Y-branch Directional Coupler type Ti: $LiNbO_3$ Optical Switch/Modulator

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ABSTRACT

Y-branch directional coupler type optical modulators with three different coupling lengths were fabricated on z-cut $LiNbO_3$ and tested at $\lambda=1.3\mu m$. One device had an exact coupling length for complete power transfer and two other devices had shorter coupling lengths. It was confirmed that, for dc operation, experimental results agreed well with theoretical results.

I. INTRODUCTION

Up to now, several type of external optical modulators have been proposed ; cut-off, uniform directional coupler(DC), alternating $\Delta\beta$ DC, Mach-Zehnder, cross coupler and Y-branch DC. Among them , the Y- branch optical modulator has a definite advantage over the uniform DC, that is, the coupling length of the Y-branch DC is shorter than that of the uniform DC by the factor of $1/\sqrt{2}$. This is one of the important factors in achieving the high-speed switching and modulation. Actual coupling length of a device is expressed as L. We denote the exact coupling lengths (for the complete power transfer) of the Y-branch DC and the uniform DC by l_y and l_c, respectively.

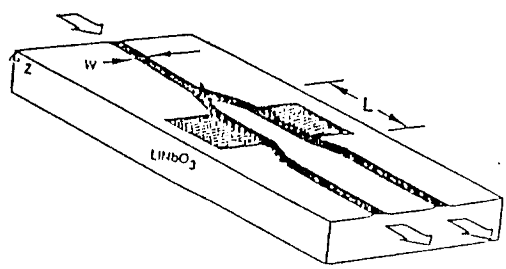

Fig. 1 Schematic diagram of Y-branch directional coupler type optical modulator

For the case of the Y-branch DC shown in Fig.1 [1],

$$R_oR_o^* = \frac{1}{2}\left[1-\frac{2xy}{r^2}\sin^2\left(\frac{\pi r}{2}\right)\right] \qquad (1)$$

where $x = \Delta\beta L/\pi$, $y = L/l_c$, $r^2 = x^2 + y^2$ and $\Delta\beta$ is the electro-optically induced change in the propagation constant. Complete power transfer first occurs when $x = y = 1/\sqrt{2}$, namely,

$$R_oR_o^* = 0 \quad \text{when} \quad L = l_y = l_c/\sqrt{2}\ \text{,and}$$

$$\Delta\beta = \pi/(\sqrt{2}l_y) = \pi/l_c \qquad (2)$$

On the other hand, $\Delta\beta$ can be expressed as

$$\Delta\beta = 2\pi/\lambda\,(n^3r_{33}\Gamma_t V_{sw}/s) \qquad (3)$$

where V_{sw} is the switching voltage, and s is the gap of an optical directional coupler. Overlap integal factor Γ_t between the optical field and the modulating RF field includes the push-pull effect. Equating Eqs. (2) and (3) leads to

$$V_{sw} = (\lambda s)/(\sqrt{2}n^3r\Gamma_t l_y) \qquad (4)$$

We note from Eq.(4) that V_{sw} is inversely propagational to the coupling length.

II. EXPERIMENT

The devices were built on z-cut $LiNbO_3$. The Y-branch directional couplers were fabricated by diffusing a 700Å thick Ti film at 1025℃ for 6 hours in a wet oxygen atmosphere. The waveguides were all 5μm wide and the couplers' gaps were also 5μm. The waveguides of the above fabrication parameters were theoretically and experimentally confirmed to support the single TM mode at 1.3μm. 1500Å thick SiO_2 films were deposited in order to avoid the large insertion loss due to the metallic electrodes. RF sputtering technique was used for the SiO_2 buffer layer. The deposited SiO_2 buffer layers were annealed at 600℃ for 4 hours in an oxygen atmosphere to eliminate the possibility of current leakage in the low-frequency (including dc) operation [2]. Al electrodes of semi-infinite coplanar strip structure were then situated on top of the waveguides in the coupler section. Inner edges of the Al electrodes were aligned with the inner edges of Ti prior to the diffusion to maximize the overlap integral between the optical field and the modulating RF field. The devices were tested at λ=1.3μm.

It was experimentally confirmed that l_y (the coupling length for the complete power transfer in the case of the Y-branch DC) was 3.25mm. Three device of L=l_y, 0.75l_y and 0.5l_y were tested. No current leakages through the SiO_2 buffers were detected in all devices.

For the device of L=l_y, the applied switching voltage was 10 V while the theoretical value was 9 V. In the Eq.(4), Γ_t was put 0.515

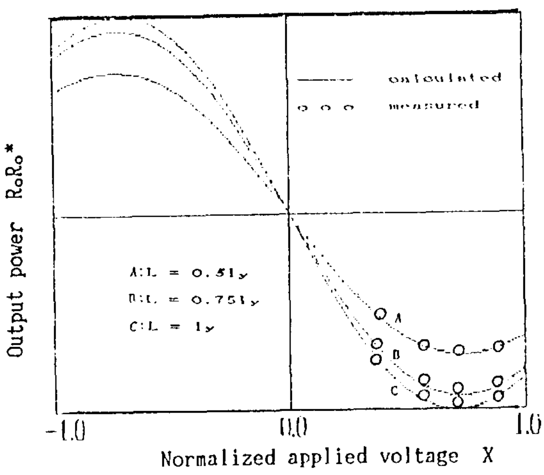

Fig. 2 Output power RR as a function of $\Delta\beta L/\pi$

through the simulation [3]. In the calaulation, the semi-infinite coplanar strip electrodes structure was taken into consideration. Experimental result of optical power outputs are plottes with respect to $\Delta\beta L/\pi$ in Fig. 2 and compared with the theoretical calculation.

In summary, Y-branch directional coupler type optical modulators with three different coupling lengths were fabricated and tested at $\lambda=1.3\mu m$. In dc operation, optical power outputs showed good agreement with the theoretical expectation. The annealing parameters of SiO_2 buffer layer without affecting the index profile of the diffused channel waveguides was also presented.

References

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