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Widely Tunable 40 Gbps Transmitter Utilizing a High-Impedance Traveling-Wave EAM and SG-DBR Laser

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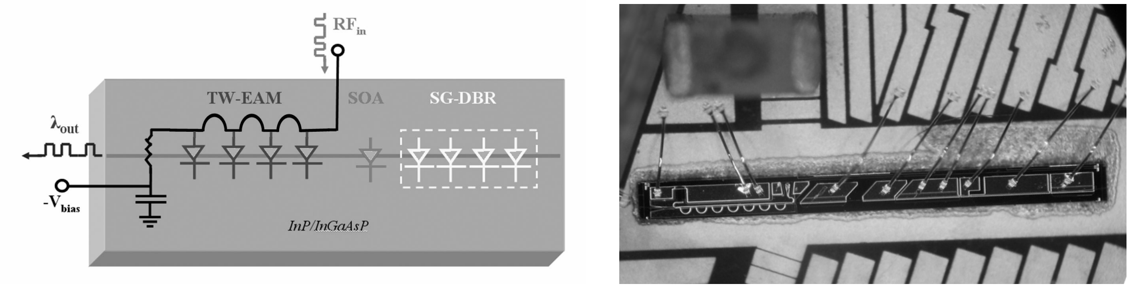
Abstract: A tunable transmitter featuring an SG-DBR laser is integrated with an undercut-etched, high impedance traveling-wave EAM. This device demonstrates 40 Gbps operation with >8.5 dB extinction over 25 nm tuning with 2.1 V drive.

OCIS codes: (140.3600) Tunable lasers; (230.4110) Modulators; (230.4205) MQW modulators; (230.7020) Traveling-wave devices

1. Introduction

Electroabsorption modulators (EAMs) are advantageous optical components for transmission of digital data due to their low drive voltage and high bandwidth. Traveling-wave (TW) designs which utilize transmission line electrodes have shown to significantly enhance the bandwidth of EAMs compared with the RC response of typical lumped element devices. However, one major limitation of most TW-EAMs is the low characteristic impedance of the capacitively-loaded electrode which creates a large mismatch between the device and 50 Ω electronic drivers. Two techniques for reducing the capacitance per unit length of the EAM which have been demonstrated are selective undercutting of the modulator core [1], and periodic loading by distributing the EAM along high-impedance interconnects [2]. Recently, we have implemented both of these methods in the same device to effectively double the characteristic impedance from 20 Ω to 40 Ω as well as achieve velocity matching of the electrical and optical signals [3]. In this work, for the first time, we present a high-impedance TW-EAM monolithically integrated with a sampled grating (SG)-DBR laser and output optical amplifier to form a widely-tunable transmitter. This device demonstrates greater than 15 dB/V DC modulation efficiency and greater than 8 dB extinction at 40 Gb/s over 25 nm of optical bandwidth.



(a) Circuit diagram of integrated transmitter

(b) Photograph of fabricated transmitter on carrier

Fig. 1.

2. Design and Fabrication

The transmitter consists of a five stage SG-DBR laser followed by an output semiconductor optical amplifier (SOA) and TW-EAM which all share a common waveguide. A circuit diagram of the full device is shown in Fig. 1(a). The epitaxial layer structure for this device utilized a dual quantum well waveguide (DQW) [4] with 10 QWs centered in the InGaAsP core for modulation efficiency and 7 offset QWs above the core to provide gain. The photoluminescence peaks corresponding to the band edges of the two QW regions were 1470 nm and 1540 nm, respectively. The offset quantum wells were selectively etched from all but the laser gain and SOA regions before regrowth of the p-type InP cladding. The laser and SOA were designed with a surface ridge waveguide structure which tapered into an undercut waveguide for the modulator region. To achieve the undercut, first a deeply etched ridge was defined by reactive ion etching down into the n-cladding. Then a selective wet etch of sulfuric acid and peroxide mixed with water (1:1:10) was performed for 30 minutes to laterally reduce the width of the InGaAsP core from 3 μm to approximately 1.15 μm. A cross section of the modulator waveguide is shown in Figure 2. For this amount of undercut, simulations of the mode profile as a function of the waveguide core width show less than 2 percent decrease in the modal overlap with the centered quantum wells. Therefore the modulation efficiency is not significantly affected when the diode junction capacitance is reduced.

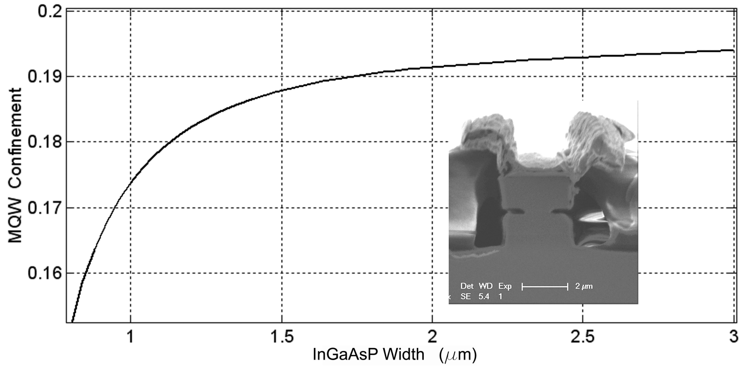
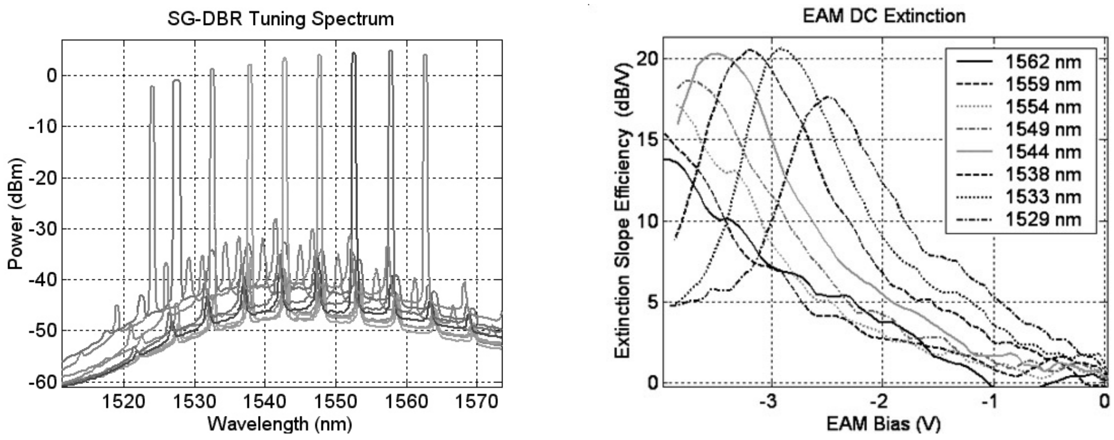


Fig. 2. Overlap of the optical mode with the EAM quantum wells for varying amount of undercut. Inset: cross section of the EAM waveguide.

Following the undercut etch, the EAM structure was buried with photo-defined benzocyclobutene (BCB) as a low-k dielectric. The BCB was etched to expose the modulator ridge top before metal contacts were formed. The modulator electrode was designed as a segmented microstrip line which alternated between passive and EAM-loaded sections. Over the 1600 μm of total length, the microstrip electrode contacted the ridge in eight separate 50 μm sections, yielding an effective modulator length of 400 μm. The optical path length between modulator sections was designed to match the phase of the electrical line to maintain coherent interaction of the two traveling waves along the entire length. A coplanar waveguide (CPW) was implemented at the input of the EAM electrode for directly contacting with a high-speed probe. At the opposite end of the EAM, a thin-film 35 Ω thin film NiCr resistor was deposited by e-beam evaporation. The resistor was followed by on-chip, and off-chip capacitors in parallel to provide an RF ground as shown in the device photograph. (Fig. 1(b))



(a) Supermode tuning spectrum of SG-DBR laser

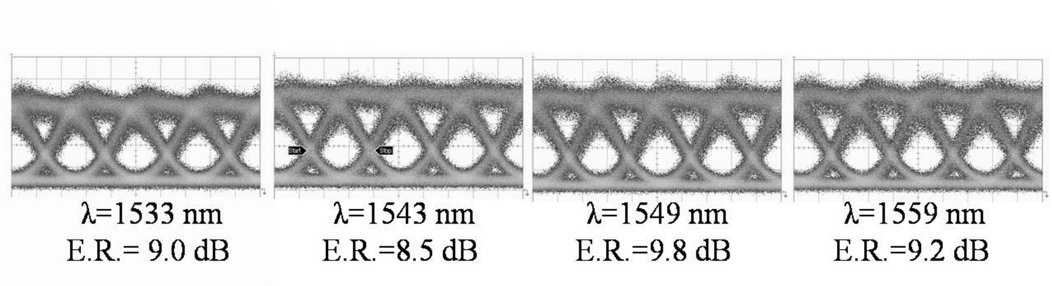
(b) DC modulation efficiency of the periodically loaded, undercut TW-EAM over the SG-DBR tuning range.

Fig. 3.

3. Transmitter Results

The fabricated SG-DBR laser is continuously tunable over the range of 1524 nm to 1563 nm. Figure 3(a) shows the tuning over 9 supermodes achieved by vernier tuning of the front and rear mirrors with laser and SOA bias currents of 125 mA and 75 mA, respectively. The side mode suppression ratio is greater than 30 dB in all cases. The variation in the output power from -2 dBm to 4 dBm is caused by both the gain spectrum of the offset QWs and the wavelength-dependent loss of the centered wells. The DC extinction characteristics of the TW-EAM were measured for reverse biases of 0 to 4 V over the wavelength range of the SG-DBR. As shown in Figure 3, the bias point of the modulator can be optimized to achieve greater than 15 dB/V peak extinction efficiency for more than 30 nm of output tuning. The efficiency of the modulator begins to decrease at the longer wavelengths because of the larger detuning between the optical energy and the band edge of the quantum well.

Dynamic, large signal modulation experiments have been performed at 40 Gb/s non-return-to-zero (NRZ) to demonstrate the high bandwidth of this device. Figure 4 shows the observed optical eye diagrams of for wavelengths of 1533, 1543, 1549, and 1559 nm with 2.1 V peak-to-peak drive. The EAM bias was -1.9, -2.5, -3.0 and -3.4 V, respectively. For all wavelengths, the eyes are clearly open with extinction ratios ranging from 8.5 to 9.8 dB.



λ=1533 nm
E.R.= 9.0 dB

λ=1543 nm
E.R.=8.5 dB

λ=1549 nm
E.R.=9.8 dB

λ=1559 nm
E.R.=9.2 dB

Fig. 4. 40 Gb/s NRZ eye diagrams

4. Conclusion

We have successfully developed a fabrication process for an integrated transmitter which combines a SG-DBR laser and high impedance TW-EAM. The 400 μm long modulator utilizes periodically loaded electrodes as well as an undercut waveguide to achieve very low capacitance per unit length. For over 25 nm of tuning, this device demonstrates greater than 15 dB/V peak efficiency and efficient modulation at 40 Gb/s NRZ with a 2.1 V electrical drive.

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