Field-Modulated Packet Forwarding Chips for Label-Switched Optical Routing

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Abstract: We demonstrate a single-chip 40 Gb/s wavelength converter based on an SG-DBR laser and field-modulated optical gate. This device also performs 10 Gb/s label encoding for all-optical packet forwarding.

OCIS codes: (230.7405) Wavelength conversion devices, (140.3600) Lasers, tunable (250.7360) Waveguide modulators.

1. Introduction

Wavelength division multiplexing (WDM) has become the enabling technology for utilizing the available bandwidth (BW) in fiber optic links. However, as BW usage increases, the capacity of the network nodes must be scaled to accommodate larger amounts of data received and transmitted through each fiber. The capacity of today's OEO routing architecture will soon approach its limit in terms of processing and buffering requirements, as well as overall power dissipation. To resolve these issues, next generation WDM networks will necessitate that much of the routing functionality be performed in the optical domain. One proposed method is all-optical label switching, which allows individual IP packets to be optically routed by dynamic wavelength assignment [1]. Labels which are written onto each payload are identified using a look-up table to control the output wavelength of a tunable wavelength converter. This type of architecture allows for minimal electronic processing and can support very high bit rates, since only the labels must be electronically recovered at each node.

In this work, we present a novel packet forwarding chip (PFC) which can be used as the core component for label-switched routing. This device performs wavelength conversion of data up to 40 Gb/s and additionally has the capability to write, or rewrite labels at 10 Gb/s. Wavelength conversion is accomplished by a field modulation technique, which combines a high-power receiver with an electroabsorption modulator (EAM) to create a high-speed optical gate. The EAM modulates the output of an on-chip tunable laser to transcribe the input data signal onto the selected output wavelength of an on-chip tunable laser. A second EAM is also integrated in this device to allow external modulation for label encoding to the same output wavelength.

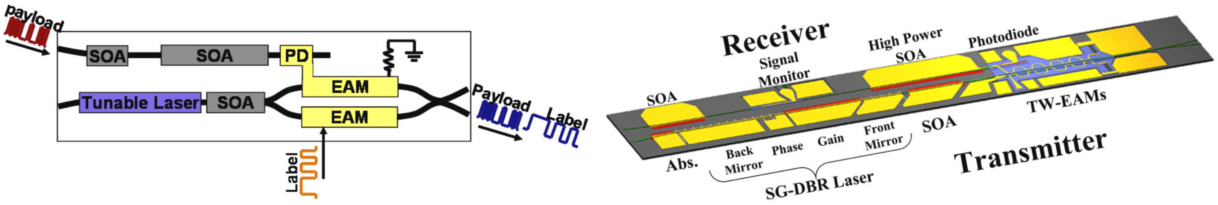

Fig. 1. (left) Field modulated PFC diagram depicting wavelength conversion and label writing functions. (right) Schematic of fabricated device showing integrated components. Footprint is 4.0 mm x 0.55 mm.

Although similar packet forwarding chips using SOA-based wavelength conversion have previously been demonstrated [2], the field-modulated approach offers a number of advantages for optical routing applications. These include increased network transparency, conversion to a similar (or the same) wavelength as the input signal, and elimination of optical filtering requirements at the output. Furthermore, field-modulated wavelength converters have demonstrated the potential for 2R, or 3R regeneration [3], which will be beneficial for cascaded optical routing through multiple nodes.

2. PFC design

The PFC is a highly-complex photonic integrated circuit that requires multiple components with diverse functionalities on a single chip. The device is separated into two ridge-waveguide regions which differentiate between the receiving and transmitting functions of the device. The receiver side consists of two SOA preamplifiers followed by a high-power photodiode (PD). The transmitter side consists of a widely tunable sampled grating (SG)-

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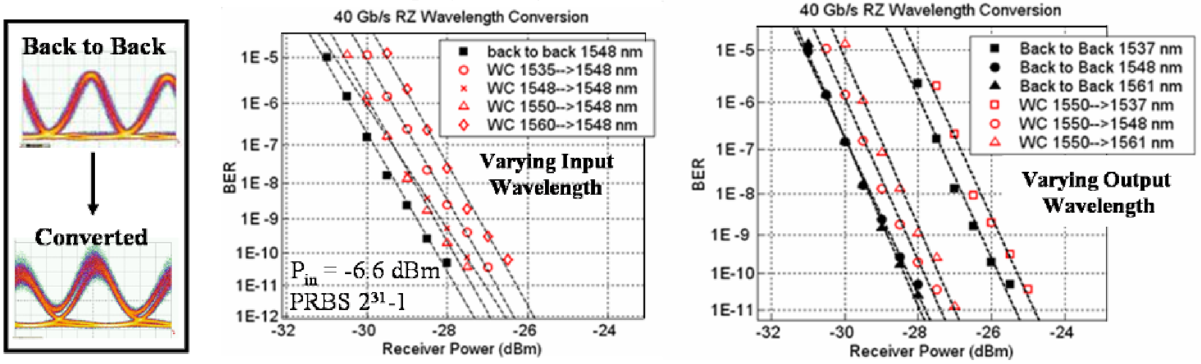
DBR laser, followed by an output SOA and two parallel EAMs. The SG-DBR laser light is coupled through both EAMs using a 1x2 MMI splitter followed by a 2x2 MMI combiner at the output. Figure 1 shows a basic diagram of the PFC architecture as well as a device schematic showing each of the components drawn to scale.

This device was fabricated using a dual quantum well integration platform [4] on a S-doped InP substrate. The layer structure consists of a single waveguide core with two multi-quantum-well (MQW) stacks. An offset MQW provides gain for the active components while the centered MQW is designed to provide modulation efficiency. The offset MQW is selectively removed from passive regions prior to a single blanket regrowth of the p-type InP cladding and p-contact layer. Wavelength conversion relies on directly driving the EAM with the PD photocurrent; therefore achieving high output saturation power in the receiver is very important. To improve the receiver saturation characteristics, the PFC uses a laterally flared waveguide SOA design followed by an offset MQW-PD [5]. In this device, the receiver is capable of 20 dB of gain with 32 mA of DC photocurrent generation at the 1-dB gain-compression output power. We have implemented an advanced traveling wave (TW) design in the EAMs to achieve very high BW. Both the converting and label-writing EAM make use of periodic microstrip electrodes and selectively undercut waveguide geometry to raise the characteristic impedance and improve velocity matching [6]. The absorption-edge of the centered MQW (10 wells) has been chosen to be 1470 nm to achieve low passive loss but high modulation efficiency when biased. Under reverse bias, the 250 μm long modulator achieves 10-14 dB/V modulation efficiency across 30 nm of tuning from the SG-DBR laser. Integrated thin film resistors (25 Ω) are also included to terminate the EAMs and simplify biasing.



(a) (b) (c)

Fig 2. (a) 40 Gb/s back-to-back (1550 nm) and wavelength converted eye diagrams (1550→1548 nm) (b) Wavelength converted BER measurements for varying input wavelength and (c) varying output wavelength compared with back-to-back transmission.

3. Wavelength Conversion Performance

The wavelength conversion performance of the PFC has been evaluated by bit error rate (BER) measurements using 40 Gb/s RZ data. The receiver SOAs were biased to 8 kA/cm^2,, which was determined to give the highest saturation power. The SG-DBR gain section and output SOA were biased to 5.5 kA/cm^2 and the mirror currents were tuned to achieve the desired output wavelength. The PD-EAM gate bias was chosen to be between -3.5 V and -5.0 V, determined by the maximum slope efficiency of the EAM at each output wavelength. The optimal input power into the device was found to be a trade off between achieving the maximum photocurrent swing and minimal pattern dependence caused by receiver saturation. For RZ data, the optimal input power was determined to be -6.6 dBm, which is slightly below the 1-dB compression point of the receiver. Using this input power, BER measurements were performed for varying input wavelengths to and varying output wavelengths from the PFC. Figure 2 shows the BER measurements for the wavelength converted signals compared with back-to-back transmission. The back-to-back data was taken at the same wavelength as the output of the PFC to eliminate the wavelength dependence in the measurement setup. For 25 nm of input tuning, and 22 nm output tuning, error free operation was achieved with less than 2 dB power penalty compared with the back-to-back. This includes the case of conversion to the input wavelength (1548 nm → 1548 nm). The power penalty shows a minimum when the input wavelength corresponds to the gain peak of the receiver SOAs (1550 nm). The output extinction ratio of the converted signal was measured to be between 10 and 12 dB in all cases. The facet-to-facet conversion efficiency, defined as the ratio of output power to input power, was measured to be between -3 dB and -8 dB.. The lowest conversion efficiency occurred at the shortest output wavelength (1537 nm), due to higher passive loss.. The total power dissipation measured for the PFC during 40 Gb/s RZ PRBS wavelength conversion was 1.5 W.

4. Label Writing Performance

Demonstrations of optical label writing have been performed using PRBS data to modulate the EAM in the other transmitter arm of the PFC. The slower modulation rate of 10 Gb/s NRZ was chosen so that labels could be more easily processed by control electronics in the router architecture. A 2.0 V peak-to-peak drive signal was applied by directly contacting the chip with a ground-signal-ground probe. Again, the DC bias for the EAM was adjusted to take advantage of the maximum modulation efficiency for each wavelength. Figure 3 shows the BER for the 10 Gb/s modulation for varying output wavelengths, along with corresponding eyes diagrams. The output extinction ratio was measured to be 9-10 dB and the output power was -6 to -6.5 dBm. Less than 1 dB power penalty over the output tuning range was observed.

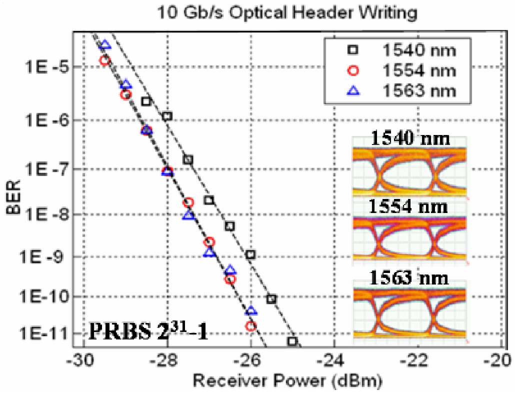


Fig 3. BER measurements for 10 Gb/s NRZ optical label writing for varying SG-DBR wavelengths. Insets show corresponding eye diagrams with 2.0 V peak-to-peak drive.

5. Conclusion

This work has discussed the design and performance of the first field-modulated packet forwarding chip, which can be used for label-switched optical routing. This device demonstrates error free wavelength conversion at 40 Gb/s for over 22 nm of input and output wavelength tuning, with less than 2 dB power penalty compared with back-to-back transmission. Output extinction ratios of greater than 10 dB were measured. This device also enables 10 Gb/s label encoding, with greater than 9 dB extinction for a 2.0 V drive. Future work is focused on dynamic characterization of this device including fast wavelength switching and label encoding of individual packets to demonstrate wavelength selected routing.

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