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Compact Photonic Integrated Spatial Mode Controller Based on Thin Film Lithium Niobate

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Abstract: *We demonstrate the compact photonic-integrated spatial mode controller based on arrayed-waveguide-grating (AWG) using the thin-film z-cut lithium niobate platform. The fabricated integrated chip exhibited 100 output channels with intervals of 50 pm. The controlling time is measured less than 0.5 μs for the amplitude control. ©2022 The Author(s)*

Introduction

In recent years, due to the rapid development of photonic integration technology, especially silicon-based photonic integration technology, traditional optical spatial mode controller based on optical waveguides has aroused great research interest [1-4]. Optical phased arrays, arrayed waveguide gratings, optical amplitude controlling arrays, etc. can be developed based on optical waveguides. Therefore, optical spatial mode controller based on photonic integration technology is potentially expected to break through the bottleneck of traditional liquid crystal and MEMS technologies. Breakthroughs have been made in aspects such as conversion speed. These optical phased array chips achieve beam deflection by controlling the phase of the emission unit, and have very wide application potential. At present, the single-channel waveshaper of Finisar is commercially available, which mainly uses discrete diffraction gratings and 2-dimensional LCoS arrays to achieve different frequencies of light wavelength division processing. Due to the use of discrete optical devices, the size and stability of the device are not easy to control and limit its performance.

In this paper, we present the optical spatial mode control chip based on arrayed waveguide grating (AWG). By adopting photonic integration technology, the phase and amplitude control of different frequency components of incident light waves has been realized on a single chip with a compact size.

Design Structure and Fabrication

As schematically shown in Fig. 1(a), the integrated spatial mode controller chip is based on a reflective structure and consists of the AWG, a phase and amplitude control array, and a reflector array. All the waveguides are made of z-cut thin film lithium niobate materials, and the calculated field distribution of ridge waveguide is shown in Fig. 1(b). The arrayed waveguide grating consists of input and output waveguides, two slab waveguides (free propagation area) and a series of arrayed waveguides. The phase and amplitude control array consists of a series of Mach-Zehnder interferometers. The reflector array consists of a series of total reflectors based on ring mirrors. The AWG is used as a wave splitting device to project incident light to different output waveguides at different frequencies, and then the amplitude and phase modulation of each frequency component is performed separately through the phase and amplitude control array. Each individual frequency component enters the total reflector after being modulated, returns to the same arrayed waveguide grating in the original path, and finally returns to the input waveguide of the arrayed waveguide and is separated from the incident signal by the circulator. By controlling the phase shift array and the amplitude modulation array, the incident light signal can be processed in the frequency domain to realize functions such as optical filters and waveform generators.

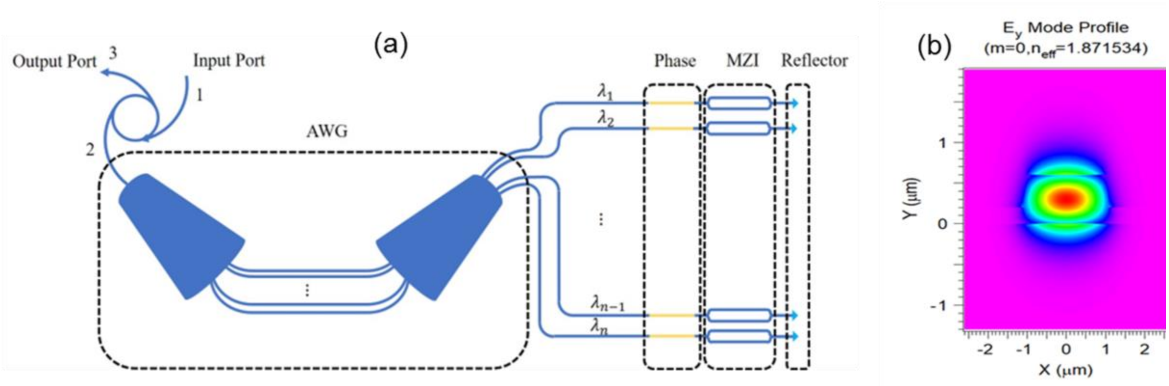

Fig. 1: (a) Schematic structure of proposed spatial mode control chip, (b) calculated field distributions of ridge waveguide.

The integrated chip of photonic spatial mode control chip has been fabricated. The 600 nm-thick thin film lithium niobate was etched to 400 nm by shallow etching to form the ridge waveguide. After the deposition of 800 nm thick SiO_2 cover layer above the ridge waveguide, the metal electrodes were evaporated on the top and back of the waveguide in the phase shift region. Fig. 2 (a) and (b) show the SEM pictures of the etched ridge and the gap between channels. It is obvious that the etched ridge has a good profile with quite smooth side walls and clear gaps between channels. Fig. 2 (c) shows the microscope image of the fabricated integrated chip.

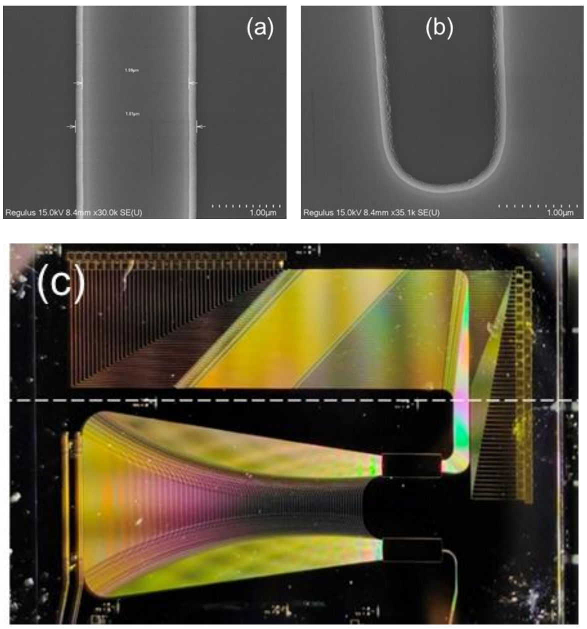

Fig. 2: The scanning electron microscopic (SEM) images of the etched ridge (a) and the gap between channels (b), (c) the microscope image of fabricated integrated spatial mode control chip.

It is seen that the AWG adopts folding layout to reduce the overall size. In the array waveguide area, the length difference between the array waveguides is shared by the straight waveguide and the curved waveguide, and the length of the straight waveguide and the curved waveguide accounts for the same proportion of the total length in each array waveguide, which will reduce the influence of the phase difference of the array waveguide caused by the propagation of light in the curved waveguide.

The U-shaped waveguide composed of curved waveguide and straight waveguide is used to connect the AWG and modulator array, which can maximize the chip space and reduce the overall size of the chip. It is worth noting that the waveguide length of each channel is adjusted so that the total optical path experienced by light of different frequencies after entering different output channels is equal, thus avoiding the phase error and loss caused by different optical paths. In order to further reduce the chip size, adjacent reflectors are staggered as shown in Fig. 2 (c).

Device Characteristics

The number of output channels of the fabricated AWG is 100. Fig. 3 shows the measured transmission spectra. It is seen that there exists cross talk between the channels, which mainly comes from the phase error accumulated by the propagation of light in the array waveguide. The channel spacing is kept of about 50 pm as shown in the Fig. 3.

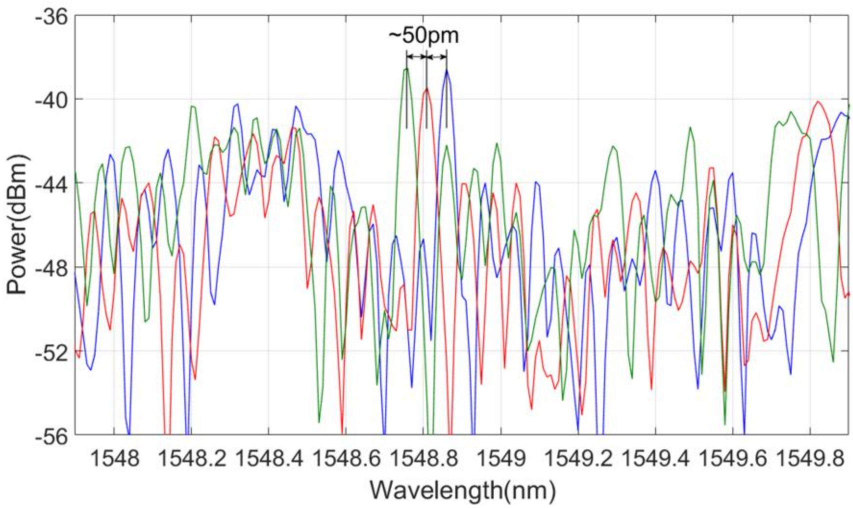

Fig. 3: Measured transmission spectra of fabricated AWG.

Fig. 4: The fabricated amplitude controller based on Mach Zehnder interferometer and total reflector with ring mirror.

As shown in Fig. 4, the amplitude controller includes a Mach Zehnder interferometer and a full reflector based on a ring mirror. In the test, the output light of the tunable laser is input through port 1 and output through port 2 of the circulator, and then coupled into the input waveguide of the amplitude controller through the polarization controller. After amplitude controlling and total mirror reflection, the signal returns to the original path and finally outputs by the port 3 of the circulator and enters into the detector. The amplitude controller applies the voltage to control the signal amplitude, and the voltage signal enters the oscilloscope to record the response time of the amplitude controller.

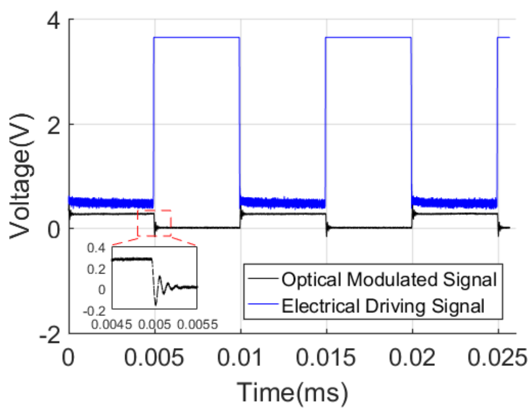

Fig. 5: Measured optical modulated signal of the fabricated amplitude controller

By applying a square wave signal with a period of 0.01 ms and a duty cycle of 50%, we measured the performance of the amplitude controller and the results are shown in Fig. 5. It is seen that the modulated signal has a certain jitter at first, and then tends to be stable with the controlling time less than 0.5 μs.

Conclusion

In conclusion, we demonstrated a photonic integrated spatial mode control chip based on the thin film lithium niobate. The fabricated integrated chip exhibited 100 output channels with intervals of 50 pm. The controlling time is measured less than 0.5 μs for the amplitude control. The proposed spatial mode controller has advantages of compact size, easy fabrication, and thus has wide applications for optical filters, waveform generators, etc.

Acknowledgements

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