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Conference Paper

Correction of Y-Branches on Proton-exchanged Waveguides in Lithium Niobate By Femtosecond Writing Technology

N.N. SKRYABIN[1,2], M.A. BUKHARIN[2], S.M. KOSTRITSKII[3], Yu. N. KORKISHKO[3], V.A. FEDOROV[3], D.V. KHUDYAKOV[4]

[1]Moscow Institute of Physics and Technology
[2]Optosystems Ltd., Troitsk, Moscow, Russian Federation
[3]RPC Optolink, Zelenograd, Moscow, Russia
[4]Physics Instrumentation Center of the GPI RAS, Moscow, Russian Federation

Abstract

Correction Y-branches power dividers of the multi-function integrated optics chips on proton-exchanged waveguides in lithium niobate by the technology of direct femtosecond laser writing were investigated. Optimal correction parameters and their influence on temperature stability of Y-splitter are determined.

Keywords: lithium niobate, Y-splitters, proton exchange, femtosecond writing, refractive index, integrated optics.

Corresponding Author:
M.A. Bukharin
Mikhail.bukharin@phystech.edu
S.M. Kostritskii
skostritskii@optolink.ru

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1. Introduction

Proton-exchanged lithium niobate (LiNbO$_3$) waveguide with the standard Y-branching geometry is common element of the multi-function integrated optics chips (MIOC). Although technologies for fabrication are mature, the parasitic spectral selectivity is established to be serious drawback of MIOC [1]. It has been attributed to the technological uncertainty of photolithography and proton exchange processes, providing excess of refractive index increment within Y-branching area. The resulting Y-branching power dividers were observed to undergo asynchronous, oscillatory power exchange between the output arms at monotonous temperature variation [1]. Note, that even a small temperature-dependent variation of splitting ratio may present dramatic problem for some particular applications [1].

The direct femtosecond laser writing (DFLW) is one of the most perspective and versatile technology for fabrication of integrated optic devices in various materials, including glasses and crystals [2]. It was shown that DFLW in the bulk of LiNbO$_3$ leads to

two distinct types of modification: an extraordinary index increase ($\Delta n_e > 0$) as type I and an extraordinary index decrease ($\Delta n_e < 0$) as type II [3]. Recently we demonstrated technique of the DFLW of tracks at record low depth under surface of LiNbO$_3$ [4]. In this paper, we report on the solution of the temperature instability of the splitting ratio problem in the Y-branching area using the technology of the DFLW as an extra correction track with a reduced extraordinary index ($\Delta n_e < 0$) may be written into any area of a proton-exchanged waveguide with excessive refractive index increase.

2. Materials and methods

A series of power dividers utilizing the Y-branching were delineated in X-cut LiNbO$_3$ substrates. 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]. To fabricate these waveguide structures with the aid of the annealed proton exchange (APE) technique, the substrates were proton exchanged at 175 °C for 180 min in benzoic acid and annealed at 360 °C for 7 – 7.5 hours.

The low-loss Y-splitter, utilizing a Y-branching, is formed by three single-mode channel waveguides, Fig.1. The so-called cosine shape of Y-branching was found to be most reliable for MIOC design [1] and, therefore, was used to fabricate the Y-splitter. This shape can be described by the following equations [1]:

$$y(x) = y_s + \frac{y_e - y_s}{2} \cdot \left(1 - cos\left[\frac{\pi}{x_e} \cdot x \right] \right)$$
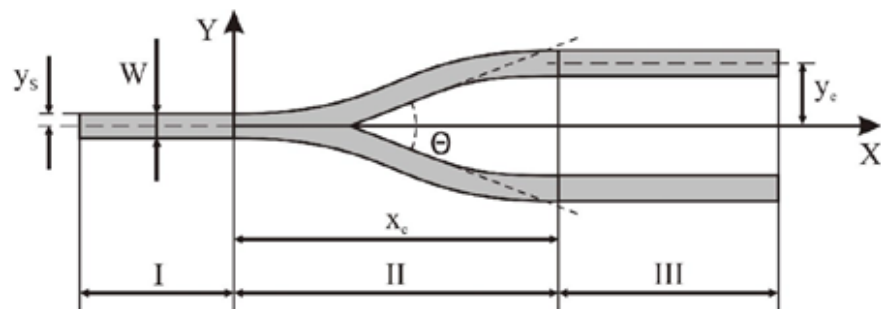
Figure 1: Layout of the Y-branching power divider. Θ is branching angle, W is channel waveguide width.

The parameters x_s and y_s have values within the ranges of 7 – 16 mm and 0.16 – 0.2 mm, respectively. The effective dilution angle is Θ = 1.9°. The width of tapered subsection near branching point is 2W, Fig. 2.
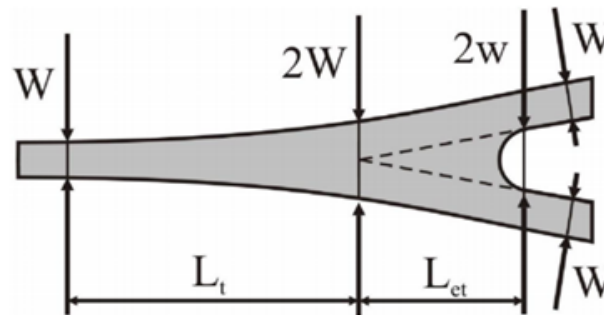
Figure 2: Topology of branching region: L_t – taper length, L_{et} and 2w – length and width of extra taper [1]. Dashed lines show Y-branching without extra taper.

For the DFLW of tracks under the surface of sample LiNbO$_3$ crystal a commercial oscillator without additional power amplifier (HighQ FemtoTRAIN 1040-3) was used (Fig. 3). It produces linearly polarized pulses with a duration of 360 fs at a wavelength of 1040 nm and runs at a repetition rate of 0,1 MHz. The samples were translated by two Standa 8MT175 (axis y-z) and a Newport UTS50CC (axis x) linear stages with velocity 10 µm/s. To reduce the high intensity of radiation to the surface of the material and to prevent ablation laser was focused into the sample by a 100x, NA = 1.25 oil-immersion microscope objective with distilled water (n$_{water}$ = 1.32) instead of immersion oil (n$_{oil}$ = 1.51). This replace was associated with the low breakdown threshold of immersion oil, which could lead to a strong heating output plane of the microscope objective and deformation. Water, in contrast to an immersion oil in case of exceeding the breakdown threshold, did not form combustion products and vaporized without contaminating the microscope objective and without causing significant heating. The laser beam was linearly polarized parallel to the direction of movement of the sample (along axis Y) by a half-wave plate with a Glan prism system, which ensured a greater longitudinal homogeneity of tracks.

To study the DFLW effect on temperature stability of Y-branching power dividers, the fiber-pigtailed MIOCs were placed in isolated chamber. The two thermoelectric Peltier elements were soldered on water-cooler base in this chamber. These two thermoelectric Peltier elements are used to change temperature in the range from 0 to +60 ∘C. One of these elements is the thermoelectric heater operating in the 23 - 60 °C range and the second one is the thermoelectric cooler, allowing for precise variation of the temperature of MIOC within the range from 0 to +23 °C. Platinum temperature sensor was glued inside the chamber, utilizing special epoxy thermal conductive composition.

The optical 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 polarization-maintaining fiber was used to decrease sharply the degree
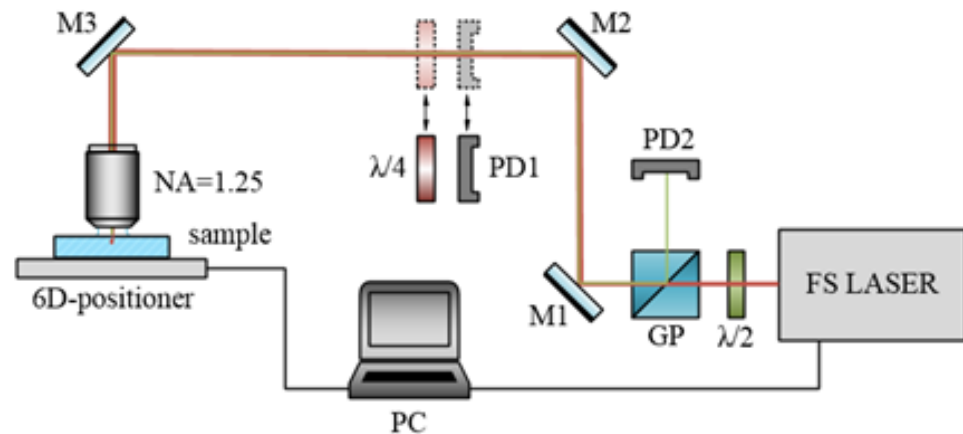
Figure 3: The scheme of the installation for the DFLW. FS-laser is a femtosecond laser, λ/2 and λ/4 are half-wave and quarter-wave plates, respectively, GP - Glan prism (polarizer), M1-M3 - dielectric mirrors, PD1 - thermal power meter, PD2 - semiconductor power meter, NA = 1.25 - micro-objective, 6D-positioner - an automated system of movement in three coordinates and three angles of the sample, controlled from a PC.

of residual polarization of a superluminescent diode 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 [1]. RIFOC 575L optical power meter have been used as photodetector.

3. Results and discussion

MIOCs (i.e., Y-splitters) have been investigated for temperature stability before and after the DFLW correction. At the same time, MIOCs with large temperature drifts of the optical power splitting ratio were selected for the DFLW correction: Splitting ratio of our worst MIOC shows nonmonotonic variation from 64:36% to 36:64% at the temperature change within the range from 0 to +60 °C. At room temperature the splitting ratio was 48.5:51.5%, which was slightly different from the projected value of 50:50% for an ideal Y-splitter. It means that the temperature change leads to significant redistribution of optical power between the two output arms (section III, Fig. 1) due to change of the multi-mode interference in the Y-branching area of splitter (section II, Fig.1).

Extra correction type II modification tracks with reduced extraordinary refractive index (Δn_e = - 3x10^{-3}) with a width of d = 1 μm, a length of L_{cor} = L_1 + L_2 and a height of h = 4 μm by DFLW with pulse energies 40 – 46 nJ were fabricated (Fig. 4). L_1 was inside extra taper region and reduced a coupling between the branching waveguides, and its continuation L_2 suppressed coupling in the further propagation. The value of

L_1 was varied from 40 to 60 μm (60 μm is the maximum value of the correction track that did not go beyond the extra taper, whose length is L_{et} = 100 μm). The value of L_2 was varied from 10 to 40 μm (40 μm is a length at which branching waveguides will be already at a sufficient distance). Tracks were at a depth of 2 μm to 6 μm, and covered most of the proton-exchange waveguide, whose depth is 6 μm. Thus, correction tracks of different lengths L_{cor} (from 50 to 100 μm) were written. The microphotographs of corrected Y-splitter are shown in Fig. 5.
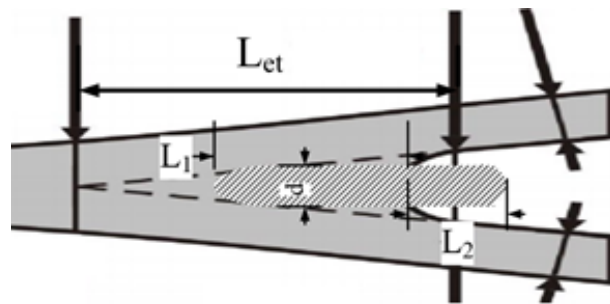
Figure 4: Topology of extra correction DFLW track: L_1 – length of track in proton-exchanged $LiNbO_3$, L_2 – length of track in $LiNbO_3$ covered by mask at APE.
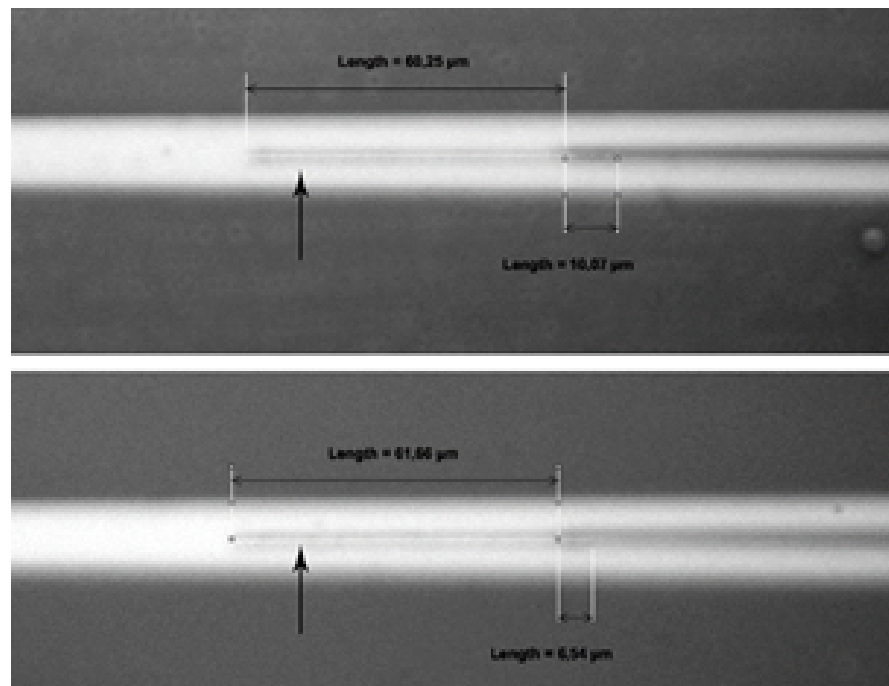
Figure 5: A photomicrographs of the corrected the Y-splitters.

It was experimentally revealed that DFLW tracks with a length of 70 μm significantly reduce the temperature sensitivity of the Y-splitter so that the splitting ratio of MIOC remains practically unchanged: This ratio shows very small variations (within 0.1%) over the entire temperature range studied. At the same time, the DFLW correction of

Y-splitters in the MIOC structure increases the total optical insertion losses of the MIOC by a small amount from 0.1 to 1.3 dB, which is acceptable for some applications [1, 5].

4. Summary

In the paper, we have reported Y-splitter of MIOC operating at wavelengths near 1550 nm correction by using technology DFLW. The optimal parameters of the correction have been experimentally found. It has been shown that MIOC becomes quite stable in temperature over the entire range. Such MIOC with a high stability of the splitting ratio at small optical insertion losses are of undoubted interest for use in medium- and high-precision optical gyroscopes [5].

Acknowledgments

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