ULTRA WIDE ELECTRICAL BANDWIDTH GaAs/AlGaAs ELECTROOPTIC MODULATORS

(Invited)

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ABSTRACT

A high speed GaAs/AlGaAs traveling wave Mach-Zehnder electrooptic modulator has been fabricated. The device uses a novel slow wave electrode design to achieve phase velocity matching and has a measured electrical bandwidth greater than 40 GHz. An improved electrode design has been characterized and is currently being integrated into a modulator to increase the bandwidth further.

I. INTRODUCTION

High speed optical modulators are essential components for the transmission of microwave and millimeter wave analog and digital signals over optical fibers. The main limitation on the electrical bandwidth is the capacitance of the electrode used to apply the electrical signal to the modulator. If the device is driven as a lumped circuit element, bandwidth is limited by the RC time constant of the electrode. It is possible to reduce the electrode capacitance by making the device very compact. Multiquantum well electroabsorption modulators are such examples [1]. Although bandwidths up to 40 GHz were achieved by such designs, they suffer from chirp, high optical insertion loss and limitations on maximum optical power that can be handled. An alternative approach uses the so called traveling wave design in which the electrode is designed as a transmission line distributing the electrode capacitance [2], [3], [4]. The traveling wave modulators have most commonly been fabricated in GaAs/AlGaAs [3] and $LiNbO_3$ [4] material systems. Of these two, only GaAs/AlGaAs offer the monolithic integration of lasers, detectors and microwave electronic circuitry on the same substrate. Our goal is to realize an integrable small signal optical modulator with a 3dB bandwidth in excess of 100GHz. Here we report a device with measured electrical bandwidth in excess of 40 GHz, and describe techniques for the next generation of even wider bandwidth devices.

In the traveling wave configuration the modulating microwave and modulated optical signals travel co-linearly along the device. It is well known that phase velocity matching of the microwave and optical signals is necessary to achieve maximum bandwidth [2]. In the case of phase velocity matching, the bandwidth of the modulator is limited by the loss of the microwave electrodes. The frequency at which the total electrode loss becomes 6.4 dB determines the 3 dB electrical bandwidth of the modulator.

II. DEVICE DESCRIPTION

The device schematic is shown in Figures 1-4. As seen in Figure 1, it consists of a coplanar

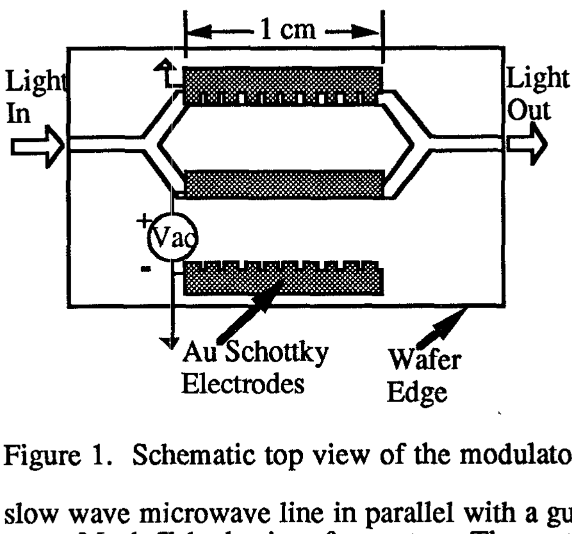

Figure 1. Schematic top view of the modulator.

slow wave microwave line in parallel with a guided wave Mach-Zehnder interferometer. The material is MBE grown unintentionally doped GaAs/AlGaAs heterostructure on [100] semi-insulating GaAs substrate. The optical guides are fabricated by wet etching ridges as shown in

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Figure 2. The SiO_2 layer reduces the optical loss by eliminating the overlap of the optical mode with the metal electrodes. The microwave electrodes consist of 200Å/200Å/1μm Ti/Pt/Au. This metal forms a Schottky contact with the unintentionally doped MBE layers. When a voltage is applied between the electrodes, two back to back Schottky diodes are biased resulting in [100] directed electric fields on the optical guides as shown in Figure 2. This results in push pull action generating phase shifts of opposite sign on both arms through the linear electrooptic effect. Therefore, a net differential phase shift between

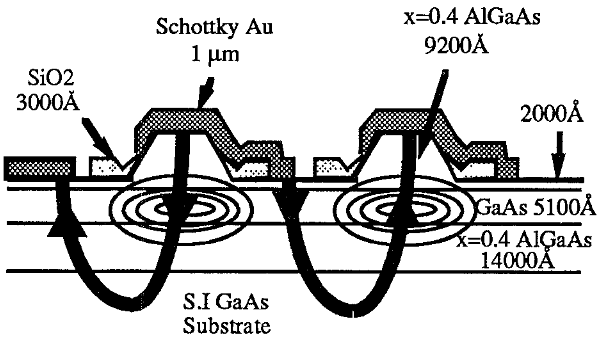

Figure 2. Cross sectional schematic of the modulator illustrating the push pull vertical electric fields.

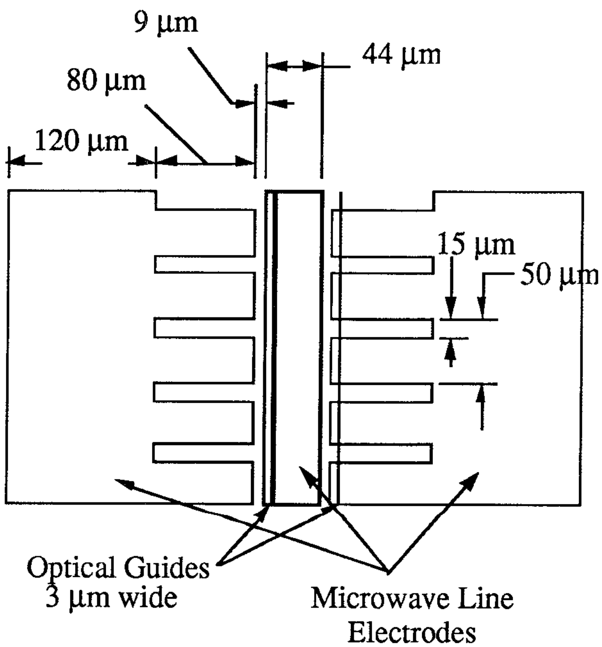

Figure 3. To scale top view schematic of a section of the modulator.

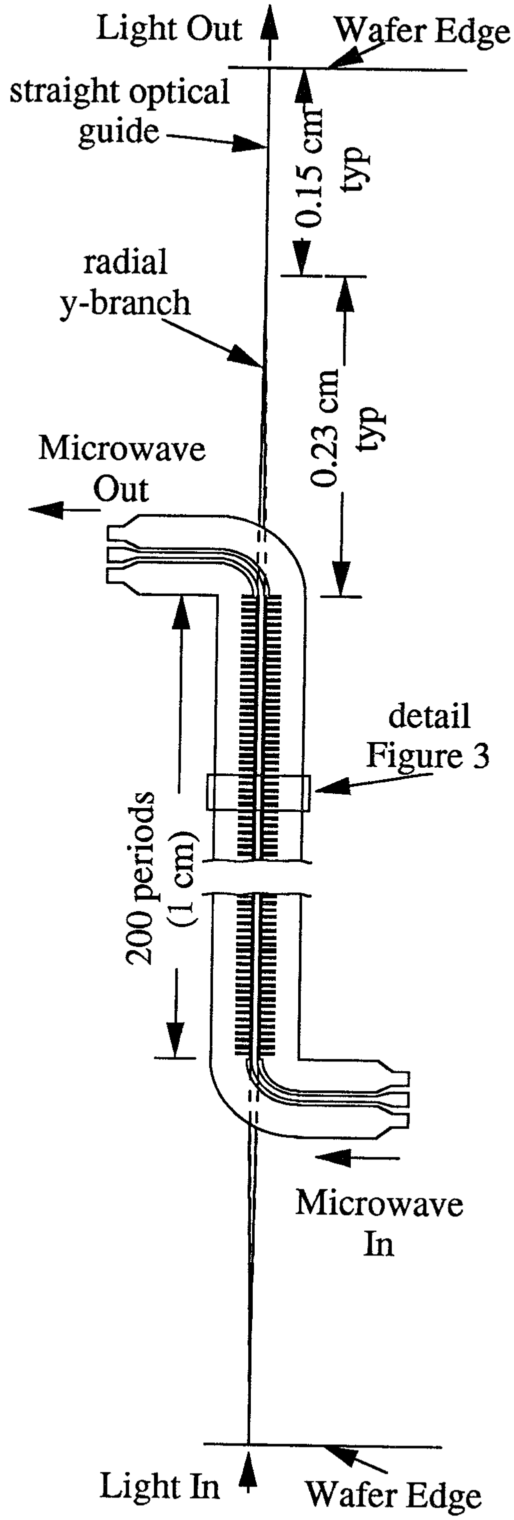

Figure 4. To scale top view of the entire modulator.

the arms of the interferometer is generated resulting in modulation.

The electrode is designed as a slow wave structure. It is a coplanar line, in which periodic slots are cut in the ground planes [5]. These slots periodically load the line increasing its inductance and capacitance per unit length, and create a slow wave structure. The mechanical dimensions of the electrodes and the modulator are shown in Figures 3 and 4. The phase velocity reduction is illustrated in Figure 5. As shown, there is very

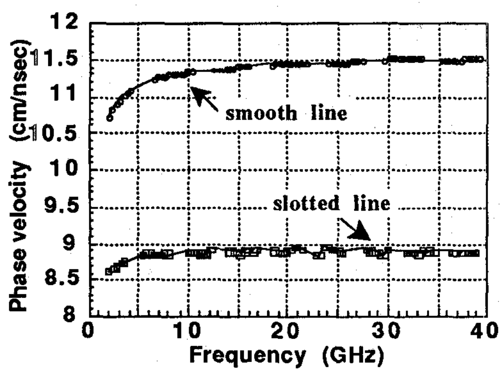

Figure 5. Electrode phase velocity vs. frequency. The result for a smooth line is also shown to illustrate the phase velocity slowing achieved.

little dispersion above 5 GHz. The phase velocity match is within 1% of the velocity of an optical wave in GaAs/AlGaAs at 1.3 μm, which is 8.9 cm/nsec. With this geometry, the phase velocity and characteristic impedance can be independently adjusted [5]. This was found out experimentally measuring over 200 different distinct line geometries. The slot width to period ratio of 0.3 is enough to obtain the maximum slowing possible. The depth of the slots determines the phase velocity slowing. The center conductor width changes the characteristic impedance but not the phase velocity. Therefore the center conductor width can be adjusted to set the impedance, once the desired phase velocity is obtained. The impedance of the electrode was measured to be 50±5Ω. Since this method achieves phase velocity matching with undoped epitaxial layers, the microwave loss is minimized. The loss at 35 GHz was measured to be 4.6 dB/cm.

III. EXPERIMENTAL RESULTS

Figure 6 shows the low frequency transfer function of the device at 1.3μm. The output of a DFB laser was end fire coupled in and out of the waveguide using microscope objectives. The microwave signal was applied with commercial coplanar probes. The large V_π value is due to the 9μm gap between the electrodes. Figure 7 illustrates the small signal electrical bandwidth of the device measured using the method outlined in

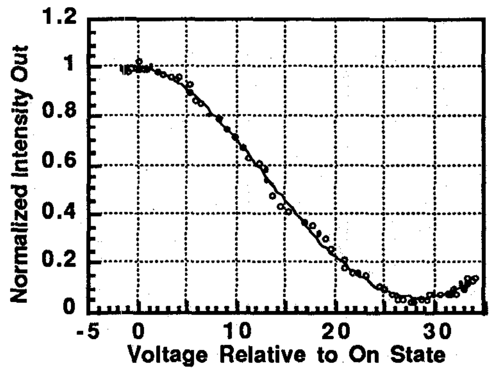

Figure 6. 35kHz transfer function of the modulator at 1.3μm.

[6]. The measurements are limited to 40 GHz due to limitations on the equipment. The ± 1.5 dB scatter in the data indicates a standing wave of small standing wave ratio on the line. This is

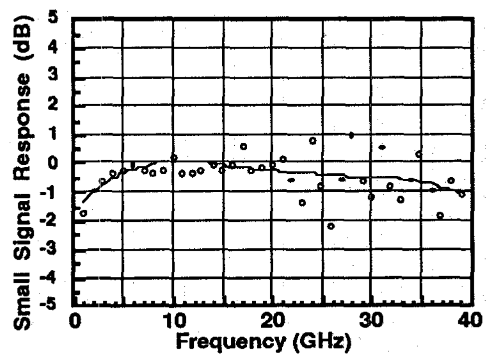

Figure 7. Modulator small signal response. The fitted curve is a fourth order polynomial.

mainly due to mode mismatch at the junction of the smooth and slotted electrodes and the lack of airbridges at the input and output bends of the modulator electrode. The actual electrical bandwidth is estimated to be 70 GHz extrapolating the electrode loss data measured up to 40 GHz.

IV. IMPROVED ELECTRODE DESIGN

The measured V_π of the modulator was high mainly due to the large gap between the electrodes. This gap was 9 μm. Obviously one can reduce V_π by reducing this gap. But as the gap gets narrower and the electric field increases, the current crowding and the microwave loss also increase. Increased microwave loss will limit the electrical bandwidth even though the phase velocity matching is preserved. To eliminate this difficulty we developed an improved electrode design shown in Figure 8. This is again a modified coplanar transmission line. T-rails stem from either side of the center conductor and from the inner side of both ground planes. In the gap between the two T-rails a small capacitor is formed. Such small capacitors periodically load the line and slow the microwave phase velocity by increasing the capacitance per unit length of the line. One can make the stems and the rails very narrow, making them look just like lumped capacitors. Since there is no transmission line current flow along the narrow rails that form the plates of tiny capacitors, one can reduce the gap between them to very low values without increasing the microwave loss. This results in a very large electric field between them. Therefore by positioning the optical guides under the rails which are separated by a very small gap, it is possible to obtain large electric fields overlapping with the optical mode. The gap may now be reduced to 2μm from the old value of 9μm and 90% of the length of the device can be made electrooptically active as opposed to the old value of 70%. This is expected to decrease V_π by a factor of 4 to 5. We fabricated such electrodes and measured the phase velocity, characteristic impedance and the microwave loss up to 40 GHz. Figure 9 shows the measured results for a 6μm gap line. Fabrication of modulators incorporating these new electrode designs is underway.

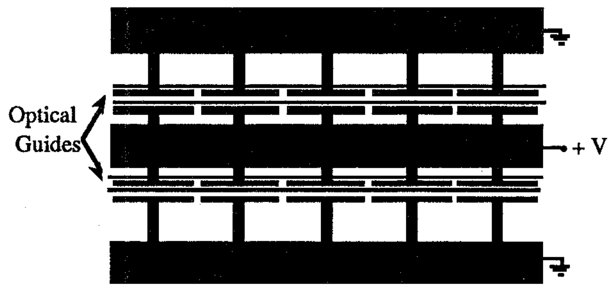

Figure 8. New lower loss smaller gap capacitively loaded modulator electrode design.

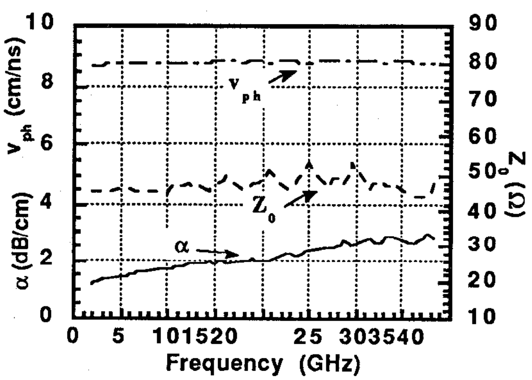

Figure 9. Measured results for the new electrode design with a 6μm gap.

V. CONCLUSIONS

This work demonstrates the wide traveling wave modulator bandwidths achievable through the use of coplanar slow wave structures on unintentionally doped epitaxial layers. Other advantages of this approach are low optical loss, chirp-free operation and the possibility of integration with other optoelectronic devices.

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