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Proposal of Electro-Optic Tunable 1×2 Multimode Interference Splitter Based on Multiple Quantum Well

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1. Introduction

Mach-Zehnder modulators (MZMs) with high extinction ratio (ER) has become more important [1] for the applications such space radio telescope millimeter-wave radio on fiber (ROF) system and advanced modulation format such as quadrature amplitude modulation (QAM). Even though the extinction ratio is infinity in an ideal case, the degradation of the ER in actual MZMs is caused by the amplitude imbalance in both arms due to fabrication errors in the arms and 3 dB-splitters. However, such fabrication errors are inevitable in actual device fabrication[2]. To adjust the imbalance of both arms in an MZM, several researches have been carried out [2,3]. On the other hand, multimode interference (MMI) devices are widely used for various photonic integrated circuits and photonic switches and tunable couplers using current injection have been proposed and developed [4-6].

In this paper, we propose electro-optic (EO) tunable 1×2 multimode interference (MZM) splitter based on multiple quantum wells (MQWs) for high ER MZMs. The proposed splitter is operated by the EO effect based on the quantum-confined Stark effect (QCSE) in an MQW. It has advantages such as compactness, low insertion loss, low power consumption. The characteristics of the tunable splitter were theoretically investigated using the beam propagation method (BPM).

2. Operation Principle

Figure 1 shows the schematics of a top view and a cross sectional waveguide structure of the proposed 1×2 MMI power splitter. It has four refractive index modulated regions and they are named as Left-Side-1, Left-Side-2, Right-Side-1, and Right-Side-2, respectively, as shown in Fig.1(a). The green circles correspond to the self-imagings in the MMI. It is assumed that the waveguide consists of a core layer with 12-set $In_{0.53}Ga_{0.47}As$/ $In_{0.52}Al_{0.48}As$ five-layer asymmetric coupled quantum wells (FACQWs), 50 nm $In_{0.52}Al_{0.24}Ga_{0.24}As$ separated confinement heterostructure (SCH) layers, and p/n-doped InP cladding layers, as shown in Fig. 1(b). The FACQW is expected to exhibit large electrorefractive index change with very low absorption loss [7]. The total thickness of the core layer is approximately 300 nm. In the modulation regions, electric fields can be applied through a pin diode structure and the changes in refractive index occur due to the QCSE in the multiple FACQW. Figure 2 shows the measured characteristics of the electrorefractive index change of the InGaAs/InAlAs multiple FACQW waveguide[8]. In the following, we discuss the characteristics of the proposed device using this electrorefractive index change.

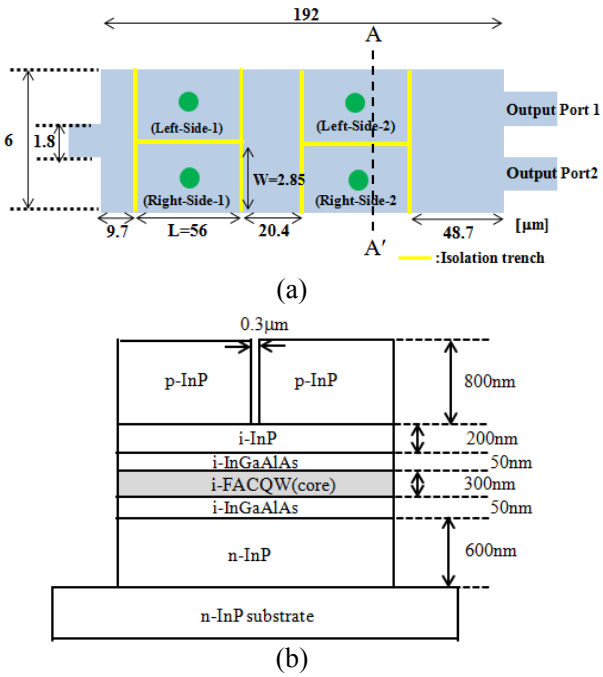


Fig. 1. Schematics of the proposed MMI splitter. (a) top view, (b) cross sectional view of the waveguide in the line A-A' in (a).

Each modulation region has a length of L=56 μm and a width W of 2.8 μm. It is surrounded by isolation trenches (yellow lines in Fig. 1(a)) with a width of 0.3 μm and a depth of 0.8 μm (corresponding to the thickness of the p-InP upper cladding layer) to prevent spreading of electric fields and define the modulation regions. The total length and width of the device are 192 and 6 μm, respectively.

By applying electric fields to Left-Side-1 and Right-Side-2 (or Right-Side-1 and Left-Side-2) simultaneously, optical power splitting ratio can be altered. Figure 3 shows the electric field distributions simulated by the beam propagation method (BPM). In the simulation, isolation trenches are omitted for calculation simplicity, however it was confirmed by the finite difference time domain (FDTD) simulation that the propagation loss does not increase even with the isolation trenches.

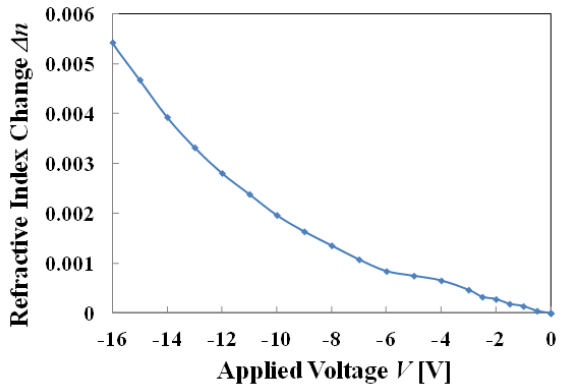
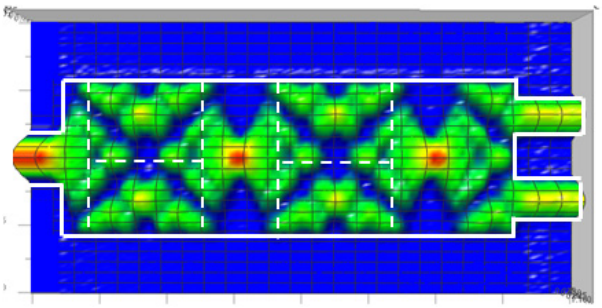
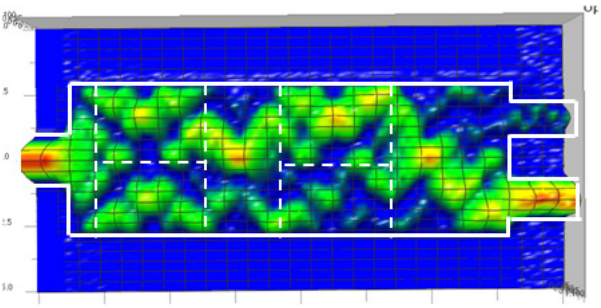


Fig. 2. Measured characteristics of the electrorefractive index change of the InGaAs/InAlAs multiple FACQW waveguide.



(a)



(b)

Fig.3. Electric field distributions simulated by beam propagation method (BPM) (a) without refractive index modulation and (b) with refractive index modulation.

In the 1×2 MMI, the input port is located in the center and even modes are excited without reverse bias voltages; therefore the self-images of electric fields are formed symmetrically and the power splitting ratio is 50:50 at the output ports, as shown in Fig. 3(a). By modifying the phases of the self-images in Fig. 3(a), odd modes are also excited and the formation of subsequent self-images can be controlled [5,9], leading to the change of splitting ratio at the output. When the refractive index of the regions Left-Side-1 and Right-Side-2 are simultaneously changed by 0.004, power splitting ratio is successfully changed to approximately 80:20, as shown in Fig. 3(b).

3. Power Splitting Characteristics

Figure 4 shows the calculated normalized light powers

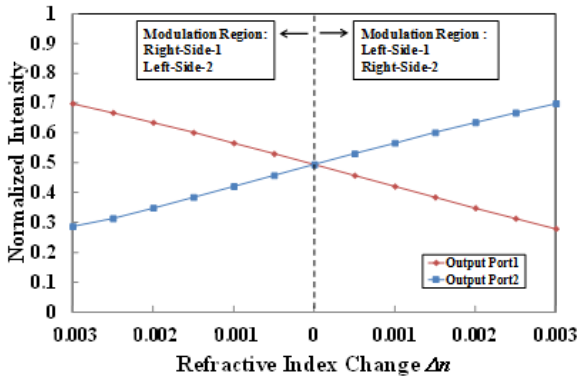


Fig. 4. Calculated normalized light powers at the output ports as functions of change in refractive index of the core layers of the index modulated regions.

at the output ports as functions of change in refractive index of the core layers of the index modulated regions. It shows that the splitting ratio is continuously adjustable from Output Port1: Output Port2 = 50: 50 to 70:30 when the refractive indices are changed from 0 to 0.003. This change in index can be achieved at an applied voltage of 12 V by using the FACQW core layer, as shown in Fig. 2; therefore if this device is used as 3-dB couplers of an MZM for adjusting the balance between both arms, a very high extinction ratio can be realized.

4. Conclusion

We have proposed a compact tunable 1×2 MMI splitter based on multiple InGaAs/InAlAs FACQW and and theoretically investigated its tunable characteristics. By changing slightly the refractive indices of the localized areas of the MMI, the power splitting ratio can be tuned widely with low insertion loss. If this device is used as 3-dB couplers of an MZM for adjusting the balance between both arms, a very high extinction ratio can be realized.

Acknowledgements

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