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ANALYSIS OF CHROMIUM CLAD OPTICAL WAVEGUIDE FOR TE PASS POLARIZER USING POLYMER BUFFER LAYER

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ABSTRACT

Attenuation characteristics of chromium clad optical waveguide are theoretically investigated at the wavelength of 0.6328 µm. Theoretical results are obtained by solving complex multilayer eigenvalue equations by Transfer Matrix Method (TMM). It is proposed that the TM mode attenuation can be significantly increased by inserting a low index polymer buffer layer between the dielectric guide and metal clad layer. By using low index polymer buffer layer a resonant coupling condition between guided modes and surface plasmon modes is obtained to improve the attenuation characteristics. The generated field profiles for the proposed structure suggest that TE mode field is mainly confined within the waveguide thickness and TM mode field exhibit an absorption peak in metal layer at a particular buffer thickness. This property can be used to design a high extinction ratio TE pass polarizer. Effect of metal thickness and buffer layer thickness is also discussed.

Keywords: ***Plasmonic waveguide, Chromium cladding, Polymer buffer layer, Polarizer, Transfer matrix method.***

1. INTRODUCTION

Multilayer waveguides are used in implementing variety of optical devices including semiconductor lasers, modulators, waveguide polarizers and directional couplers [1-2]. Theoretical study of metal clad dielectric waveguides has been extensively covered by many researchers [4-9]. It has been already reported in previously published papers that waveguide structure with chromium can support surface plasmon mode as well as damped leaky modes [3-4]. We proposed a multilayer optical waveguide structure with chromium as a cladding layer. It has been observed that the proposed structure can support guided modes as well as surface plasmon modes. Surface plasmon polaritons (SPPs) are electromagnetic waves coupled to the coherent oscillations of a metal's free electron density and propagate along the interface between a dielectric and a metal [6-11]. SPPs generally have much smaller wavelength than those of free propagating electromagnetic waves which makes them a prospective candidate for compact integrated optical circuits [10]. It has been observed that chromium consist of greater attenuation than an order of magnitude over measured attenuation in silver, aluminium and gold [3]. Due to this characteristic chromium can be explored for polarization effects. In this paper we have observed the attenuation characteristics and the interaction of guided modes and modes exist due to chromium cladding in the proposed structure. We investigated two structure of chromium clad optical waveguide. One structure is analyzed for attenuation characteristics without buffer layer and in another structure buffer layer effect is observed. It is shown that a low index polymer buffer layer can be introduced between guiding layer and clad to produce good attenuation peaks for selecting a particular (TE) polarization. Chromium clad waveguide has not been exploited upto much extent for polarization properties.

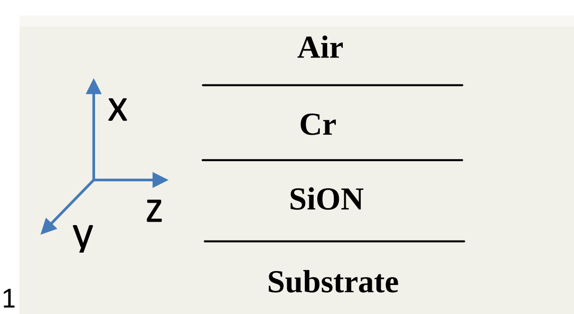

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Fig. 1. Schematic cross section of three layer chromium clad waveguide.

After exploring these structures, it is proposed that a high extinction ratio, low insertion loss TE pass polarizer can be designed. There are many ways to produce a waveguide polarizer, e.g. using selective attenuation in metal/semiconductor cladding or cut off effect in waveguides [11-18]. Polarizer is a key component for integrated optical devices which require a single polarization for the operation. The response of the structure shown in Fig.1 is not suitable to design an efficient polarizer due to low extinction ratio. Therefore, a buffer layer is introduced in the structure as shown in Fig.2, which helps in resonant coupling of guided modes (TM) with the surface plasmon modes supported by the guiding layer and metal layer respectively.

Polymer films can be chosen as the buffer material and have been used widely in integrated optics because they have excellent waveguiding characteristics [19-20]. Also, the advantage of using polymer buffer layer is that, there are large number of polymers with refractive index ranging from 1.4 to 1.7 [21].

2. Solution of the Eigen Value Equation for Optical Waveguide

The thin film Transfer matrix method (TMM) is used to calculate the eigenvalue equations in the multilayer slab waveguide structure. The transfer matrix of each layer is calculated and the effective indices are found by solving eigen functions numerically. The method (TMM) is presented in Appendix-I.

3. Chromium Clad Optical Waveguide

The multilayer substrate/SiON/Cr/air structure and the coordinates are shown in Fig.1. The substrate and the waveguide (SiON) layer are considered to be lossless and are given by real refractive index values. The metal cladding layer (chromium) is characterized by complex value of refractive index. A thickness of 1.5 µm is selected for the waveguide which is sufficient to support fundamental modes.

4. Result and Discussion

In this section we will focus on the optical guided modes and surface plasmon (SP) modes supported by the multilayer metal clad waveguide structure. We will also concentrate on the interaction of guided modes with the surface plasmon (SP) modes in the proposed structures as shown in Fig.2.

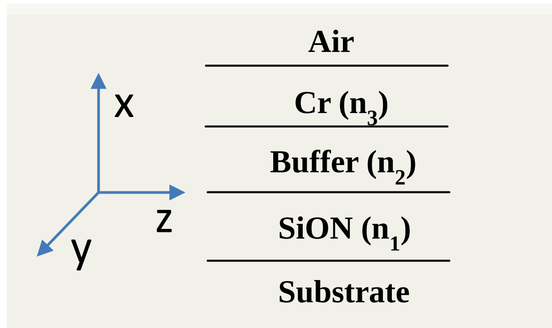

Fig. 2. Schematic cross section of four layer chromium clad waveguide with buffer layer. n_1 =1.546, n_2 = 1.52, n_3 = 3.19 – 2.26 j, n_s =1.54.

In the calculations, we considered $\lambda = 0.6328$ µm, SiON guide layer n_1 = 1.546, substrate layer index n_s = 1.540, cladding layer (Cr) index n_3 = 3.19 – 2.26 j and air cover index n_c = 1.0. We used SiON waveguide for its highly desirable features such as low insertion loss, wide range of refractive index tailoring and realization of compact devices [22]. Fig.1 shows the chromium clad waveguide structure without buffer layer. Fig.3 depicts the variations of TE and TM mode attenuation curves with the chromium thickness.

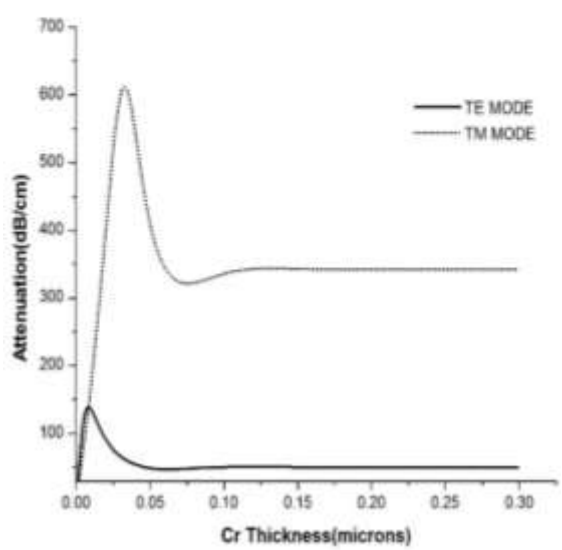

Fig. 3. TE and TM mode attenuation constant versus Cr film thickness.

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As the thickness of the chromium layer is increased mode attenuation starts increasing and reached at the peak at a particular thickness of metal layer for both polarization (TE/TM) respectively. It can be observed that there is a difference of mode attenuations between TE and TM modes. This difference is present due to coupling of the surface plasmon modes with guided modes. As the surface plasmon modes supported by metal clad waveguide structure interact only with TM guided modes supported by the waveguide layer, a mode coupling is obtained. Due to this coupling of SP modes which are transverse magnetic in nature with TM guided modes, almost all the energy of TM guided modes absorbed by the metal layer. Hence, there is a large loss available for TM guided modes. However, the corresponding maximum loss value for TE mode is quite low. As can be seen in Fig.3 the maximum value of TM mode attenuation is 611 dB/cm, which is present at 0.033 µm thickness of chromium layer and at the same thickness the corresponding attenuation for TE polarization is 61 dB/cm. This attenuation characteristic may lead to design a TE pass polarizer. But at these selected parameter (waveguide thickness, metal thickness and refractive indices) the proposed polarizer may not be very efficient. Its efficiency in terms of high extinction ratio and low insertion loss can be further improved. We propose that a polymer buffer layer can be used to increase the extinction ratio and to reduce the insertion loss.

4.1. Effect of Buffer Layer and TE Pass Polarizer

Chromium layer has been already used in various multilayer waveguide structures as a positive permittivity metal substrate and its mode attenuation characteristics have been observed [3]**.** But their characteristic has not been studied upto much extent with a role of cladding layer in waveguides. Buffer layer effects are also to be discussed in detail to design optical devices with this kind of structures [3]. Fig.2 shows the proposed structure with polymer buffer layer. Fig.4 and Fig.5 shows the attenuation characteristics of TE and TM mode polarizations respectively for the proposed buffered structure. It can be observed that due to introduction of polymer buffer layer the attenuation characteristics have drastically changed. Now, a large difference in attenuation value for TE and TM polarizations can be noticed. With the buffered structure, 100 nm thickness of chromium is used as an optimized value. Due to buffer layer a resonant

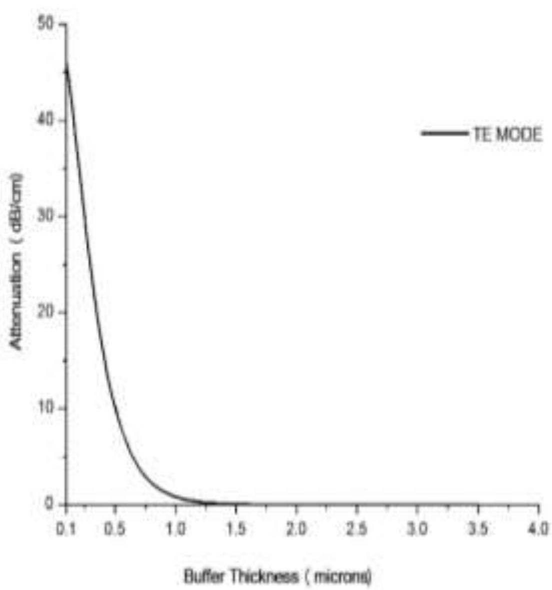

Fig. 4. Variation of TE mode attenuation as a function of buffer thickness at Cr thickness of 0.1 µm.

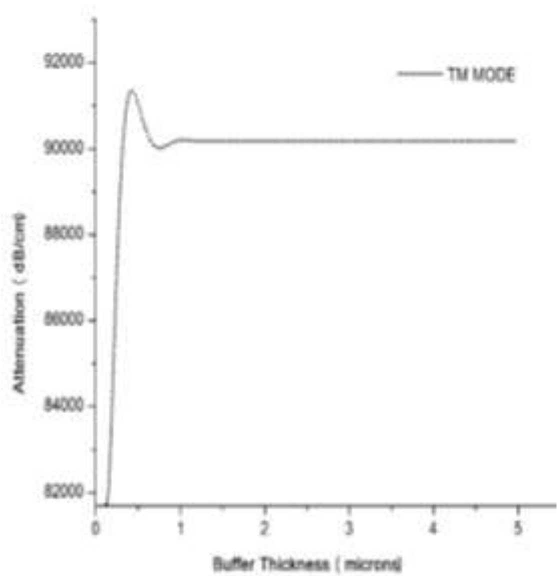

Fig. 5. Variation of TM mode attenuation as function of buffer thickness at Cr thickness of 0.1 µm.

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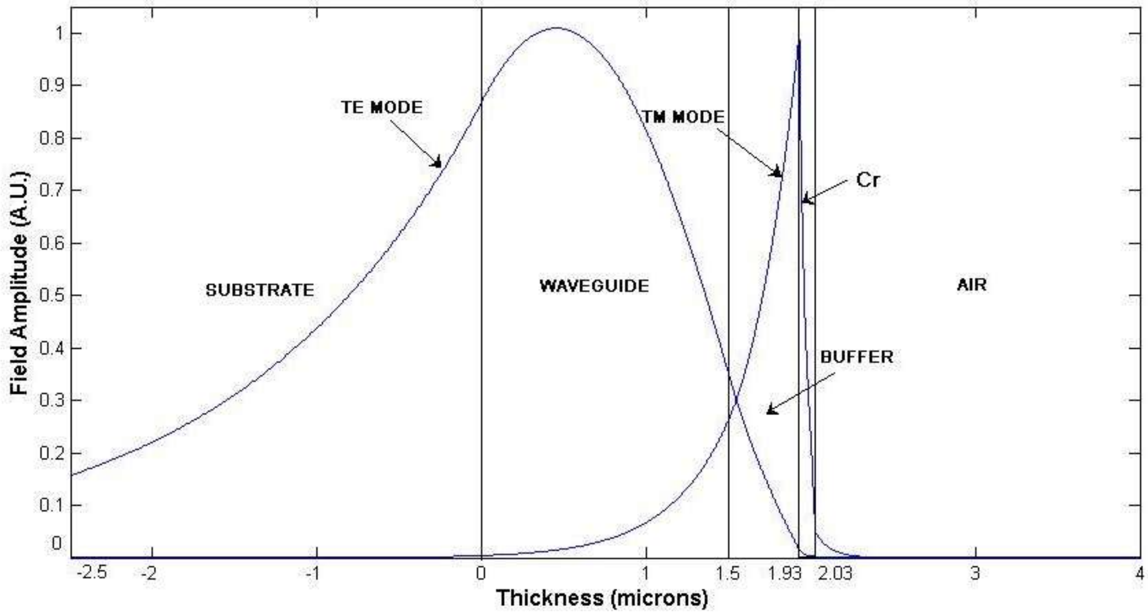

Fig. 6. TE and TM mode field distribution for TE pass polarizer. (Cr thickness= 0.1 µm. and buffer thickness =0.43µm).

coupling between guided TM modes and surface plasmon modes is achieved. In other words, an excellent phase matching take place between SP modes and TM guided modes and all the energy of guided TM modes is absorbed in the metal layer. As surface plasmon do not interact with guided TE modes, all the energy of the TE guided modes is confined within the guiding layer. Hence, there is no much attenuation exist for TE mode polarization and this property can be used to design a high extinction ratio, low insertion loss TE pass polarizer. For designing a TE pass polarizer an optimized thickness of buffer layer is chosen. At this optimized thickness (0.43 µm) the maximum attenuation for TM mode polarization is 91354 dB/cm and corresponding TE mode attenuation is 14 dB/cm. The value of the attenuation curves strongly suggest to design a high extinction ratio TE pass polarizer. Fig.6 shows the mode field profile, which also supports the design of TE pass polarizer. It can be observed that the field of TM mode is confined in the chromium thickness and TE mode field is confined within the waveguide layer. A TE pass polarizer with extinction ratio of 9134 dB and insertion loss of 1.4 dB can be designed for the length of 1mm. Mode field profile clearly indicate that propagation of the mode for TM polarization has the nature of surface plasmon mode.

5. CONCLUSION

We have theoretically studied the attenuation characteristics of chromium clad optical waveguide at the wavelength of 0.6328 µm. It is shown that optical waveguide clad with chromium exhibit high attenuation peak for TM polarization. This is due to the resonant coupling between surface plasmon modes supported by metal thickness and TM guided modes supported by guiding layer. The effect of polymer buffer layer is also observed. It is proposed that a polymer buffer layer between guiding layer and metal can largely change the attenuation characteristics of both (TE/TM) polarizations. We determined that a high extinction ratio, low insertion loss TE pass polarizer can be designed by suitably choosing the structural parameters and material indices.

APPENDIX-I

Transfer Matrix Method

Consider a non-magnetic multilayer structure as shown in Fig.1 and Fig.2. The z-axis is the direction of mode propagation. Every layer i is characterized

by its thickness and its complex refractive index. Maxwell's curl equations for source-free, time-harmonics fields in anisotropic media are:

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$$\nabla \times \overline{E} = -j\omega\mu_o \overline{H} \quad (1)$$

$$\nabla \times \overline{H} = j\omega\varepsilon_o\varepsilon_r \overline{E} \quad (2)$$

Where ε_o is the free space permittivity, ω is the angular frequency and ε_r is the relative permittivity. The field component E_x, E_z, H_y will vanishes for TE mode, whereas H_x, H_z, E_y will vanishes for TM mode. With these assumptions the wave equation for the i-th layer reduces to

$$\frac{d^2}{dx^2} F_{y,i}(x) - (\beta^2 - k_o^2 n_i^2) F_{y,i}(x) = 0, \quad x_i \le x \le x_{i+1} \quad (3)$$

Where $F_y = \begin{cases} E_y, & TE \\ H_y, & TM \end{cases}$,

$\beta = \beta_{re} + \beta_{im}$ is the complex propagation constant of the mode, $k_o = 2\pi / \lambda_o$ is the free space wave number. The layers have complex refractive indices $n = n_{re} + jn_{im}$, where the imaginary part is due to gain or loss. The effective index n_{eff} and the absorption coefficient α are given, respectively, by [1,22-23]

$$N_{eff} = \beta_{re} / k_o \quad (4)$$

$$\alpha = 2\beta_{im} \quad (5)$$

The general solution of the wave equation in each homogeneous layer (i) is well known

$$F_{y,i}(x) = A_i \exp(k_i(x - x_i)) + B_i \exp(-k(x - x_i)) \quad (6)$$

Where $k_i = \sqrt{\beta^2 - k_0^2 n_i^2}$, A_i and B_i are the complex field coefficient that vary from layer to layer, and x_i is the position of the interface between layer i and $i+1$. By imposing the continuity conditions of the field and its derivatives for each interface, it is easy to find [24-25]

$$\begin{bmatrix} A_{i+1} \\ B_{i+1} \end{bmatrix} = T_i \begin{bmatrix} A_i \\ B_i \end{bmatrix} \quad (7)$$

Where,

$$T_i = \frac{1}{2} \begin{bmatrix} \left(1 + \eta_i \frac{k_i}{k_{i+1}}\right) \exp(k_i d_i) & \left(1 - \eta_i \frac{k_i}{k_{i+1}}\right) \exp(-k_i d_i) \\ \left(1 - \eta_i \frac{k_i}{k_{i+1}}\right) \exp(k_i d_i) & \left(1 + \eta_i \frac{k_i}{k_{i+1}}\right) \exp(-k_i d_i) \end{bmatrix} \quad (8)$$

Where d_i is the $i-$th layer thickness and

$$\eta_i = \begin{cases} 1, & TE \\ n_{i+1}^2 / n_i^2 & TM \end{cases}$$

Field coefficients can be related in the cladding (A_c and B_c) with the coefficients in the substrate (A_s and B_s) as follows:

$$\begin{bmatrix} A_s \\ B_s \end{bmatrix} = T \begin{bmatrix} A_c \\ B_c \end{bmatrix} \quad (9)$$

Where $T = T_N ....T_2 T_1 T_c = \begin{bmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{bmatrix}$ and N is the total number of layers.

For the guiding modes, the fields should be evanescent in the cladding and the substrate layers, so $A_c = 0$ and $B_s = 0$ that results the characteristics equation [24].

$$t_{11}(\beta) = 0 \quad (10)$$

This equation is solved to find the complex propagation constants for both (TE/TM) polarizations.

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