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RESEARCH ARTICLE

Fabrication of buried channel optical waveguide splitter

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Abstract An electric field technique was developed to fabricate buried channel waveguides on optical glass. A voltage of 800 V was applied on the glass to accelerate the field-driven ion exchange process by expeditiously replacing host sodium ions in the glass with silver ions. As a result, the optical loss for channel waveguides was measured using the edge coupling technique with a He-Ne laser. Loss of 0.35 dB/cm was obtained for the channel waveguides with 25 μm in depth, which is relatively low for waveguides of such depth at red wavelength band.

Keywords glass waveguide splitter, high electric field, ion exchange

1 Introduction

Optical waveguides have been widely used in optical communication and sensing systems to transmit and route optical signals over distances. Common substrate materials utilized include silicon, $LiNbO_3$, and glass. Glass has been used to build a variety of integrated optics modules that are compatible with the optical fibers, which has low cost, low loss of optical signals, and has the capability of integrating many components on the same substrate. Ion exchange in glass is one of the major candidates for fabrication of the passive components used in fiber-optic telecommunication, such as splitters and wavelength division multiplexers [–3]. If a glass substrate is immersed in a salt melt at a temperature right below the melting point of the glass, the metal ions of the modifiers (denoted by A) are free to move and can be exchanged with other metal ions, e.g., Ag^+, in the salt melt (denoted by B). The phys-ical phenomena responsible for the exchange process are diffusion and convection. Refractive index modulation is caused by three major physical changes: ionic polarizability, molar volume, and stresses created by the exchange of ions with different radii. The ion-exchange process in a glass substrate can be spatially controlled by using a patterned mask with apertures. The most well known method to fabricate waveguides on glass is the exchange of Na^+ in the glass with Tl^+, or K^+ in molten nitrate [–6].

Our concern are mainly in fabricating deep (5–30 μm) channel waveguides for optical applications. To fabricate buried channel waveguides and reduce the process time, a relatively high electric field was adopted to enhance the transport of the dopant ions into the glass substrate [7,8]. Because of the very nature of molten nitrate at high temperature, the dry silver film method was employed as an alternative [9].

2 Process for waveguide fabrication

The fabrication setup is depicted in Fig. 1. The K9 glass substrates were thoroughly cleaned with the cleaning solvent, and a roughly 5.0 μm thick silver film was electron-beam evaporated onto the substrates in high vacuum (approximately 11.5 Torr).

The composition (in wt%) of the K9 glass with a thickness of 2 mm chosen in this experiment consists of: SiO_2 (77.89%), Na_2O (18.23%), K_2O (2.35%) and others (1.53%). The entire process was carried out in an oven at a specified temperature. Both current and voltage were monitored concurrently during the entire fabrication process, as indicated in Fig. 1. It can be noticed that the silver-deposited K9 glass substrate is simply sandwiched between two stainless steel plates with no separate aluminum film deposited immediately above or below the glass substrate serving as the anode and cathode, respectively. After the glass substrate reached the stable temperature, the high electric field of 400 V/mm voltage was applied, and then the applied voltage ionized the silver atoms in the silver film so that an efficient ionic dopant source could be provided for the migration process. Meanwhile, the applied electrical field also drove the Na^+ ions out of the glass substrate to make the Ag^+ ions move in and fill up the vacant sites later. Once the high electric field process was completed, the glass waveguide was thoroughly cleaned to remove the remaining silver residues.

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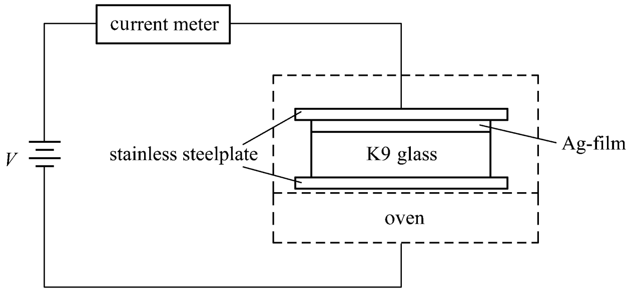


Fig. 1 Fabrication setup for waveguide fabrication

The time cost to complete the entire process depends on the temperature, the electric field applied across the substrate, and the amount of the dopant metal film initially deposited on the substrate. In Fig. 2, the plots of current versus time for channel waveguides, fabricated from a roughly 5.0 μm silver film on a glass under different processing temperatures with an applied voltage of 800 V (approximately 400 V/mm), are presented.

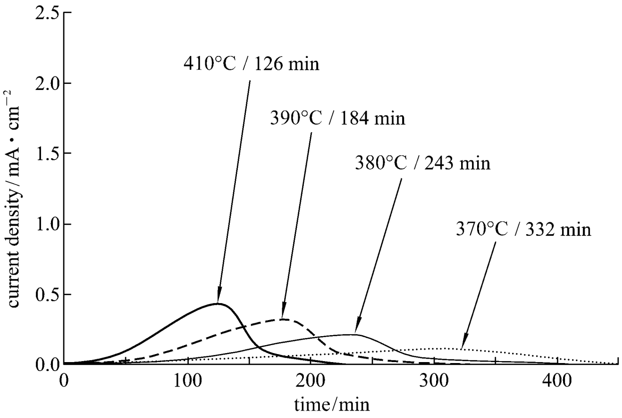


Fig. 2 Current density versus time (the applied voltage is 800 V and the thickness of silver film evaporated onto the 2 mm-thick K9 substrate is 5.0 μm)

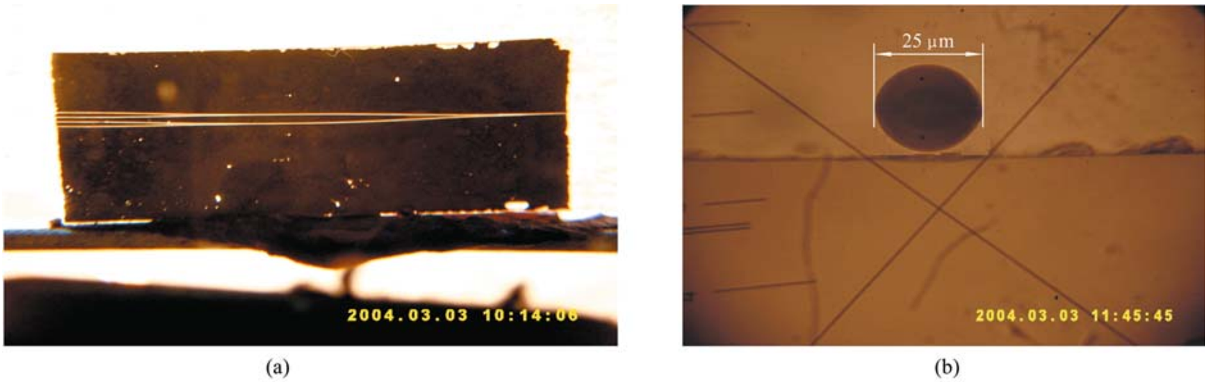
At the onset, the current rises up slowly as the silver film begins to be ionized when the field is applied. Since the measured current includes Na^+ ion current and Ag^+ ion current, the initial trend shown by either curves implies that the Na^+ ions were driven out of the glass gradually and the Ag^+ ions also drifted into the glass gradually. This phenomenon is due to the unequal ionic mobility between the silver and sodium ions inside the glass. The mobility of sodium ions in glass is larger than that of the silver ions. Thus, the Na^+ ions moved away from the silver-glass interface into the glass faster than the Ag^+ migration front.

3 Optical characterization

A high-power optical microscope (HOPM2-80) was used to observe the end face of the waveguide, and the waveguide depth was also measured. The effective refractive index of the fundamental mode is almost the same as that of the waveguide region. The refractive index of the waveguide region thus can be approximated as the effective index of the fundamental mode, which is 1.533. The refractive index of the original K9 glass is 1.517. Hence, the refractive index change Δn caused by the Na^+-Ag^+ ion-exchange in the waveguide region is 0.016.

The end face of the channel waveguide is shown in Fig. 3. The depth of the channel waveguide fabricated from the silver film was about 25 μm in the silver stripe.

The lowest measured attenuation was found to be 0.35 dB/cm among the samples fabricated at 632.8 nm wavelength using the edge coupling technique. Possible causes of the loss include the scatterings due to the silver atoms reduced from silver ions in the waveguide during the process and the uneven waveguide boundaries. It is believed that further refinement on the lithographic and etching processes and adjustment on the process will reduce the attenuation. For waveguides of such depth, a 0.35 dB/cm loss is considered to be relatively low, and is good enough in many optical propagation applications. The results on the waveguide depth and index change are very consistent among different samples, indicating that this process is reproducible.



(a)

(b)

Fig. 3 Buried channel waveguide splitter produced from the silver stripes. (a) 1×4 buried channel waveguide splitter; (b) end face of 1×4 waveguide splitter

4 Conclusion

The low-loss channel waveguides on K9 glass have been successfully fabricated using a relatively simple fabrication setup. The optical attenuation of the channel waveguides was measured to be 0.35 dB/cm, which is considered to be relatively low and is good enough in optical propagation for the channel waveguides of 25 μm width.

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