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# Adjustment of the coupling ratio by laser ablation of Ti:LiNbO<sub>3</sub> directional couplers

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The coupling ratio of directional couplers in Z-cut Y-propagation and X-cut Z-propagation LiNbO<sub>3</sub> crystals was adjusted by laser ablation. The coupling ratio change is more efficient for the TM-mode of Z-cut couplers. The method can be used to correct the uncertainty of the coupling ratio for directional couplers that occurs during fabrication process.

*Keywords:* Ablation; Directional couplers; Integrated optics

## 1. Introduction

Titanium-indiffused lithium niobate optical directional couplers are key integrated optics devices used as power dividers, wavelength filters, switches [1] and modulators [2]. Several parameters for designing directional coupler are required such as the geometrical dimensions of the titanium stripe and the condition of the diffusion. In principle, theoretical approaches based on the beam propagation method (BPM) [3] allow the coupling length to be evaluated from the knowledge of the fabrication parameters. However, it is difficult to fabricate accurately a directional coupler as it was originally designed. One of the most critical fabrication parameters which determines the coupling length is the waveguide spacing [4]. The latter requires severe control of the fabrication process to achieve a predictable coupling ratio.

A possible method to correct the defect is to change the propagation constant of the waveguides. This modification can be achieved by deposition of a high-index film at the surface of the waveguide [5] or by using a metallic film on the directional coupler with an accurate lithographic process

[6]. Another solution proposed by Bulmer et al. [7] consists in using laser ablation to overcome similar problems that occur in LiNbO<sub>3</sub> integrated interferometric modulators. Recently, we reported results obtained by using laser ablation in the fabrication process of a polarization-independent LiNbO<sub>3</sub> Mach-Zehnder modulator [8]. This method is more efficient than the photolithographic correction since the process is quicker and more accurate.

In this letter, we report the results of the coupling ratio adjustment of directional couplers using laser ablation. The basic principle consists in reducing the effective refractive index of the guided mode by using laser ablation in the coupled waveguides, thus resulting in an exponential decrease of the coupling length and modification of the light coupling coefficient [4]. This method has been applied to directional couplers integrated in Z-cut Y-propagation and in X-cut Z-propagation lithium niobate crystal.

## 2. Experimental procedure

The directional couplers were fabricated in a Z-cut Y-propagation and an X-cut Z-propagation LiNbO<sub>3</sub> crystal. The Ti stripes patterned on the LiNbO<sub>3</sub> crystal are 500-Å-thick, 6-μm-wide, 5-mm-long and 4-μm waveguide spacing for single mode operation at 1300 nm. The Ti stripes are diffused for 10 h at 1050°C. To achieve laser

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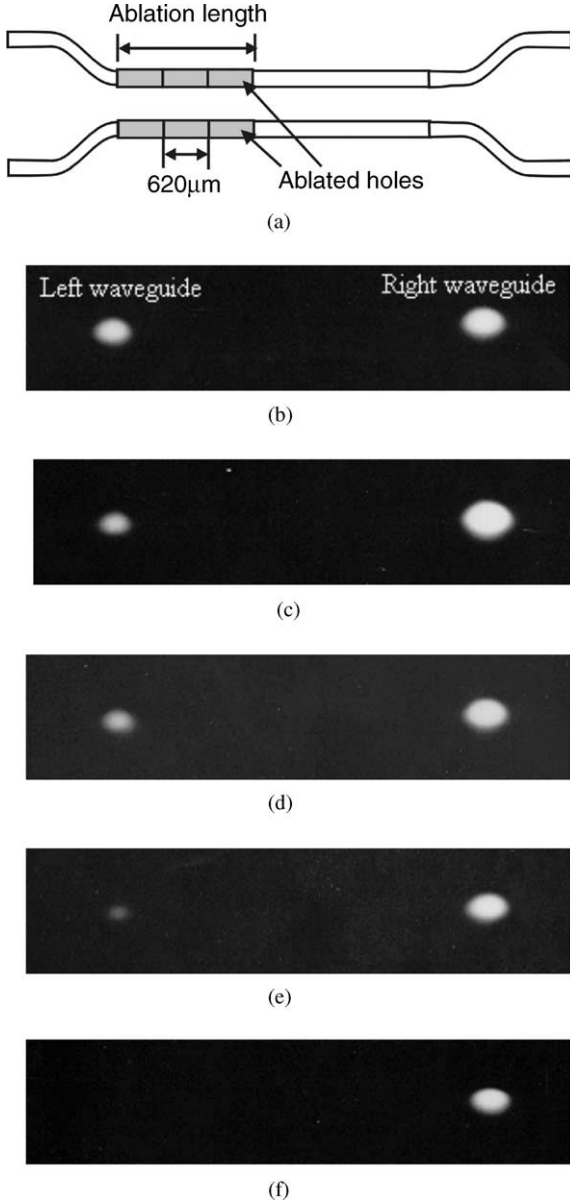


Fig. 1. (a) Ablated holes on the surface of the directional coupler; (b) output intensity distribution for the TM-mode of a Z-cut Y-propagation directional coupler before laser ablation; (c) after 100-nm deep ablation over a length of 1240  $\mu\text{m}$ ; (d) 2480  $\mu\text{m}$ ; (e) 3720  $\mu\text{m}$ ; and (f) 4340  $\mu\text{m}$ .

ablation and to control dynamically the coupling length, we used a KrF (Krypton–fluorine) excimer laser emitting at 249-nm wavelength. The length of the each ablation spot on the waveguides of the directional couplers is 620  $\mu\text{m}$  long. The ablation laser is applied on the waveguides to form one hole by the latter ones [see Fig. 1(a)]. The flux of the laser is adjusted at 4 J/cm<sup>2</sup> resulting in an ablation rate to be 100 nm/pulse on the surface of the waveguides. The detail experimental setup was described elsewhere [8]. The light of a 1300-nm laser diode is launched into one of the waveguides of the directional coupler. The polarization is oriented at 45° from the X-axis of the crystal in order to

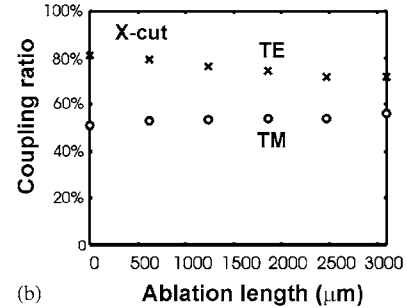
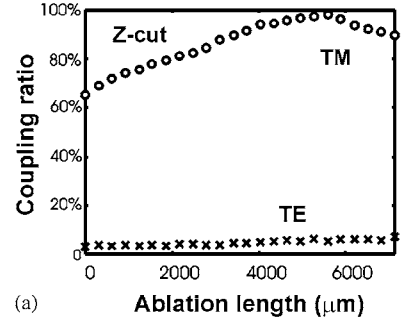


Fig. 2. Coupling ratio versus ablation length: (a) for a Z-cut Y-propagation; and (b) for an X-cut Z-propagation directional coupler.

excite simultaneously the TE- and TM-modes. Both modes of the light transmitted by the directional coupler are analyzed by a polarizer. The light coupling and the losses are calculated simultaneously by a computer from the light intensity distribution at the two outputs of the waveguides.

### 3. Results and discussion

Fig. 1(b)–(f) show the evolution of the energy of the TM-mode at the outputs of a Z-cut and Y-propagation LiNbO<sub>3</sub> directional coupler when varying the length of the ablated region. The laser light is launched in the left waveguide. A significant coupling ratio change from 65% to 98% is obtained with a 4340- $\mu\text{m}$ -long ablated section on the surface of the coupler. The change of the coupling ratio induced by different ablation length is shown in Fig. 2(a) and (b) for the directional couplers integrated in Z- and X-cut LiNbO<sub>3</sub> crystals, respectively. The coupling ratio for the TM mode of the Z-cut LiNbO<sub>3</sub> couplers is changed from 65% to 90% via 100% after 7-mm-long ablation process. In this case, the change of the coupling ratio after ablation process is 45% (=35% + 10%). The change of the coupling ratio for the TE-modes of the Z-cut LiNbO<sub>3</sub> couplers is 5% after 7-mm-long ablation process. The change of the coupling ratio for the TM- and the TE-modes of the X-cut LiNbO<sub>3</sub> couplers is 6% and 10% after 3-mm-long ablation process, respectively. The TM-mode of the Z-cut directional coupler shows more sensitivity to the ablation process on the waveguides of the directional couplers. This

can be explained by the fact that the spatial distribution of the TM-mode for the Z-cut LiNbO<sub>3</sub> waveguides which is related to the extraordinary refractive index is located near the waveguide surface [9]. This behavior may help to fabricate a polarization-independent directional coupler in Z-cut LiNbO<sub>3</sub> by adjusting the coupling ratio in the TM-mode to reach the TE-mode using ablation process.

For 1% change of the coupling ratio for the Z-cut LiNbO<sub>3</sub> couplers (i.e. to change the coupling ratio from  $x\%$  to  $x \pm 1\%$ ), the loss induced by ablation process is 0.15 and 0.4 dB for the TM- and TE-modes, respectively. For the 1% change of the coupling ratio for the X-cut LiNbO<sub>3</sub> couplers, the loss induced by ablation process is 0.86 and 0.9 dB for the TM- and TE-modes, respectively. These results show that the coupling ratio of the Z-cut LiNbO<sub>3</sub> directional couplers in the TM-mode is suitable to be adjusted by ablation process due to the higher sensitivity of the coupling ratio change and lower loss to the ablation process.

#### 4. Conclusion

We reported a method that allows dynamic correction of defects in the coupling length introduced during the fabrication process of directional couplers integrated in LiNbO<sub>3</sub> crystal. This method was applied to directional couplers integrated in X-cut and Z-propagation and in Z-cut and Y-propagation LiNbO<sub>3</sub> crystals to analyze the coupling ratio change for the TM- and TE-modes. The results show that the coupling ratio change is the most efficient for the TM-mode of Z-cut Y-propagation directional couplers. The loss induced by ablation process can be negligible for small coupling ratio adjustment. A good stability of the processed samples was observed.

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