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Characteristics of P-I-i-I-N GaAs/$Al_{0.35}Ga_{0.65}As$ Phase Modulator and MultiMode Interference used in the TE/TM Mode Splitter

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1. Introduction

TE/TM mode splitting is an important integrated-optic function for polarization-sensitive optical systems. Various guided-wave TE/TM mode splitters have been demonstrated by using an asymmetric Y-junction [1] and a double-mode waveguide with different TE and TM coupling lengths [2]. Their insertion losses and extinction ratios were around 3~6dB and 10~20dB, respectively. We propose a MZI TE/TM mode splitter utilizing multimode interference (MMI) and the linear electro-optic (LEO) effect splitter as shown in Fig.1.

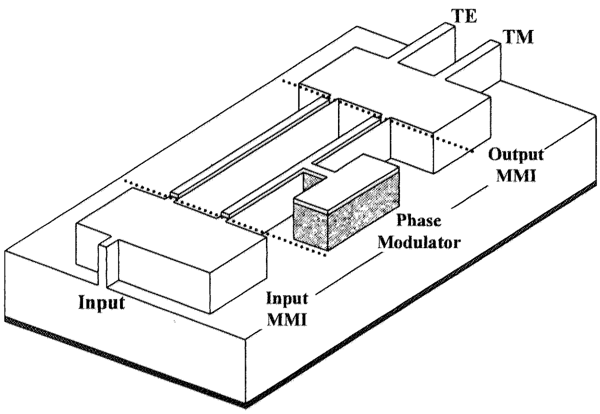


Fig.1. Schematic diagram of a MZI TE/TM mode splitter utilizing multimode interference and phase modulator

Recently, MMI couplers for splitting and combining of light signals have received a lot of attention because of simple structure, low excess loss, and insensitive polarization -dependence [3]. It has also been reported that the phase of TE mode can be changed selectively by using the LEO effect in a III-V semiconductor ridge waveguide phase modulator [4]. In this letter, we report a fabricated P-I-i-I-N GaAs/$Al_{0.35}Ga_{0.65}As$ phase modulator with selective phase change only for TE mode and MMI. TE-selective phase modulation can be achieved by deploying the LEO effect. Choosing an operating wavelength far from the GaAs band-gap wavelength and restricting the distribution of optical mode mainly in the region of the applied electric field can make other effects negligible.

2. Experiments

Figure 2 (a) shows the epitaxial layers of sample, which is grown by MOCVD on a (100) n^+-GaAs substrate. In this structure, an undoped material with a large index difference from the GaAs guiding layer confines the optical field to the intrinsic material, minimizing absorption in doped layers. Thin confinement layers are used to maximize the modulator efficiency. The thick n^+-$Al_{0.35}Ga_{0.65}As$ layer prevents optical leakage into the GaAs substrate.

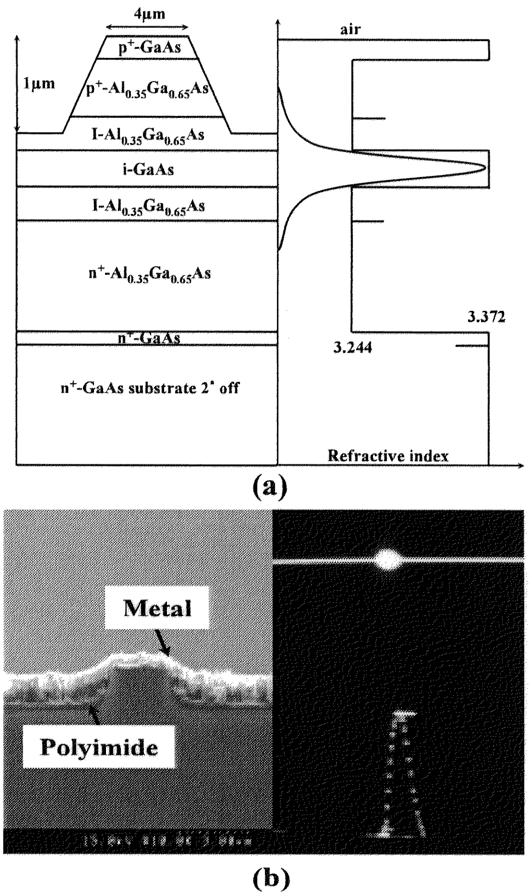
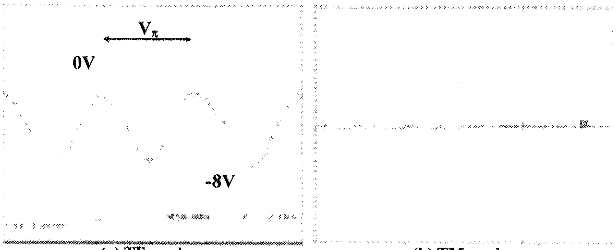


Fig.2. (a) Schematic cross section of epitaxial layer
(b) SEM showing the cleaved endface of a waveguide phase modulator and near field intensity distribution

1) P-I-i-I-N GaAs/$Al_{0.35}Ga_{0.65}As$ phase modulator

Waveguides oriented parallel to the $[01\bar{1}]$ direction with ribs of width 4μm and height 1μm were fabricated by conventional photolithography and wet chemical etching. The waveguide ribs were then buried completely by a thick layer of polyimide and bared by etching the polyimide in an O_2 plasma asher. Ohmic contacts were formed by using an electron-beam evaporator, followed by thermal annealing at 410°C for 30 seconds using RTA. Phase modulators with length of 4mm were prepared by cleaving the sample and then by soldering it onto an Au submount with silver paste. Figure 2 (b) shows a scanning electron micrograph of the cross section of waveguide and the observed near-field pattern for TE mode. The fabricated phase modulator supports only single-mode propagation for width of 4μm and height of 1μm. This fact agrees with the calculated result that is obtained by using the 3-D BPM_CAD.



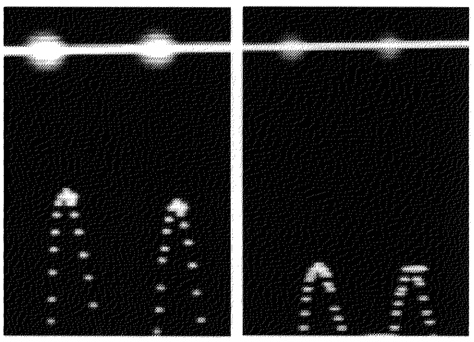
(a) TE mode (b) TM mode

Fig.3. Oscilloscope display of the modulated light intensity from the FP sample under a 3-Hz triangular voltage waveform applied to the electrodes

Figure 3 shows the variation in the transmitted intensity that is due to FP resonance as a function of applied reverse bias voltage for TE- and TM mode, respectively. Fringes of the FP resonator [5] formed by the waveguide and two cleaved endfaces were scanned by applying a 3-Hz ac signal on top of a dc reverse bias voltage to vary the optical phase. A triangular wave varying from 0V to -8V was applied to the phase modulator. From Fig.3, the switching voltage (V_π) was 7.1V, from which the phase shift efficiency ($\Delta\varphi$) was determined to be 6.3°/V·mm for TE mode. Also, no modulation was observed for TM mode, which is confirming that the tuning occurs from the LEO.

2) Multimode Interference (MMI) Coupler

The input multimode interference coupler acts as a 3-dB splitter. TE/TM input lights are sent into the input coupler through a single-mode input waveguide as shown in Fig. 1. The input lights are coupled into guided modes in the multimode waveguide. Then, the TE and TM guided modes interfere traveling with different propagation constants, and construct two self-images at the end of the input MMI coupler. At this time, the length of MMI coupler is 2733μm.



(a) TE **(b) TM**

Fig.4. Splitted two self-images at the end of the input MMI coupler

Figure 4 shows TE and TM self-images, respectively, which are seen as 3dB at the end of the input MMI coupler. Because the length of input MMI coupler is optimized TE mode, TM mode is less than TE mode.

3. Conclusions

The P-I-i-I-N GaAs/$Al_{0.35}Ga_{0.65}As$ TE-selective waveguide phase modulator and MMI coupler for λ=1.55μm have been designed, fabricated, and characterized. First, the phase modulation efficiency of phase modulator was measured by the Fabry-Perot interference technique. The modulator efficiency obtained by voltage tuning was 6.3°/V·mm for TE mode. At the same time, no modulation was observed for TM mode. Second, input MMI coupler which has 2733μm length constructed two self-images.

As a result, we are going to use these devices effectively in the MZI TE-TM mode splitter as shown in Fig.1.

Acknowledgements

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