A photonic integrated spatial mode controller with reflective structure

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***Abstract*—A photonic integrated spatial mode controller was demonstrated, which consisted of a 100-channel arrayed-waveguide-grating (AWG), a phase and amplitude modulator array and a reflector array based on the thin-film z-cut lithium niobate platform. The fabricated integrated chip exhibited a narrow channel interval of about 50 pm. The measured response time of the amplitude controller based on a Mach-Zehnder interferometer (MZI) is less than 0.5 us.**

Keywords—arrayed-waveguide grating, lithium niobate, spatial mode controller, photonic integration

I. INTRODUCTION

Optical signal processing chip can synchronously modulate optical signals in all-optical network, so it has attracted wide attention in recent years [1]. Although the typical device of spatial optical mode controller, Liquid Crystal on Silicon (LCoS) SLM, has a very mature technology and has been widely commercialized [2], it is still limited by slow control speed and limited control range. In addition to liquid-crystal-based spatial light modulator (LC-SLM), there are conventional optical spatial mode controllers based on optical waveguides, which include tunable optical filter (TOF) [3], optical arbitrary waveform generator (OAWG) [4]. The development of photonic integration technology allows them to be implemented at compact sizes.

This work presents an AWG based optical spatial mode controller. The waveguides are formed on thin-film z-cut LN platform. The optical spatial mode controller proposed consists an AWG with 50 pm channel spacing, 21 MZI based phase and amplitude modulators and 100 total reflectors. The AWG was used to divide the input light by frequency component. Because different wavelengths of light are emitted to different output waveguides of the AWG, they are modulated by different controllers and reflected back to the input waveguide through the reflector. The measured response time of the amplitude controller based on an MZI is less than 0.5 us. As far as we know, this is the first known implementation of an AWG based spatial mode controller which used thin-film LN platform.

II. DESIGN STRUCTURE AND FABRICATION

As shown in Fig. 1(a), our proposed spatial mode controller chip is a reflective structure as a whole. It consists of an AWG, an MZIs based controller array and a reflector array. In our design, different frequency components of the input light are divided by the AWG and they are transmitted to different output waveguides. So, each of them can be modulated by the phase and amplitude controller in the corresponding output waveguide respectively. If the light of a certain frequency is modulated, it will not enter the scatter, but enter the total reflector based on the ring. So the light transmitted to the ring will return to the input waveguide of the chip, thus finally being extracted. The chip is able to realize the frequency domain processing of the input light. As a result, our device has complex functions and can be used as both an TOF and an OAWG.

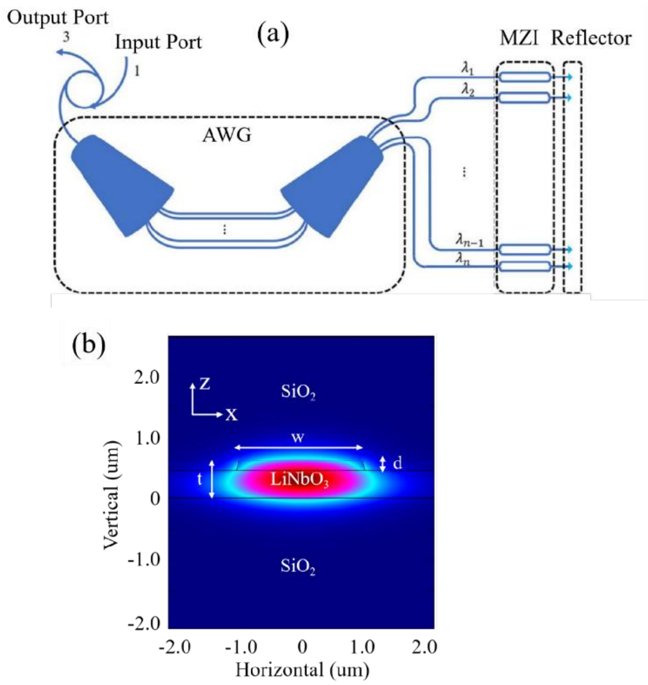

Fig.1. (a)Schematic diagram of the spatial mode control chip;(b) Simulated TE mode profile with w=2μm, t=600 nm, d=150nm

Z-cut thin film LN was used to form all the waveguides because the refractive index distribution remains the same when light propagating in different directions on the plane. Our design includes a lot of folding design in order to make the structure compact. When designing curved waveguides, the use of z-cut thin film LN shows great convenience. The AWG consists of input and output waveguides, two slab waveguides and waveguide array. The channel spacing of the AWG is set as 50 pm. The width of input waveguides, output waveguides and array waveguides are 2 μm. A fixed phase difference will be accumulated because the same length difference of the adjacent waveguides. So, the etch depth of this part is set at 150 nm, while TE mode is adopted. Fig.1(b) shows the simulated TE mode profile. The light field is more distributed in the slab of the waveguide, which can reduce the random phase error due to non-smooth side walls. In addition, because the waveguide is formed on LN, the phase and amplitude can be controlled electrically.

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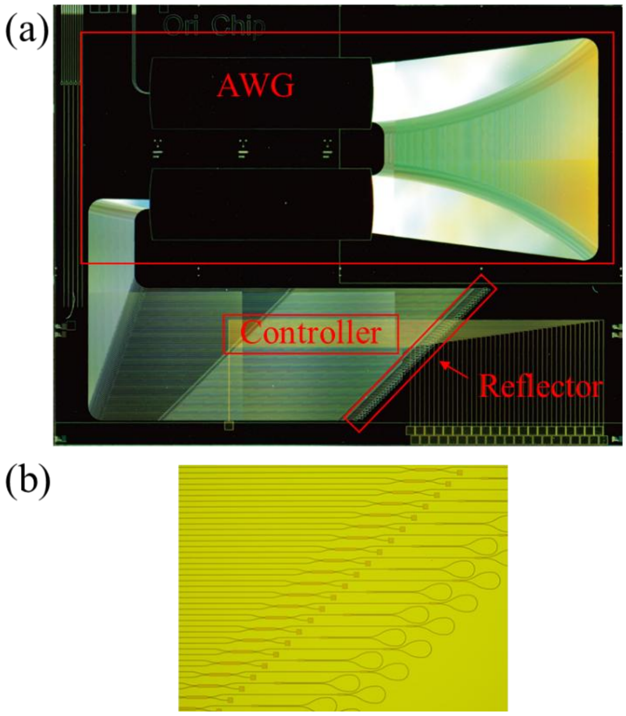

Fig. 2. (a)The microscope image of the fabricated chip; (b) the scanning electron microscope (SEM) image of reflectors based on ring mirrors

The waveguides were patterned by an i-line stepper on the chromium (Cr) layer, which was evaporated on the wafer by electron beam evaporation (EBE). The Cr hard mask and LN was etched by inductively coupled plasma reactive ion etching (ICP-RIE). Fig. 2(a) shows the scanning electron microscope (SEM) image of the etched waveguide, which shows that the sidewalls are quite smooth. Then a 2um SiO2 isolation layer was deposited by plasma enhanced chemical vapor deposition (PECVD). Via opening for the metal electrodes on either side of the two arms of the MZIs followed. The metal electrodes were then evaporated by EBE. Fig. 2(b) shows the scanning electron microscope (SEM) image of reflectors based on ring mirrors.

Fig. 2(a) shows the microscope image of the fabricated chip. As we can see, folding layout makes the size small. For different array waveguides, the proportions of curved waveguides and straight waveguides remain the same, which is designed to reduce the phase error. U-shaped waveguides were adopted to reduce the space between the AWG and modulators. And their total length of different channels is the same, thus avoiding the phase error due to different optical paths.

III. MEASUREMENT

The spatial mode controller proposed has 21 MZI-based phase and amplitude modulators, which are electrically controlled. If no electrical signal is applied to the two arms of the MZI, light of the corresponding frequency component will be scattered, because the lower output waveguide of the second MMI is connected to a scatter. In this case, this channel is “closed”, which is true for all channels. So, ±10V square wave signal with a period of 0.01ms and a duty cycle of 50% is applied to one selected channel. The wavelength of the tunable laser is swept. The amplitude of the optical signal changes with the wavelength and there is a maximum signal, the wavelength of which is the one corresponding to the channel. Fig. 4 shows the measured optical modulated signal of a channel at the corresponding wavelength. As we can see, the modulated optical signal rises at first with a response time less than 0.5 μs, then goes down and flattens out finally.

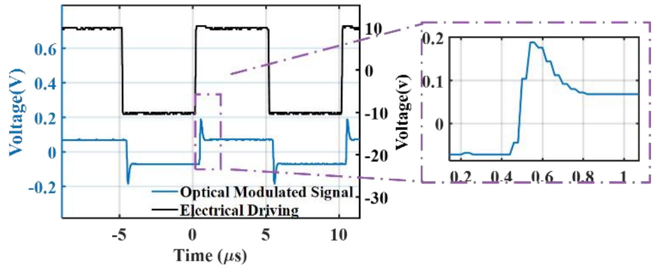

Fig.4. Optical modulated signal of the fabricated amplitude controller, and one rise is zoomed in and shown as the inset

The peak-to-peak voltage value (Vpp) represents the intensity of the reflected optical signal at different wavelength. We record the Vpp of the selected channel every 5 pm to form the reflection spectrum of the channel. We use the 3th input waveguide and record the reflection spectra of 3 elected adjacent channels. Fig.5 shows that the wavelength spacing of adjacent channels is about 50 pm, which agrees well with the design. The phase error accumulated when light propagate in the array waveguide still cause some crosstalk between channels.

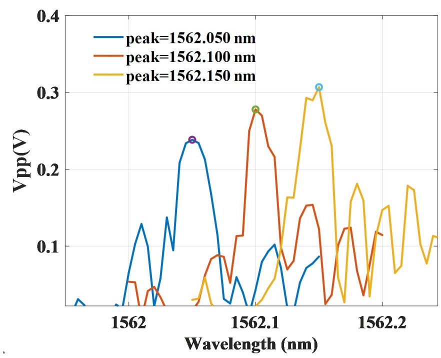

Fig.5. Measured reflection spectra of 3 adjacent channels

IV. CONCLUSION

This work presents an AWG based optical spatial mode controller using the thin-film z-cut LN platform. An AWG with 50 pm channel spacing, 21 electrically controlled MZI based phase and amplitude modulators and 100 total reflectors based on the ring consist the optical spatial mode controller proposed. The AWG was used to divide the input light by frequency component. Because light of different wavelengths is emitted to different output waveguides of the AWG, they are modulated by different controllers and reflected back to the input waveguide through the reflector. The measured channel spacing of the optical spatial mode controller is 50pm. The measured response time of the amplitude controller based on an MZI is less than 0.5 us. This is the first known implementation of an AWG based spatial mode controller which used thin-film LN platform.

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