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Analysis of Buried Rectangular Channel Dielectric Waveguide by Effective Index Method (EIM)

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***Abstract*— *One essential component structure in integrated optics is buried rectangular waveguide. This paper attempted to overview and analyzed the buried dielectric waveguide using effective index method. This method involved in replacing buried rectangular waveguide with slab waveguide. It is used to simplify a two dimensional waveguide to a one dimensional waveguide Furthermore, it is considered as a curtail technique to analysis the optical properties of this type of waveguide. For instance, field distribution, normalized model index and propagation constant have been analyzed and proposed. In addition, the effect of waveguide dimension on both propagation constant and effective index method was described. Moreover, the light propagation has been described in terms of propagation constant and and wavelength which is 1.55 µm.*

***Keywords*— *Effective Index Method, buried rectangular waveguides, optical waveguides.*

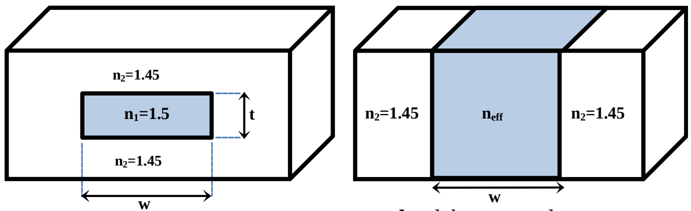
I. INTRODUCTION

In general, dielectric optical waveguide is a design for guiding light in spatial region that light propagates in [1-4]. Similar to the electronic circuit which its components need to be integrated, the optical systems components such as lenses, light sources detectors are need to be assembled. So in order to guide the light through these components, an optical waveguide can be used [4-6]. Dielectric optical waveguide has different structure. However, all the structures have the same property of increased refractive index [7]. In other words, a waveguide has a region of higher refractive index than the surrounding medium. As mentioned above, waveguide has different structure such as a planner and channel waveguides; also which can be divided into rib, strip, diffused and buried waveguides [8-12]. Optical waveguides are possible to fabricate in different techniques for instance, epitaxy or polishing methods, lithographic with thermal indiffusion and pulsed laser beams. Furthermore, choosing one of these methods depends on the aspects of the cost, losses, mode size and its impact on the material itself [13-16]. Nevertheless, waveguides have wide application for example, optical fiber communications, photonic, integrated circuit, optical data transmission, waveguide laser, mode cleaner, interferometers … etc. [17], [19].

In this work a type of buried rectangular channel dielectric waveguide is taken to be analysis. It is considered as an elementary structure in integrated optics. The calculation and the analysis of the waveguide are important to investigate the properties of the waveguide for example, the field distribution, propagation constant, penetration depth and effective refractive index. In this paper a refractive index method is used to analysis the buried waveguide.

II. METHODOLOGY

A buried rectangular channel dielectric waveguide in this work is two dimensional waveguide with refractive index of n1=1.5, surrounded by a medium of slightly lower refractive index n2=1.45. However, the aim of this design is to analysis the normalised modal index b for fundamental TE and TM mode as a function of normalised parameter V by using the effective index method. Recently this method has been used to analysis the rectangular waveguide. It is involved "replace a rectangular-core waveguide by an equivalent slab waveguide with an effective refractive index calculated from another slab waveguide" [2] as shown in figure (1). Moreover, the most important thing about this method is that it gives an accurate results and high efficiency calculation [14].



a- buried rectangular **b-** slab rectangular

Fig. 1. The reduction of a- buried rectangular waveguide to b- slab waveguide by EIM

This reduction will be done with using different mathematical modules associated with both the buried and slab waveguides. First of all, for TM modes, by varying the value of normalised thickness / frequency parameter V from (2.5 to 5.5), the values of w, and the new thickness of the slab waveguide were calculated by using the following equation:

$$V = w\sqrt{\left(k_1^2 - k_2^2\right)} \quad (1)$$

Additionally, the values of the Buried rectangular waveguide thickness t were calculated from the values of w by using the simple relation t= w/2. After the values of t were obtained, the effective index neff was calculated for each value of t for TE modes (vertical slab). The value of refractive index depends on the values of thickness t and the operation wavelength. For example if λ=1.55 µm and the t=0.8 then the n_{eff}= 1.466003.

We have n_{eff} values for middle region and n_2 = 1.45 for both side of the horizontal slab waveguide which remains

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unchanged. As a consequence, the values of propagation constant β were estimated for TM modes (horizontal slab) from the relation:

$$\beta = nK_o \quad (2)$$

where $K_o = 2\pi/\lambda$. Now, it can be easy to calculate the values of normalised modal index b by using the equation below:

$$b = \left(\beta^2 - k_2^2\right) / \left(k_{eff}^2 - k_2^2\right) \quad (3)$$

where $K_2 = 2\pi n_2 / \lambda$ and $K_{eff} = 2\pi n_{eff} / \lambda$ and again the wavelength used 1.55 µm. Nevertheless, the steps above were repeated for the TE modes.

III. RESULTS AND DISCUSSION

After using the methodology as mentioned early, all the parameters were calculated firstly for he buried waveguide and then for the slab waveguide. In appendix Table (1) shows some of the estimated values. It can be seen that the values of both refractive index of the cladding and the thickness w were remain the same during the calculations. Moreover, the refractive index of the core n1 was estimated into the effective one neff. However, for TE modes (vertical slab), both of the propagation constant and the normalized model were calculated and it can be seen they are increased as the thickness of the core increased. Similarly, for the TM modes (horizontal slab) both of the β and b were increased but the ratio was higher than that of the TE modes.

From figure (2) shows the model index parameter as a function of the normalized V, which were taken from (2.9-5.5). It is appear that the relation for both of the TE and TM fundamental mode is a linear relation. Moreover, it can be note that the TE mode (dash line) takes the higher values than the TM mode (solid line).

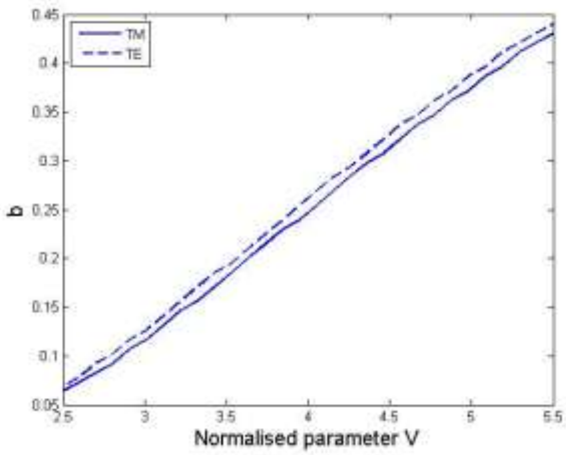

Fig. 2. The normalized modal index b as a function of V for fundamental TE and TM modes.

Because of the propagation constant β depends on the waveguide properties, structure and the wavelength used, it is possible to describe light propagation in terms of a normalized propagation constant or wavelength. Figure (3) demonstrates that performance with different values of wavelengths.

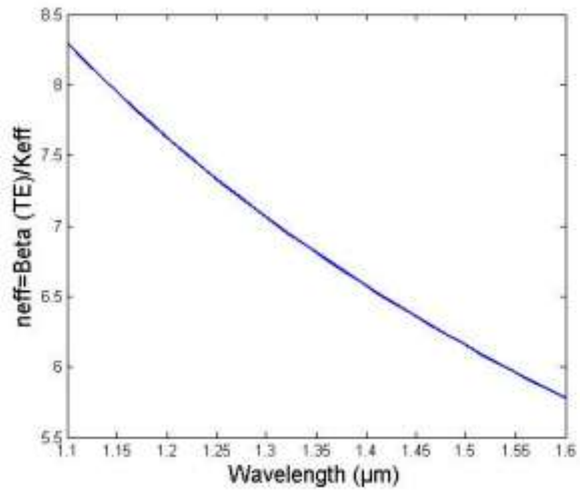

Fig. 3. effective refractive index as a function of wavelength for fundamental TE mode

Moreover, figure (4) illustrates the relation between the estimated thickness of the core and the new effective index for the TE mode. As the thickness of the core increase, the effective index for TE mode will increase as well. In addition, the value of propagation constant β also increases and it makes the propagation light within the structure of waveguide completely propagates into the core, hence, propagation loss will minimize. This behavior is similar to the relation when the TM mode is applied.

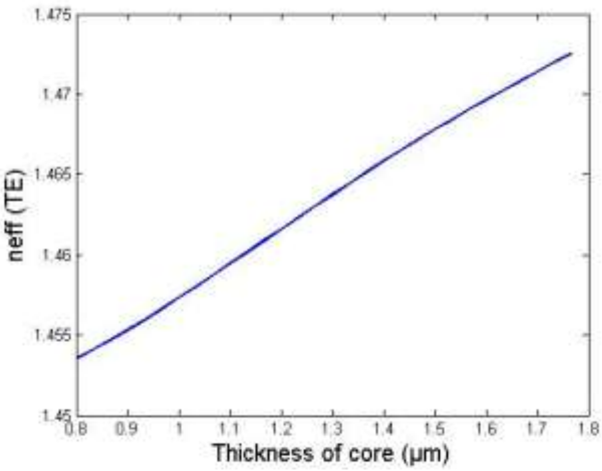

Fig. 4. effective refractive index as a function of thickness for fundamental TE mode

In spite of this method is a scalar method, it still allows to take the polarization of the higher mode into account. If we have two dimensional waveguide, the electric field vector of the mode is pointing along the y-axis and the equation should be solved for TM polarization. To estimate the TM eigen mode of the two dimensional waveguide, the appropriate boundary conditions must be applied. However, figures (5 and 6) show the TE and TM fundamental and higher order modes for.

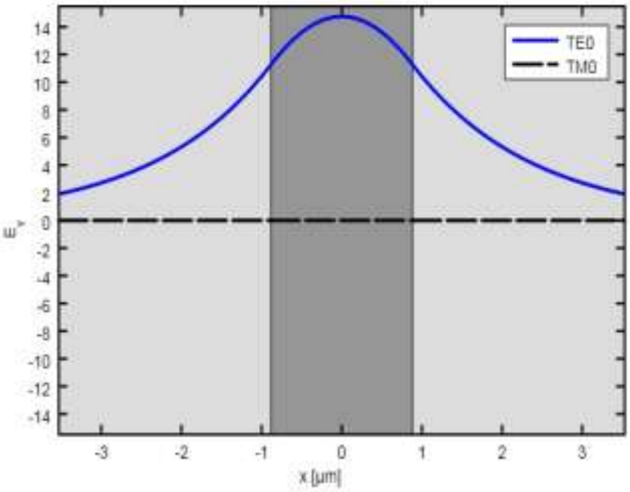

Fig. 5. the field distribution of the TE and TM fundamental modes for the wavelength 1.55 µm.

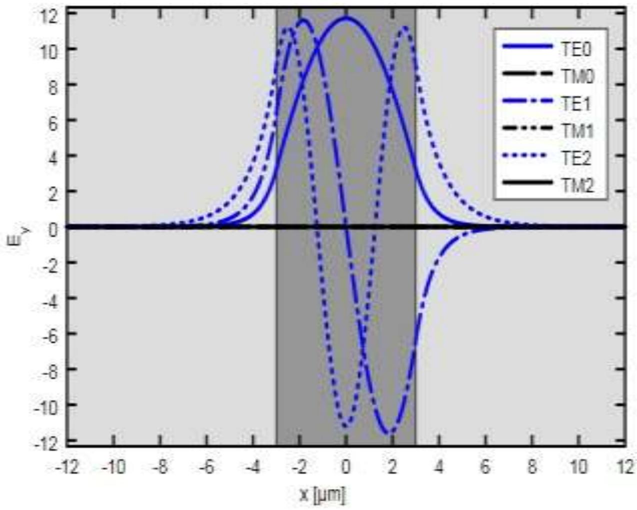

Fig. 6. the field distribution of the TE and TM higher order modes for the wavelength 1.55 µm.

IV. Conclusion

The effective index EI method has been shown in this work. After the calculation of the effective refractive index for each horizontal section for both fundamental TE and TM modes and after the estimation of new effective refractive index for the new slab waveguide, the relation between the normalized form of the normalized effective index b and the dimensionless parameter V was found. The effective index method is not only used to calculate two dimensional mode profiles but also it is used to simplify a two dimensional waveguide to a one dimensional waveguide which can be considered as a new way for further analysis methods such as the mode expansion method or the beam propagation method. Nevertheless, the EI method could be regarded as an accurate method at specific conditions such as the waveguide should has a ratio far from unity and near the cut-off. Furthermore, the errors might be occurring by using the effective index method. This is the case in the boundary of vertical dielectric interfaces. Generally, the effective index method will overestimate the propagation constants β of the waveguide modes.

Appendix

Table (1) shows some of points taken from the results

Buried Waveguide						Slab Waveguide				TE			TM		
V	n_2	n_1	n_2	t	w	n_2	n_{eff}	n_2	w	β	n_{eff}	b	β	n_{eff}	b
2.9	1.45	1.5	1.45	0.93	1.87	1.45	1.46616	1.45	1.87	5.902	1.45600	0.1077	5.916	1.45388	0.1175
3.4	1.45	1.5	1.45	1.10	2.20	1.45	1.46955	1.45	2.20	5.916	1.45946	0.1711	5.93	1.45931	0.1857
3.9	1.45	1.5	1.45	1.26	2.53	1.45	1.47261	1.45	2.53	5.931	1.46305	0.2395	5.944	1.46288	0.2542
4.4	1.45	1.5	1.45	1.43	2.86	1.45	1.47532	1.45	2.86	5.945	1.46649	0.3080	5.957	1.46631	0.3227
4.9	1.45	1.5	1.45	1.62	3.20	1.45	1.47771	1.45	3.20	5.958	1.46966	0.3718	5.968	1.46949	0.3866
5.5	1.45	1.5	1.45	1.76	3.53	1.45	1.47981	1.45	3.53	5.969	1.47251	0.4309	5.916	1.47235	0.4407

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