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Measurement of optical transmission losses in co-exchanged Ag^+ and K^+ optical waveguides prepared by thermal ion exchange process

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ABSTRACT

Interest in the area of optoelectronics stimulates the potential applications in the last few years. Optical waveguides are the potential candidates for integrated optical devices such as wavelength division multiplexing, the power splitter-combiner, optical filter and sensing applications also. In order to design optical waveguide components, waveguiding region should have specific index of refraction. Due to non-availability of sufficient number of suitable high quality materials with proper refractive index for particular application, there is a need of tailoring the materials of proper refractive index. In the present work, planar optical waveguides of co-exchanged Ag^+ and K^+ are fabricated by thermal ion exchange process. The structural properties are studied by XRD and EDAX and the optical transmission losses are measured by prism coupling technique are reported.

Keywords: Ion Exchange Process; Planar Optical Waveguides; Transmission Loss; Prism Coupling

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INTRODUCTION

Integrated optics has monolithic and hybrid approach in different applications like optical signal processing, optical sensor. The basic idea of integrated optics was outlined by Anderson [1] and then Miller introduced the term "Integrated Optics" [2]. Major factors playing important role in the development of integrated optics is that single mode waveguiding and it is, therefore, incompatible with multimode fiber system. The device of interest in the integrated optics are often the counterparts of bulk optical devices like junction and directional couples, switches and modulators, filters wavelength multiplexers, lasers, amplifiers, detectors, sensing devices etc, lot of efforts are need to be put into the development of such optical components and study of light guiding structures. Since the theory of waveguiding structure is complex, sophisticated accessories are required to observe and study the waveguiding phenomenon.

The method of exchange of ions into the glass has been known for long time. The technological aspects of the ion exchange process for producing gradient refractive index in glass reported by R. Pogozinski [3]. Ion exchange process has been one of the simple and important techniques for glass waveguide fabrication for integrated optical devices. The single and two- step [4] ion exchange process has also been used by many authors for fabrication of planar optical glass optical waveguide [5-9].

To confine the light wave inside the waveguide, the light wave is need to be introduce in to the high refractive index region at angle which is greater than critical angle of the reflection. To guide the light mode, light wave should be coupled with the waveguide either from the cross section or from the prism [6]. The properties of glass optical waveguide are very sensitive to the preparation method. This paper reports the measurement of optical transmission losses [10] in co-exchanged Ag^+ and K^+ ions.

MATERIALS AND METHODS

The selection of method for fabrication of waveguide region depends upon the materials used. In the present work the thermal ion exchange process [3, 7, and 8] is used to fabricate optical waveguiding region of high purity and reproducible structure. The materials KNO_3 and $AgNO_3$ in the granules form of 99.5% purity are used.

The alumina crucible used to prepare melt of weight percent mixture of KNO_3 and $AgNO_3$. The weight percent mixture of granules of both these materials along cleaned substrate hold by a crucible enclosed in a temperature controlled furnace. The temperature of melt increased step by step and kept it constant at 633K. The diffusion of Ag^+ and K^+ ion for a particular period results with change in refractive index of glass substrate [11]. The ion diffused regions have higher index of refraction than the undiffused glass region.

The change in index of refraction of the diffused substrate was confirmed by Abele's method. The transmittance in visible region measurement using UV-VIS-NIR spectrophotometer confirms the exchange of both Ag^+ and K^+ ion on the glass substrate. The structural properties of ion exchanged substrate studied using x-ray diffraction and EDAX. The prism coupling technique [10] is used for coupling the light wave through the guiding region of the substrate. The right angle prism of extra dense flint glass with base area of 1 cm^2 and angles of side 90^o-45^o-45^o is used. All sides of the prism were highly polished and sharp edge was maintained at angle of 90^o. Both the prism were pressed form top side as well as from the bottom side of guiding region using fine brass screw attached to the prism fixture assembly. The care was taken to press the prism slightly away from the sharp edge at the prism angle of 90^o. For effective coupling of light wave, the air gap between the base of the prism and the top surface of the guiding region was adjusted in the order of wavelength of laser beam. After a proper coupling of light, the light wave travels through the guiding region in a zig-zag path. The optical transmission losses measured by measuring the output light intensity received from the output prism. The output intensity for guiding length of 1 cm measured in terms of current using silicon photodiode.

RESULTS

The structural and light guiding properties of waveguides are studied at room temperature. The ratio of weight percent mixture of $AgNO_3$ and KNO_3 was kept as 1: 1 and the number of samples prepared for different ion exchange period – 9 hours, 18 hours, 24 hours and 36 hours. The data reported in all tables is the average values of 5 to 8 samples for each duration of ion exchange period.

3.1 Structural studies

X-ray diffraction plots of 18 hours and 24 hours samples and EDAX ZAF quantification data of co-exchanged Ag^+ and K^+ ion of the waveguides samples are shown in figure 3.1 (a) and (b).

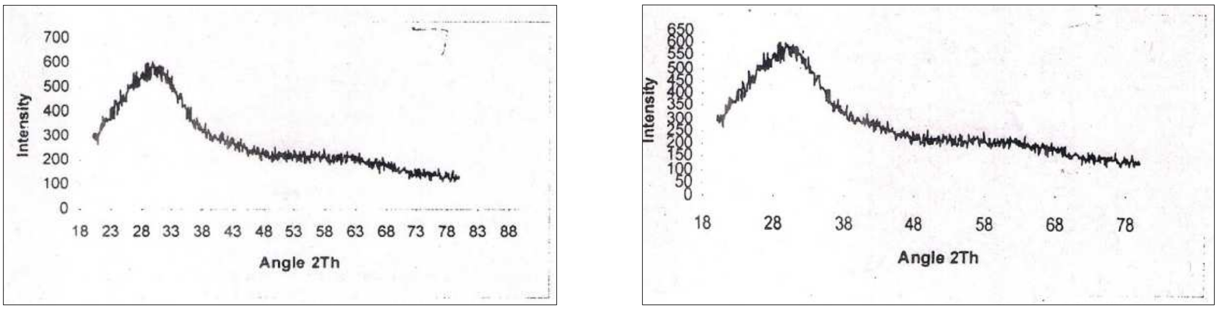
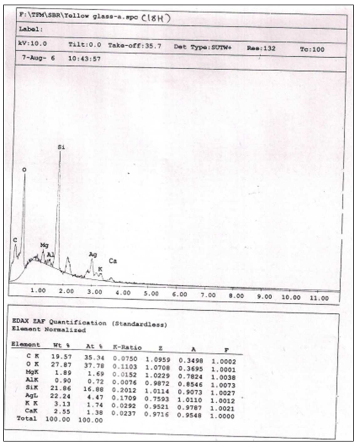
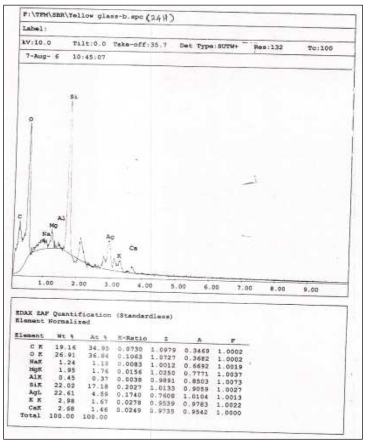


Figure 3.1 (a) and (b) : XRD Plot for 18 Hrs and 24 Hrs Sample

Exchange of ions on the surface glass substrate causes slight changes in crustal structure
The EDAX quantification data clearly showing the ions of Ag^+ and K^+ are exchanged on the glass substrates. In the sample of 18 hours ion exchange, 22.24% and 3.13% are the weight percent exchange of Ag^+ and k^+ ions respectively while in the sample of the 24 hours ion exchange, 22.61% and 2.98% are the weight percent exchange of Ag^+ and K^+ ions respectively. The details of the ZAF data are given in the Table 2 and 3.



Element	Wt %	At %	K-Ratio	Z	A	F
C K	19.57	35.34	0.0750	1.0959	0.3498	1.0002
O K	27.87	37.78	0.1103	1.0708	0.3695	1.0001
MgK	1.89	1.69	0.0152	1.0229	0.7824	1.0038
AlK	0.90	0.72	0.0076	0.9872	0.8546	1.0073
SiK	21.86	16.88	0.2012	1.0114	0.9073	1.0027
AgL	22.24	4.47	0.1709	0.7593	1.0110	1.0012
K K	3.13	1.74	0.0292	0.9521	0.9787	1.0021
CaK	2.55	1.38	0.0237	0.9716	0.9548	1.0000
Total	100.00	100.00				



Element	Wt %	At %	K-Ratio	Z	A	F
C K	19.16	34.93	0.0730	1.0979	0.3469	1.0002
O K	26.91	36.84	0.1063	1.0727	0.3682	1.0002
NaK	1.24	1.10	0.0083	1.0012	0.6692	1.0019
MgK	1.95	1.76	0.0156	1.0250	0.7771	1.0037
AlK	0.45	0.37	0.0038	0.9891	0.8503	1.0073
SiK	22.02	17.18	0.2027	1.0133	0.9059	1.0027
AgL	22.61	4.59	0.1740	0.7608	1.0104	1.0013
K K	2.98	1.67	0.0278	0.9539	0.9783	1.0022
CaK	2.68	1.46	0.0249	0.9735	0.9542	1.0000
Total	100.00	100.00				

Table 2 and 3 for samples of 18 Hrs and 24 Hrs

Exchange Time in Hours	Optical transmission loss (dB) in air medium								Average loss (dB)
9	4.4	4.8	4.7	4.1	4.6	4.4	4.5	4.6	4.5123
18	2	1.9	2.4	1.8	2.3	2.3	2.1	1.9	2.0875
24	1.59	1.65	1.58	1.59	1.59	1.58	1.59	1.56	1.5912
36	1.63	1.61	1.65	1.59	1.64	1.66	1.65	1.68	1.6387
48	1.43	1.55	1.39	1.45	1.49	1.48	1.46	1.58	1.4787

3.2 Optical Transmission Loss

The optical transmission losses per cm length of waveguides are measured using prism coupling technique in the air medium at room temperature. The scattered and the average values of transmission loss through the waveguide are given in the Table 1.

From the data given in the table, it is clearly seen that the optical transmission loss through the waveguide seem to be depend on the ion exchange period. The transmission loss is significantly reduces for waveguides prepared for 24, 36, 48 hours exchange period of ions.

DISCUSSION

The result obtained for these waveguides shows that the optical transmission loss through these waveguides depends on the ion exchange period. The waveguiding region can be fabricate on the substrate surface by increasing the index of refraction at the place where light need to be guide. Glass substrate mainly made up of silica, Na_2O, K_2O, CaO network inside of which lighter Na^+ ions are relatively free to move from the substrate surface. When the glass is immersed in the melt bath of $AgNO_3$ and KNO_3, the ions Ag^+ and K^+ concentration experiences abrupt discontinuity on the both side of substrate surface and the exchange of Na^+ ion by Ag^+ and K^+ ions are takesplace. The jumping of these ions with adjacent side of substrate motivates the exchange process. Since the jumping frequency is thermally activated, during the ionic movement, only coupled ions or two or more ions are exchanged by prohibiting individual exchange of single ion. After the exchange of ions, the change in structure of material is to be understood properly. The glasses of practical interest to exchange ions are composed of metal oxide group, glass forming intermediate and modifying oxides.

The main objective of ion exchange process in waveguide fabrication is to tailor suitable refractive index of substrate surface. During exchange of ions, heavier ions are diffused out of the substrate and are replaced by lighter ions, diffuse in the form of medium. The both surfaces of the substrate are enriched by these lighter ions.

Fabricated optical waveguides, generally, have properties which are somewhat different than starting bulk material. In general refractive index [12] is lesser than that of bulk. One of the reasons for deviation of refractive index from bulk value may be the change in density of region being lesser than of bulk. Contaminations, imperfection due to surface roughness are also responsible for small deviation in refractive index [13]. Crystallographic orientation also influences the refractive index of ion exchanges region of substrate.

The objective of mixing two different materials with different optical density for optical waveguide fabrication is to tailor refractive index of waveguiding region which will have lesser optical transmission loss and to check the feasibility of such low loss waveguides for sensing and other applications. The primary cause for change in refractive index ion exchanged region is the polarisibility difference in the ions of material used. Polarisibility is directly related to the index of refraction through Lorentz-Lorentz relation [14]. However secondary change may result due to changes in the properties of substrate material [12]. Such a change affect immediately on the waveguide behavior as well as long term mechanical and optical stability. This effect may appear if photonic device has been used for extended period of time. Smaller variation in molar density with concentration may cause residual stress development in optical waveguides. Combination of known and unknown materials with their refractive index and dispersion effect affect resultant refractive index. Difference in melting point of materials of lighter ion results with some surplus phases in the substrate. Exchange of ions in the substrate develop residual stresses in both ion exchanged part and non-exchanged part of the substrate. This resulting change in refractive index may governed by the stress – optical coefficient. Such a change in stress contributes increase in index of refraction of ion exchanged substrate surface [15]. Change in index profile of two step ion exchange in BK-7 glass substrate has also been reported [16].

Exchange of ions on the surface glass substrate causes slight changes in crustal structure which results as a change in polarisibility of the ions. The EDAX quantification data also shows the thermal diffusion of Ag^+ and K^+ ions and they are exchanged on the glass substrates. In the sample of 18 hours ion exchange, 22.24% and 3.13% are the weight percent exchange of Ag^+ and k^+ ions respectively while in the sample of the 24 hours ion exchange, 22.61% and 2.98% are the weight percent exchange of Ag^+ and K^+ ions respectively [Table 2 and 3]

Optical transmission loss may be the inherent property of material and it may enhance during exchange of ions on the substrate surface. Transition of metal oxide present in the substrate as impurities may be a one of the reason for transmission loss. Many transition metal ions absorb light in the visible region. Another significant cause of losses through the optical waveguide is the micro cracks, internal voids and impurities, residual stresses retained during the glass making process [17, 18] and thermal ion exchange process. Scattering losses may also enhance during ion exchange process due to thermal stresses, use of corrosive ion exchange salts and handling. Because of lower affinity of oxygen the optical density of exchanges ions may reduces in the substrate. Such an ion exchanged waveguides have yellowish color which becomes almost opaque [5, 19]. For detail understanding of the feasibility of optical activity of waveguides, with lesser optical transmission loss, co-exchanging with different concentration of materials, at different temperatures for different period of exchange of ions has to be optimized. Efforts are also required to find out optimum condition for exchanged ions for fabricating waveguides because the theoretical analysis of ionic mass transfer during the fabrication process is need to analyse.

Zhang et al [20] reported a series of discrete leaky modes are enters due to prism coupling method. Annealing of mixed Ag^+ and k^+ waveguides in air form a cluster of potassium and silver [21]. Optical transmission loss through these waveguides was studied as a function of incident optical flounce and wavelength is also reported [22]. The data given in the table 3.3(a) it is very clear that optical transmission loss through these waveguides seem to be reducing by increasing period of exchange of ions means can be used as low loss optical waveguide. Similar optical losses for co-exchanged waveguides have also been reported [23, 24]. Sensing characteristics in terms of optical transmission loss [22] of these waveguides can also be studied as a function of optical flounce, wavelength and melt concentration by simple direct and detection method.

CONCLUSION

In the optical waveguides of co-exchanged K+ and Ag+ ion prepared by thermal ion exchange process, the wave guiding region can be fabricate on the substrate surface by increasing the index of refraction at the place where light need to be guide. The tailoring of the suitable refractive index of the substrate surface is possible by thermal ion exchange process. The optical transmission loss through these waveguide seems to be depending on the ion exchange period. The transmission loss is significantly reduces by increasing exchange period of ions. Transition of metal oxide present in the substrate as a impurities may be a one of the reason for transmission loss. Many transition metal ions absorb light in the visible region. Another cause of losses through the optical waveguide is the micro cracks, internal voids and impurities, residual stresses retained during the ion exchange process period.

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