power penalty over 30nm with 10dB extinction and input fiber-coupled power less than 2mW.

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1. Introduction

Wavelength agile photonic integrated circuits are key components for increased functionality in next generation optical networks. As these functionalities drive to higher bit rates and complexity levels, the benefits of monolithic integration such as scalability and reduced packaging costs become increasingly important. In particular, components such as wavelength converters that have the potential to reduce blocking probabilities and provide dynamic wavelength management in high traffic WDM networks have become more and more attractive. Recently, wavelength converters based on photocurrent driven technology, where an input optical signal is detected and used to drive a reverse biased Electroabsorption modulator, have been shown to support data rates up to 320 Gb/s [1]. Of particular interest is the single-chip, monolithically integrated photocurrent driven device where an optically preamplified receiver is used to reduce power requirements for wavelength conversion with no additional drive electronics. Such devices have been demonstrated using a common InGaAsP/InP materials platform with both Electroabsorption (EAM) and Mach Zehnder (MZM) Modulators integrated with a widely tunable Sampled Grating DBR (SGDBR) laser, Semiconductor Optical Amplifiers (SOA), and a photodetector. Data rates up to 2.5 Gb/s have been demonstrated with wide tunability [2, 3]. However, this approach has suffered from high input power requirements. In this work a shallow multi-quantum well stack has been introduced into the modulator layer structure for higher modulation efficiency without a corresponding increase in capacitance compared to previously reported Franz Keldysh devices [2]. In addition, a high gain optical pre-amplifier has been included for lower input power requirements.

2. Device architecture and epitaxial layer structure

The wavelength converter architecture consists of two neighboring ridges interconnected with a coupling capacitor and terminated with a load resistor. A transmitter ridge contains a standard four section widely tunable sampled grating DBR laser [4] monolithically integrated with a 300- μm -long SOA and a 400 μm EAM. A receiver ridge contains a monolithically integrated input optical pre-amplifier and photodetector. The pre-amplifier is 600 μm long and has been flared from 3 μm to 9 μm wide for high saturation power and gain. The reverse biased photodetector is 50 μm long, contains laser offset quantum wells (OQW), and is tapered from 9 to 6 μm . For wavelength conversion, the EAM and the photodetector were individually probed. The photodetector probe contained an integrated 50- Ω load while the EA modulator probe had no load. The two devices were interconnected with a high-speed RF cable and individual Bias-T's. A schematic is shown in fig 1.

The transmitter epitaxial layer structure incorporates a dual quantum well stack design. A set of offset quantum wells [4] provides gain in the laser (Photoluminescence = 1550 nm) while a separate set of quantum wells, centered in the InGaAsP quaternary waveguide (PL = 1300 nm), provides broadband modulation efficiency when reverse biased in the EAM. The centered QW stack contains 7 x 90 Å compressively strained wells and 6 x 50 Å tensile strained barriers (PL = 1465 nm). The receiver layer structure consists of the same OQW stack, but does not have the centered wells that are present in the transmitter. Currently, the receiver and transmitter are not monolithically integrated. However, the low PL (1465 nm) of the centered wells, suitable laser tuning characteristics (tuning > 30 nm), and the fact that the both sections have identical regrowth and fabrication steps, shows that the dual quantum

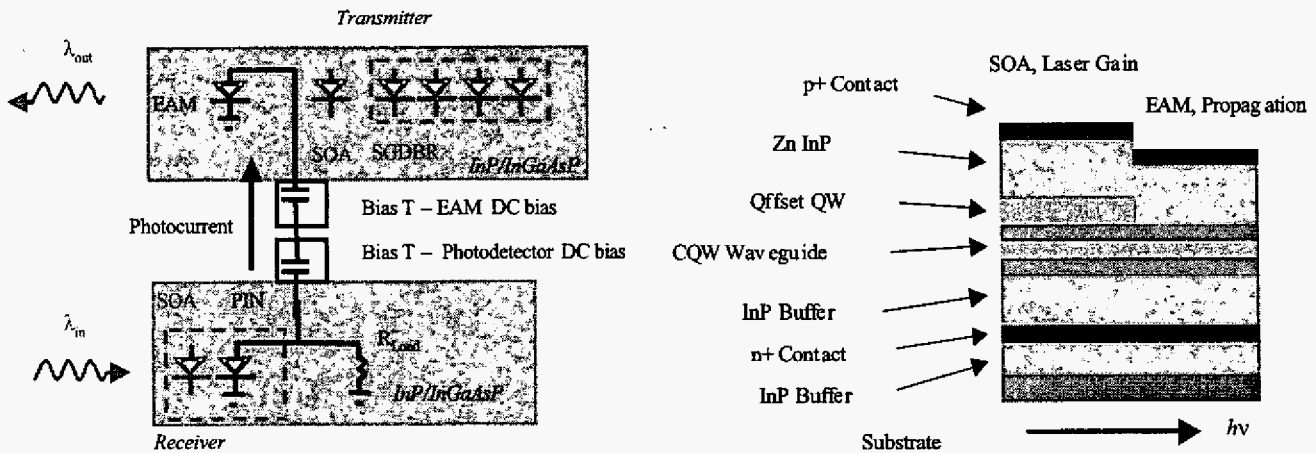


Fig 1. Wavelength Converter Bias schematic (left) and Transmitter epi-layer stack (right).

well base structure should be well suited for single chip wavelength converter fabrication. A schematic of the CQW and OQW transmitter layer stack is shown in fig 1.

3. Results

DC extinction curves, receiver characteristics, bandwidth measurements and BER curves have been generated for the 50 Ω terminated EA based wavelength converter device. In these experiments, the laser gain section, pre-amplifier SOA, and transmitter SOA are biased at 160 mA, 250 mA, and 120 mA respectively and the device was maintained at 16^o C with a thermoelectric cooler. DC extinction measurements for the 400 μ m EAM show greater than 20 dB extinction over 30 nm with less than -4V bias. Results are shown in fig 2. Receivers were characterized by measuring the voltage swing over the 50-ohm loaded probe on the photodetector through the RF cable and both Bias-T's as shown in fig 1. A 1548.1 nm input optical signal at various optical power levels was fed into the optical pre-amplifier under various SOA bias currents. The photodetector was biased to -4.5 V for maximum efficiency. A peak-to-peak voltage swing of greater than 2.5 V can be seen with waveguide powers up to 3 dBm. A summary of the results can be seen in fig 2.

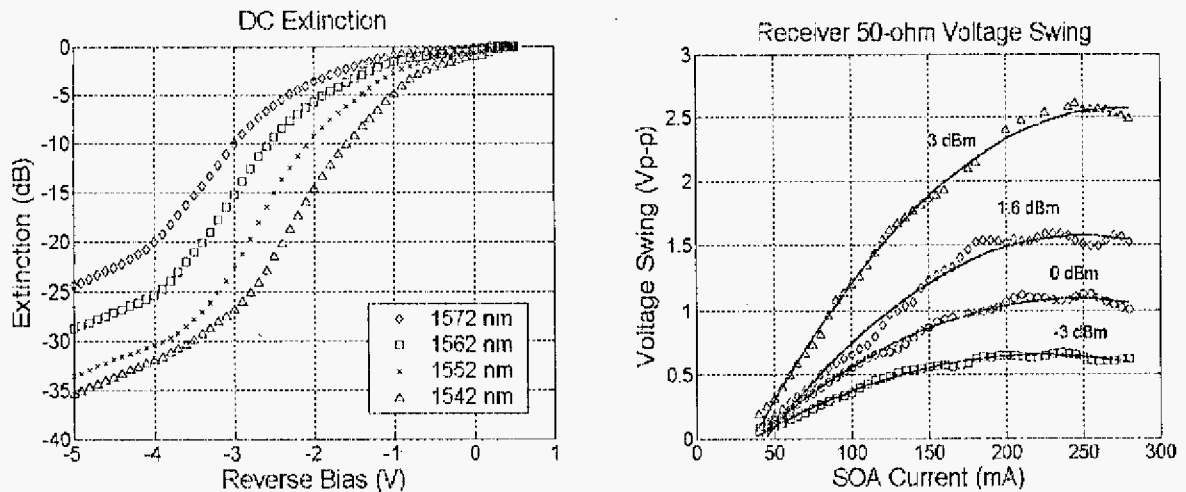


Fig. 2. DC Extinction Characteristics for EA Wavelength Converter (left) and 50 ohm terminated Receiver Characteristics (right). Receiver input wavelength is 1548.1 nm at 10 Gb/s with 2⁷-1 NRZ data. Waveguide power levels are indicated for various SOA bias currents.

Bandwidth measurements were performed for 50 Ω terminated discrete EA modulator and photodetector separately and for the integrated wavelength converter. S₂₁ results showed ~10 GHz and ~20 GHz bandwidth for modulator

OTuM4

and photodetector respectively and ~ 7 GHz optical to optical bandwidth for the wavelength converter (1548.1 nm to 1565 nm). For these experiments, the photodetector bias was again set at -4.5 V. Bit-error-rate (BER) curves with eye diagrams have been generated. For the BER measurements a nonreturn-to-zero (NRZ) $2^7 - 1$ pseudorandom bit stream at 10 Gb/s from a 10 Gb/s BER tester transmitter (Agilent 83433A) at a wavelength of 1548.1 nm was input into a high power Erbium Doped Fiber Amplifier (EDFA) followed by a polarization controller and an optical filter and transmitted to the device under test using a conically tipped lensed fiber. In this experiment, 4.9 mW of optical fiber power corresponding to 1.7 mW of coupled waveguide power was used and the extinction ratio of the input signal was 14 dB. Input and output coupling losses are estimated to be 5 dB and 3 dB respectively. The output optical signal of the WC was then input into a variable optical attenuator before entering the PIN Receiver. Note that no optical output filtering or amplification was required. Error-free operation has been achieved with a power penalty of less than 2.5 dB at 10 Gb/s. Results for Extinction Ratio and output power over wavelength as well as BER curves are shown in fig 3.

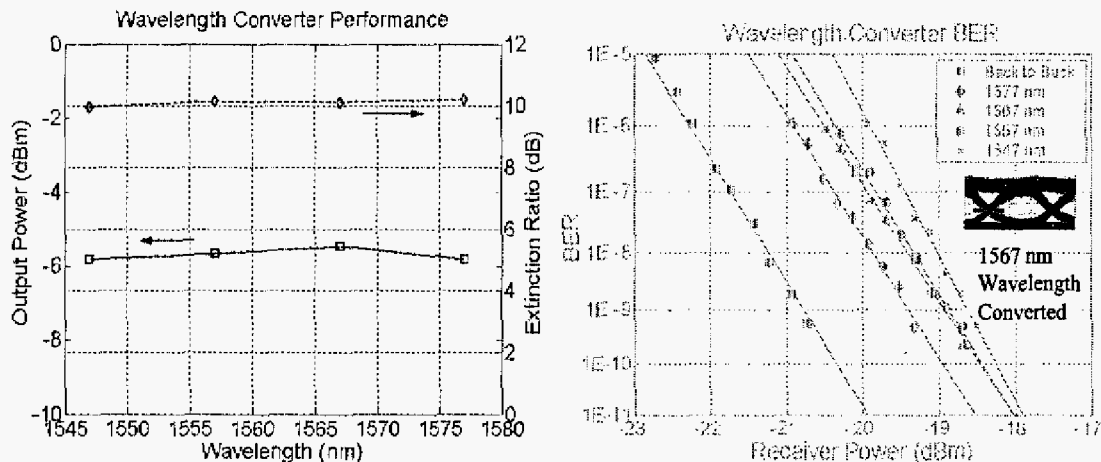


Fig. 3. Extinction Ratio and average fiber coupled output power (left) and 10 Gb/s BER curves for 50 Ω terminated EAM based wavelength converter (right). Input wavelength is 1548.1 nm with waveguide power level of 1.7 mW. Converted wavelength is indicated.

4. Conclusions

We have demonstrated wavelength conversion over 30 nm at 10 Gb/s with 10 dB optical extinction and less than 2.5 dB power penalty. Wavelength conversion required less than 5 mW (+6.8 dBm) of input fiber power and less than 2 mW (+2.3 dBm) of waveguide power. If input and output fiber coupling is neglected, overall device efficiency is estimated at only 5 dB loss with integrated high power receivers and efficient, centered QW transmitters.

5. References

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