A Novel technique to measure propagation loss of optical waveguides

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Abstract

A method to measure the propagation loss of optical waveguides is discussed. The measurement system involves two 3 dB couplers, a CCD camera and a signal processing unit. The propagation loss measured from this technique is found to be independent of coupling conditions. The propagation properties of waveguides prepared by proton exchange (PE) in Lithium Niobate ($LiNbO_3$) and Silver ion exchange in BK7 glass substrates are examined. Finally the variation of mode propagation loss for various annealing parameters of PE waveguides is discussed.

I. Introduction

Optical waveguides based on $LiNbO_3$ and glass substrates have attracted great interest in the field of integrated optics for the devices to be used in high speed optical communication and sensor technology. However, there are very few techniques available for the measurement of propagation loss of optical waveguides and they involve either destructive (cut back) method [1] or complex interferometric experimental set-up [2]. Sliding prism loss measurement has been a popular technique, where the prism coupler is slid along the light streak of the waveguide and the light output from the prism is measured as a function of propagation length [3]. In another method known as fiber probe measurement, an optical fiber is scanned along the streak of the waveguide to collect the scattered light into the fiber [4]. Although these methods are widely used, their accuracy and reproducibility depend on the mechanical operation involved in the system. A method that overcomes the mechanical operation involves capturing the light streak in the waveguide and finding the optical power as a function of propagation length using computer analysis. But this method suffers from the disadvantage of requiring significant surface scattering of the waveguide under consideration [5] and can not be applied to the buried waveguides.

Here, we discuss a new method for measuring the propagation loss that employs two 3 dB couplers and a detection system. In addition to the reproducibility this method is free from the mechanical operation of the system and can also be applied to the buried waveguides. We have examined propagation loss of waveguides prepared by PE on $LiNbO_3$ and silver ion exchange on BK7 glass substrates and found that this method does offer a simple means to measure the propagation loss independent of coupling coefficients. Finally we have studied the propagation properties of the proton exchanged waveguide by varying the annealing parameter.

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II. System description

The experimental scheme for this technique is shown in Figure 1 wherein two identical 3 dB couplers (C_1 and C_2) are aligned as shown. Coupling between the fiber and the waveguide is set to be equal at both the waveguide endfaces. This is ensured by aligning the fiber and waveguide in a way to get equal back reflected power at A_1 and A_2 when light is launched from S_1 and S_2 separately. The distance between the fiber and waveguide is kept within the diffraction limit.

Light from a semiconductor laser source (HP 81654A) of wavelength 1.53 μm is launched into the waveguide endface 2 using coupler C_2. The light output power, P_1, from the coupler end A_1 is measured using photodetector (HP 81633B) . In all the input light suffers coupling loss and Fresnel reflection loss at endface 2, propagation loss (α) between waveguide endfaces and Fresnel reflection loss and coupling loss at endface 1.

When the intensity of S_2 is P_o, then P_1 is given by

$$P_1 = \frac{P_0}{4}(1-F_f)^2(1-F_{wg})^2 e^{\alpha L} C_{fw} C_{wf} \qquad (1)$$

where,

$F_f = \left(\frac{n_f - n_a}{n_f + n_a}\right)^2$ is Fresnel reflection coefficient at fiber end

with n_f = core refractive index of fiber, and n_a = 1 (air) ,

$F_{wg} = \left(\frac{n_w - n_a}{n_w + n_a}\right)^2$ is Fresnel reflection coefficient at waveguide end

with n_w = surface refractive index of the waveguide,

α = propagation loss coefficient per unit length of the waveguide, L is the length of the waveguide in cm, C_{fw} and C_{wf} are the coupling coefficients from fiber to waveguide and from waveguide to fiber, respectively.

Now, the coupler C_2 is removed and light (P_0) is launched into the waveguide endface 1 using coupler C_1. The back reflected light P_2 is measured at the same point (A_1). In this case the input light suffers apart from Fresnel reflection and coupling loss at endfaces 1 and 2, to and fro propagation loss between the waveguide endfaces. P_2 is given by

$$P_2 = \frac{P_0}{4}(1-F_f)^2(1-F_{wg})^2 F_{wg} e^{2\alpha L} C_{fw} C_{wf} \qquad (2)$$

From equation 1 and 2, the propagation loss coefficient is obtained as

$$\alpha = \frac{1}{L}\ln\left(\frac{1}{F_{wg}}\frac{P_2}{P_1}\right) \qquad (3)$$

In order to calculate the Fresnel reflection coefficient, the refractive index of the waveguide is to be obtained. In our case , we have used the Propagation Mode Near Field Method [6], wherein the refractive index profile of the optical waveguide is computed from the propagation mode near field data captured by an infrared vidicon (FIND-R-SCOPE 85400A). Since the transfer characteristics of the infrared vidicon is non-linear one plots (see Figure 2) the optical intensity I and the digital output values V from the vidicon to obtain γ as given below

$$I = DV^{1/\gamma} \qquad (4)$$

Where D is a constant, I is optical intensity and γ is obtained from the gradient of the transfer characteristic of infrared vidicon..

III Results and discussions:

In order to verify the effectiveness of the present technique, the propagation loss is found for different waveguides fabricated by PE on $LiNbO_3$ and silver exchange on BK7 glass substrates.

A low loss PE single mode 3-D channel waveguide at 1.53 µm operating wavelength is fabricated by thermal ion exchange technique by immersing a x-cut $LiNbO_3$ substrate in molten dilute benzoic acid (proton source) at 224° C for 90 minutes. To reduce the surface scattering and redistribute the H^+ ions, the substrate is annealed for two hours at 400°C.

To fabricate a silver ion exchanged 3-D channel waveguide, a two step ion exchange process has been carried out in a BK7 glass substrate. In the first step the waveguide is formed by the field assisted Ag^+- Na^+ ion exchange technique using a diluted molten silver ion source and in the second step a reverse ion exchange is carried out to burry the waveguide inside the substrate. Since the waveguide is buried in second step the surface scattering loss and the fiber waveguide mode mismatch loss are minimized

A. Proton exchanged waveguides:

The PE single mode waveguide is tested using the present technique and the propagation loss for this waveguide has been found for different coupling coefficients and plotted as shown in Figure 3. To achieve maximum coupling between the fiber and the waveguide, the fiber is scanned along horizontal and vertical directions to get the maximum output power. To attain different coupling conditions, the fiber has been misaligned equally in horizontal direction at both the waveguide endfaces and the coupling coefficient has been normalized with respect to the maximum obtained output power. The average propagation loss for this waveguide is found to be 0.66 dB/cm, and this is comparable to the result reported earlier

The propagation loss of proton exchanged waveguide is examined for different annealing durations at 400°C. The result in Figure 4 shows a steep decline in the loss for small annealing time and this decline is less significant as the annealing time is increased. This indicates that for small annealing durations $LiNbO_3$ crystal does not attain single phase structure and the decrease in propagation loss shows that the crystal approaches the single phase condition as annealing duration increases.

The accuracy of the present scheme is dependent on the refractive index computed as discussed in section II above. For example,in the case of PE waveguides, if the error in the refractive index calculation is 5%, then the error in the propagation loss is 4.3%.

B. Silver ion exchanged waveguide:

The propagation loss of the silver ion exchanged waveguide is tested using the present technique for different coupling conditions as explained above and the result is shown in Figure 5. The average propagation loss for this waveguide is found to be 0.89 dB/cm. This is in agreement with the results reported earlier.

Conclusion:

We have demonstrated a novel technique to measure the mode propagation loss of optical waveguides which is simple and reproducible over the existing methods. Propagation loss of single mode 3-D waveguides prepared by proton exchange in LiNbO3 and Ag^+- Na^+ ion exchange in BK7 glass substrates has been obtained. In a typical PE sample the average propagation loss is found to be 0.66 dB/cm with an error of 4.3%,Then the variation of propagation loss with various annealing time has been examined for proton exchanged waveguides. The novel feature of this method is the use of ratio of the two measured optical powers P_1 and P_2 to eliminate the effect of coupling conditions.

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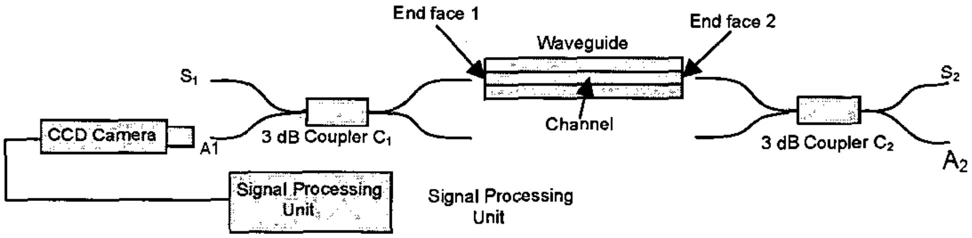

Figure 1 Experimental set-up for propagation loss measurement

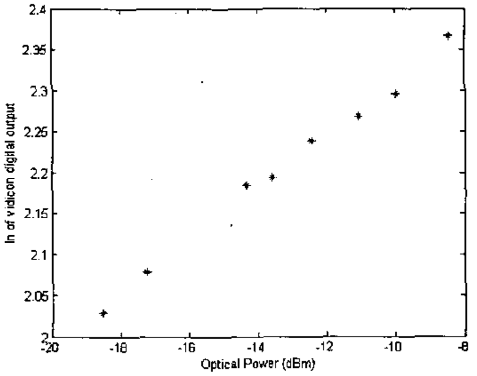

Figure 2 Transfer characteristics of infrared Camera.

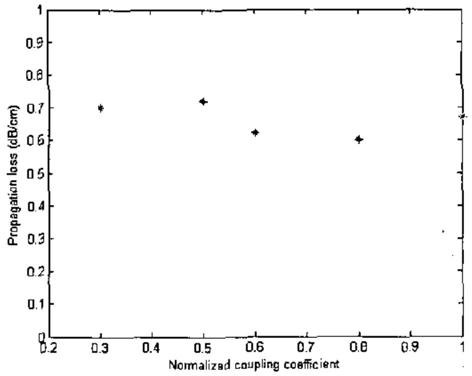

Figure 3. Propagation loss of proton exchanged Lithium Niobate waveguide for various coupling conditions.

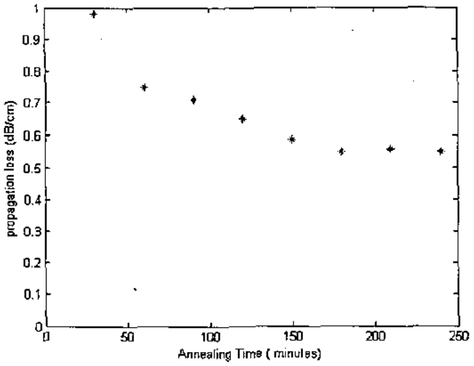

Figure 4. Variation of propagation loss of proton Exchanged waveguides in $LiNbO_3$ for different annealing time.

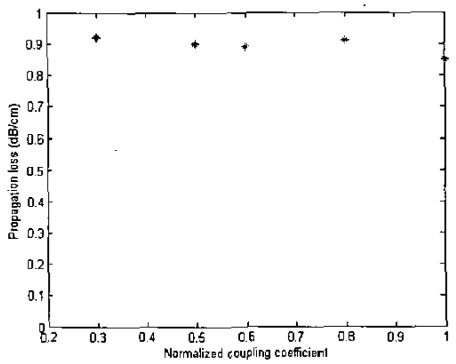

Figure 5 Propagation loss of silver ion exchanged BK7 waveguide for various coupling conditions.