A HIGH FREQUENCY GaAlAs TRAVELLING WAVE ELECTRO-OPTIC MODULATOR AT 0.82μm

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Experimental GaAlAs modulators operating at 0.82μm using a Mach-Zehnder interferometer configuration were designed and fabricated. Coplanar 50Ω travelling wave microwave electrodes were used to obtain a bandwidth-length product of 11.95 GHz-cm. The design, fabrication and DC performance of the GaAlAs travelling wave modulator is presented.

I. Introduction

The development of high frequency integrated microwave-optical components and circuits on GaAs substrates is required for highly agile and light weight optically controlled GaAs MMIC based phased array antennas for future space communication and tracking systems [1]. External modulation of a GaAlAs solid state laser output by a modulator is a means to convert a microwave signal to an optical signal, thus allowing the benefits of low weight and low crosstalk to be applied to these systems.

Waveguide electro-optic indirect modulators fabricated on $LiNbO_3$ and GaAs substrates and operating at 1.3μm have previously been reported in the literature [2,3,4]. It is unlikely that with the present technology, $LiNbO_3$ modulators can easily be integrated with the present day GaAs MMIC substrates. On the other hand, GaAs modulators cannot be integrated with GaAlAs laser sources due to high absorption of the GaAs at 0.82μm wavelength.

In this paper, we present the fabrication of a triple heterostructure GaAlAs travelling wave electro-optic modulator which operates at 0.82μm wavelength and avoids the absorption problems associated with pure GaAs. The detailed analysis and design of the electro-optic modulator has been previously reported [5,6]. The modulator uses a 50Ω travelling wave coplanar waveguide electrode and needs no matching network. It has a high bandwidth and is capable of integration with GaAs/GaAlAs laser diodes. Although GaAs has a smaller electro-optic coefficient and requires higher microwave drive power levels than $LiNbO_3$, the modulator presented here allows true integration with GaAs MMIC technology.

II. Design of the Modulator

The electro-optic modulator, shown schematically in Fig. 1, is comprised of two essential components; a) the optical waveguide Mach-Zehnder interferometer and b) the microwave coplanar waveguide.

A material problem associated with 0.82μm operation of a GaAs modulator is that GaAs is highly absorptive at this wavelength. This is avoided by the substitution of a small percentage of aluminum to form GaAlAs which shifts the absorption edge of the compound semiconductor to shorter wavelengths. In the design of the present modulator , aluminum concentrations greater than 10% were chosen so that all three GaAlAs layers are transparent at 0.82μm. In

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determining the response of the modulator, the electro-optic coeficient for GaAs is used in the assumption that the small percentage of aluminum does not significantly alter the electro-optic coefficient.

Optical propagation losses in semiconductor waveguides are also a disadvantage of GaAs modulators. In our design, a strip loaded ridge structure was chosen for the optical waveguide. Three layers of GaAlAs with differing aluminum concentrations were grown over a semi-insulating substrate (Fig. 2). The upper layer was etched to form the loading ridge, but the optical signal propagates in the middle layer. This configuration concentrates the light energy away from the etched edges of the loading ridge, reducing the intensity of light scattered by the edges and therefore reducing the propagation losses. To prevent additional losses, the first layer above the semi-insulating GaAs is chosen to be thick enough so that the signal will not extend into the substrate and be absorbed by the GaAs.

To provide the microwave field in the required orientation, a coplanar travelling wave electrode structure was chosen. The electrodes were designed for 50Ω impedance on semi-insulating GaAs. Since there is no doping in any layer, the low intrinsic carrier concentration of GaAs allows the substrate to be treated as a dielectric. The absence of ohmic and rectifying behavior makes the transmission line electrodes possible. The conductor and gap widths are chosen to provide the 50Ω characteristic impedance. The greatest advantage in choosing the coplanar transmission line structure is the elimination of the matching networks throughout the operating bandwidth of the modulator.

The bandwidth of the proposed device is determined by the walkoff between the light and wicrowave signal which propagates through the device at different velocities. The calculated 3db bandwidth-length product of 11.95 GHz-cm is for full scale intensity modulation without any optimization of the waveguiding structure. This may further be accomplished by finding the proper coplanar waveguide dimensions so that the propagation constant of the microwave signal can be brought closer to that of the optical signal. If the modulation depth is reduced, the corresponding bandwidth-length product is increased.

III. Fabrication

The modulator was fabricated in a three layer $Ga_{1-x}Al_xAs$ heterostructure grown on a semi-insulating GaAs substrate. The GaAlAs layers were grown by MBE at Perkin Elmer and coinsisted of a 3.5μ thick lower cladding layer of $Ga_{.87}Al_{.13}As$, a 0.8μ thick middle guiding layer of $Ga_{.90}Al_{.10}As$, and an 0.8μ thick top cladding layer of $Ga_{.87}Al_{.13}As$. The entire GaAlAs heterostructure was capped by 100A of GaAs for protection prior to fabrication.

Fabrication took place by standard photolithography using an E-beam generated mask. The waveguiding ridges were defined by wet chemical etching in a solution of H_3PO_4:H_2O_2:H_2O::3:1:25 to a ridge height of 1400A. The 'Y' branch of the interferometer was defined to a feature size of<1μm (Fig. 2) and the edges of the waveguiding ridges were generally smooth and clean (Fig. 3). The travelling waveguide electrode pattern was produced by liftoff techniques using E-beam evaporated metals. Two types of electrodes were applied; rectifying, Schottky (Ti/Au,AU) and ohmic (Au/Ge, Ni, Au).

IV. Modulator Characteristics

Testing of the modulator is accomplished by butt coupling of the laser radiation to the cleaved end facet of the device from a single mode optical fiber pig-tailed to a GaAlAs laser diode (Ortel-SL620s). The output facet of the modulator is imaged by an IR sensitive camera and displayed on a video monitor. Sucessful coupling to the modulator produces a single intensity peak at the output facet with little lateral leakage observable. A modulator cleaved midway along the parallel branches of the Mach-Zehnder interferometer shows two intensity peaks, one under each optical waveguide (Fig. 4).

DC measurements on modulators have shown that the turn-off voltage, Vp, is approximately 30V.

V. Conclusion

A GaAlAs electro-optic Mach-Zehnder modulator operating at 0.82μm has been designed and fabricated. Because the waveguiding layer is transparent at 0.82μm the design is potentially integratable with a GaAlAs laser diode. Theoretical calculations indicate a 3db bandwidth-length product of 11.95 GHz-cm for 100% modulation depth.

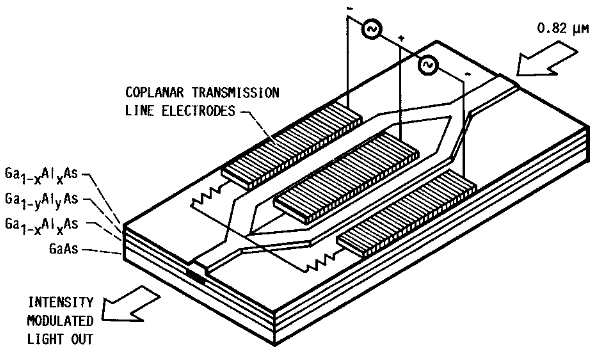

Figure 1. Schematic view of the GaAlAs Mach-Zahnder electro-optic modulator. The dimensions of the coplanar waveguide are chosen for 50Ω characteristic impedance.

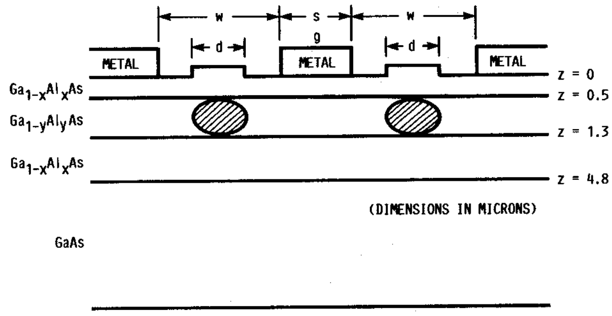

Figure 2. A cross-sectional schematic of the modulator structure.

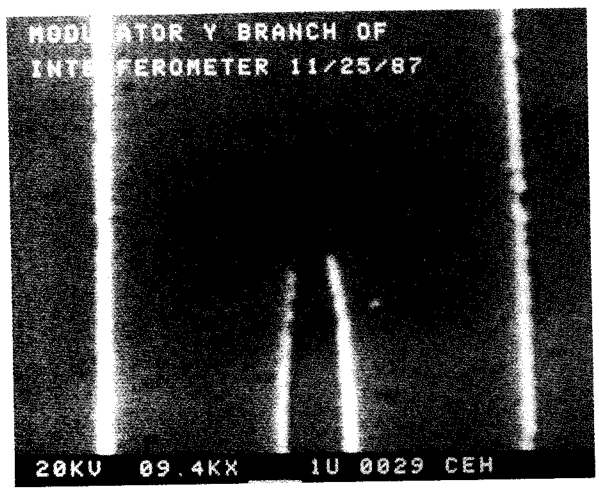

Figure 3. "Y" branch of the Mach-Zehnder interferometer. The gap between the branches is approximately 1μm at its narrowest point.

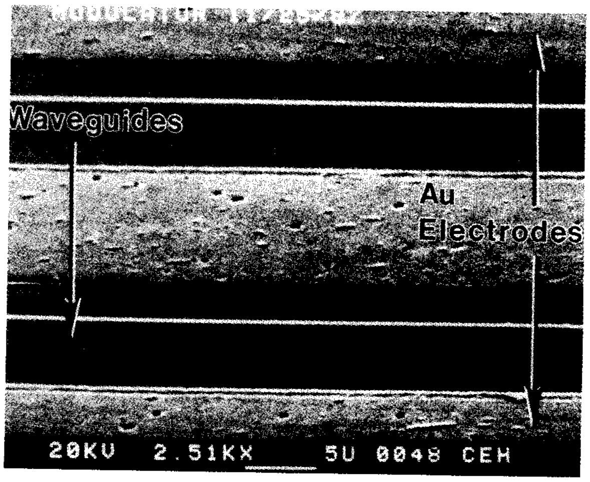

Figure 4. The parallel waveguides of the interferometer with the coplanar electrodes. The edges of the waveguides are generally smooth and free of defects.

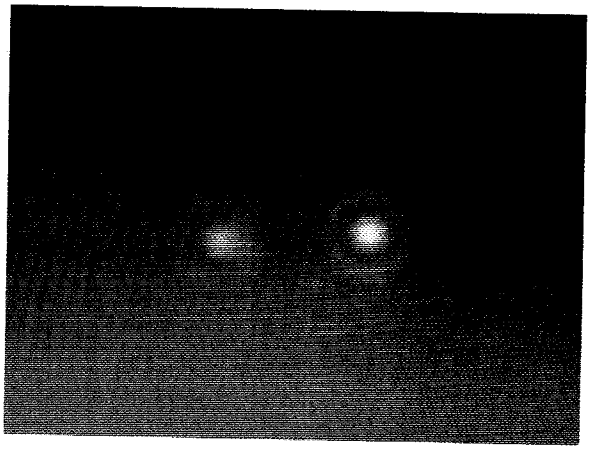

Figure 5. Output of a modulator cleaved midway along the interferometer. Each of the intensity peaks lies under one of the parallel waveguides.

VI. References

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