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Theoretical study of polymeric metal clad optical waveguide polarizer

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Abstract

Planar optical waveguides consisting of thin dielectric films and buffer layers with metal cladding have been investigated theoretically. A computer program was written to calculate the exact zeroes of complex eigenvalue equation for TE and TM modes in multilayer metal clad waveguide polarizer. Numerical results and illustrations are given for Polycarbonate waveguide with other polymers as buffer and Al, Ag and Au as cladding metals at 0.6238 μm. It is also shown that, using thin (finite) films of metal produce more efficient polarizers as compared to semi-infinite metal films. Effect of low index buffer layer on attenuation of TM/TE modes is also investigated.

Keywords: Integrated optics; Optical waveguide polarizer; Complex refractive index

1. Introduction

Polymers have attracted great interest for photonic components in optical communication and optical sensing that enable unique functions without sacrificing high performance [1–3]. Advanced planar polymer technologies are suitable in every respect. Polymeric materials permit the mass production of low-cost high-performance circuit on many planar substrates (like Glass, Si and InP) [4]. In addition they provide the possibility for a much higher degree of ruggedness. In contrast to the inorganic material (like $LiNbO_3$), the Electro-Optic (EO) polymers have also been investigated due to their advantages such as, large optical non-linearity coefficients, fast response, low dielectric constants, simple fabrication process and easy fabrication of multilayer structure [4]. Further, material properties can be tailored for specific applications. Polymers are important class of materials for advance sensor photonics [4]. In particular, Polycarbonate (PC) has high transparency (more than 89%), ease of processing and high physical, chemical, mechanical and thermal stability and are mechanically strong and can therefore be profitably used in many Integrated Optic (IO) devices [5,6]. Polycarbonate films have extensively been studied and its use in mode polarization filter for IO has already been reported [5]. However, a more compatible polarizer can be designed if we use metal clad optical waveguides. A dielectric film (buffer) layer is sandwiched between the waveguide (PC) layer and the metal outer layer. The surface plasmon waves supported by the metal surface, being of TM type, interact only with the TM-guided mode through the evanescent fields in the cover region between them. As a consequence, either the TM-guided mode of dielectric film is completely absorbed or its power is substantially reduced, but TE mode propagates through the interaction region essentially with no attenuation. This large TM-to-TE loss ratio can be used to produce a polarization filter for IO [7–9].

In the case of mode filter, it is necessary to obtain a sufficient extinction ratio without introducing a significant loss in the transmitted light. A TM-guided mode exhibits an absorption peak as a function of thickness of the low index buffer layer in the multilayer structure shown in Fig. 1. The purpose of this paper is to investigate attenuation characteristics of the polymeric multilayer metal clad optical waveguides by exact

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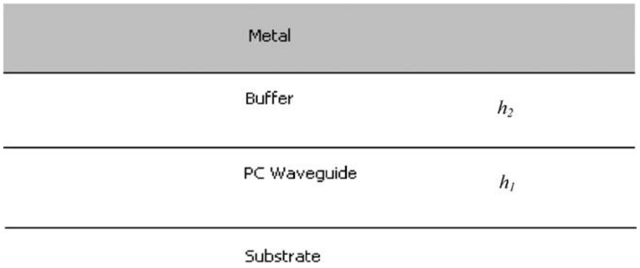

Fig. 1. A metal clad film waveguide structure.

numerical method. The dependence of attenuation constant on buffer layer thickness, its refractive index and different cladding metals are presented. It is also observed that for an efficient design of a polarizer, a thick layer of material is not required and the configuration in Fig. 1 is modified by taking finite thickness of the metal layer (Fig. 7). This results in a more efficient and high extinction ratio polarizer.

The thin film transfer matrix formulation [10,11] is used as the primary tool for the multilayer waveguide analysis. The thin film transfer matrix theory can easily form the dispersion equation of a multilayer waveguide consisting of any combination of lossless and lossy (dielectric and metal) layers. The guided mode propagation constants of the structure correspond to the zero of the equation.

2. Transfer matrix method for analysis of multilayer systems

The transfer matrix analysis provides an easy formulation of the multilayer problem [10,11]. In this method each layer is characterized by a 2 × 2 matrix,

$$M_j = \begin{bmatrix} \cos(k_j h_i) & \frac{\mathrm{i}}{k_j}\sin(k_j h_j) \\ \mathrm{i}k_j \sin(k_j h_j) & \cos(k_j h_j) \end{bmatrix}.$$

In our case $j = 1, 2, 3$.

$$\mathrm{i} = \sqrt{-1}$$

and

$$k_j = \sqrt{n_j^2 k_0^2 - k_z^2},$$

where $k_0 = \frac{2\pi}{\lambda}$

and n_j and $k_z(\beta - \mathrm{i}\alpha)$ are complex refractive index and complex propagation constant respectively and $h_j =$ thickness of the jth layer. α is the attenuation coefficient (dB/cm) of the guided mode and λ is the wavelength of light (in our study $\lambda = 0.6328\,\mu\mathrm{m}$).This wavelength was chosen for two reasons first, we would realize the polarizer at this wavelength and secondly, these guides find their use in many biological/chemical sensors operating at 0.6328 μm.

The total multilayer system for Fig. 1 is given by the matrix product of the two characteristic matrices.

$$\mathrm{M} = \begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix} = \mathrm{M}_1 \times \mathrm{M}_2.$$

Once the characteristic matrix of a multilayer structure is known, we can easily get the eigenvalue equation or dispersion equation for TE polarization [11]

$$f(k_z) = \mathrm{i}(\gamma_s m_{11} + \gamma_c m_{22}) - m_{21} + \gamma_c \gamma_s m_{12} = 0,$$

where

$$\gamma_s = (k_z^2 - n_s^2 k_0^2) = -k_s^2$$
$$\gamma_c = (k_z^2 - n_c^2 k_0^2) = -k_c^2.$$

Similar expression can be obtained for TM polarization.

3. Solution of dispersion equation

The relation has been solved numerically using Muller iteration method [12]. This method was chosen because it does not require the evaluation of any derivative of the dispersion relation. It has been found that this method converges fairly rapidly to the solution and computation time is small.

3.1. Effect of buffer layer

The materials used for buffer layer calculations are the polymers Poly(tetrafluoroethylene), Poly(trifluoroethyl Acrylate), Poly(vinylisobutyl ether) and PMMA with refractive indices 1.35, 1.407, 1.4507 and 1.49, respectively. These polymers have the solvents different from that of Polycarbonate (waveguide) and therefore can be deposited on it. The thickness of these films can easily be controlled by controlling the spinner speed [13]. The effect of the variation of the buffer layer thickness on guided modes supported by this guide are examined for the metals Al, Ag, and Au with refractive indices $1.2 - j7$, $0.065 - j4$ and $0.14 - j3.5$ respectively. For a free space wavelength $\lambda = 0.6328\,\mu\mathrm{m}$ (which corresponds to He–Ne laser), the plots of the attenuation coefficient (α) versus the buffer layer thickness h_2 are shown in Figs. 2–5 for TM_0 and TE_0 modes. TE losses decay monotonically as h_2 increases. The TM loss is higher than TE when $h_2 = 0$. As h_2 increases, loss increases several orders of magnitude (for TM) and then decreases sharply. The absorption maxima appearing in Figs. 2–5 for different buffer layer materials result from strong coupling between the normal guided mode in layer 1 (through buffer) and lossy surface plasmon wave supported by metal buffer layer interface for TM waves. For TE modes there is no such coupling. It can also be seen that buffer thickness increases as its index increases for all the metals. Further it is observed that as the