Characterization of ion exchanged integrated lightwave devices with an apertureless scanning near-field optical microscope

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An apertureless scanning near-field optical microscope is used to characterize ion exchange lightwave devices. Experimental images of field propagation are presented in such devices as channel and segmented waveguides. This tool permits accurate measurement of propagation constants and mode profiles.

Keywords: guided-wave optics, ion exchange technology, characterization methods, scanning near-field microscopy

Introduction

The mapping of optical field propagation in confined waveguides structures is very important for a comprehensive understanding of these structures design. Near Field Scanning Optical Microscopes (NSOM) permit non-destructive investigations of the optical evanescent field, which propagates at the surface of lightwave devices, with a subwavelenght resolution.

The technique is particularly suitable for the study of ions exchanged integrated devices because of the graded nature of the refractive index profile entailed by the ions diffusion process: the classical investigation methods as cut-back measurements are destructive, or not enough accurate to give good description of hidden characteristics such as profile and propagation constants of the guided field. In addition diffused waveguide geometry cannot be precisely known because of the lack of topography information.

There are currently two main classes of NSOM probes. First kind uses tapered optical fibers [1] used to pick up the light from the near field region of the studied structures. The light is coupled into the fiber and detected at the other fiber extremity. The alternative approach is based on the use of an apertureless sharp dielectric or metal tip, acting as a scattering center in the near field region. The radiated field emitted by the tip end is collected by an external optical detection system. This configuration is so called Apertureless-NSOM (ANSOM). This second approach presents many advantages [2] regarding the first one in term of tip design and realization facilities, tip robustness, high resolving power (related to the tip diameter) and achromatic behavior.

We propose to characterize quantitatively the signal collected with an ANSOM in the near field region of ion-exchanged waveguides realized in a silicate glass substrate. In the first part, we present the experimental apparatus. In the second part, a quantitative study of an integrated channel waveguide shows the ASNOM accuracy and preliminary results with other lightwave devices as light propagation in segmented waveguides are presented.

Experimental

The experimental configuration used for this study is depicted in Fig. 1. The ANSOM has been developed from a commercial AFM (model M5 from Park Scientific Instruments). The optical probe is a sharp silicon or metal tip with a terminal radius of above 50 nm. The waveguide sample is mounted on two nano and micro scale x-y piezoelectric scanners. Thanks to these scanners, the

tip is able to scan the sample in the surface near field zone of the guided waves. The tip to surface distance is controlled by the atomic force regulation in the intermittent-contact mode (also called “tapping mode”). This entails a tip vibration in the z direction, perpendicularly to the sample. The vibration amplitude is about 25 nm at f=180 kHz frequency. The atomic force feedback ensures constant vibration amplitude during the image recording session and leads to the topography measurement. The inset in Fig.1 shows AFM topography of the waveguide top surface recorded over a 10x10 µm2 scanned area. It reveals relics (amplitude of a couple nanometers) of the diffusion aperture mask of 1.7 µm width. This lets us localize precisely the studied waveguide. Simultaneously to this atomic force microscopy, the optical scattered flux, from the tip end in local interaction with guided waves, is far-field collected thanks to a confocal optical microscope.

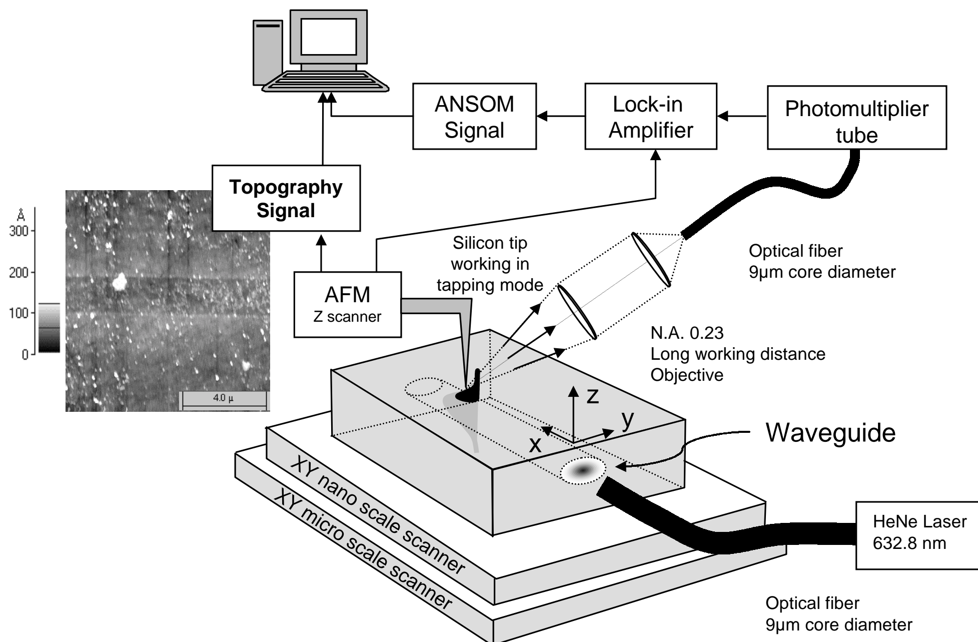

Figure 1: Experimental ANSOM configuration used for the study. An evanescent wave is generated at the air/waveguide interface by total internal reflection in the waveguide.

The optical signal part, transported in the surface evanescent field, and scattered in the detection direction is very weak, but a lock-in signal extraction technique at the tip vibration frequency f provides a reasonably high level of ANSOM signal.

Mapping the propagation of light

The optical waveguide under study has been produced using two-steps Ag+/Na+ ions exchange process in a silicate glass substrate, and buried at about 3µm beneath the glass top surface by the mean of thermal rediffusion process. A full detailed description of the fabrication steps is given elsewhere [3]. The guide was formed through a 1.7 µm diffusion aperture width. The diffusion process entails a transverse graded index profile, which is not measurable with accuracy in the case of such confined waveguide, but its mean index variation is empirically estimated to be about 10^{-2} above the substrate refractive index value of 1.515. Far field measurements of the waveguide mode field dimensions with a CCD beam profiler showed that single transverse mode at wavelength=1.55

µm was supported whereas multimode transverse operation was revealed at wavelength=0.633 µm. We set our working wavelength to 0.633 µm in order to visualize the waveguide multimode behavior with the ANSOM technique.

The ANSOM image reveals a strong intensity beat operation along the direction of propagation in the waveguide. This is characteristic of a multimode behavior. More precisely the beat occurs at least between the 3 lowest order modes. The modulus of the Fast Fourier Transform (FFT) amplitude spectrum calculated on a longitudinal profile on the direction of propagation, extracted from the raw image 1 (along the white dashed line) shows two strong maxima corresponding to periodicities of 206.9 ±0.2 nm and 207.8±0.2.These peaks reveal the presence of a periodic intensity variation in the direction of propagation due to the cavity formed between the waveguide entrance and exit facets. In fact the existence of 3 supported guided modes entails a superposition of 3 standing wave patterns with periodicities of $\lambda_0/2n_{eff(i)}$, i=0,1,2 . We showed experimentally that the deposition of an anti reflection liquid index on the output waveguide facet makes the fringes pattern to vanish. The corresponding calculated effective indexes are 1.529±0.002 and 1.522±0.002 for respectively mode TE0 and mode TE2. These values are in good agreement with the experimental measurement of the beat length. The fringes pattern related to the TE1 mode is not visible. This is due to the relatively low spectral resolution on the FFT spectrum. We need to perform a longer scan to discriminate the three modes contributions in the standing wave pattern.

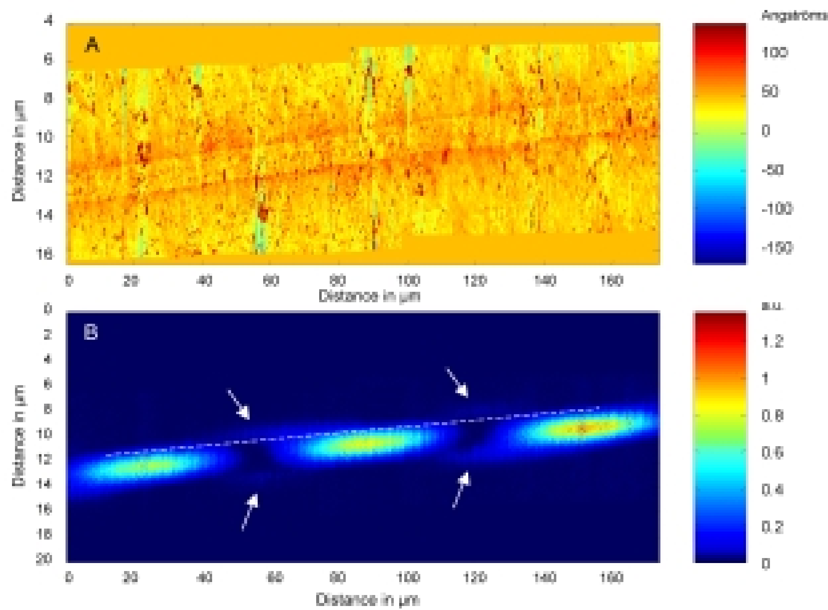

Figure 2: Waveguide characterization. A: topography image. B: Optical intensity mapping. White arrows point out the TE_2 mode contribution, the white dashed line represents the waveguide longitudinal direction. The FFT profile was performed along this line (see text for comments).

The ASNOM is a very accurate tool to determine effective index. This can be helpful in the case of segmented waveguide [4]. The segmentation can be used to obtain effective index closed to the substrate index in a controlled way by tuning the length of the segment or the period of segmentation. Fig. 3A shows the surface topography of a segmented waveguide. This optical waveguide has been produced using K+/Na+ ions exchange process in a silicate glass substrate. No burying process has been used. In this case, because of respective sizes of exchanged ions at the surface the glass inflates. Hence, one segment is visible through the topography image.

Fig 3B is the ASNOM image. The image shows a multimode behavior since the field is not centered, focusing effect is observed. These images are presently under study in our laboratory. We intend to measure effective index and study the propagation of light in such structures.

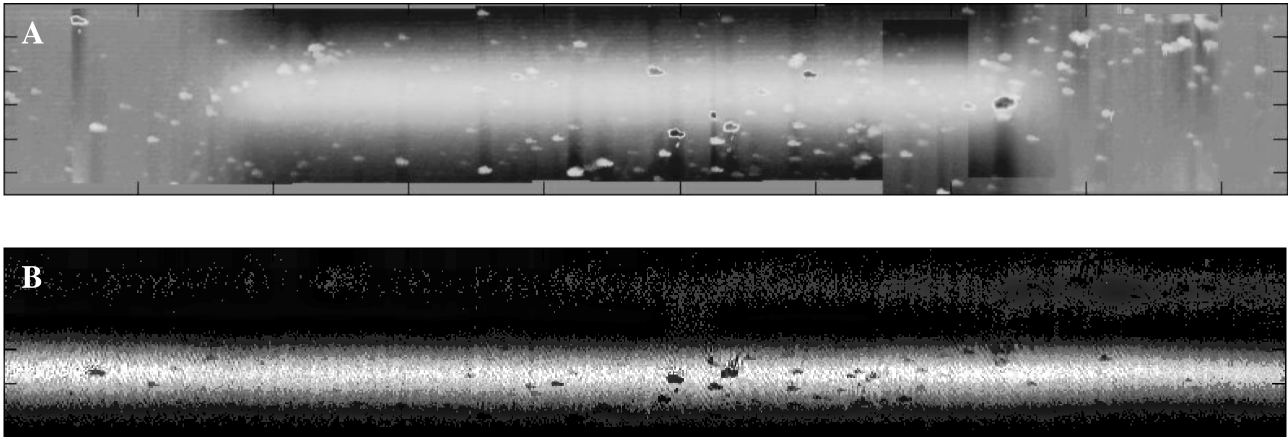

Figure 3: AFM topography image(A) and ASNOM image of a single segment on an ion exchange segmented waveguide. Both images represent a 15 µm by 110 µm scan.

Conclusion

Glass integrated ion exchanged waveguides have been successfully characterized by Apertureless Near-field Scanning Optical Microscopy (ANSOM). The experimental setup was made from the combination of a commercial AFM microscope and an optical confocal detection system. The main advantage is to record topography images and optical near-field images simultaneously, with the benefit of the high scanning probe resolution (tip radius of few tens of nanometers) along with a large scan size.

The Fourier transform analysis of the intensity profile lets us evaluate directly the effective index of eigenmodes with a precision of 2.10^{-3}. This shows that ANSOM can be an accurate tool. We intend to perform longer scans to increase precision on the refractive index measurement.

Promising investigations are made to develop a heterodyne signal detection scheme based on a Mach-Zender interferometer [5]. Besides the removal of background field contribution, the interferometric setup will allow the simultaneous mapping of both propagated field intensity and phase. We anticipate the ANSOM technique to become a key measurement tool for ion exchanged optical waveguide and more generally for integrated lightwave devices.

[1] M. L. M. Balistreri, J. P. Korterik, G. J. Veldhuis, L. Kuipers, N. F. Van Hulst, J.Appl.Phys. **89(6)**, 3307-3314, 2001

[2] R. Bachelot, P. Gleyzes, A. C. Boccara, Opt. Lett. **20**, 1924

[3] J. E. Broquin, Proc. SPIE, **4277**, 105-115, 2001

[4] Z. Weissman, A. Hardy, J. Lightwave Technol **11(11)**, 1831-1837, 1993

[5] M. L. M. Balistreri, J. P. Korterik, L. Kuipers, N. F. Van Hulst, Phys. Rev. Lett. **85(2),** 294-297, 2000