Optimization of integrated optic components by refractive index profile measurements

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Summary

Refractive index profiles of planar and channel waveguides in glass have been measured with high accuracy, using the so-called refracted near-field technique. Systematic investigations of profile shapes in dependence on technological parameters have been performed, the qualitative and quantitative results of which can be used for profile modelling calculations. On the base of measured refractive index profiles we calculated both the modal composition and the intensity distribution of the guided light by the use of the effective index method. The results are in good agreement with experimental data. A direct measurement of stress-induced birefringence in ion-exchanged channel waveguides has been performed for the first time. The present profile measurement technique can be applied to waveguides in LiNbO3, polymers and other substrates, however, with several practical limitations.

1. Introduction

In order to reduce the fabrication effort for integrated optic components, which become more and more complex at present, modelling procedures attain an increasing interest. The effective index method and beam propagation (BPM) calculations are commonly used tools for the prediction of waveguide properties and component parameters, respectively. A successful application of these methods implies the accurate knowledge of the waveguide refractive index profile. Thus, in the stage of development of integrated optic components on the base of planar and channel waveguides a method for precise, non-destructive and efficient profile measurement should be available in order to find out rapidly the optimal waveguide preparation conditions. This is especially true for ion-exchanged waveguides in glass, because for this process the prediction of refractive index profiles is very difficult in practice.

2. Refractive index profile measurement

Several years ago we showed1 that the so-called refracted near-field (RNF) method, which comprises the most widely-used optical fiber profiling technique, with several modifications into the customary experimental setup, can be applied successfully also to planar and channel
waveguide profiling. This method is very precise (accuracy of refractive index determination = 10^{-4}) and gives high resolution (about 0.5 µm). Its main advantages, however, are the universality (single mode and highly multi mode planar and channel waveguides) and the high efficiency (practically no additional sample preparation is required for the measurement).

The assembly we used in our experiments is shown in Fig. 1. The liquid cell used with fibers was replaced by a polished BK7 glass block which serves as sample holder and refractive index reference. The substrate was put with the waveguide downwards onto the glass block, leaving an immersion liquid film between them. In order to obtain definite plane optical surfaces the flat end face of the substrate together with the front surface of the glass block have been covered by a standard 170 µm microscope slide. An expanded unpolarized laser beam is focused onto this common plane input surface by a microscope objective and light escaping the back surface of the glass block and passing the aperture stop (disc) is measured with a large area uniform photodiode. Choosing an appropriate beam expansion ratio, a linear dependence between the measured light power and the refractive index at the focal point has been achieved. In order to obtain unitary and clear conditions for all measurements a sectorial stop in front of the microscope objective is introduced.

Fig. 1: *Scheme of the experimental assembly of our RNF setup,* (1-immersion liquid film; 2-aperture stop; 3-reference glass block; 4-substrate with waveguide region below; 5-microscope objective; 6-sectorial stop)

The waveguide refractive index profile is then measured by scanning the sample in x and y direction. During the last year the laboratory experimental setup has been developed to a compact equipment, which allows simple handling, computer driven measurement process and data processing. With the mean of this equipment the measurement process for a channel waveguide profile takes only a few minutes. At present, this equipment is even commercially available.
3. Ion exchanged waveguides

3.1. Multimode waveguide components

In many local area networks (LAN) and intensity-modulated fiber sensor applications multimode step-index or graded-index fibers are used for light transmission. Here, integrated optic elements may serve for passive light distribution or combination or as sensing elements. In order to reduce optical losses in such systems, the refractive index profiles of the waveguides must be as close as possible to the fiber profile. Contrary to step index channel waveguides, where profile matching to step index fibers is possible in only one step, the profile matching to graded index fibers requires a two-step ion exchange process.

Figure 2 shows the completely buried refractive index profile of a planar waveguide with nearly parabolic shape.

![Graph showing the refractive index profile of a planar waveguide](image)

Fig. 2: Completely buried planar waveguide with nearly parabolic profile

This profile has been obtained in a special glass type (25c) developed for Ag+-Na+-exchange by the following steps:

1. step: thermal diffusion, 10 hours at 270°C in a 1 mol-% AgNO₃-melt
2. step: field assisted buraying, 30 minutes at 270°C in an eutectic melt of KNO₃ and NaNO₃ with an external electric field of 15 V/mm.
Similar profiles with almost circular cross section have been obtained also for multimode channel waveguides, resulting in very small fiber-to-waveguide losses of less then 0.5dB.

3.2. Single mode waveguide optimization

For single mode waveguide elements in general definite parameters of the waveguides, such as mode number, propagation constants and intensity distribution of the guided light must be adjusted. All these quantities are correlated to the refractive index profile and can be calculated from the latter. It has already been shown that the presented RNF technique can be successfully applied to single mode waveguides in glass 3 and 4.

Here, we demonstrate, how the measured refractive index profiles can be used to predict the above mentioned quantities. For cannel waveguides, produced by a thermal K+-Na+ exchange process, we measured at first the refractive index profile by our RNF technique. Than we used the effective index method in order to calculate both the mode propagation constants (effective refractive indices) and the intensity distribution of the fundamental modes. The latter has also been controlled experimentally by imaging onto a CCD camera. We found a good agreement between the predicted and measured modal field distributions.

A sufficiently precise prediction of channel waveguide profiles for given technological parameters (glass type, exchanged ions, temperature, time, width of mask window, electrical field strength) will be possible in near future. This, however, requires again systematic investigations of the index profiles as a function of these parameters in order to obtain sufficient qualitative and quantitative information about the interdiffusion coefficients and ion mobilities, which can then serve as a base for profile estimations and calculations.

3.3. Waveguide birefringence

It is well known that the K+-Na+ exchange in different types of glasses leads to a stress-induced birefringence of the exchanged layer. This has been demonstrated by m-line-spectroscopy on appropriate waveguide films, from which polarization-dependent profiles appeared as the result of WKB calculations. This waveguide birefringence we measured also with the use of our profile measurement technique. Figure 3 shows the refractive index profiles of both TE and TM polarization for a planar waveguide, produced by K+-Na+ exchange of BK7 glass in a diluted KNO3-melt. A refractive index difference of about 0.0014 has been measured. Up to now, it was not clear, whether this birefringence is preserved in channel waveguides or not.
Our measurements showed that this birefringence is still present but considerably reduced. It varied from 0.0002 for weakly guiding waveguides (3.5 µm mask window) to 0.0007 for well-confined waveguides (10µm mask window). So, the corresponding beat-lengths are in the range of 1 cm down to 1 mm and such waveguides can be used for the realization of special components such as polarization dependent beam splitters.

3.4. Other waveguide materials

3.4.1 Polymers

Several preliminary experiments have been performed on polymer waveguides, embedded between two polymeric substrate plates. The accuracy, however, is still not good enough. It can be increased, when the end face quality is nearly the same as for glass waveguides.

3.4.2 LiNbO₃ waveguides

For RNF profile measurements of waveguides in high refractive index substrates a serious practical problem appears with the immersion liquid. The only high index (n>=2.2) immersion melts existing up to now contain Br, As and S and, thus, are not well-suited for wide practical use. For that reason we used short pieces of the substrate. The measured light escapes from the back surface of these pieces and must not be reflected from the lower surface. Up to now we used microscope objectives with numerical aperture of 0.1 and 0.2 and, consequently, the spatial resolution is not very high (~4 µm). With the use of this technique, profile measurements of out-diffused planar waveguides could be measured with high
accuracy and the formation of a surface layer with decreased extra-ordinary refractive index during the Ti-indiffusion process in wet As atmosphere has been found.

4. References


