IEICE Electronics Express, Vol.9, No.7, 712–717

200-GHz spacing, 8ch, high-speed wavelength selective arrayed-waveguide grating using buried PLZT waveguides

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Abstract: A wavelength selective AWG (arrayed-waveguide grating) was fabricated using buried PLZT ((Pb, La)(Zr, Ti)O_3) waveguides. It has 8 output channels with 200 GHz spacing. The buried PLZT waveguides have lower propagation loss and higher optical confinement compared to the previously reported ridge PLZT waveguides. Therefore, using buried PLZT waveguides, an AWG with shorter channel spacing than a conventional AWG can be designed and fabricated. The 3-dB bandwidth was 110 GHz, the maximum control voltage was 14 V, and the tuning range was 1600 GHz. Wavelength tuning was successfully demonstrated with a crosstalk of about −14 dB for TE (transverse electric) polarized light and −13 dB for TM (transverse magnetic) polarized light.

Keywords: arrayed-waveguide grating, PLZT, buried PLZT waveguide, tunable filter, electro-optic effect, planar lightwave circuits
Classification: Optoelectronics, Lasers and quantum electronics, Ultrafast optics, Silicon photonics, Planar lightwave circuits

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DOI: 10.1587/elex.9.712
Received March 14, 2012
Accepted March 27, 2012
Published April 12, 2012

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1 Introduction

In future optical network, an optical node is required to have high throughput more than 100 Tbit/s. A high throughput optical node requires a high-speed optical switch and a wavelength selective filter, which can be driven within several nanoseconds. The wavelength selective filter selects an assigned wavelength signal from wavelength division multiplexed signals in the optical node. Wavelength selective filters using the thermo-optic effect in a polymer [1], the acousto-optic effect in $LiNbO_3$ [2], and the electro-optic effect in $LiNbO_3$ [3] or a semiconductor [4] have been reported. The response time of wavelength selective filters using thermo-optic effect is several milliseconds and those using acousto-optic effect is of the order of microseconds. On the other hand, wavelength selective filters using the electro-optic effect can respond within nanoseconds. The electro-optic coefficient of PLZT is much higher than that of $LiNbO_3$ [5]. Therefore, the driving voltage of PLZT is much lower than that of $LiNbO_3$ when the lengths of the electrodes are the same. Moreover, a PLZT waveguide has stronger optical confinement compared to a Ti diffused $LiNbO_3$ waveguide, which leads to smaller optical circuits [6]. We previously reported on a 4×4 optical switch [7] using buried PLZT waveguides, and a wavelength selective AWG [8] using ridge PLZT waveguides. The PLZT optical switch had a low polarization dependence, and the switching time was about 10 ns limited by the driving electronics. The PLZT wavelength selective AWG had 8 channels with 500 GHz spacing, and the wavelength selection time was 15 ns.

DOI: 10.1587/elex.9.712
Received March 14, 2012
Accepted March 27, 2012
Published April 12, 2012

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In this paper, a 200 GHz channel spacing wavelength selective AWG was designed and fabricated. The buried PLZT waveguides enabled narrower channel spacing.

2 Design and fabrication of the wavelength selective AWG

Fig. 1 (a) shows a schematic diagram of the wavelength selective AWG. It consists of input waveguides, a 1st slab waveguide, an arrayed-waveguide with an electrode on each waveguide, a 2nd slab waveguide, and output waveguides. Fig. 1 (b) shows an enlarged view of the 2nd slab waveguide.

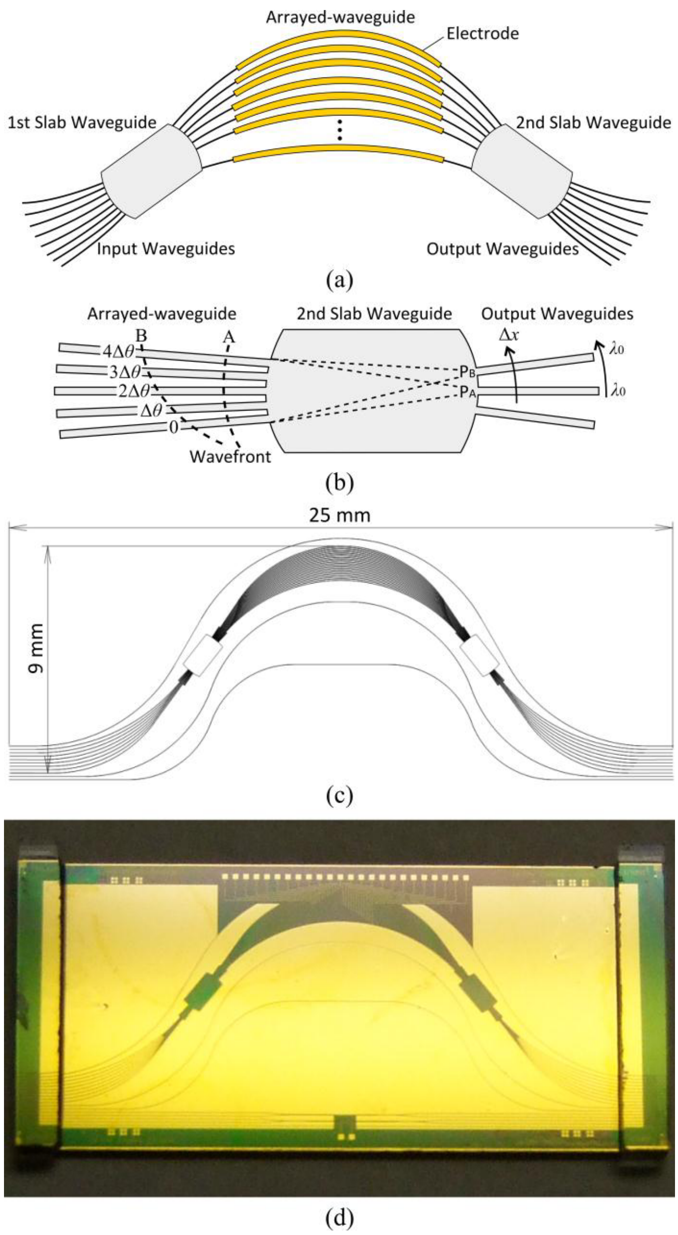

Fig. 1. (a) Configuration of the wavelength selective AWG. (b) Enlarged view of the 2nd slab waveguide. (c) Mask pattern for fabricating the wavelength selective AWG. (d) Photograph of fabricated chip.

DOI: 10.1587/elex.9.712
Received March 14, 2012
Accepted March 27, 2012
Published April 12, 2012

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With no control voltage applied to the electrodes, the wavefront is circular and parallel to the boundary of the 2nd slab, as shown by curve A. Light with the center wavelength is focused at the central output port, P_A. By applying a voltage to each electrode, the light propagating in each waveguide in an arrayed-waveguide suffers an additional phase shift due to the electro-optic effect. The wavefront becomes skewed, as shown by curve B, and the light is focused at the upper port, P_B. The displacement of the focus point, Δx, is described by

$$\Delta x = \frac{\lambda f}{2\pi n_s d}\Delta\theta. \quad (1)$$

Where λ is the center wavelength, f is the length of the slab waveguide, n_s is the effective index of the slab waveguide, d is the spacing between adjacent arrayed-waveguide, and $\Delta\theta$ is the phase shift due to the electro-optic effect. The phase of the light propagating through the k^{th} waveguide in the arrayed-waveguide is $(k-1)\Delta\theta$. Fig. 1 (c) shows the mask pattern of the wavelength selective AWG. The device has 8 channels with 200 GHz spacing. The diffraction order is 120, the path difference between adjacent waveguides in an arrayed-waveguide is 77.1 μm, the FSR (free spectral range) is 1600 GHz, and the number of waveguides in the arrayed-waveguide is 24. The device size is 9.0 mm × 25.0 mm. An electrode with a length of 4 mm was formed on each waveguide of the arrayed-waveguide. The wavelength of the output light is selected by controlling the voltages applied to the 24 electrodes. The tuning range is 1600 GHz, which is equal to the FSR of the AWG. A photograph of the chip is shown in Fig. 1 (d).

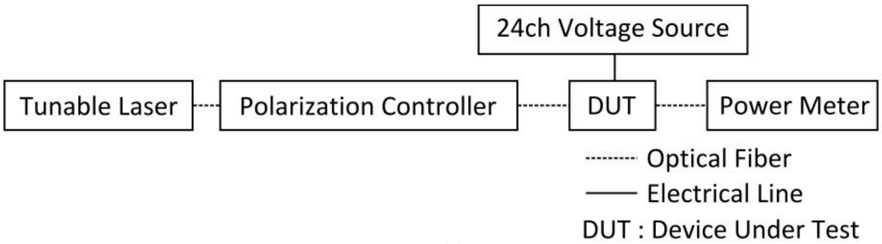
A thin-film of PLZT was grown by solid-phase epitaxy on a NST (Nb-doped $SrTiO_3$) substrate. A PLZT core layer was patterned by ICP (induced coupled plasma) etching. PLZT over cladding was grown, and buried the waveguide core. Electrodes were fabricated by sputtering and a lift-off process. The waveguide propagation loss is about 1 dB/cm. The waveguide was single mode and the minimum bending radius was 3.0 mm according to BPM (beam propagation method) calculations.

3 Experimental results

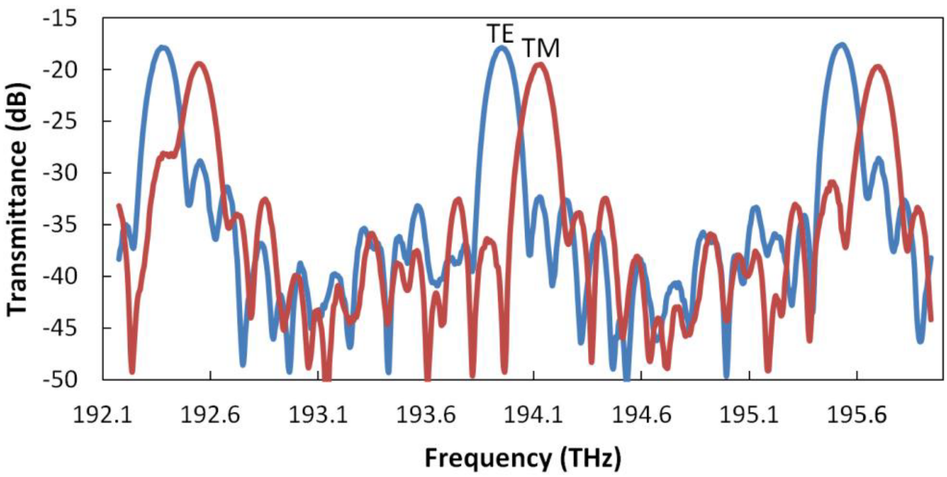
Fig. 2 (a) shows the experimental setup for measuring the wavelength tuning characteristics of the wavelength selective AWG. The polarization of the laser beam was set by a polarization controller, and the light was launched into the central input port of the wavelength selective AWG. A control voltage was applied to each electrode on the arrayed-waveguide. The optical power of the central output port was monitored, and the transmission spectrum was measured for both TE and TM mode excitation. Fig. 2 (b) shows the transmission spectra of the wavelength selective AWG without a control voltage. The fiber-to-fiber insertion loss at the peak frequency of the transmission spectrum was 18 dB for the TE mode, and 19 dB for the TM mode. From the results of the reference waveguide measurements, the waveguide propagation loss was 3 dB, and the coupling loss from the fiber to the PLZT waveguide was 5 dB/connection. The latter was larger than expected

DOI: 10.1587/elex.9.712
Received March 14, 2012
Accepted March 27, 2012
Published April 12, 2012

1 dB/connection because of the fiber misalignments due to imperfect polished waveguide facets. The AWG excess loss was about 5 dB. It is partially due to the radiation loss at bending waveguides of the AWG and could be reduced by increasing confinement. The crosstalks for the TE and TM mode were −14 dB, and −13 dB, respectively. The 3-dB bandwidth was 110 GHz for both TE and TM mode. The difference in peak frequency for each mode was 190 GHz, and the birefringence of the buried PLZT waveguide was estimated to be 0.002.



(a)



(b)

Fig. 2. (a) Experimental setup for measuring the wavelength selective AWG characteristics. (b) Transmission spectra for TE and TM mode excitation without a control voltage.

The wavelength channel selection operation was demonstrated when the TM mode was excited, as shown in Fig. 3. The phase difference, $\Delta\theta$, between adjacent arrayed-waveguide was set to $1/4\pi$ for a 1-channel shift, $2/4\pi$ for a 2-channel shift, $3/4\pi$ for a 3-channel shift, and, $4/4\pi$ for a 4-channel shift. It was set to $-1/4\pi$, $-2/4\pi$, and $-3/4\pi$, for 5-, 6-, and 7-channel shifts, respectively. The voltages required to achieve phase shifts of $1/4\pi$, $2/4\pi$, $3/4\pi$, and $4/4\pi$ were 2.0 V, 4.7 V, 6.0 V, and 10.0 V, respectively. Phase differences of $-1/4\pi$, $-2/4\pi$, and $-3/4\pi$ were also achieved with 2.0 V, 4.7 V, and 6.0 V. All of the channels were successfully selected. It should be noted that any wavelength within the FSR can be selected by adjusting the control voltages to electrodes.

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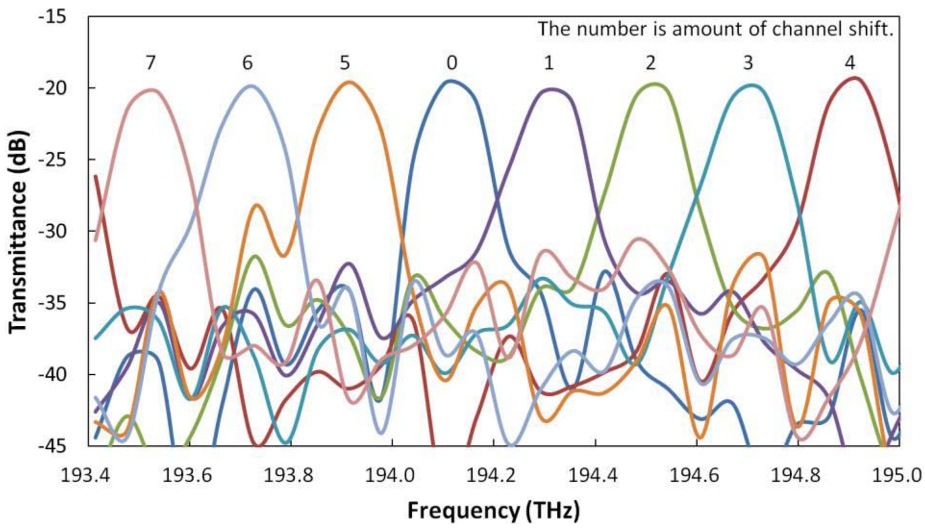

Fig. 3. Wavelength channel selection operation.

4 Conclusion

We fabricated a wavelength selective AWG module. This device has 8 channels with 200 GHz spacing. The insertion losses for TE and TM polarized light were 18 dB and 19 dB, respectively. This includes a coupling loss of 10 dB and a waveguide propagation loss of 3 dB. The crosstalks for TE and TM polarized light were −14 dB and −13 dB, respectively. Wavelength channel selection operation was successfully demonstrated.

Acknowledgement

This research was partially supported by New Energy and Industrial Technology Development Organization.

DOI: 10.1587/elex.9.712
Received March 14, 2012
Accepted March 27, 2012
Published April 12, 2012