PLANAR OPTICAL WAVEGUIDES USING A SILVER-SODIUM ION EXCHANGE

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ABSTRACT

A planar optical waveguide fabrication is reported using a silver-sodium, electric field enhanced, Al thin film masked, ion exchange process. In this study, silver atoms from the thin film replace the sodium ions in soda-lime glass, resulting in a higher index of refraction. It should be noted that soda lime glass was used as a substrate even though it varies in composition, contains metallic impurities and is generally not of optical quality. Problems related with sterling silver and design width are discussed. A better understanding of requirements for coupling light into the waveguide, edge polishing, index profiling, focusing of the source etc, is needed to further analyze this wave guide.

INTRODUCTION

From a historical perspective, the basic design of optical systems did not change for many years and consisted of bulky and heavy components which required careful alignment and protection against vibration, moisture and temperature drift. The concept of integration of optical components was motivated during the early 1970's by a desire to minimize these problems and make them more compatible with modern technology. Integrated optics is basically guided wave optics, where light is constrained (within a guide) by total internal reflections to propagate in discrete guided modes. In order to transmit light from one component to another, guiding structures have replaced light transmission through space.

Most text books carry an indepth theoretical analysis of light wave propagation along waveguides [1-8]. The basics of the theory is given here in order to understand wave propagation due to total internal reflections along a waveguide. Figure 1 shows the conditions for total internal reflection. They are as follows:

$$n(f) > n(s), n(c)$$
$$\sin \theta c = n(s)/n(f)$$

Condition for guiding the lowest order mode depends on wavelength Lambda, and is given by the following equation :

$$h \sim lambda/2*\{n(f) - n(s)\}$$

If 'h' is allowed to increase, other discrete modes can propagate.

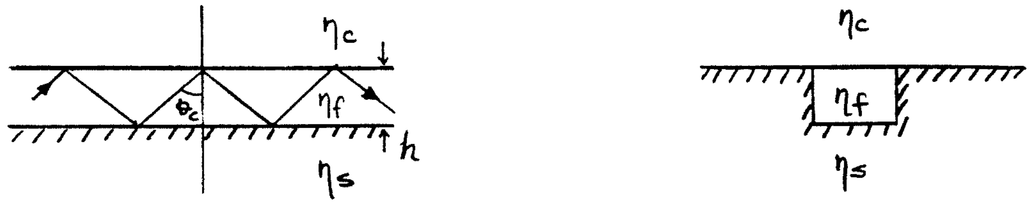

Figure 1 - The guided mode.

Another important concept is that of the evanescent field, a field that extends outside the boundaries of the waveguide. It is this field that allows coupling between waveguides. It can also be used to determine index profiles and the number of allowable modes in a given waveguide [9,10].

Recently, considerable attention has been given to glass waveguides due to their compatibility with optical fibers, ease of fabrication and low cost [1,2,3]. The ion exchange process is a popular technique for fabricating graded index planar optical waveguides in glass. This method involves exchanging monovalent cations such as Li, Cs, Rb, Ti, Ag, or k with Na present in the glass as Na2O.

The need for Na makes soda lime glass, which is rich in sodium, inexpensive and readily available as commercial microscope slides a good choice. Even though soda lime glass varies in composition, contains metallic impurities, and is generally not of optical quality, it was used as the substrate in the following waveguide feasibility study.

EXPERIMENT

This project consists of three phases. The first phase was to develop a computer program which could generate data files for the Mann 3000 pattern generator. The pattern used for the study consisted of two straight line segments connected by a S curve as shown in Figure 2.

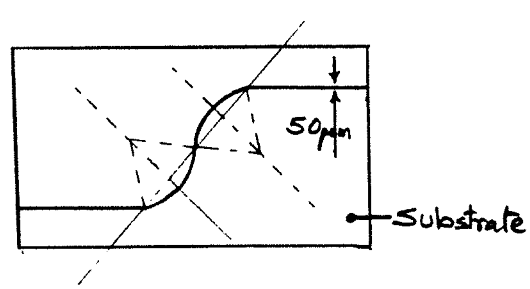

Figure 2 - Waveguide design.

The S curve was chosen to demonstrate total internal reflections. The channel is designed to avoid abrupt twists. A sudden change of 4 degrees will leak approximately 1 dB of the propagating optical power(guide NA = 0.2) [13]. Given the length and height of the main rectangle and the width of the waveguide, the program creates a data file in the Mann 3000 format. A width of 50um was chosen in order to propagate multimodes [13]. Due to the exposure scheme of the pattern generator, the mask for the 50um width waveguide was made via reversal processing. The exposed areas are bleached out, and a second flood exposure is done to expose previously unexposed areas.

The second phase consisted of the ion exchange process. The ion exchange is performed through an aluminum mask on the substrate glass. A 2500A thick Al film was thermally evaporated onto the substrates at a pressure of 1.5E-5torr. Prior to deposition the slides received a clean on the MTI scrubber. The cleaned side of the slides received a spin coat of KTI-820. A specially constructed chuck was used to hold the slides without a vacuum. After a convection prebake, a 36 mJ/cm2 exposure was done on a contact printer. Shiply 351 developer was used with a 1:1 DI water. A visual check showed a good image formation. A convection postbake followed for 30min at 150C. The waveguide was etched into the Al mask using Al etchant. In order to balance the thermally induced stress of the patterned Al film, the slides received 2500A of evaporated Al on the unpatterned side.

This study is done utilizing electric field assisted Ag-Na exchange because of several advantages offered by the process: the total amount of silver ions in glass can be controlled accurately by the Ag film thickness [4], the index profiles of the waveguides are very insensitive to temperature variations during fabrication [5], and the surface index of the waveguides can be controlled in wide ranges [4,6]. The patterned side of the slides were then coated with silver, with film thickness of 470A. This film of silver was the Ag ion source.

A hot plate capable of 400C was used as the thermal source. The diffusion was electric field aided: produced between the Al plate, (positive) and the hotplate surface (ground). The sandwich structure is shown in Figure 3.

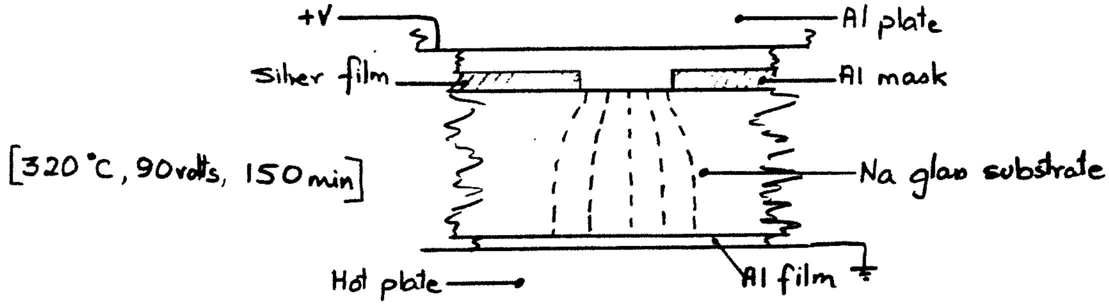

Figure 3 - The sandwich structure.

Finally the remaining silver film and the Al mask were etched off. The following composition of bleaching solution was used to etch the silver film: 1 lit of H_2O, 9.5 gm of $K_2Cr_2O_7$, 12 ml of H_2SO_4.

RESULTS/ANALYSIS

The following observations were made after stripping the silver source film and the Al masking film. The waveguide was visible to the unaided eye. Observations under the microscope showed a continuous guide formation with no breaks. Also to be noticed were a number of circular defect on the Al masked areas of the glass substrates.

The circular defects were not noticed on the undiffused slides. No hillocks were seen under dark field observation on the unpatterned Al mask. However, such speckles could be seen under transmitted light on the microscope, after pattern etching and subsequent stripping of the photoresist. This would indicate some problem with the photoresist step, such as small air bubbles, which escaped subsequently, leaving a void in the masking photoresist layer. The end result would be the diffusion of silver through the pinholes into the glass.

Another possibility would be the diffusion of contamination particles trapped between the glass and the Al film. This could have originated from some particles on the glass not removed by the clean, or from such contaminants on the Al pallets which were then evaporated onto the slide. A possible solution would be to subject the slides to a plasma clean before evaporation.

Sterling silver was used for an ion source. Sterling silver comprises of 92.7% silver and about 7% Cu. The effect of Cu on the ion exchange process is not known. Fine silver (100% pure silver) could be investigated for an ion source in future studies.

As seen from the theory, the depth of the diffusion or the height 'h' of the waveguide controls the number of modes propagating along the guide. From this, the minimum 'h' required for propagation of the single mode for 632.8nm light is calculated to be 1.82um. Values of h greater than this would result in the propagation of additional modes. As a result, obtaining the cross sectional profile of the guide is important. This is more so because of the saddle shape of the profile. This results from an increase in the electric field at the edges of the guide [15]. Some profiles obtained under the same conditions as used here, are given in Figure 4.

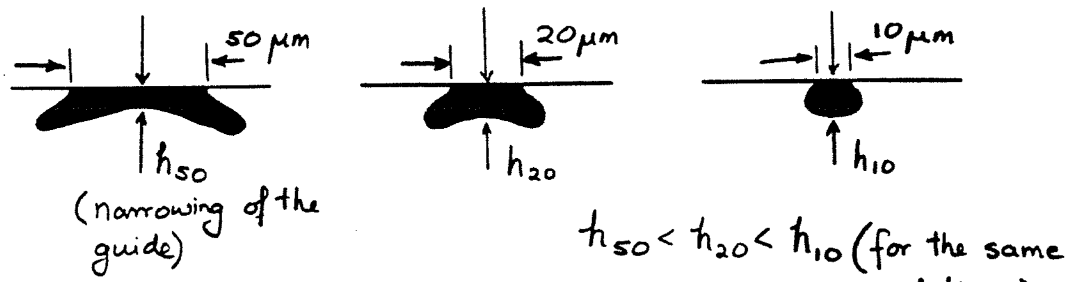

Figure 4 - Profiles.

The narrowing of the guide at center is of interest. From these photographs, it is obvious the widening of the guide alone does not solve coupling problems as expected. The 50um width was chosen in order to easily detect the propagation of multi modes. In contrary, a narrower guide in the range of 10um is seen to have a better semicircular profile (with a greater h) which is preferred for a guide. By shining a laser perpendicular to the waveguide and measuring the diffraction pattern, the width of the guide or the saddle was calculated to be 62um or an increase of 12um from design.

While the areal profile was visible, the cross sectional profile was not visible. Some problems associated with this are due to edge polishing. Since the polishing process is tedious, and due to the lack of expertise in this field, the slides were sent out to a commercial polisher. However, microscopic examination shows flaws such as chips and trenches on the polished surface. While a low quality saddle like profile was visible, the well defined profile seen in the above photographs could not be detected, mainly due to surface flaws.

CONCLUSION

Wave guides were fabricated using the Ag-Na electric field enhanced ion exchange process. However, the following recommendations are made to the above described process. A design for the masks should have an array of guides having widths comprising of 10, 20, 50 and 100 um. Appolo work station interfacing with the MEBES electron beam mask making and exposure system needs to be explored with regards to patterning. Problems such as polishing and propagation loss associated width soda lime glass substrates, needs to be further investigated. Fine silver (100% silver) should replace sterling silver as an ion source layer. A capping layer such as gold should be used to prevent oxidation of the silver layer. SEM profiles of the silver film over the Al mask will be needed in order to analyse and control the electric field pattern. Institu polishing techniques need to be developed.

In order to analyse the waveguide, an understanding of light coupling techniques and index profiling methods need to be further studied and developed.

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