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Nano-Second Speed PLZT Waveguide Switches and Filters

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Nano-second speed optical switches and filters fabricated in epitaxially grown (Pb,La)(Zr,La)O_3 (PLZT) waveguides are introduced. The optical switches including 1x2, 1x4, 1x8, 1x16, 2x2, and 4x4 ports have switching time less than 10 ns and the AWG based 8x1 wavelength selective filter has 15 ns switching time. A PLZT buried waveguide is successfully developed to minimize insertion loss and polarization dependence in the optical switches.

I. INTRODUCTION

There have been increasing interests in high-speed switching and filtering devices for packet based optical networks in telecommunications and data centers. High-speed switching and filtering device technologies include semiconductors [1] and $LiNbO_3$ [2]. However, it is not easy to meet various requirements such as response speed, power consumption, polarization independence, and insertion loss.

We have developed (Pb,La)(Zr,Ti)O_3 (PLZT) [3] waveguide devices [4,5] by unique solid-phase epitaxy (SPE) [6] motivated by the fact that PLZT is an efficient and polarization insensitive electro-optic material although it has been very difficult to grow high-quality PLZT optical waveguides and fabricate channel waveguides. The epitaxial PLZT waveguide grown on a semiconductor substrate is also attractive for further minimizing driving voltages. We report nano-second speed MZ type optical path switches and a AWG based wavelength selective filter using epitaxial PLZT optical waveguides grown on Nb-doped $SrTiO_3$ (NST) semiconductor wafer. Those high-speed devices have excellent performances in terms of low-driving voltage, low-power consumption, low polarization independence, and low insertion loss suitable not only for optical packet/burst switched networks but also for existing optical networks.

II. PLZT WAVEGUIDE FABRICATION

The SPE process for PLZT thin-film is composed of a precursor solution deposition step and a rapid thermal annealing step. A PLZT bottom clad layer and a PLZT core layer are grown by the SPE on a NST wafer. A 3 μm-wide channel-waveguide is formed by an ICP etching process. A ridge shape channel waveguide is fabricated in this way. A buried channel waveguide requires a PLZT top clad layer. The core layer has higher index than the clad layers to confine the light in the core layer. The clad layers prevent optical absorption by the NST and top electrodes. An indium-tin oxide top electrode layer with an Au contact layer is fabricated on the surface of the PLZT channel waveguides using sputtering and a lift-off process. A cross-sectional structure of the PLZT buried waveguide is shown in Fig. 1. The top electrodes are connected to bond pads by Au interconnects. Edge facets are optically polished after dicing.

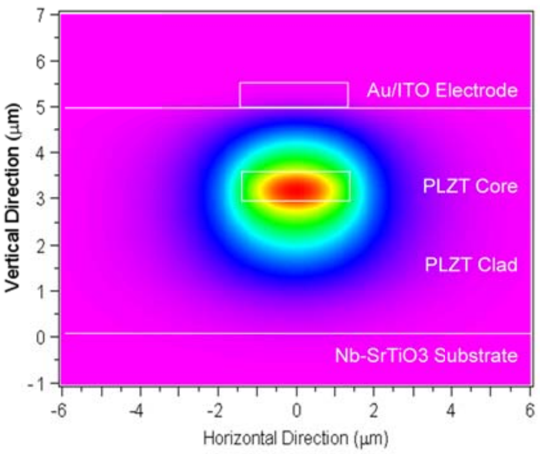

Fig. 1. PLZT buried waveguide structure.

III. PLZT SWITCHES

A building block for PLZT optical switches is a modified balance bridge type 1x2 switch. The balance bridge type switch is composed of a MZ modulator with top electrodes and input and output 3dB couplers as shown in Fig. 2. An input optical signal is delivered to the cross port and bar port under no voltage application (3 dB splitting state). By applying a voltage to one of top electrodes (A is on or B is on), the signal is promptly switched to the cross port or the bar port due to the resulting electro-optic index change.

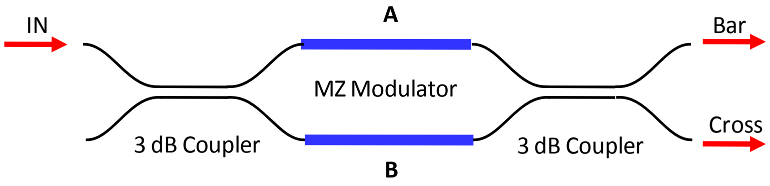

Fig. 2. 1x2 MZ optical switch element.

Fig. 3 shows a typical switching curve at 1550 nm wavelength in the buried waveguide type 1x2 switch as a function of voltage application to the electrode B. The insertion loss, the PDL, and the crosstalk/extinction ratio are 3 dB, 0.3 dB, and 27 dB at 7.5V, respectively. A typical crosstalk in a matrix 2x2 switch consisted of four 1x2 switch elements is better than 35 dB due to a two stage switch architecture. Switching rise and fall time of the 1x2 switch element is about 3 ns as shown in Fig. 4.

The 1xN switch has a simple tree structure as shown in Fig. 5 so that the introduced optical signal is delivered to one of N output ports. A 1x8 switch chip has a length of about 17 mm and typical insertion loss is 5 dB. A 4x4 switch has a strictly non-blocking tree structure as shown in Fig. 6. An optical signal from any input port is delivered to any output port without disturbing other connections. The tree structure 4x4 has two stage switch nature as well as the 2x2 switch. The first stage switches and the second stage switches work as delivery switches and the third stage switches and the fourth stage switches work as gate switches so that cross talk can be minimized. A 4x4 switch chip has a length of about 22 mm and typical insertion loss is 6 dB. Fig. 7 shows the 4x4 PLZT switch module with a high-speed driving circuit. The driving circuit gives 10V at around 5 ns speed to the twenty four 1x2 switch elements in the 4x4 switch. The switching time is less than 10 ns.

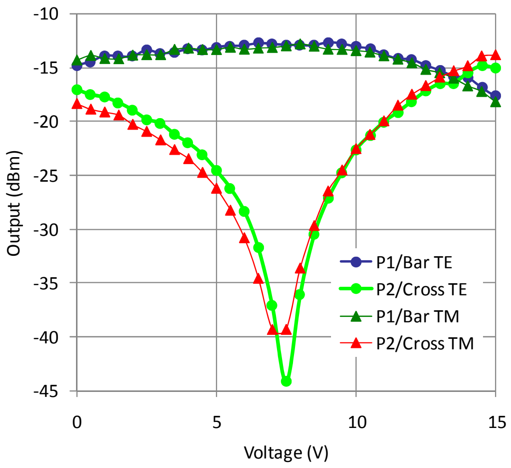

Fig. 3. Switching curve in the 1x2 PLZT switch.

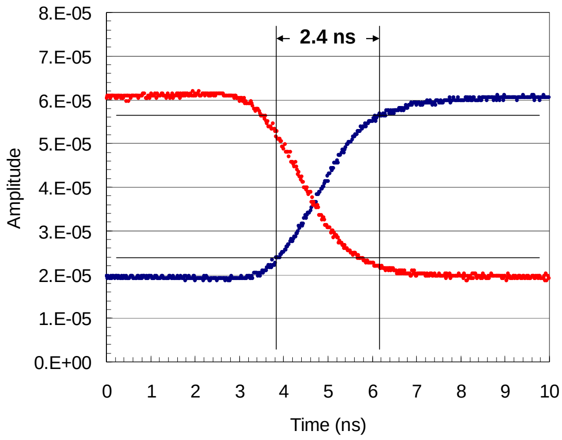

Fig. 4. Switching rise and fall response.

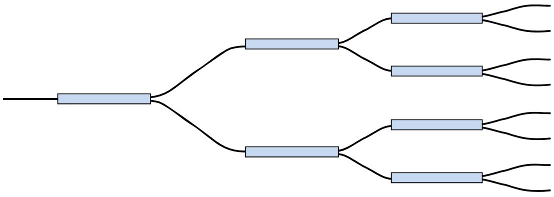

Fig. 5. Tree structure 1x8 switch.

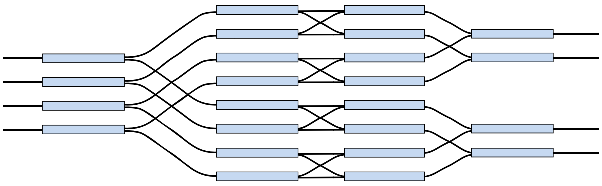

Fig. 6. Non-blocking 4x4 switch structure.

A network based on the nano-second PLZT switch can switch frequently to allocate the bandwidth efficiently. That is because the high switching speeds allow guard time to be minimized. On the other hand, a network based on a conventional milli-second speed switch is not efficient because its switching overhead is very large as compared with data size. Therefore, this drastic reduction in guard time makes data transfer very efficient and realistic in networks including optical packet switching [7], optical burst switching, and time division slot switching.

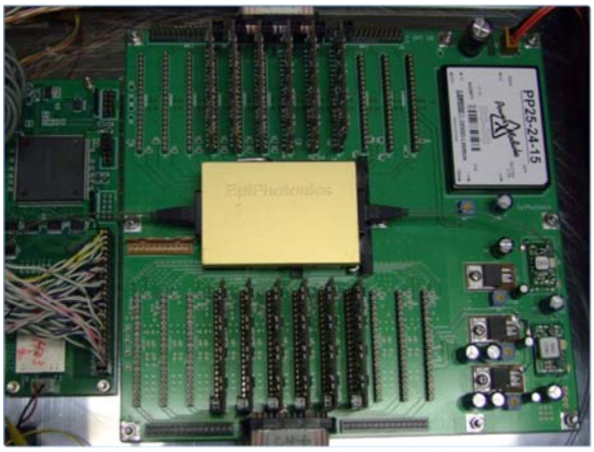

Fig. 7. 4x4 PLZT optical switch subsystem.

IV. PLZT WAVELENGTH SELECTIVE FILTERS

A PLZT wavelength selective filter is based on an 8-ch, 500 GHz or 200 GHz-spacing, AWG as shown in Fig. 8. When the control voltage is applied to electrodes located on arrayed waveguides, an additional light path difference is created between the adjacent arrayed-waveguides, and the shift of a focal point will occur. The phase shift of 2π in each waveguide is sufficient to select any wavelength from the certain output waveguide.

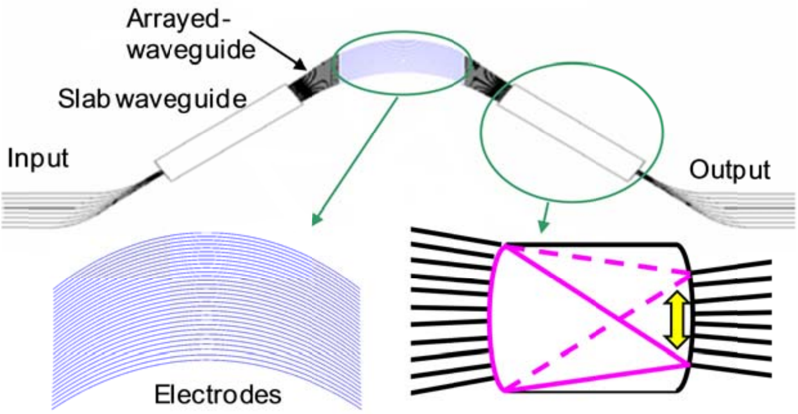

Fig. 8. Wavelength selective filter.

The 3-dB bandwidth is 2.3 nm in the ridge waveguide filter. The adjacent crosstalk is approximately -18.5 dB. Fig. 9 shows the transmission spectra for the output port 4 when the voltages were applied to the electrodes. When the voltage approaches 22V, the phase shift due to the voltage become π and the complete wavelength tuning from 1559 nm to 1543 nm is achieved. The maximum tuning range is 4,000 GHz (approximately 32 nm around 1.55 um) since the channel spacing is 500 GHz and the number of channels is 8. The tuning speed of about 15 ns was confirmed at the peak-to-peak driving voltage of 14.0 V.

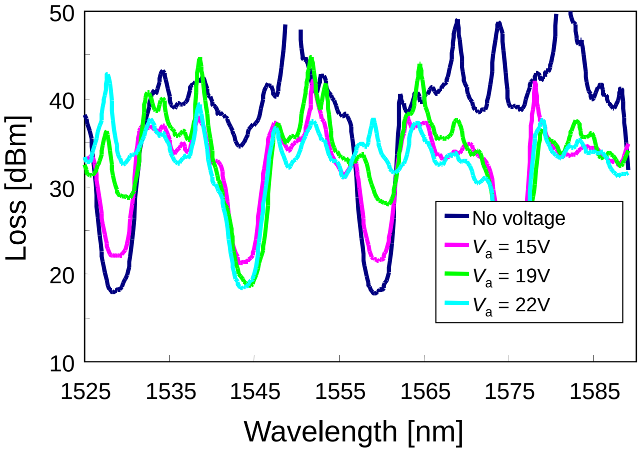

Fig. 9. Transmission spectra in the wavelength selective filter.

V. SUMMARY

High-speed switches and filters using PLZT waveguides are introduced. MZ type switches including 1x1, 1x2, 1x4, 1x8, 1x16, 2x2, and 4x4 ports show the switching speed less than 10 ns. An AWG type wavelength selective filter showed the switching/filtering speed of 15 ns. The high-speed PLZT switches and filters will be of key enabler for optical packet/burst based networks.

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