Arrayed Waveguide Grating Based on Z-cut Lithium Niobate Platform

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***Abstract*—Arrayed waveguide grating (AWG) is the core optical device in ultra-large capacity wavelength division multiplexing system, which can be used in many fields such as optical filtering, wavelength meter, optical wave multiplexing and demultiplexing. In this paper, we propose an 100 channel AWG based on Z-cut lithium niobate platform with wavelength intervals of 50 pm and insertion loss of 13 dB.**

Keywords—arrayed waveguide grating, Z-cut lithium niobate, wavelength division multiplexing

I. INTRODUCTION

In recent years, communication technology is experiencing unprecedented challenges with the rapid development of big data, 5G communication and blockchain [1-3]. The main technology adopted in optical communication system is wavelength division multiplexing [4]. As the core optical waveguide device of ultra-large capacity wavelength division multiplexing system, AWG has numerous advantages of large number of channels, small channel interval, flat output spectrum, low preparation cost and easy to realize monolithic integration, which can be applied in optical filtering, optical wave multiplexing, demultiplexing, wavelength meter and many other fields [5]. In 1988, Professor Smit of Netherlands University firstly proposed for the application of AWG in wavelength division multiplexing system for multiplexing and demultiplexing [6]. Over the next few decades, research of AWGs grew rapidly and play an important role in many fields.

As an emerging photonic integrated material, thin-film lithium niobate has many advantages, such as low transmission loss, large optically transparent window, and significant electro-optical effect. with the rapid development of micro-nano processing technology, many high-performance optical devices based on the integrated Lithium Niobate On Insulators (LNOI) can be fabricated and used in many technical fields, such as optical networks and optical communications. Therefore, this paper studies a multi-channel, high-resolution, low-insertion loss AWG optical integrated chip based on the Z-cut thin film lithium niobate platform.

II. DESIGN AND SIMULATION

AWG is composed of input waveguides, free propagation regions 1 (FPR1) , array waveguides, free propagation regions 2 (FPR2) and output waveguides. The two ends of array waveguide are evenly distributed on the grating circumference of FPR1 and FPR2. The schematic diagram of AWG is shown in Figure 1. There is a fixed length difference (ΔL) between adjacent array waveguides, so the optical signal has a fixed phase difference (Δφ) after passing through the adjacent array waveguides, as shown in (1). When a multiplexed optical signal enters the input waveguide, diffraction occurs in FPR1, and the diffracted light enters each array waveguide with the same power. The multi-channel light output through the array waveguide interfered in the FPR2. Light with different wavelengths would carry different phase differences and was focused on different output waveguides after the interference superposition. Finally, light with different wavelengths enter the output waveguide at their respective positions to achieve wave demultiplexing.

$$\Delta\varphi = \mathrm{k}\,\Delta L = 2\,\pi\,n\,\Delta L\,/\,\lambda \tag{1}$$

Due to the reversibility of the optical path, the function of photosynthesizing wave multiplexing can be completed by reverse transmission along the above path.

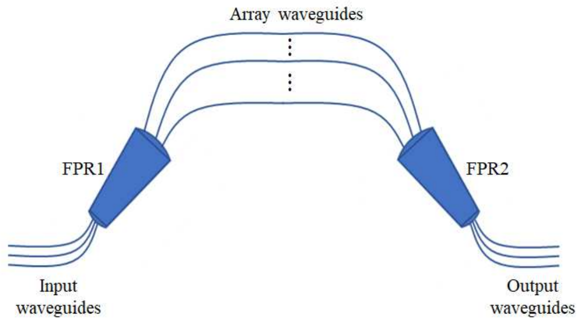

Fig. 1. Schematic diagram of the AWG

The Transverse Electric (TE) mode is selected to realize wave demultiplexing and multiplexing because TE mode can be well confined by ridge waveguides and has lower loss. The Z-cut lithium niobate material has the same refractive index in the XY plane, which reduces the influence of anisotropy of lithium niobate on TE mode propagation in curved waveguides. We used Rsoft to simulate and design the waveguide structure, and finally determined that the input waveguide, output waveguide and array waveguide imply etch depth of 400 nm for a layer thickness of 600 nm, width of waveguides is 2 µm. Both FPR1 and FPR2 adopt slab waveguide structure. The number of array waveguides is 401, and the length difference of array waveguides is 52.61 µm. The length difference of array waveguides is is borne by the straight waveguides and the curved waveguides, and the length of the straight waveguide and the curved waveguide in each array waveguide account for the same proportion of the total length, which can reduce the influence of the phase difference on the array waveguide due to the propagation of light in the curved waveguide. An inverted parabolic transitional structure is selected to connect the array waveguide and FPR to reduce coupling losses. The transitional regions are spaced 1 µm apart on the grating circle. Based on the theoretical model of Fourier diffraction, the

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layout of AWG with 100 output channels and wavelength spacing of 50 pm was designed.

III. Experiment And Measurement

A. Experiment

In this work a 4-inch z-cut thin film lithium niobate wafer is used with a 450 µm silicon substrate on which 2 µm silicon oxide and 600 nm lithium niobate film are deposited. A 170 nm thick chromium (Cr) was evaporated using an Electron Beam Evaporator (EBE) device as a mask for etching lithium niobate waveguides. The 2 µm photoresist is then spun applied to the layer of Cr and a waveguide pattern is defined on the photoresist using a stepper lithography machine. Using photoresist and CR as masks, the waveguide pattern was transferred to lithium niobate waveguides by using Inductive Coupled Plasma (ICP) etching equipment. Using the Plasma Enhanced Chemical Vapor Deposition (PECVD) device, a 2 µm silica overlay was deposited on the wafer.

The Scanning Electron Microscopy (SEM) diagram of array waveguide is shown in Figure 2, and measured width of the waveguide is 2.1 µm, which is basically consistent with the design value. The waveguide sidewalls are smooth, so the transmission losses of the waveguide can be reduced. Figure 3(a) shows a microscope diagram of 100 output waveguides, and Figure 3(b) shows a microscope diagram of an inverted parabolic transition waveguides from the free propagation region to the array waveguides. From the smooth edge of waveguides in the Figure 2 and Figure 3, it can be seen that the structure and size of the AWG are better realized by the process.

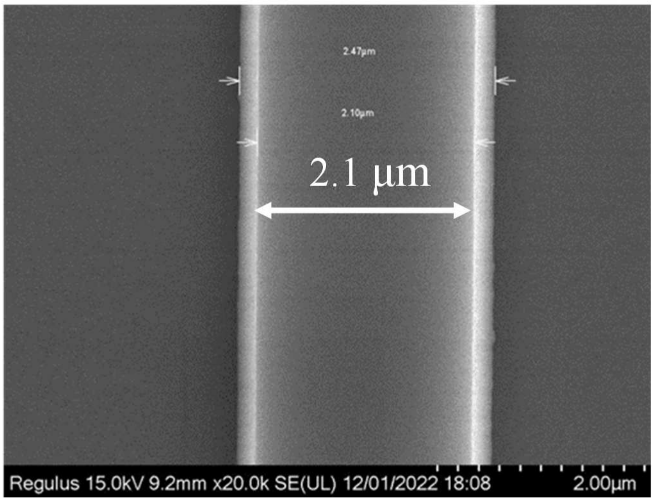

Fig. 2. The SEM diagram of the array waveguide

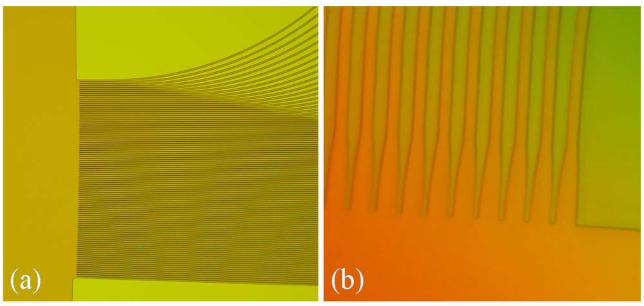

Fig. 3. Microscopic diagram of 100 output waveguides(a), and the transitional waveguides (b)

B. Measurement

With tunable laser as light source, Light passes through the Fiber Polarization Controller (FPC) incident on the AWG chip in TE mode, using lens fiber to realize the coupling of AWG. output fiber is connected to optical power meter. The transmission spectrum of each channel of AWG can be measured by using Matlab to control the wavelength of the input light, reading the value of the power meter at the same time, and plotting power as a function of wavelength. The coupling loss of AWG measured by the on-chip straight waveguide is 10 dB for the coupling at both ends (ignoring the transmission loss of the straight waveguide). The wavelengths of input light are spaced at 10 pm intervals to obtain the transmission spectra of the adjacent 4 channels of AWG, as shown in Figure 4. It can be seen that the peak wavelengths of the 4 channels are spaced at 50 pm apart, and the insertion loss of AWG is measured to a level of 13 dB.

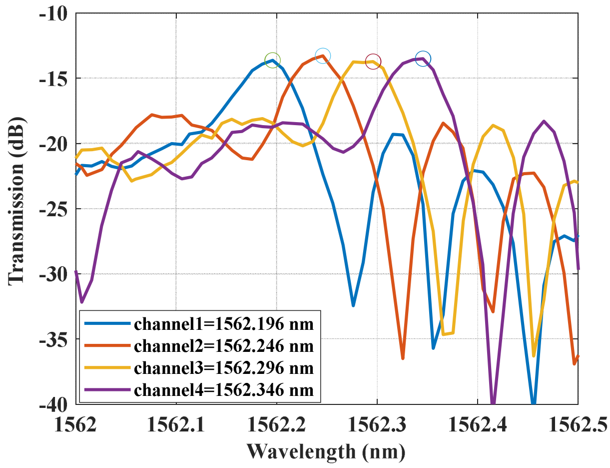

Fig. 4. Transmission spectrum of 4 adjacent output channels

IV. Conclusion

In this paper, an AWG with 100 channels based on the Z-cut lithium niobate platform is designed and fabricated with channel interval of 50 pm and insertion loss of 13 dB. To our knowledge, this is by far the AWG with the highest number of channels, lowest insertion loss, and smallest channel spacing based on the lithium niobate-based platform. In the future, we will optimize the design of waveguide structure and the etching process of lithium niobate to further reduce the insertion loss and channel crosstalk of AWG.

References

[1] J. Baghdady, K. Miller, K. Morgan, M. Byrd, S. Osler, R. Ragusa, W. Li, B. M. Cochenour, and E. G. Johnson, “Multi-gigabit/s underwater optical communication link using orbital angular momentum multiplexing,” Opt. Express 24(9), 9794–9805 (2016).

[2] A. Jahid, M. H. Alsharif, and T. J. Hall, “A Contemporary Survey on Free Space Optical Communication: Potential, Technical Challenges, Recent Advances and Research Direction,” J. Netw. Comput. Appl. 200, 103311 (2022).

[3] L. Jiang, J. C. Feng, L. S. Yan, A. L. Yi, S. S. Li, H. Yang, Y. X. Dong, L. S. Wang, A. B. Wang, Y. C. Wang, W. Pan, and B. Luo, “Chaotic optical communications at 56 Gbit/s over 100-km fiber transmission based on a chaos generation model driven by long short-term memory networks,” Opt. Lett. 47(10), 2382–2385 (2022).

[4] C. A. Brackett, “Dense wavelength division multiplexing networks: principles and applications,” IEEE J. Sel. Areas Comm. 8(6), 948–964 (1990).

[5] S. Chen, F. Yao, S. Ren, G. Wang, and M. Huang, “Cost-effective improvement of the performance of awg-based fbg wavelength

interrogation via a cascaded neural network," Opt. Express 30(5), 7647–7663 (2022).

[6] M. K. Smit, "New focusing and dispersive planar component based on an optical phased array," Electron. Lett. 24(7), 385–386 (1988).