Fabrication of glass optical power splitter in thallium source by ion-exchange method

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

[1]*Department of Physics, Suzhou University, Suzhou 215006*

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

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The use of a new thallium-ion (Tl^+) source for glass optical power splitter fabrication based on a $NaNO_3$-Tl_2SO_4 mixture is proposed and demonstrated. Planar optical power splitters were made using glasses such as K_6, K_8, K_9. The optical quality of the devices prepared compares favorably with the quality obtained using other fabrication techniques (such as dry etching) and the processing time is considerably reduced.

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Some researchers have used Ion-exchange techniques for fabrication of integrated devices such as waveguide lasers, sensors, coupler, and phase and amplitude modulators for a number of years[1]. For the fabrication of devices based on glass waveguides, changes are produced in two physical parameters of the substrates: ion polarizability and density in glass. As a result of both changes, an increase of the surface refractive index can happen, which would be sufficient to guide a light beam along the whole length of a modified glass substrate.

In fact, ion exchange in glasses occurs between a Na^+ ion and another monovalent 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 15% for the fabrication of optical power splitters during a thallium exchange processing time of 54 hours[2,3]. Figure 1 illustrates a optical power splitter under the conduction.

Here we demonstrate the use of a thallium-ion source that allows us to increase the processing time and temperature required in comparison with conventional K^+ or Ag^+ sources. The main idea exploited here is the possibility of increasing the diffusion rate of an external ion by increasing the substrate temperature to near the glass transition temperature, T_g, maintaining mechanical stability of the glass as well as low surface stress by the co-diffusion of other compensating ions. For this purpose, it is needed that there is a thallium-rich melt with high temperature stability and no aggressive action on the glass surface. The presence of other appropriate ions in the melt is also necessary to compensate for the glass surface stress produced by the thallium-ion (Tl^+) exchange.

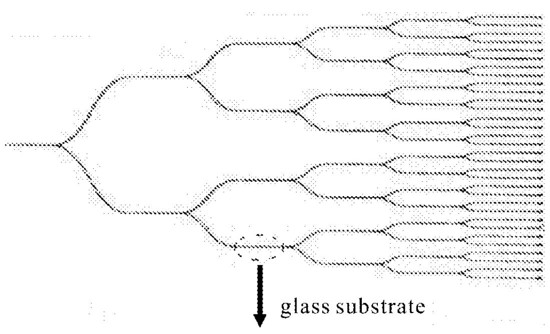

Fig. 1. Optical power splitters in glass.

We investigated several solutions with different thallium compounds and found that an 85% of Tl_2SO_4 and 15% of $NaNO_3$ mixture provides excellent performance (in the case the total initial salt mass used was 85 g (Tl_2SO_4) and 15 g ($NaNO_3$)).

We initially clean all the substrates in organic solvents and deionized water, and then place inside a special pot that contained Tl_2SO_4-$NaNO_3$ mixture. And heat the pot in a temperature-controlled furnace for ion-exchange processing by our temperature-controlled equipment. The reaction was performed at various temperatures.

The temperatures used for glass optical power splitter fabrication were adjusted from 500 to 510 °C. We use the temperatures for the various sodium concentration substrates. A summary of the results is presented in Table 1,

Table 1. Optical Power Splitter Characteristics for Different Processing Parameters

Sample	Diffusion Time (h)	Diffusion Temperature (°C)	Total Modes Number	Surface Index Change
K_6	8	500	1	0.020
	16	500	1	0.020
	24	510	2	0.020
	54	510	3	0.020
K_8	8	500	1	0.025
	16	500	1	0.025
	24	510	2	0.025
	54	510	3	0.025
K_9	8	500	1	0.030
	16	500	2	0.030
	24	510	4	0.033
	54	510	6	0.033

which shows the processing time used, the corresponding number of single- and multi-modes obtained, and the surface refractive-index changes, Δn, that were measured using the Yamin inference method[4].

Figure 2 illustrates the refractive-index profile that was calculated using the average method outlined in K_9 glass[5]. To determine diffusion coefficient D, we approximated the index profile of splitter by the function $n(x) = n_1 + \Delta n \mathrm{erfc}(x/\tau)$, $x \geq 0$, where erfc is the complementary error function, $\tau = \sqrt{4Dt}$ is the effective penetration depth, t is the diffusion time, and $x = 0$ represents the air-glass interface such that $n(x) = 1$ when $x < 0$. The diffusion coefficient obtained for K_9 at 510 °C was $D = 180\ \mu m^2/h$. The propagation losses of the prepared optical power splitter were determined by measuring the weak scattered light intensity from the side of the waveguide. The losses of $1 \times N (N \leq 8)$ splitters were smaller than 0.15 dB/cm at 632.8 nm and 0.2 dB/cm at 1.3 μm. And the optical power splitters match in integrated devices.

For all the substrates that we used, the waveguide formation time was more than the time required when one uses conventional ion-exchange sources such as pure KNO_3 or $NaNO_3$, and mixture containing $AgNO_3$ and $NaNO_3$. Single-mode and multi-mode splitters fabricated with K_9, K_6, and K_8 glasses in various times are necessary when conventional melts are used.

An important result was the fabrication of single-mode splitter with commercial K_6 and K_8 glasses after 8 − 16 h of Tl^+ in-diffusion at 500 °C. This material has a large potential for single-mode splitter. Another important result was the fabrication of multi-mode splitter with more modes in K_9, K_6 and K_8 glasses after 24 h and more of Tl^+ in-diffusion at 500 and 510 °C. This material has a large potential for single-mode and multi-mode splitters. Some researchers reported a processing time of several hours to obtain single-mode waveguide because of the small sodium concentration presenting in commercial substrates[6].

The diffusion of these ions through the substrate surface is responsible for the reduction of glass surface tension and for the large Tl^+ in-diffusion rate that is due to the reduction of ion-exchange activation energy. We attribute the good performance of the new Tl^+ source to the presence of SO_4^{2-} and NO_3^- in the high-temperature melt. Also, one can expect a low structural stress while using the $NaNO_3$-Tl_2SO_4 ion-source because of the size compensation in co-diffusion for Tl^+, SO_4^{2-}, and NO_3^- ions. Although the Tl^+ ion exchange generates compressive stress, the co-diffusion of SO_4^{2-} and NO_3^- releases the stress in the structure because these ions have a smaller volume than the sodium ion. Therefore, the magnitude of the total stress is only smaller than what is observed with Tl^+ ion exchange.

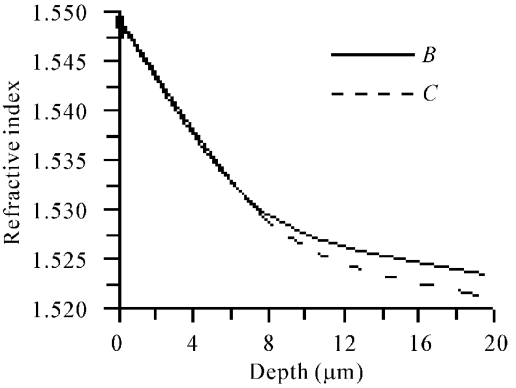

Fig. 2. Refractive index profile for a K_9 substrate: solid curve B, calculated with the average method of Ref. [5]; dashed curve C, obtained with the complementary error function.

We have demonstrated the use of $NaNO_3$-Tl_2SO_4 instead of conventional ion sources, which allows for certain processing times while maintaining good optical quality of the prepared optical power splitter and gets single-mode and multi-mode splitters. Both single-mode and multi-mode splitters were fabricated with K_9, K_6, and K_8 glasses in various times and temperatures for our needs.

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