1.31μm and 1.55μm 파장에서 금속 defined Electro-Optic Polymer Waveguide

Metal-defined Electro-Optic Polymer Waveguide Operating at both 1.31μm and 1.55μm Wavelength

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Abstract

We report experimental results demonstrating a novel metal defined polymer optical waveguide with a low loss in electro-optic polymers for the first time. The polymer optical waveguides are created using a metal film on the top of upper cladding without any conventional etching process. The fabricated waveguides have an excellent lateral optical mode confinement at both 1.31 □m and 1.55 □m wavelength, resulting in a fiber-to lens optical insertion loss of ~ 7 dB at 1.55 □m and ~4.5 dB at 1.31 □m wavelength in a 3.5cm total length for TM polarizations, respectively. We also present the optical loss dependence of the waveguide as a function of optical wavelengths. These results may be used in the complex design of integrated polymer optical circuits that need simpler and cheaper fabrication process.

1. Introduction

Several methods, such as reactive ion etching [1, 2], UV-bleaching [3], laser writing [4], poling-induced writing [5], and molding/embossing [6] have been developed to define optical waveguides in passive and active polymers. In addition to these technologies, we introduce a novel waveguide defining method that uses a metal film to produce low-loss optical waveguides in electro-optic polymers.

Metal-defined optical waveguides (MDOWs) in polymers can be explained by an induced stress field that locally modifies the optical refractive index and can provide the lateral optical confinement of waveguides. In terms of the stress-induced effects (strain-induced or photo-elastic effect) on optical materials, it has been originally used for semiconductors/silicon and ferroelectric materials, such as InGaAs/InP [7], SiGe/Si [8, 9] MgO-BaTiO$_3$ [10], and $LiNbO_3$ [11], to increase the refractive index of optical waveguide for lateral light confinement without both chemical etching and regrowth of core-layer. In such stress-induced waveguides, the stress is normally introduced selectively into waveguide structures by deposition of materials, including SiO_2 [11], WNi [12], and Si_3N_4 [9] at certain temperatures. Generally, after cooling process to room temperature, the strain is created at the semiconductor hetero-structures or the interface between stressor and ferroelectric material due to their different thermal expansion coefficients. It is also well known that a deposition process itself may introduce a significant intrinsic stress, in addition to the thermal stress due to the cooling [7]. This intrinsic stress may even dominate over the stress induced by thermal expansion mismatch, especially when a film is formed at low temperature [10].

However, this approach for creating high quality optical waveguides has not been implemented onto polymer materials such as passive and active (electro-optic) polymers. In this letter, we demonstrated MDOWs in the electro-optic polymer APC-CLD1 and APC-CWC2 guest-host system for the first time. This technique gives a new way of defining polymer optical waveguide operating at the communication wavelengths with low optical loss that are simple and low cost solution for the optical polymer waveguide based devices.

2. Fabrication of MDOWs

Fig. 1 depicts the schematic cross-sectional view of the MDOW that consists of a metal film and a 3-layered polymer. The metal film was defined in the channel width of 4m by photolithography. The core layers of MDOWs are formed using two electro-optic polymers [13, 15], CLD1-APC and CWC2-APC, which are the second-order nonlinear optic guest−host polymers that consisted of a phenyltetraene bridged high ì chromophore guest and an amorphous polycarbonate host.

For metal film stressors such as Au and Cr/Au were e-beam evaporated onto the samples in a vacuum pressure of ~ 10^{-8} Torr with evaporation rate of ~0.3 /s. The vacuum temperature during evaporating was measured to be 60℃.

3. Experimental Results and Discussion

The optical near-field patterns of the guided modes in the MDOWs are shown in Fig. 2 for a straight waveguide and Fig. 3 for a mach-zehnder y-branch waveguide section at wavelength of 1.31 ㎛ and 1.55 ㎛. It is clear that all the waveguides support only a single mode operation at both wavelengths. The optical mode in the lateral direction was not only well confined, but also mainly guided in the core layer. Therefore, it was confirmed that the lateral confinement of the MDOWs was also comparable to those in ref. [14]. In addition, the mode shapes of the MDOWs at 1.3 ㎛ wavelength is more circular than at 1.55 ㎛ wavelength, indicating that the metal film is more effective in enhancing the index of refraction of the core layer at 1.3㎛ wavelength in terms of lateral confinement. The active polymers used in this experiment was mixed with the APC polymer solution in 25wt.% concentration and its refractive indices were measured to be ~1.5904 for TM and ~1.5986 for TE polarization at 1.3 ㎛ wavelength, while ~1.5808 for TM, ~1.5902 for TE polarization at 1.55 ㎛ wavelength. In our previous calculations with conventional rib-type waveguides [2], the required effective index contrast $\Delta Neff$, which is the difference of the effective index of waveguide slab and that of waveguide center of the lowest order mode, is of ~0.003 to produce the single-mode waveguide with good confinement. Therefore we assumed that the fabricated MDOWs are able to induce a similar $\Delta Neff$ like a ridge-type waveguide as confirmed in Fig. 2 and 3, and Table I.

Optical fiber to-lens losses of the MDOWs are measured at both 1.31 ㎛ and 1.55 ㎛ wavelength using un-poled devices as shown in Table I. It is also confirmed that the optical losses of the MDOWs are comparable (at 1.55 ㎛ wavelength) to or better (at 1.31 ㎛ wavelength) than those of the reported our ridge waveguides [1-3]. In our experiment, the absortion loss due to the metal film was negligible in the part of the loss mechanism. The dominant loss mechanism at both wavelengths is probably the material losses as described in [15]. Therefore, it appears that the MDOWs does not induce extra optical losses. Table I also implies that the total fiber-to-lens coupling loss at 1.3 ㎛ wavelength is much less than at 1.55 ㎛ wavelength. It is fact that the confinement of light at 1.3 ㎛ is stronger than at 1.55 ㎛ wavelength, introducing a reduced fiber-waveguide coupling loss.

The wavelength dependent transfer function of un-poled MDOWs was investigated using Optical Spectrum Analyzer (OSA, HP 70915B). The curve shapes of both TM and TE modes closely resemble the material absorption spectra of the polymer core material as reported in [15]. The normalized fiber-to-fiber loss at 1.31 ㎛ wavelength is lower than 1.55 ㎛ wavelength for both TM and TE polarizations that was well matched to results from Table I. This may be explained by the following an evidence [16], the unpoled electro-optic chromophore results in a higher index of refraction at 1.3 ㎛ wavelength than 1.55 ㎛ wavelength leading to higher optical confinement factor. Consequently, it was confirmed that the MDOWs result in a lower optical propagation loss at 1.3 ㎛ than 1.55 ㎛ wavelength as shown in Fig. 5.

The device propagation losses were obtained by the cut-back method as shown in Fig. 5. The estimated values of the propagation loss were ~1.30 dB/cm for both TE and TM polarization at 1.55 ㎛ wavelength, while ~1.09 dB/cm for both TE and TM at 1.31 ㎛ wavelength, respectively. The measured material absorption loss of TM polarization in unpoled slab waveguides using the immersion technique were ~1.0 dB/cm at 1.3 ㎛ wavelength, and ~1.2 dB/cm at 1.55 ㎛ wavelength [15]. Therefore, the optical loss of the MDOWs has a closer value to that of the chromophore material loss.

4. Conclusion

We demonstrated a metal-defined optical waveguides in electro-optic polymer material using an evaporated metal film as a stress source. The optical losses of the fabricated metal-defined waveguides are comparable to those observed for ridge type waveguides. These experimental results indicate that the MDOWs can be a promising alternative to commonly used dry etching technique for defining optical waveguide circuits. Moreover, this approach can be applicable to any passive optical polymer waveguides.

References

1. Pedro Barrios, and Hong Koo Kim, *Appl. Phys. Lett.* 73, 1017 (1998).
2. O. Eknoyan, H. F. Taylor, Z. Tang, V. P. Swenson, and J. M. Marx, *Appl. Phys. Lett.* 60, 407 (1992).
3. Q. Z. Liu, L. S. Yu, S. S. Lau, H. P. Zappe, and J. E. Epler, *IEEE Photon. Technol. Lett.* 8, 806 (1996).
4. CLD1 and CWC2 are based on a guest-host polymer consisting of highly nonlinear chromophore with phenyltetraene bridge and amorphous carbonate.
5. Seong Ku Kim, W. Yuan, H. R. Fetterman, C. Zhang, C. Wang, and W.H.Steier, *J. of the Korean Physical Society*, 43, L645 (2003).
6. C. Zhang, L. R. Dalton, M-C Oh, H. Zhang, and W. H. Steier, *Chem. Master.* 13, 3043 (2001).
7. K. Geary, SeongKu Kim, B-J Seo, and H.R.Fetterman, *J. of Lightwave Technology*, submitted.