1×4 buried optical power splitter fabricated by Tl^+-Na^+ ion-exchange

Zigang Zhou (周自刚)[1,2] **and Desen Liu (刘德森)**[1]

[1] *Department of Physics, Southwest China Normal University, Chongqing 400715*
[2] *Department of Physics, Suzhou University, Suzhou 215006*

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A new 1 × 4 buried optical power splitter with curved Y-junction structure has been successfully designed by a beam propagation method (BPM) software and fabricated by two-step ion-exchange in glass. The optical qualities of the device are favorable in comparison with that obtained with dry etching fabrication techniques.

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The ion exchange in a glass substrate is probably the most widespread and inexpensive technology used to fabricate integrated optical circuits and a major candidate for the fabrication of passive components. Some researchers have used ion-exchange techniques for fabrication of integrated devices in fiber-optic telecommunication such as waveguide lasers, splitters, sensors, couplers, wavelength division multiplexers, and phase and amplitude modulators for many years[1]. But in passive devices based on glass waveguides, optical power splitters are of interest for optical telecommunications. However, The specifications of splitters are primarily determined by the refractive index and optical waveguide geometry structure in glass.

The local variation of the refractive index in glass has also been used in microlenses[2]. Recently, we proposed and demonstrated the use of a new thallium-ion (Tl^+) source for glass optical power splitter fabrication based on a $NaNO_3$-Tl_2SO_4 mixture[3]. In this paper, we present a detailed modelling of a new 1 × 4 buried splitter with curved Y-junction structure, which is designed by a beam propagation method (BPM) software and fabricated by two-step ion-exchange in glass. The modes propagating through the curved waveguides ensure a symmetrical distribution.

For getting a more symmetric profile and a deeper buried waveguide, it is important to develop a more exact model for describing the ion-exchange. This is the typical situation occurring in the geometrically simple but critical case of a Y-junction branching. The geometry of a 1 × 4 optical power splitter with optical curved waveguide is depicted in Fig. 1.

The model is based on the solution of the ion diffusion kinetics equation by a finite difference approach and has been validated experimentally in the planar waveguide. Structures of device behaviors in case the refractive index profiles are determined using a BPM software. Figure 2 illustrates a new Y-junction structure designed by the BPM software. The curved waveguide allows some flexibility to reduce the size of integrated optics components. Its characteristics depend on the radius of curvature.

The model is based on the solution of the equation

$$y = \frac{h}{l}x - \frac{h}{2\pi}\sin\left(\frac{2\pi x}{l}\right), \tag{1}$$

where x and y are the transverse and lateral axis, respectively, h is waveguide distance to the transverse axis, and l is waveguide distance to the lateral axis. The radius of curvature R

$$R = \frac{l^2}{2\pi h}\left[\sin\left(\frac{2\pi x}{l}\right)\right]^{-1}. \tag{2}$$

Using the BPM software, we get $l_1 = 800$ μm, $h_1 = 40$ μm, $l_2 = 450$ μm, $h_2 = 20$ μm ($n_b = 1.518$) for $l^2/h \geq 1000$. Where l_1 and h_1 are waveguide distances of the 1 × 2 splitter, and l_2 and h_2 are waveguide distances of the 1 × 4 splitter.

When a glass substrate is immersed in a metal salt melt at a temperature well below the melting point of the glass, the metal A ions of the modifiers in salt are free to move and to be exchanged with another metal B ions in glass. The physical phenomena responsible for the exchange process are diffusion and convection. Refractive index modulation is caused by three major physical changes[4]: ionic polarizability, molar volume, and stresses created by the exchange of ions with different radii. The ion-exchange process in a glass substrate

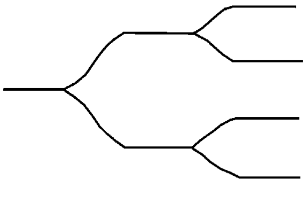

Fig. 1. 1 × 4 splitter.

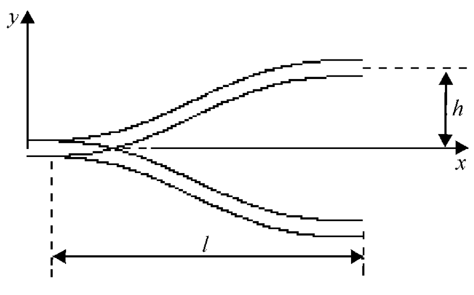

Fig. 2. Structure of Y-junction designed by the BPM software.

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can be spatially controlled using a patterned mask with apertures. The diffusion equation describing the thermal ion exchange of two monovalent ions in glass is given as in Ref. [5].

In fact, ion-exchange in glass occurs between a Na^+ ion and another monovalent Tl^+ ion that is present in the melt bath. Hence, an appropriate amount of sodium in the substrate is one of the important requirements for efficient ion exchange. Typically, we require a sodium concentration of approximately 20% for the fabrication of optical power splitters during a thallium exchange with processing time of 54 hours[3]. The temperatures used for glass optical power splitter fabrication were adjusted from 500 to 505 °C. We use the temperatures for our sodium concentration substrates[4].

To get buried splitter, we use two-step ion-exchange. Firstly, a glass substrate with a titanium layer of about 0.3 μm thickness is immersed in pure Tl_2SO_4 melts at 505 °C. After exchange processing time of 54 hours, a surface waveguiding region is delineated by Tl^+-Na^+ ion-exchange. Secondly, the second ion-exchange is performed after removing the mask, and the first surface waveguide is immersed in pure $NaNO_3$ melts at 505 °C. After exchange time of 36 hours, a buried waveguide is fabricated by Na^+-Tl^+ ion-exchange. Figure 3 illustrates two-step ion-exchange process.

The propagation losses of the optical power splitter were determined by the weak scattered light intensity from the side of the waveguide. The optical qualities of the device are better than that of the splitter obtained with dry etching. A summary of the results is presented in Table 1 which shows the optical qualities for 1 × 4 splitters obtained with two-step ion-exchange and dry etching fabrication techniques.

The excess loss of the 1 × 4 buried optical power splitter was smaller than 0.2 dB/cm at 632.8 nm and 0.25 dB/cm at 1310 nm. And the buried optical power splitter has reduced losses due to surface scattering and an improved matching to integrated devices[6,7]. Figure 4 illustrates a Y-junction 1 × 4 splitter under He-Ne light illumination.

Table 1. 1 × 4 Splitters Specifications for Different Fabrication Techniques

Fabrication Techniques	Ion-Exchange	Dry Etching
Division Ratio	1 : 1 : 1 : 1	1 : 1 : 1 : 1
Max. Insertion Loss (dB)	9.2	10.6
Excess Loss (dB)	0.25	1.5
Uniformity Loss (dB)	0.95	2.5
Operating Wavelength (nm)	1270 – 1340 1520 – 1580	1300 – 1320 1540 – 1560

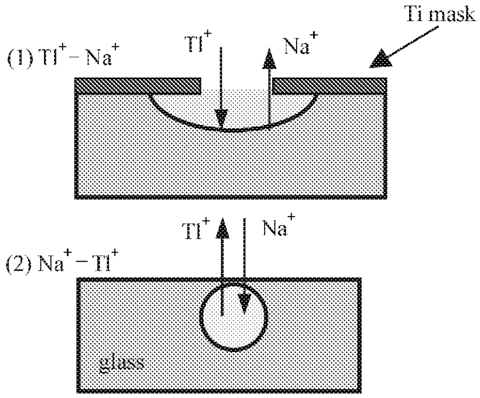

Fig. 3. Two-step ion-exchange process.

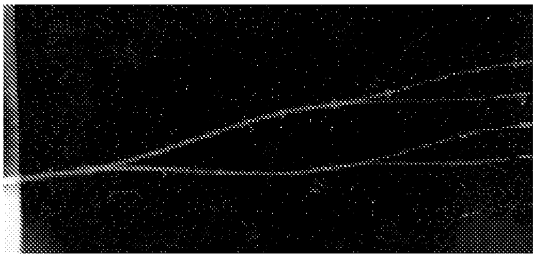

Fig. 4. A 1 × 4 splitter of Y-junction under He-Ne light illumination.

A new 1 × 4 buried optical power splitter with curved Y-junction structure has been successfully designed and fabricated by a BPM software and two-step ion-exchange in glass. The optical splitter qualities of the device are favorable in comparison with that fabricated with dry etching techniques.

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References

1. Z. G. Zhou and D. S. Liu, Opt. Technique (in Chinese) **29,** 79 (2003).
2. Z. G. Zhou and D. S. Liu, Acta Photon. Sin. (in Chinese) **28,** 451 (1999).
3. Z. G. Zhou and D. S. Liu, Chin. Opt. Lett. **1,** 404 (2003).
4. R. P. Salmio, J. Saarinen, J. Turunen, and A. Tervonen, Appl. Opt. **36,** 2049 (1997).
5. Z. G. Zhou and D. S. Liu, Acta Opt. Sin. (in Chinese) **23,** 694 (2003).
6. D. Salazar, H. Porte, and H. Márquez, Appl. Opt. **36,** 8987 (1997).
7. O. G. Hellese, P. Benech, and R. Rimet, Appl. Opt. **34,** 7702 (1995).