High Speed Etched Facet Traveling Wave Modulators for Micro Transfer Print Integration

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Abstract: Traveling wave etched facet waveguide modulators are designed and fabricated. Measurements demonstrate a 56 GHz bandwidth at 1275 nm with power handling greater than 20 dBm. Micro transfer printing onto silicon has also been demonstrated.

OCIS codes: (250.5300) Photonic Integrated Circuits; (250.7360) Waveguide Modulators; (230.4110) Modulators

1. Introduction

Traveling wave (TW) modulators are often leveraged in applications requiring both high bandwidth and high efficiency such as short reach optical links in data centers [1], beam steering [2], and optical isolators [3]. To utilize the high efficiency of indium phosphide (InP) for modulators and the low loss of other platforms such as silicon nitride (SiN), etched facets can be utilized to enable heterogeneous integration [4]. In this paper, we report on high speed InP TW electro-absorption modulators (EAMs) fabricated with epitaxy that includes an indium aluminum arsenide (InAlAs) release layer for micro transfer printing (MTP). Modulators characterized in discrete form demonstrated 56 GHz 3-dB bandwidth and preliminary MTP onto bare silicon (Si) was performed.

2. Device Design, Fabrication and Results

A cross section and CAD layout of the TW modulator is shown in Fig. 1(a). A periodically loaded Au-based microstrip feed using BCB dielectric is used as the RF feed. Series resistance, line inductance, parallel conductance, and capacitance of the unloaded line was simulated using Ansys HFSS. Diode series resistance and junction capacitance was added analytically using measured values from devices with similar epitaxy. The equivalent circuit model is shown in Fig. 1(b).

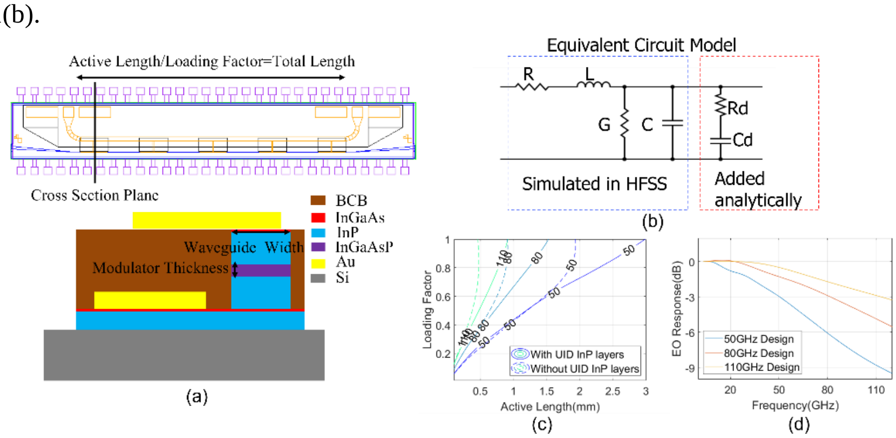

Fig. 1. (a) Cross section of designed microstrip modulator transferred to silicon; (b) Distributed circuit model for loaded microstrip transmission line; (c) Design space for modified and conventional epitaxy for several bandwidth targets; (d) Simulated response for 2.6 mm,1.2 mm and 0.6 mm traveling wave modulators with a 20 Ω load impedance and 100% loading.

Diode junction capacitance is the primary limiter of InP TW modulator bandwidth. To combat this effect, this work includes 75 nm thick unintentionally doped (UID) layers of InP above and below the indium gallium arsenide phosphide (InGaAsP) waveguide core. This increases the thickness of the depletion region, significantly reducing capacitance. For this modified epitaxy design, the UID layer significantly increases the maximum modulator length for a specific bandwidth requirement as illustrated in Fig. 1(c). The lower capacitance also allows for a higher impedance transmission line feed, reducing mismatch to standard 50 Ω sources and therefore lowering drive requirements. The simulated EO responses for several designs meeting common bandwidth targets are shown in Fig. 1(d). For direct comparison of MTP and discrete devices, both were fabricated on the same substrate. Fabricated devices on the native InP substrate are shown in Fig. 2(a). The development of a high-quality etched facet is necessary for MTP integration (shown in Fig. 2(b)). For MTP, two-port devices with input and output on opposite sides of the chip present integration challenges, so it is desirable to have turns to enable single-sided device geometries. This was realized with a convex turning mirror bend demonstrating a measured loss of 1.27 dB per 180˚ bend. This loss was measured via test structures with multiple 180˚ bends as shown in Fig. 2(c). A CAD layout of a single-sided TW EAM with a compact 180˚ turning mirror is shown in Fig. 2(d).

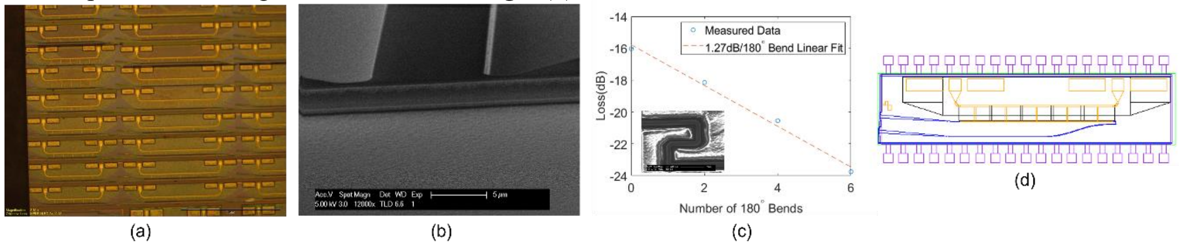

Fig. 2. (a) Microscope image of fabricated TW modulators; (b) High quality vertical etched facet for MTP devices; (c) Loss measurements for 180˚ bends with inset test structure; (d) CAD layout for single-sided MTP device with 180° turning mirror.

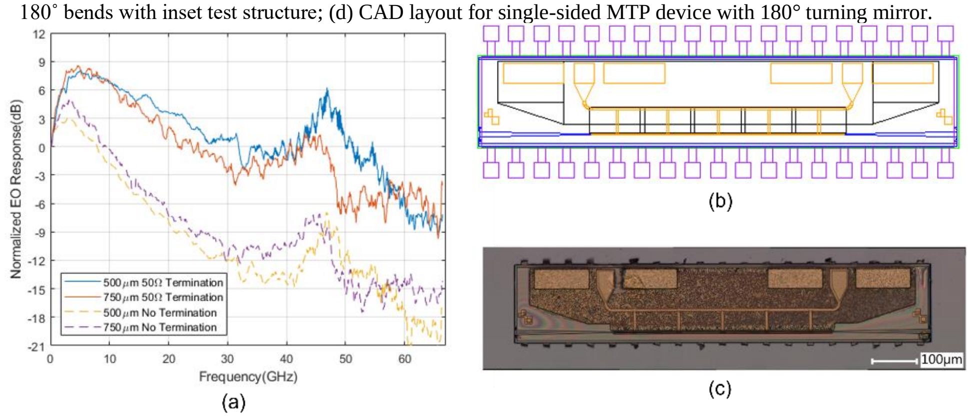

Fig. 3. (a) Bandwidth measurements of discrete TW modulators; (b) CAD layout of MTP TW EAM (c) TW modulator printed onto bare Si.

Preliminary measurements demonstrate bandwidth up to 56 GHz for a 500 μm long modulator and 30 GHz bandwidth for a 750 μm long modulator, both of which are terminated with a 50 Ω probe impedance. Comparison of resistive and open terminated devices clearly illustrate traveling wave effects (Fig. 3(a)). The peaking near 45 GHz matches closely with the free spectral range of the of the optical waveguides. Simulations show that a lower and on-chip termination of 15 Ω, along with a 25 pF capacitor, would enable a bandwidth in excess of 100 GHz for both 500 μm and 750 μm long devices. Implementation of lower termination impedance is ongoing. Finally, Fig. 3(b) and Fig. 3(c) show the CAD layout and a microscope image of a TW modulator that was released from the InP and successfully transfer printed to a bare Si wafer respectively. Future work will characterize printed devices and demonstrate alignment and coupling to SiN waveguides on Si.

3. Conclusions

TW modulators with etched facets for MTP were designed and fabricated. Some devices included 180° bends to enable simplified MTP; these bends demonstrated a measured loss of 1.27 dB per 180˚ bend. A 56 GHz bandwidth was measured for a discrete 500 μm TW modulator at wavelength of 1275 nm and using a 50 Ω probe termination. Preliminary MTP on bare Si was also demonstrated.

4. Acknowledgement

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5. References

[1] T. Hirokawa, et al., "Analog Coherent Detection for Energy Efficient Intra-Data Center Links at 200 Gbps Per Wavelength," J. Lightwave Technol. 39, 520-531 (2021)
[2] M. Jarrahi, et al., "Optical switching based on high-speed phased array optical beam steering," Appl. Phys. Lett. 92, 014106 (2008)
[3] P. Dong, "Travelling-wave Mach-Zehnder modulators functioning as optical isolators," Opt. Express 23, 10498-10505 (2015)
[4] R. Loi, *et al*., "Micro-transfer-printing of InP Photonic Devices to Silicon Photonics," *2019 Photonics & Electromagnetics Research Symposium - Spring (PIERS-Spring)*, 2019, pp. 242-248, doi: 10.1109/PIERS-Spring46901.2019.9017709.