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Potassium and silver ion-exchanged dual-core glass waveguides with gratings

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A two-step double ion-exchange process is employed to produce dual-core waveguides in glass. First, potassium ion exchange is carried out at 400 °C. Then, silver ion exchange is performed at 300 °C. The fabricated waveguides have low losses, large single-mode regions, and more symmetrical profiles than single ion-exchanged waveguides. Etched gratings are also made in dual-core waveguides. Very high efficiencies are demonstrated in these waveguides.

Ion exchange has been the most popular technique to produce waveguides in glass substrates.[1] Potassium and silver ions have been used extensively. Potassium ion-exchanged waveguides are well suited for making basic components such as Y-branches and directional couplers.[2–4] However, they do not have enough flexibility for fabrication of more sophisticated devices such as waveguides with gratings. Deep gratings are needed to achieve efficient interaction between guided light and grating in these waveguides. Silver ion exchange has been used to produce efficient grating-assisted glass waveguides.[5] However, waveguides made by silver ion exchange through a metallic mask have relatively high losses due to the silver metal colloids which are formed during the exchange process.[6]

Silver and potassium double ion-exchange process has been used to produce waveguides with ionic masking[7] and buried waveguides.[8] In the present work, we have employed this process to produce dual-core waveguides. These waveguides are characterized and their properties are investigated. Etched gratings are also made in these waveguides and their performance is tested.

Double ion-exchanged waveguides are fabricated in Corning 0211 glass substrate. First, potassium ion exchange is carried out in a pure potassium nitrate molten salt. Then, a silver ion exchange is performed in a pure silver nitrate molten salt. For channel waveguides, an aluminum mask is used. For comparison purposes single ion-exchanged waveguides in pure silver nitrate with similar depth to that of the double ion-exchanged waveguides are also made. The fabrication parameters are given in Table I.

In slab waveguides, the effective refractive indices are measured (at 0.6328 μm) and the index profiles are determined as explained in Ref. 9. The results are shown in Fig. 1. In double ion-exchanged waveguides there are two distinct regions corresponding to the two types of exchange processes. The maximum index change in the silver ion-exchanged region is similar to that in the single silver ion-exchanged waveguide. However, silver ion exchange is slower with the presence of potassium ions. The diffusion coefficient of silver ions at 300 °C in a double ion-exchange process is 0.008 μm^2/min, only one third of that of single silver ion exchange at the same temperature (0.025 μm^2/min).

In channel waveguides, the mode profiles and transmission spectra are determined using the techniques explained elsewhere.[5] The results are depicted in Fig. 2. We have observed that the transversal mode profile of the double ion-exchanged waveguide with larger silver exchange time (KAg2) is more symmetrical than that of the single silver ion-exchanged waveguide. We believe that the maximum index change is slightly below the glass surface due to the reduced sodium concentration near the surface after the potassium ion exchange. The transmission spectra measurement results indicate that the single-mode operation region of the double ion-exchanged waveguide is larger than that of the pure silver ion-exchanged waveguide, and this region increases with the increase of silver ion-exchange time. This indicates again that the index profiles (or mode profiles) of the double ion-exchanged waveguides are more symmetrical.

Etched gratings are made in the double ion-exchanged waveguides by using a standard holographic setup and a plasma etch process.[5] Diffraction and reflection properties of these gratings are studied. To measure the diffraction efficiency, light from a He-Ne laser (0.6328 μm) is coupled

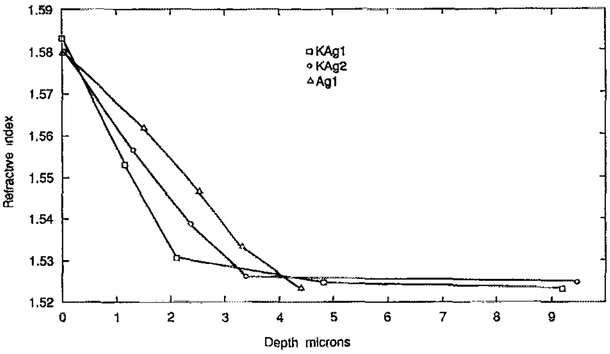

FIG. 1. Index profiles of single and double ion-exchanged glass slab waveguides. See Table I for fabrication parameters.

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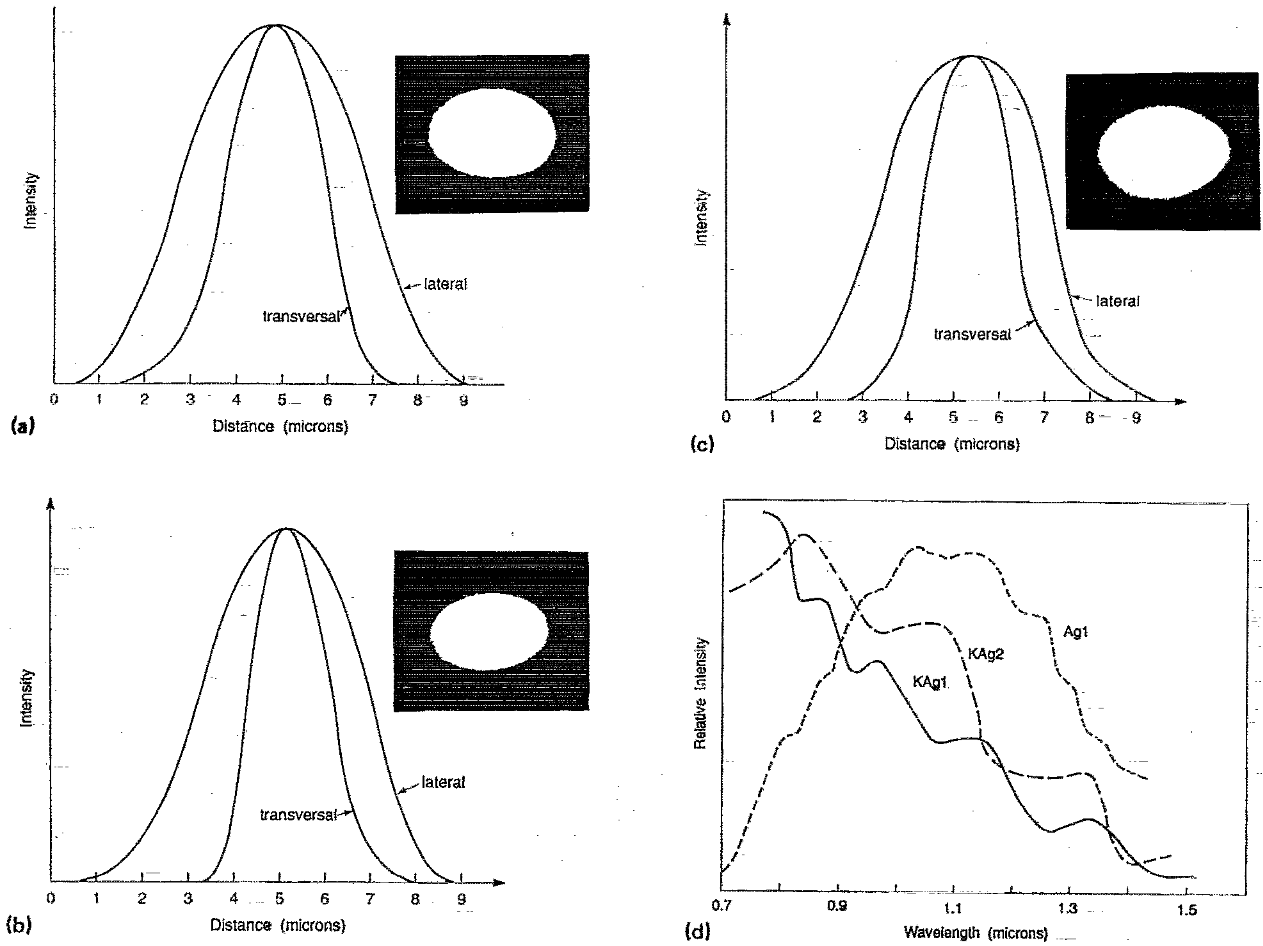

FIG. 2. (a),(b),(c) are near-field mode profiles at 1.3 μm for samples KAg2, KAg1 and Ag1, respectively. (d) is the transmission spectra of these waveguides. Mask width is 2.5 μm. Other fabrication parameters are given in Table I.

into the waveguides, and the transmitted light at the output and the light diffracted into the air by the grating are measured. The ratios of the total power in the diffracted lights to that of the transmitted light are summarized in Table II. For the double ion-exchanged sample with shorter silver ion-exchange time (KAg1), the diffraction efficiency depends on the coupling at the input of the waveguide, because in this waveguide light at 0.6328 μm can be guided in silver or potassium ion-exchanged region. For the sample with longer silver ion-exchange time (KAg2) in which light is guided only in the silver region, the behavior is more like the single silver ion-exchange waveguide, but the diffraction efficiency is more than two times higher. To measure the transmission spectrum, a light-emitting diode (LED) is used as a light source. Figure 3 gives the result for sample KAg1. More than 95% reflectivity is observed at 1.261 μm with a bandwidth of about 7 Å. At this wavelength the waveguide is single mode and the light is guided in the silver ion-exchanged region. There exists a small dip in the main peak. This is most probably due to the nonuniformity in the grating.

In conclusion, we have fabricated and characterized potassium and silver double ion-exchanged waveguides. We have observed very high efficiency in the double ion-exchanged waveguides with gratings. Double ion-exchanged waveguides have other uses and advantages over conventional single ion-exchanged ones. In addition to low losses and large single-mode regions, the mode profiles of

TABLE I. Temperature and time employed in fabrication of single (Ag 1*s*, Ag1) and double (KAg 1*s*, KAg1, KAg 2*s*, KAg2) ion-exchanged waveguides in Corning 0211 glass substrate.

Sample	Waveguide	K^+ exchange	Ag^+ exchange
KAg 1*s*	Slab	400 °C, 140 min	300 °C, 150 min
KAg1	Channel	400 °C, 140 min	300 °C, 150 min
KAg 2*s*	Slab	400 °C, 140 min	300 °C, 300 min
KAg2	Channel	400 °C, 140 min	300 °C, 300 min
Ag 1*s*	Slab	···	300 °C, 120 min
Ag1	Channel	···	300 °C, 120 min

TABLE II. Comparison of diffraction efficiencies by gratings made in single and double ion-exchanged glass channel waveguides.

Sample	Diffracted power in air / Transmitted power
KAg1	4–42
KAg2	83
Ag1	32

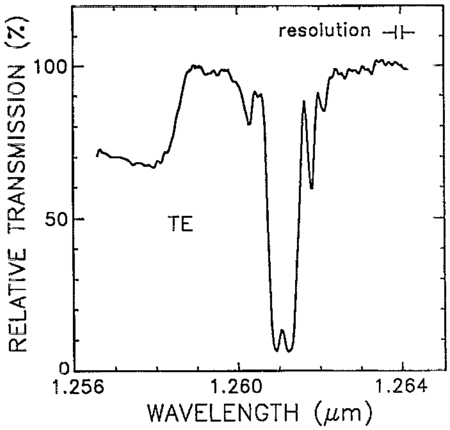

FIG. 3. Transmission spectrum of a double ion-exchanged waveguide with etched grating (KAg1). Grating depth is 0.15 μm and its period is 0.42 μm.

double ion-exchanged waveguides can be more symmetrical than single ion-exchanged waveguides. The most important aspect of the double ion-exchange process is probably that it offers the flexibility to produce more sophisticated devices.[10]

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[1] S. I. Najafi and M. J. Li, "Ion-exchanged glass integrated optical components", invited paper, IEEE International Workshop on Photonic, Networks, Components and Applications, Montebello, October 1990.

[2] S. I. Najafi, Appl. Opt. **27**, 3728 (1988).

[3] R. A. Betts, F. Lui, and S. Dagias, IEEE Photon. Tech. Lett. **2**, 481 (1990).

[4] S. I. Najafi and C. Wu, Appl. Opt. **28**, 2459 (1989).

[5] M. J. Li, S. I. Najafi, J. Albert, and K.O. Hill, SPIE Conference Vol. 1334, San Diego, July 1990, paper No. 15.

[6] R. G. Walker, C. D. W. Wilkinson, and J. A. H. Wilkinson, Appl. Opt. **22**, 1923 (1983).

[7] W. J. Wang, M. J. Li, S. Honkanen, and S. I. Najafi, Topical Meeting on Glasses for Optoelectronics, The Hague (March 1991), SPIE Proceedings, Vol. 1513, paper No. 50.

[8] M. J. Li, S. Honkanen, W. J. Wang, and S. I. Najafi, Topical Meeting on Micro-Optics, The Hague (March 1991), SPIE Proceedings, Vol. 1506, paper No. 2.

[9] J. M. White and P. F. Heidrich, Appl. Opt. **15**, 151 (1976).

[10] M. J. Li, S. Honkanen, and S. I. Najafi, Topical Meeting on Glasses for Optoelectronics, The Hague (March 1991), SPIE Proceeding, Vol. 1513, paper No. 47.