Parasitic spectral selectivity of Y-branching power dividers on proton-exchanged $LiNbO_3$ waveguides

S.M. Kostritskii, Yu.N. Korkishko, V.A. Fedorov,
E.I. Maslennikov, A.A. Dikevich
Optolink Ltd, Zelenograd, Proezd 4806, bd.5, 124498,
Moscow, Russia;
skostritskii@optolink.ru

Abstract **- Insertion losses, splitting ratio and its spectral dependence were measured for Y-splitters based on channel proton-exchanged $LiNbO_3$ waveguides. The parasitic spectral selectivity was suppressed by optimization of branching topology.**

Keywords - Lithium niobate, waveguides, Y-branching

I. INTRODUCTION

Optical channel waveguides in lithium niobate are very useful elements for building a variety of integrated optical components. For example, the key component of fiber optical gyroscope (FOG) is the multi-function integrated optic chip (MIOC), which is an important part of the Sagnac interferometer. Proton exchange (PE) is now an established technique for fabricating integrated optical devices in $LiNbO_3$ and offers possibility of obtaining low-loss MIOC [1]. As the MIOC consists inherently a Y-branching splitter, the wavelength sensitivity of Y-splitter can present the dramatic problem if uncertainty of the light source centre wavelength is sufficient to induce marked variations in the mode coupling between two channel waveguides in branching region of Y-splitter. Moreover, suppression of parasitic spectral selectivity is rather difficult task for real devices because of inherent asymmetry of Y-branching region, appearing due to technological uncertainty of photolithography and etching processes [2]. Thus, a careful design of the Y-branching is mandatory to obtain high performance MIOCs, that demands an optimisation of Y- branching topology.

II. EXPERIMENTAL

A series of power dividers utilizing the different geometries of Y-branching splitters and straight channel guides were delineated in X-cut $LiNbO_3$ substrates, using standard photolithographic technique. The channel width W of waveguides forming an Y-splitter was varied in the range from 5.6 to 6.2 μm, where formation of a low-loss single mode channel waveguide, operating within a wavelength region from 1500 to 1580 nm, is expected [1,2]. To fabricate these waveguide structures with the aid of the APE technique, the substrates were proton exchanged at 175 °C for 50÷70 min in pure benzoic acid and annealed at 360 °C for 6÷7.5 hours. It allows us to fabricate the low-loss Y-splitter, utilizing a Y-branching (section II in Fig.1) formed by three single-mode channel waveguides (sections I and III, Fig.1).

The different geometries of Y-branching were used to fabricate three different types of Y-splitter for further comparative study, aiming to find geometry. The most reliable geometries for MIOC design are found to be described by the following equations:

$$y(x) = y_s + \frac{y_e - y_s}{x_e - x_s}(x - x_s) \qquad (1)$$

$$y(x) = y_s + A\left\{1 - \cos\left[\frac{2\pi}{p}(x - x_s)\right]\right\} \qquad (2)$$

for so-called linear and cosine branching, respectively. The parameters x_s and y_s have values within the ranges of 7÷16 mm and 0.16÷0.2 mm, respectively. The width of tapered subsection of the section II near branching point is 2W.

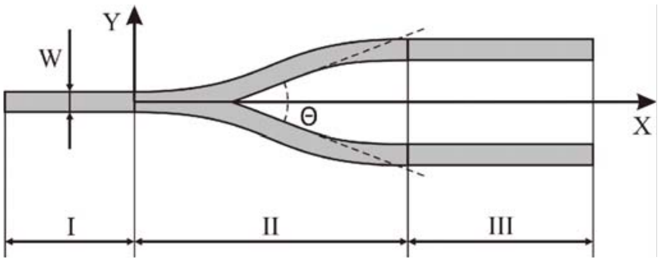

Figure 1. Layout of the Y-branching power divider. Θ is branching angle, W is channel waveguide width.

The main parameters of MIOCs were measured by coupling depolarized light into the waveguides with the aid of an isotropic single mode fiber. A fiber Lyot depolarizer utilizing PM fiber was used to decrease sharply DOP of a superluminescent diode (SLD) radiation (central wavelength is ~1540 nm) and, hence, minimize a polarization-dependent error in measurement results. To determine insertion losses and splitting ratio, we use a fiber-to-fiber coupling set-up. The IR-radiation from the output ports of Y-splitter was directed into a photodiode, operating in its linear region. Spectral dependence of output power at each output ports was measured with the aid of an optical spectral analyzer YOKOGAWA AQ6370.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The power transfer coefficient (PTC) is established to be critical parameter of the Y-branching, as this parameter is most sensitive to the variations in Y- branching topology and fabrication conditions. PTC is evaluated experimentally as ratio between smaller output power and sum of both output powers, i.e. PTC is directly related to a splitting ratio that is main parameter characterizing performance of the power divider. A perfect Y-branching power divider should have PTC = 0.5, and deviation of actual PTC from this value is caused by parasitic asymmetry of Y-branching section due to technological imperfections and modes interaction, as this branching section may be regarded as analog of the directional coupler with weighted coupling [3], i.e. a normalized deviation parameter (0.5 – PTC) is proportional to $\Delta\beta/\Theta\cdot\gamma_3$, where $\Delta\beta$ is accidental asymmetry of Y- branching caused by technological imperfections, Θ is branching angle, γ_3 is transverse component of phase constant, giving the strength of local normal mode coupling. According to the theory of Y-branching splitter [3], the shaped branching (2) has a resulting length advantage over the linear branching (1). To reach an appropriate value of PTC near 0.5, the branching angle should be large enough to decrease sufficiently the mode coupling. However the insertion losses represent the important limiting factor for further improvement of Y-branching splitter via Θ increase.

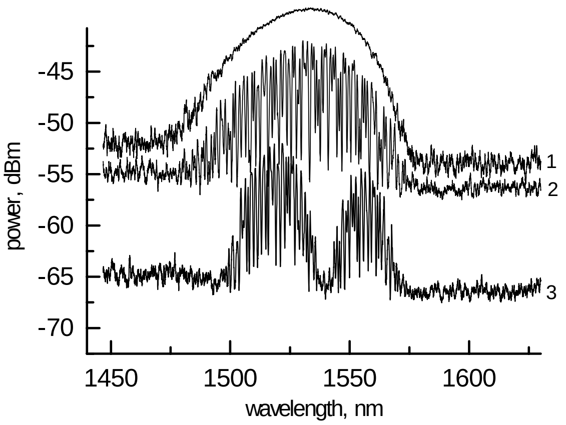

Figure 2. Spectral dependence of the power of IR radiation: (1) at SLD output fiber, (2) at output pigtail of straight channel waveguide (channel width W = 6.0 μm), (3) at output port of Y-branching power divider with cosine geometry (see Eq.(2)) and branching angle Θ is 1.4°. The power at second output port has spectral dependence oscillations of opposite sign. Thus, PTC varies from 0 to 0.5 within spectral band of SLD. To escape spectra overlapping, curve 3 is shifted for -10 dBm relative to curves 1 and 3.

In fact, the following statement may be derived from experiments with the Y-branching power dividers based on annealed PE $LiNbO_3$ waveguides: a larger value of Θ is higher insertion losses for the power dividers of any studied geometry (1,2). At the same, the cosine branching (2) provides a smallest insertion loss among the geometries studied at any fixed value of Θ. Thus, optimisation of Y-branching power divider should find the compromise between smaller PTC and higher losses via choice of geometry and fabrication conditions providing appropriate values of both parameters. Simulation with beam propagation method shows that the cosine branching (2) with average branching angle Θ = 1.4° is the optimal geometry, as it allows to obtain the branching loss (α_b) about 0.3 dB at PTC $\leq$ 0.485. Our experimental study confirms this theoretical finding. However, very strong parasitic spectral selectivity is observed for output of MIOC, that utilizes this Y-branching geometry, Fig.2(3). It has been attributed to the inherent asymmetry of Y-branching region, appearing due to technological uncertainty of the photolithography and etching processes.

To suppress this parasitic effect, the extra taper was introduced into section II of theY-branching power dividers in order to decrease the influence of technological uncertainty on mode coupling within initial stage of channel branching (Fig.3). This modification of Y-branching geometry gives the only partial suppression of the spectral selectivity (see Fig.4(1)), when appropriate levels of PTC and losses is obtained with growth of length and width of this extra taper.

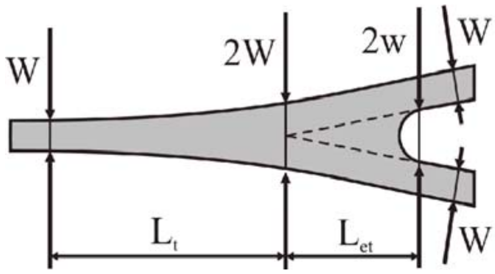

Figure 3.Topology of branching region: L_t – taper length, L_{et} and 2w – length and width of extra taper. Dashed lines show Y-branching without extra taper.

Note, that even such a small wavelength-selective variation of PTC may present a dramatic problem for some particular applications, e.g. high-precision FOG [4]. To minimize the spectral selectivity, the branching angle Θ should be increased, but a branching loss (α_b) must grow [2,3]. Thus, Θ = 1.9° is evaluated as the optimal value for the cosine-branching with extra taper of L_{et} = 100 μm, 2w = 1.18 μm and W= 6 μm, when α_b = 0.6 dB, Fig. 4(2).

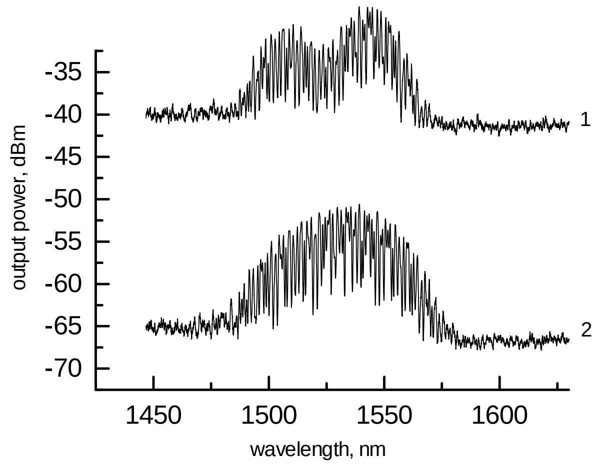

Figure 4. Spectral dependence of the power of IR radiation at output port of Y-branching power divider with cosine topology and the extra taper introduced in branching region (see Fig.3): (1) Θ =1.4° and the extra taper has L_{et} = 130 μm and 2w = 1.26 μm, (2) Θ = 1.9°, L_{et} = 100 μm and 2w = 1.18 μm. To escape overlapping, curve 2 is shifted for -24 dBm relative to curve 1.

Further increase of Θ, L_{et} and 2w is out of practical interest, as it will induce sharp growth of α_b. Note, that the cosine-branching Y-splitter with the same Θ but a much smaller extra taper, including the case of extra taper absence, demonstrates marked parasitic spectral selectivity.

REFERENCES

[1] M.M. Howerton, W.K. Burns, P.R. Skeath, and A.S. Greenblatt, “Dependence of refractive index on hydrogen concentration in proton exchanged $LiNbO_3$.” IEEE J. Quant. Electron., vol. 27, pp. 593-600, 1991.

[2] S.M. Kostritskii, “Photorefractive effect in $LiNbO_3$-based integrated optical circuits at wavelengths of third telecom window”, Applied Physics B, vol. 95, pp. 421-428, May 2009.

[3] W.K. Burns, and A.F. Milton, Waveguide transitions and junctions, In: Guided-wave optoelectronics, T. Tamir (ed.), Springer-Verlag, 1988.

[4] H. Lefevre, “The Fiber-Optic Gyroscope”, Artech House, 1993.