Chapter V
Novel Mach-Zehnder All- optical Switches based on Electroabsorption Modulator

5.1 Introduction

All-optical switch is one of the key components in ultra fast optical communications. Mach-Zehnder interferometer (MZI) [1] type of all-optical switches has been frequently used for wavelength conversion [2][3] in WDM applications, for demultiplexing [4] in OTDM and for all-optical 3R regeneration [5].

In conventional all-optical MZI switches, SOA is the most commonly used device as the nonlinear medium to obtain an efficient interaction between the signal and the control beam due to its large carrier related refractive index changes and its ability to provide gain to the signal [6]. Hundreds of papers have been published in this device in the past 10 years.

However, few reports are found on the all-optical switch by using EAM. The applications of the EAM in all optical processing are focusing on the wavelength conversion [7], 3R regenerator [8][9] and demultiplexing using XAM [10][11]. The application of the XPM in wavelength conversion was firstly investigated in [12] [13].

In this chapter, we propose a novel all-optical switch by using EAM with the configuration of MZI (MZI-EAM). In our proposal, the EAM consists of InGaAlAs/InGaAlAs MQW, and is monolithically integrated with MMI by butt-joint technique with ex-situ cleaning. To our knowledge, we are the only ones to work on this in the world*.

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* In OECC 2005, a paper was presented with the similar operation scheme (We 1.5.1). However, the material and the regrowth method were different with those in our work.

5.2 Operation Principle of the novel Mach-Zehnder all optical Switch by using electroabsorption modulator

Our proposal originates from the MZI SOA all optical switch, which is schematically shown in Fig.5.1 (a).

In the SOA based all-optical switch, two control pulses are introduced into SOAs to induce phase change in both arms. The switching window opens during the delay time between two pulses, as shown in the top right of Fig.5.1 (a). The faster pulse causes a refractive index change by changing the carrier density, thus one part of the signal light undergoes a phase change. After a short delay time, the second pulse is fed into the other SOA, causing the similar phase change of the other part of the signal light. After the MMI, these two parts of the light interfere with each other, resulting in phase shift during the delay time and cancellation of the slow recovering of the phase state caused by the first control pulse.

Due to the limit of the slow recovery (~100ps), the push-pull is necessary for high-speed operation in the above configuration.

In the MZI-EAM all-optical switch, only one pulse is necessary due to the inherent short recovery time in EAM at reversed bias voltage (~10ps). As shown in Fig.5.1 (b), the control pulse is injected into the upper EAM. It changes the refractive index of this EAM by increasing the carrier density. Therefore, the part of the signal propagating in the same EAM undergoes phase shift and consequently, alters the position of the constructive interference on either the upper or the lower output port of the device. Mean while, in the other EAM, no phase shift take place to the other part of the signal. By choosing appropriate parameters, switching can be induced by shifting the interference from one port to the other port.

The advantages of the MZI-EAM all-optical switch come from both EAM and the non-push-pull configuration. No current is injected and the ASE noise is eliminated together with power consumption reduction. The speed is not limited by the delay time, but by the recovery of EAM, which is determined by the applied bias. More over, the avoidance of the push-pull simplifies the design and operation.

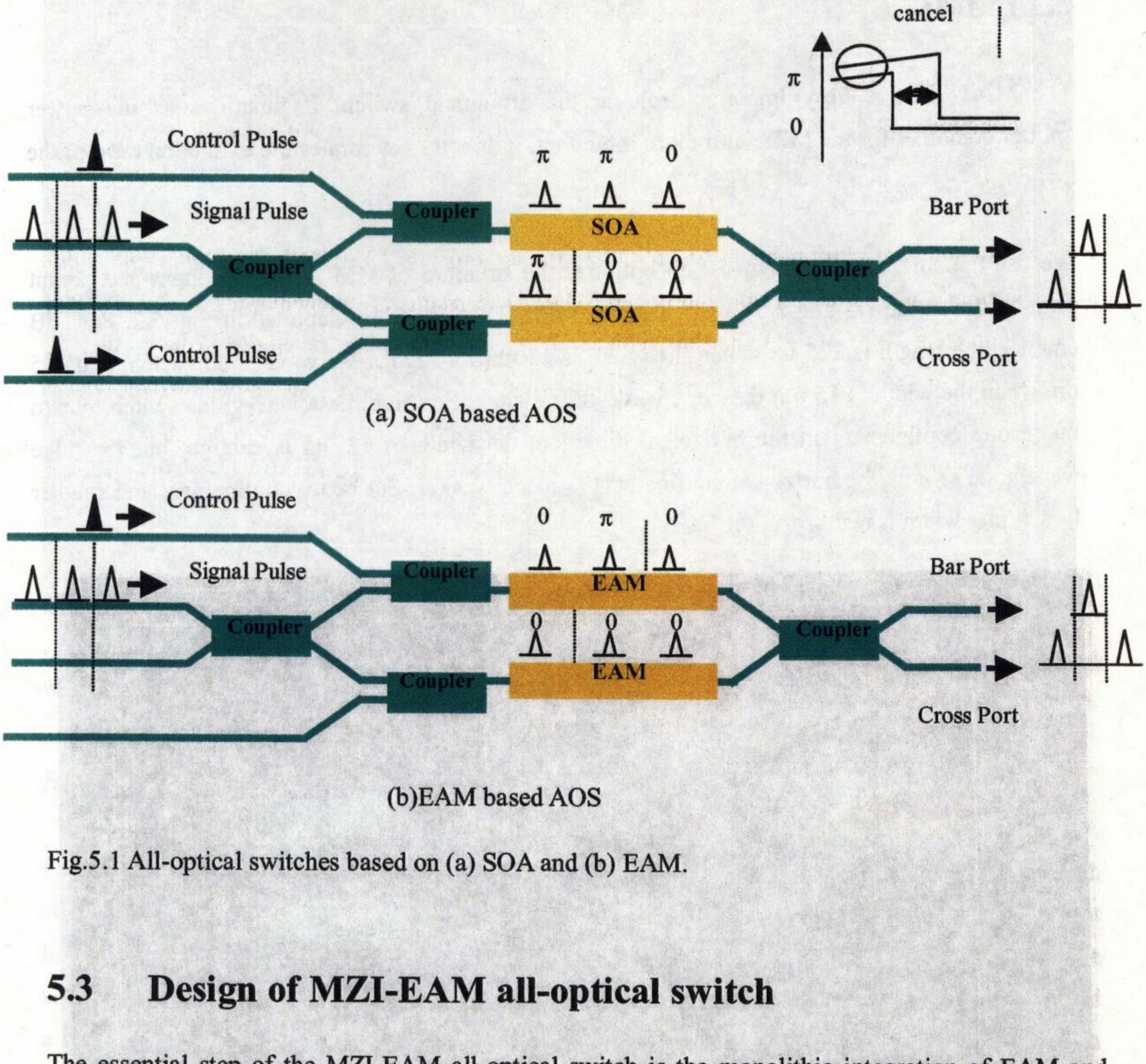


Fig.5.1 All-optical switches based on (a) SOA and (b) EAM.

5.3 Design of MZI-EAM all-optical switch

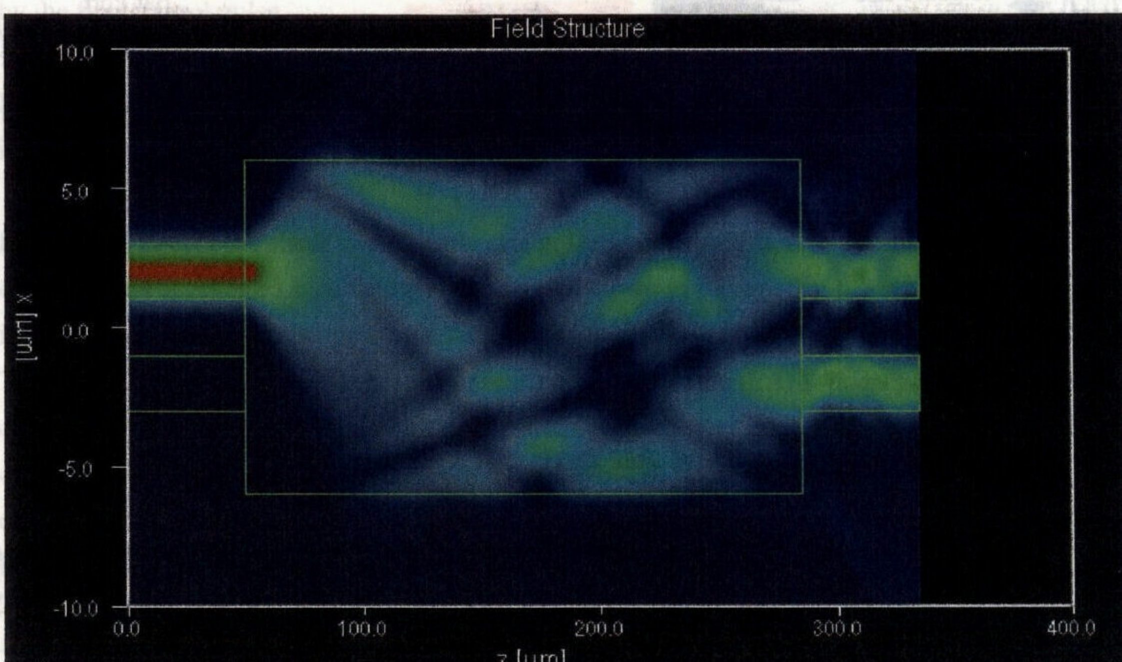
The essential step of the MZI-EAM all-optical switch is the monolithic integration of EAM and passive components. In our experiments, all switches are fabricated on the samples grown by two-step butt-joint regrowth.

The most important component is the EAM. The performance of the EAM has been fully investigated in Chapter III. In this switch, the width of the waveguide is 2um and the length is 150 um.

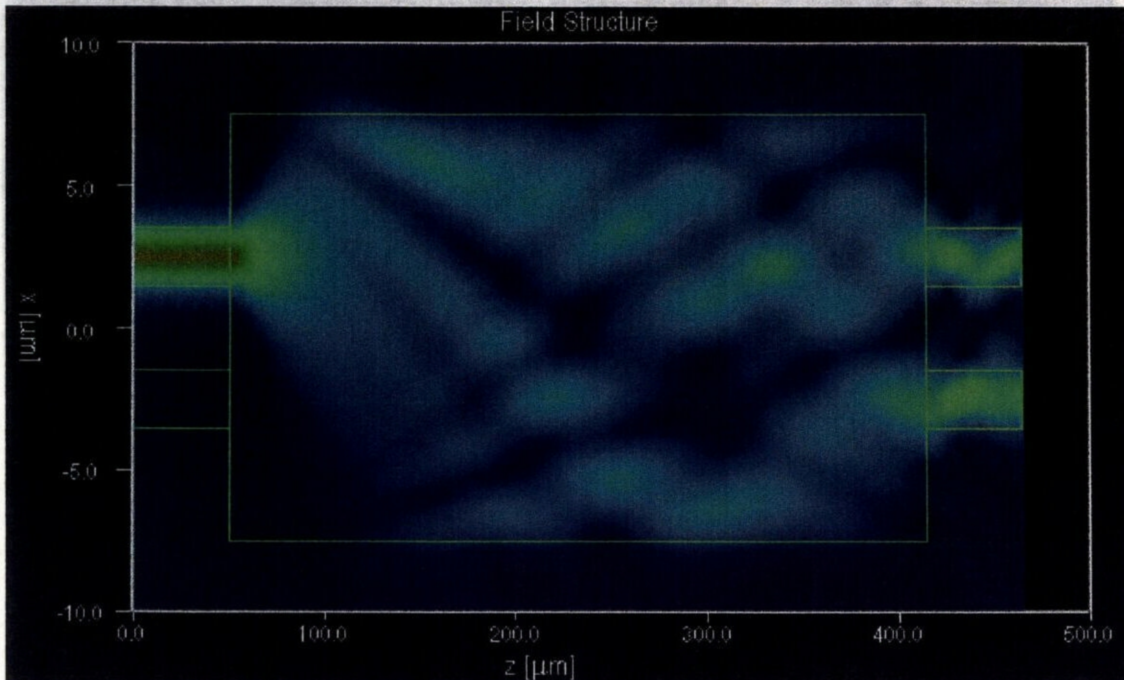
5.3.1 MMI

The MMI plays a very important role in the all-optical switch. It functions as the power splitter/combiner for the MZI. And more important, it directly determines the extinction ratio of the switch.

We use the software "Prometheus" to optimize the structure of MMI. Both the input and output ports locate at the 1/3 and 2/3 position of the MMI. The results are depicted in Fig. 5.2. For 3dB coupler, the length is 225 um when the width is 12 um for high mesa waveguide switch, and 355 um when the width is 15 um for ridge waveguide switch. For high mesa waveguide switch, due to the strong confinement in the horizontal direction, the width of 12 um is enough; but for ridge waveguide switch, the horizontal confinement is much weaker. For better confinement and smaller loss, wider width is necessary.



(a) For high mesa



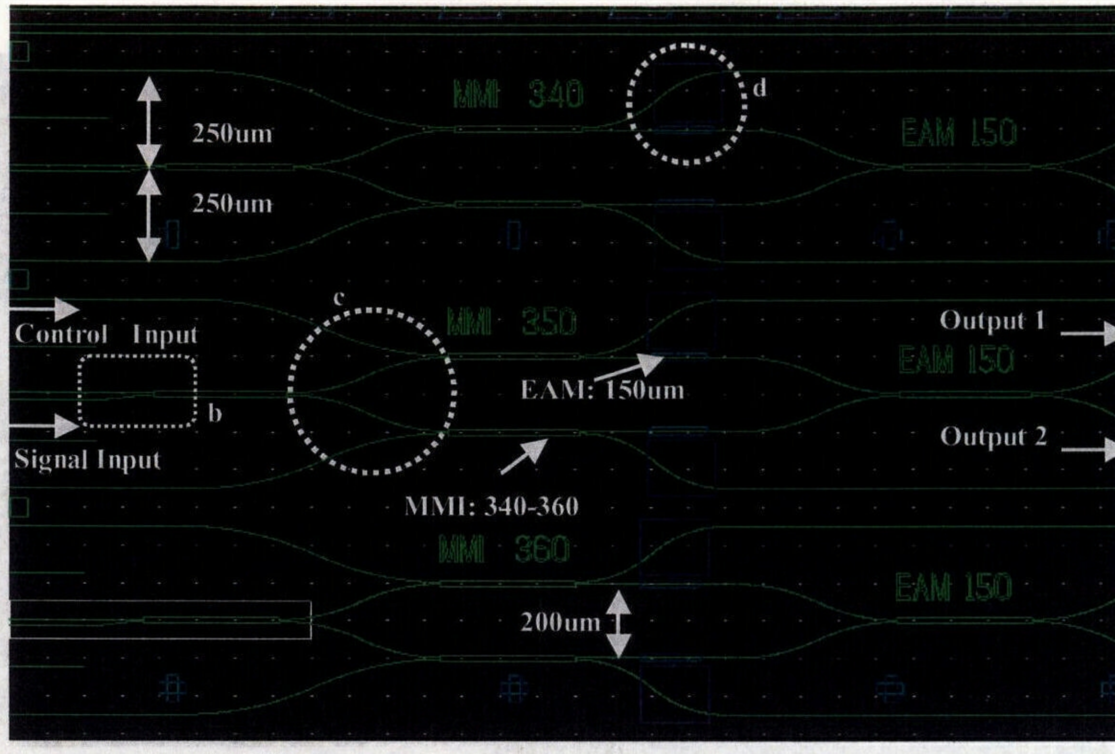
(b) For ridge

Fig. 5.2 Calculation of paired type 3dB MMI coupler with ridge waveguide (a), and deeply etched waveguide (b).

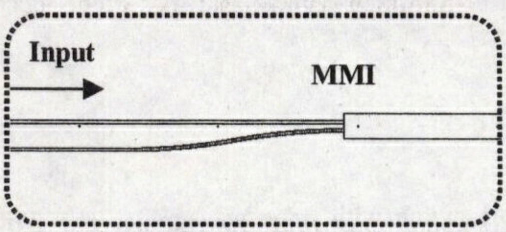
5.3.2 Switch pattern

Fig.5.3 shows the layout of the MZI-EAM all-optical switch with ridge waveguide. The switch consists of 4 MMIs and 2 EAMs. In Fig5.3 (a), there are three switches in the figure with different length of the MMI. This is for tolerance between the simulation and experiments. According to the simulation shown above, the idea length of MMI is 350um, therefore, a shorter EAM of 340 um and a longer EAM of 360 um are added in the same mask to cancel the vibration caused in the growth and process.

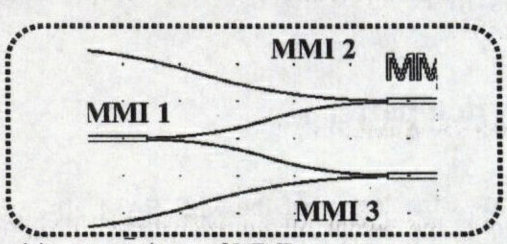
The input port for the signal light locates at the central waveguide, shown in Fig.5.3 (b). The spacing between the two output ports is 250um, and the distance between the signal input and control pulse input is also 250um, suitable for the tapered fiber array in the measurement. In Fig.5.3 (d), the SiO2 pattern is shown by the parallelogram in blue. The 75o is designed for the reduction at the interface of the butt joint. In the process, the mask consisting of thousands of SiO2 pattern is first used for the definition of the active region for EAM. The brown rectangle is the electrode of



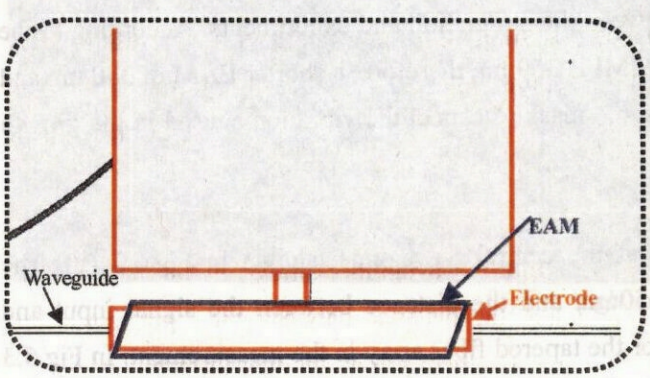
(a) Whole view of switches



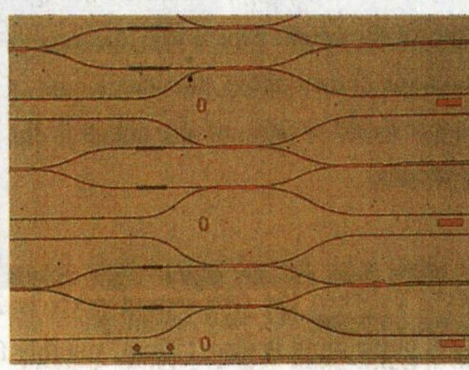
(b) Central line of the switch



(c) connections of MMIs



(d) EAM and electrode in the switch.



(e) Top view from microscope

Fig.5.3 Layout of the MZI-EAM all-optical switch with ridge waveguide. (a) The whole view. (b)