40Gb/s tandem electro-absorption modulator

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Abstract: NRZ and RZ data transmission at 40Gb/s are demonstrated for the first time using buried heterostructure tandem electro-absorption modulators monolithically integrated with a semiconductor optical amplifier and input/output spot-size converters. Zero penalty RZ transmission over a 100km dispersion managed link is achieved.

OCIS codes: 250.0250 Optoelectronics, 060.0060 Fiberoptics and optical communications, 250.7360 Waveguide modulators, 060.4080 Modulation

Introduction

Electro-absorption modulated sources are key components for current and next generation 40Gb/s fiber transport systems. EA modulators offer advantages in compactness, low cost, compatibility with monolithic integration, and lower drive voltages. In this paper we describe the design, fabrication, and transmission performance of 40Gb/s EA modulators configured for both NRZ and RZ operation. For NRZ transmission the device structure consists of a short MQW modulator integrated with spot-size converters (SSC) on both the input and output. Tandem EA modulators for pulse carver and data encoder functions were monolithically integrated along with a semiconductor optical amplifier (SOA) and input/output spot-size converters to explore RZ transmission. Both single and tandem modulator designs are realized using semi-insulating InP regrown deep ridge buried heterostructure technology. Modulation bandwidths of up to 40.5GHz are demonstrated along with a fiber-to-fiber insertion loss of 8dB for the single modulator design. The carver/encoder configuration with onboard SOA operates with better than 0dB insertion loss. NRZ and RZ transmission impairments were studied using both designs.

There are significant advantages to using short pulse RZ transmission for long distance 40Gbit/s communications systems [3]. For these systems a transmitter is required that can generate short optical pulses and encode them using data modulation. A semiconductor based Tandem Electro-Absorption Modulator (TEAM) offers a single compact device incorporating both stable short pulse generation and data modulation functions. The first demonstration of a TEAM was at 5Gb/s using two discrete InGaAsP bulk modulators[1]. Fiber-to-fiber insertion loss resulting from the two components was 15dB. To reduce the optical losses, tandem modulators integrated with optical amplifiers have been reported. As a result, tandem device fiber-to-fiber insertion loss was reduced to 9dB, and operation at 20Gb/s was demonstrated [2]. In this work, we report for the first time a tandem EA modulator with better than 0dB insertion loss and greater than 40GHz bandwidth.

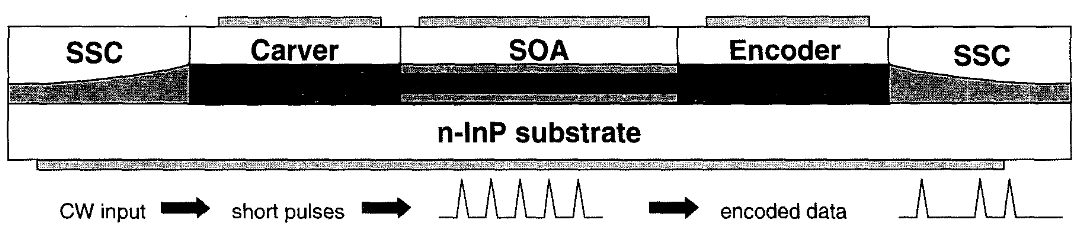

Figure 1. Tandem EA Modulator Structure

Device Design

The tandem modulator consists of a semiconductor optical amplifier sandwiched between two electro-absorption modulators, Figure 1. Spot size converters are used on the input and output waveguide to improve the optical coupling efficiency. The modulators and the SOA have a thin separate confinement heterostructure multi-quantum well active layer. The device is realized using a deep ridge buried heterostructure process. Modulators of varying widths from 2 to 3.5 μm, and lengths of 80, 100, and 120 μm were evaluated with SOA lengths of 400 and 600μm.

Fabrication Procedure

The TEAM-SOA-SSC structure shown in Figure 1 was fabricated by 4 LP-OMVPE growths. First the MQW active region of the two modulators and SOA are formed using selective area growth on a mask patterned substrate. The composition and thickness of wells and barriers have been optimized for high extinction ratio and low modulator chirp. Spot size converters are connected to the modulators by precise dry etching of the active region, followed by SAG assisted butt-joint regrowth of passive waveguides. The SAG growth produces an adiabatic vertical waveguide taper along the length of the spot size converter. Reduced waveguide thickness at the device input and output facets provides good coupling to lensed optical fiber, while a thicker waveguide at the butt-joint yields good mode matching between spot size converter and modulator. In the third step the waveguides are buried under a thick p-InP cladding layer and thin InGaAs contact layer. Narrow mesa stripes are then patterned using conventional photolithography and transferred to an SiO_2 etch mask. The deep ridge mesaís fabricated in the [011] direction are formed in an inductively coupled plasma (ICP) etching system. ICP etching conditions were optimized for mesas with sharply defined vertical side walls and smooth morphology. Following this, the mesas were imbedded in Fe doped semi-insulating InP. LP-OMVPE conditions were optimized for planar regrowth around the deep and narrow dry-etched mesas without the need for growth mask overhang. A thick spin on dielectric was then applied to reduce parasitic capacitance of the p contact pads, which were designed to facilitate flip chip mounting of the device.

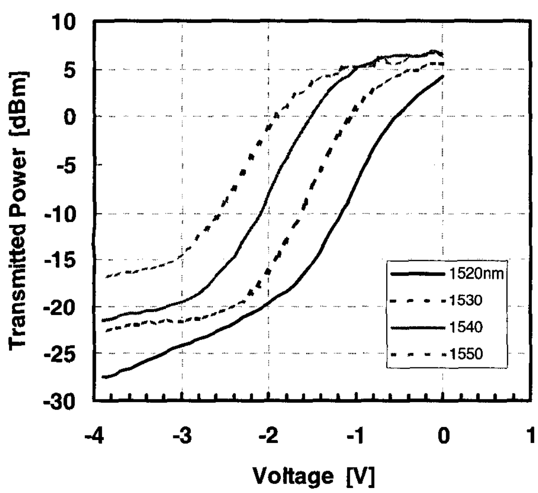

Figure 2. DC Extinction curves for the 120 μm long modulators with 3dBm input power and 100mA of SOA current. Second modulator is open circuited.

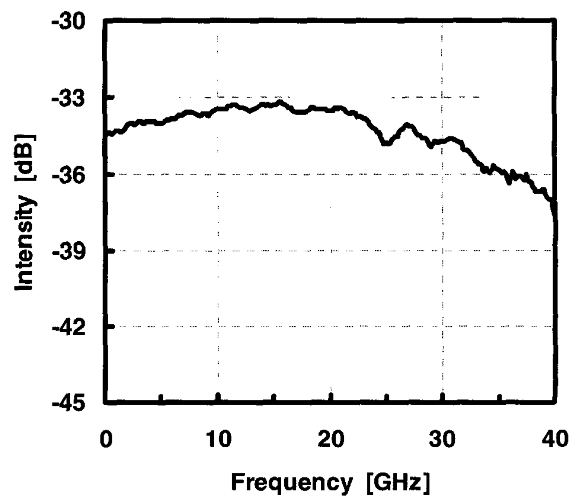

Figure 3. 40 GHz RF Bandwidth for 80μm long modulator

Device Performance

Using a tunable external cavity laser, and lensed fiber coupling optics, extinction ratio and insertion loss were measured for single and tandem modulators. Measured on-state insertion loss for single devices was as low as 8dB. TEAM devices with 600μm long SOAís, displayed up to 8.5dB fiber-to-fiber gain with 150mA SOA bias, open circuited modulators, and 0dBm input power. With both modulators at 0V, 0dB insertion loss was achieved with as little as 50mA SOA bias. Extinction curves for a 120μm long modulator are shown in Figure 2, showing DC extinction of 28dB with ñ3V bias and 20nm detuning between input wavelength and the 0V band edge. Under the same conditions, 80μm long devices displayed 22dB DC extinction. The 3dB bandwidth for the 80μm long modulator was 40.5GHz measured using a network analyzer and a calibrated detector. Dynamic extinction ratios of 13dB were achieved with 2.5Vpp drive voltage at 40Gb/s using an SHF pattern generator. Short pulse generation experiments were conducted using a high power 40GHz sine wave. With a 5Vpp drive, signal streak camera measurements revealed pulse widths of 7ps and 20dB extinction ratio. Pulse widths as short as 5.5ps were achieved at higher drive voltages. Using only the encoder modulator, NRZ 40Gb/s transmission demonstrated an open eye in the presence of up to 60ps/nm total dispersion. This is near the maximum predicted for unchirped pulse. 40Gb/s RZ transmission experiments were conducted using a 10Gb/s BERT with a 4x1 electronic multiplexer and an optical demultiplexer. Back-to-back receiver sensitivity was ñ29dBm, and negligible transmission penalty was obtained over a 100km link, consisting of a launch EDFA, 100km of TrueWaveô fiber, followed by a backward pumped Raman amplifier, and a section of dispersion compensating fiber. The extremely low observed penalty suggests that impairment free transmission can be achieved over considerably longer distances. Excellent NRZ and RZ results also confirm the high bandwidth, high extinction, and low chirp characteristics of this device.

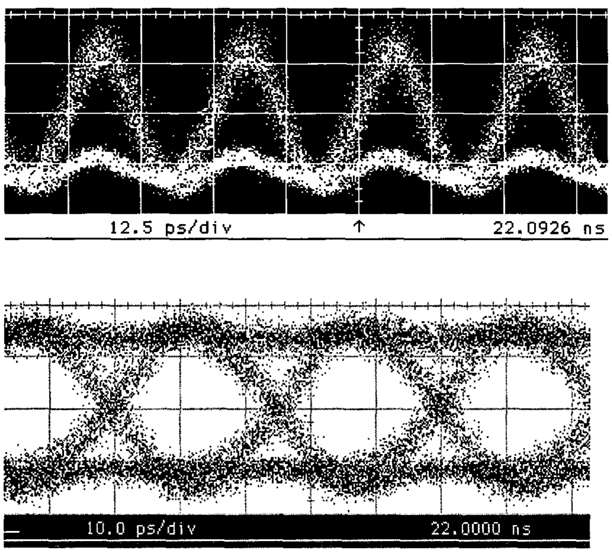

Figure 3. Unfiltered 40Gb/s RZ and NRZ Eye Diagrams. RZ 7ps pulse width is not resolved due to oscilloscope 50GHz bandwidth.

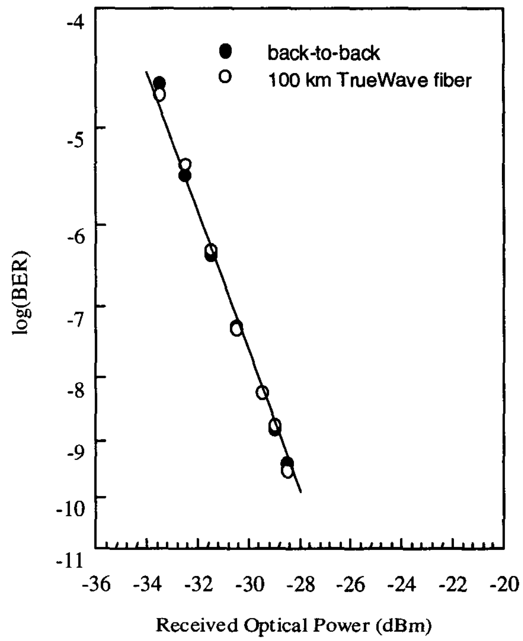

Figure 4. 40Gb/s RZ transmission result.

Conclusions

Using a SI-InP regrown deep ridge buried heterosturcture we have fabricated the first 40Gb/s tandem electro-absorption modulator with integrated semiconductor optical amplifier and input/output spot-size converters. Zero insertion loss, 13dB dynamic extinction ratio, 40GHz bandwidth, and 7ps pulse generation were simultaneously demonstrated. Over standard fiber, near transform limited 40Gb/s NRZ transmission was achieved. With a 100km dispersion managed link, error free 40Gb/s RZ data transmission was demonstrated using carver/encoder operation. The low chirp, wide bandwidth, and good extinction ratio of this device demonstrate itís utility in both short reach and long haul 40Gb/s applications.

References

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