43 GHZ MODULATION BANDWIDTH PACKAGED InGaAsP MQW EA MODULATORS WITH INTEGRATED MODE CONVERTERS

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Abstract: High speed packaged electroabsorption modulators with 43GHz modulation bandwidth, -7.5dB electrical return loss, and 6dB RF extinction for 2Vp-p at 40Gbit/s are fabricated from the InGaAsP material system with integrated mode converters.

Introduction

The next generation of communication systems will include time division multiplexed (TDM) signals at bit rates as high as 40Gbit/s. The optical sources that can be used for digital modulation are limited by drive electronics. The electroabsorption (EA) modulator is a prime candidate for high bit rate applications owing to the low driving voltage required at 40Gbit/s.

There have been previous reports of high-speed modulators based on the InGaAs/InAlAs material system[1]. There have also been reports of InGaAsP based high-speed modulators fabricated from short (120μm) chips[2]. In practice short modulator chips make it difficult to package devices owing to excess stray light coupling. There are reports of modulator modules at 40Gb/s[3]. In that report the RF extinction varies from the DC extinction by 30% indicating bandwidth limitations of their device. In this talk we will present our latest results for InGaAsP modulators which include integrated mode converters for reduced insertion loss. The packaged EA modulators exhibit bandwidths of 43GHz and electrical return loss of −15dB (0-30GHz) and −7.5dB (30-40GHz) for reverse biases of −0.5V to −4.0V. The fiber to fiber loss for packaged devices is 15dB. Eye diagrams for 2Vp-p at 40Gbit/s were measured with 6dB of extinction ratio. These are to our knowledge, the highest bandwidth coupled with lowest return loss reported for packaged devices with integrated mode converters, fabricated solely from the InGaAsP material system.

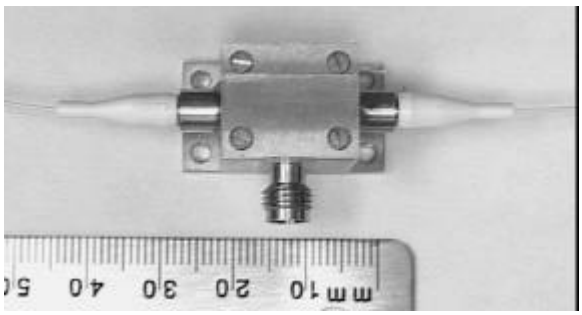
Device Structure

The maximum bandwidth obtainable by EA modulators is primarily RC time constant limited. To achieve bandwidths in excess of 40GHz the device must have a capacitance below 0.15pF coupled with a low series resistance. In order to achieve device capacitance of 0.15pF all parasitic capacitance must be eliminated. The bond pad capacitance in our structure has been reduced to 25fF by incorporating polyimide in the fabrication sequence. Keeping the modulator length to a minimum reduces the modulator capacitance. The modulators reported in this work are 80μm long and 2μm wide. The short length of the EA requires 18 quantum wells to enhance the electroabsorption effect and obtain reasonable extinction characteristics. We have integrated passive mode converters using butt joint technology to enable enhanced coupling efficiency into single mode fibers and to fabricate larger chips to reduce stray light coupling.

The EA modulators were fabricated from the InGaAsP material system and were grown on n+(100) InP substrates in a low-pressure metal-organic chemical vapour deposition system. The multiple quantum well (MQW) modulator structure is composed of strain compensated InGaAsP 1.51μm well material and InGaAsP 1.24μm barrier material. The MQW structure consists of 18 quantum wells. The MQW structure is selectively etched so the final active section of the device will have a device length of 80μm. Where the MQW is etched away a passive mode converter is grown using selective regrowth. The entire device is then capped with a thick p-InP cladding layer and a heavily doped p+-InGaAs contact layer.

The waveguides are fabricated in a reactive ion etching (RIE) system based on a CH_4/H_2 etch chemistry. The waveguides are 2μm wide in the modulator and passive sections of the chip. The waveguides are RIE etched below the active region. After waveguide formation the devices are planarized using polyimide and the p and n contacts are deposited. A picture of the packaged device is shown in figure 1.

Figure 1: Picture of packaged electroabsorption modulator with Wiltron-V connector



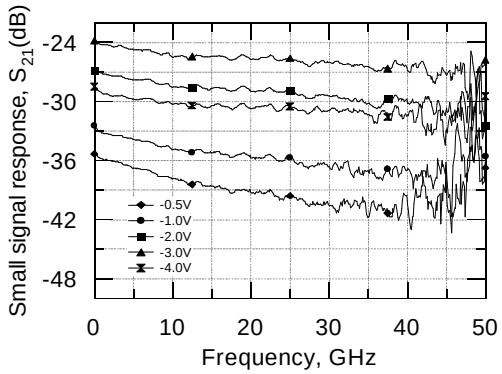
Device Results

The small signal modulation bandwidth was measured for the EA devices using an HP8510C 50GHz network analyzer and a calibrated HP photodetector. All packaged device measurements were taken with lensed single mode fibers for optical coupling, and a Wiltron-V connector for launching the microwave signal through the package wall.

Figure 2 shows a plot of the small signal modulation as a function of frequency for an 80μm long modulator operated

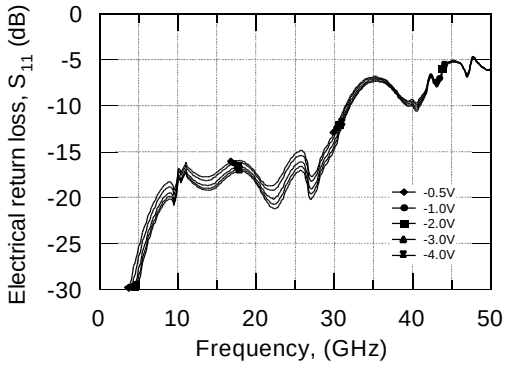
with an input optical power of 6dBm @1530nm and an electrical modulation of –8dBm. The small signal response curves show a 3dB bandwidth of 43GHz for bias voltages from –2.0V to –4V.

Figure 2: Small signal modulation response of a packaged 80㎜ EA modulator with integrated mode converters



The electrical return loss is an important parameter when a device is used in a real system with a driver circuit. The electrical return loss should be kept to a minimum for optimum RF performance. The electrical return loss for an 80μm long modulator is shown in figure 3. The electrical return loss is below –7.5dB for frequencies up to 40GHz.

Figure 3: Electrical return loss from a packaged 80㎜ EA modulator with integrated mode converters



The fiber to fiber insertion loss for devices which do not include beam expanders is greater than 30dB. This is unacceptable for real systems. The insertion loss of our packaged device with integrated mode converters was measured to be 15dB @1530nm. The extinction curves as a function of reverse bias is shown in figure 4. An overall extinction of 20dB for 5V was obtained even with an 80μm long modulator. The sharpness of the extinction curve and the total insertion loss is a subject of continued research and should be improved in future work.

The eye diagram of a high speed EA modulator measured at 40Gb/s is shown in figure 5. The RF extinction for 2.0Vp-p at 40Gb/s was 6.0dB, which is similar to the DC extintion indicating these devices are not bandwidth limited.

Figure 4: Optical insertion loss as a function of reverse bias for an 80㎜ long EA modulator

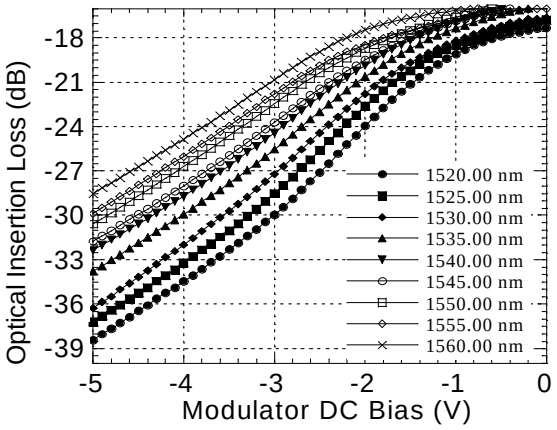
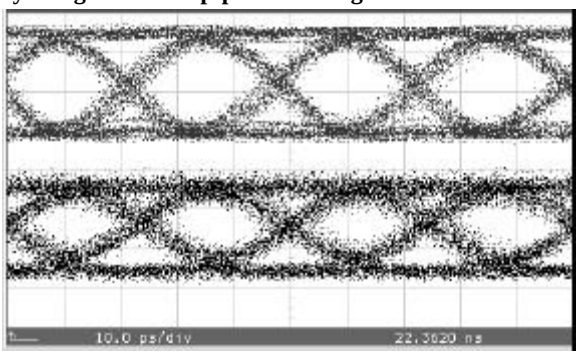


Figure 5: 40Gb/s electrical (top) and optical (bottom) eye diagram for 2Vp-p drive voltage.



References

/1/ Wakita, K., Yoshino, K., Hirano, A., Kondo, S., and Noguchi, Y., "Very-High-Speed and Low Driving-Voltage Modulator Modules for a Short Optical Pulse Generation, " *IEICE Trans. Electron.*, Vol. E81-C, No. 2, pp. 175-79, 1998.

/2/ Satzke, K., Baums, D., Cebulla, U., Haisch, H., Kaiser, D., Lach, E., Kühn, E., Weber, J., Weinmann, R., Wiedemann, P., and Zielinski, E., "Ultrahigh-bandwidth (42GHz) polarization-independent ridge waveguide electroabsorption modulator based on tensile strained InGaAsP MQW," *Electron. Lett.*, Vol. 31, No. 23, pp. 2030-32, 1995.

/3/ Takeuchi, H., Tsuzuki, K., Sato, K., Yamamoto, M., Itaya, Y., Sano, A., Yoneyama, M., and Otsuji, T., "NRZ Operation at 40Gb/s of a Compact Module Containing an MQW Electroabsorption Modulator Integrated with a DFB Laser," *IEEE Photon. Technol. Lett.*, Vol. 9, No. 5, pp. 572-574, 1997.

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