Characterization of A Directional Coupler Waveguides Five Layers based on A Variation of The Electric Field in Two Border Area

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Abstract—***Will be Analized the Effective Refractive Indeks with Electric Field Variations In Two Border Areas Layers To Design Vaweguide five layers, where the dispersion relation equation is getting through from the field equations in waveguides five layers. Wave guide five layer nonlinear structure is one of wave guide structure usually used model on design medium laser MQM and system path on device integrated optic. The composition consist of five layer usually used was L-NL-L-NL-L when L and LN as linear and non linear respectively. Will specifically examined the role of the Jacobian elliptic function Cn and Sn in the formulation of the dispersion relation to determine the type of guided modes in a nonlinear waveguide structure of five layers, which are based on the effective refractive index relation to the variation of the electric field at the boundary of two media waveguide region. There are 3 types of guided modes, namely mode symmetry, asymmetry, and antisimentri. The greater the effective refractive index is given, allowing more conditions for the value of the electric field . The dispersion equation shows a very flexible and general expression because it can be applied to the waveguides multilayer having symmetric or asymmetric structures.***

Keywords— Nonlinear waveguides, Jacobi elliptic, refractive index.

I. INTRODUCTION

Research on the stability of the optical scattering begins since 1970[1],[2]. Since then many theories have sprung up to reveal this phenomenon. Mathematical model most often used to study this phenomenon is the Helmholtz Nonlinear equation, especially to study the behavior of the optical wave modes in nonlinear wave guides. This paper reported the results of dispersion relation formulation of nonlinear slab waveguides five (5) layers, whose composition are L-NL-NL-L-L, with L and LN respectively represent the linear and nonlinear material. If the electric field in the waveguide 5 layers linear represented of sinusoidal function, electric field of solutions Helmholtz equation for nonlinear wave guides is Jacobi elliptic functions. from the dispersion relation equation being formed, then to be used to analyzed the relationship effective refractive index of the wave modes of variation of the electric field on the border of the two regions waveguides.

II. METHOD

Formulation of the electric field and magnetic field in nonlinear optical waveguides still refer to the Maxwell equations

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \tag{1}$$

$$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t} \tag{2}$$

$$\nabla . \vec{D} = \rho \tag{3}$$

$$\nabla . \vec{D} = 0 \tag{4}$$

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with $\vec{E}, \vec{D}, \vec{H}, \vec{B}, \vec{J}$, ρ are the electric field, electric shift, magnetic field, magnetic induction, density, and the current density. The Effect of symptoms to-optical nonlinear materials indicated by changes in wave form, response in wave pulse or rays [3]. If nonlinear optical materials used are similar to type-Kerr, so the inside light will propagation like symptoms Kerr, and refractive index values satisfy following relations Kerr refractive index [4], [5]:

$$n_i^{\,2} = n_{0i}^2 + \alpha_i \left|\vec{E_i}\right|^2 \tag{5}$$

As shown in Figure 1, the structure of nonlinear waveguides five-layer consist L-NL-L-NL-L resembles as stack waveguides inserted between clading materials and substrates [7].
Stack waveguides composed on a thin layer of thick linear $2a$, which inserted between the two layers of the thin film which acts as a nonlinear waveguides, each thick d_{nl1} dan d_{nl2}. Refractive index waveguide I $(a < x < b)$ is $n_1^2 = \bar{n}_1^2 + \alpha_1 \left|\vec{E}_1\right|^2$, while the refractive index of the waveguide II $(a < x < b)$ is $n_2^2 = \bar{n}_2^2 + \alpha_2 \left|\vec{E}_2\right|^2$.
The linear refractive index of the film, cover, and substrate respectively n_f, n_c, n_s.

This paper studied the effect of nonlinear optical material focused only on $\alpha_i > 0$ and the effect of absorption on the entire medium negligible. Optical wave propagation modes which are reviewed only the TE mode (*Tranverse-Electric*), ie the electric field component perpendicular to the direction of plane coming.

According to the theory of optical wave propagation modes [7][8] fields TE mode propagation in a slab waveguide structure in Figure 1 are.

$$E_y; \qquad H_x = -\frac{\beta}{\omega\mu} E_y; \qquad H_z = \frac{1}{\omega\mu}\frac{dE_y}{dx} \tag{6}$$

The third field equations satisfy the rules of maxwell

$$\frac{dH_z}{dx} + \beta H_x = -\omega\varepsilon E_y \quad (7)$$

Equations (6) substituted to (7), and after the include relationship $\varepsilon = \varepsilon_0 n^2(x)$ found

$$\frac{d^2 E_{yi}}{dx^2} + (k_0 n_i^2(x) - \beta^2) E_{yi} = 0 \quad (8)$$

and $n_i^2 = \bar{n}_i^2 + \alpha_i |E_i|^2$ applies to the refractive index in the layer 2 and 3, while for layers 1, 2, 3, $\alpha_i = 0$ so equation (8) can be written

$$\frac{d^2 E_i(x)}{dx^2} + k_0^2 \left[(\bar{n}_i^2 - N^2 + \alpha_i |E_i(x)|^2 \right] E_i(x) = 0 \quad (9)$$

Equation (9) is an equation of the electric field in the nonlinear medium satisfy nonlinear Helmholtz equation, [Jong-Sool,1996]. When the integral is given twice then get

$$\frac{1}{k_0^2}\left(\frac{dE_i(x)}{dx}\right)^2 + \left[(\bar{n}_i^2 - N^2) + \frac{1}{2}\alpha_i E_i^2(x) \right] E_i^2(x) = C_{nli} \quad (10)$$

on the initial conditions

$$0 + \left[(\bar{n}_i^2 - N^2) + \frac{1}{2}\alpha_i E_0^2(x) \right] E_0^2(x) = C_{nli} \quad (11)$$

When $N = \sqrt{b(n_f^2 - n_s^2) + n_s^2}$ obtained

$$C_{nli} = \left(n_i^2 - b_N (\bar{n}_f^2 - n_s^2) + n_s^2 \right) E_{0i}^2 + \frac{1}{2}\alpha_i E_{0i}^4 \quad (12)$$

At the time $x = b$; $x = -c$ then $b_N = 0$, eq (12) substituted into eq (10), so the above equation becomes

$$\frac{1}{k_0^2}\left(\frac{dE_i(x)}{dx}\right)^2 + \left[(\bar{n}_i^2 - N^2) + \frac{1}{2}\alpha_i E_i^2(x) \right] E_i^2(x) = \left(n_i^2 - \bar{n}_{c,s}^2 \right) E_{0i}^2 + \frac{1}{2}\alpha_i E_{0i}^4 \quad (13)$$

E_{0i} is the electric field at the boundary in $x = b$ and in $x = -c$. The electric field of nonlinear film can be written as a Jacobi elliptic function [4].

$$E_{nli}(x) = p_i cn[k_0 q_i (x + x_{0i}) | m_i] \quad (14)$$

with x_{0i} is integral constants that indicate the location of the maximum field.

$$p_i = q_i \sqrt{2m_i / \alpha_i} \quad q_i^2 = (\bar{n}_i^2 - N^2)(1/1 - 2m_i);$$

$$m_i = (|\Gamma_i| - (\bar{n}_i^2 - N^2))/2|\Gamma_i|;$$

$$\Gamma_i^2 = (\bar{n}_i^2 - N^2)^2 + 2\alpha_i C_{nli} \quad (15)$$

For $n_f < N$.

By applying the term $x = -a$. with the same treatment for $n_f < N$ so we can obtained the dispertion equation for $n_f < N$ by composing form $\tan\theta$ become $\tanh$.

The general equation dispersion relation can be written as

$$\tan\theta = \frac{U_1(N, E_{01}) - U_2(N, E_{02})}{(-1)^h + U_1(N, E_{01}).U_2(N, E_{02})}$$

With

$$U_1(N, E_{01}) = \frac{q_1 sn(u_1 | m_1) dn(u_1 | m_1)}{\gamma_f cn(u_1 | m_1)}$$

$$U_2(N, E_{02}) = \frac{q_2 sn(u_2 | m_2) dn(u_2 | m_2)}{\gamma_f cn(u_2 | m_2)}$$

$$u_1 = k_0 q_1 (a - b + x_{01}) \quad u_2 = k_0 q_2 (-a + c - x_{02}).$$

III. Result and Discussion

The relationship equation electric field above the boundary distinguished $n_f > N$ and $n_f < N$. Dispersion relation equation formulation is mainly based on the application of an electric field continuity condition (E_y) and the derivatives of (dE_y / dx). At each border two different mediums.

The parameters used in this analysis are ($\bar{n}_1 = \bar{n}_2$ =1,551), ($n_c = n_s$=1,55),(n_f =1,552), $\alpha_1 = \alpha_2$=6,38x10^{22}m^2/V^2 (MBBA liquid crystal), λ =0,515 μm, a =0,6 μm, ($d_{nl1} = d_{nl2}$=2,0 μm). Graph of field intensity E_{01}^2 dan E_{02}^2 analytically with parameter three input of effective refractive index (N) shown by Figure 2. E_{01}^2 is the intensity of the electric field at the boundary between the cover with nonlinear layer films 1, E_{02}^2 is the intensity of the electric field at the boundary between the substrat with nonlinear layer films 2. demonstrated using MATLAB program.

The graph shows that for values $E_{02}^2 > 0$ curve shows the three sections is positive, so it can be predicted that the nonlinear waveguide structure of five layers have three types of modes. With reference to the graphs produced by Picture 2, it can also determine the types of specifications guided wave modes based on the relationship of each mode effective refractive index of the variation wave electric field ($E_{01}^2 = E_{02}^2$) in border areas waveguides. Value E_{02}^2 obtained by inserting the value of the effective refractive index (N) from 1.5501 until 1.6300 with scale 0.0001, and also inserting E_{01}^2 from 1 (MV^2) until 500 (MV^2).

Do iterations to get the right value $E_{01}^2 = E_{02}^2$, so we get the graph plots the relationship between the effective refractive index with $E_{02}^2 = E_{01}^2$ as shown in Figure 3.

In Figure 4, the input power is given by 0.1 mwatt, can be seen through the images on the provision of small power input, the effect of Kerr-like nonlinearity of materials in nonlinear waveguide both sides are still not visible, meaning that it can be said is still linear. In this case still dominated by long coupling waveguide directional coupler, so the length of the coupling laser intensity coupled into the waveguide in the middle. At the time of the input power is enlarged, the refractive index in the waveguide 2 and 4 go up. Began to appear in the image (5). For the provision of power input 5 Mwatt above, the effect of self-focusing Kerr-like nonlinearity add path propagation in the waveguide 2 and 4, consequently lowering the output intensity in the waveguide 3, as shown in figure (6, 7, 8, 9, 10) The higher the input power to 20mWatt, the whole power in total in propagasikan into the waveguide 2 and 4.

The phenomenon of the cycle intensity minimum-maximum conditions, when the input power of more than 15mW, assumed as a directional coupler with a gap width equal to the width of the waveguide 2 and 4, which means the waveguide 3 is considered only as cladding only.

IV. Conclusion

As usual in nonlinear waveguides in general some scale as effective refractive index, and the power transfer coupling effect is strongly influenced by the input field.
Non Linear waveguides five layers have three types of modes, ie modes of symetry, asymetri and antisimetry,

Symmetry modes have effective refractive index value is greater than the mode symmetry and antisimetri on condition $n_f > N$ and reverse modes of symmetry refractive index is smaller when compared with other modes of asymmetry and antisimetri on condition.
The greater the value of the effective refractive index is given it will be more much conditions that allow for the field intensity.

Kerr-like nonlinearity effects in nonlinear waveguide five layers start seemingly on providing input power 5mWatt.

The dispersion relation equation in waveguide formed by the electric field equation relationships in border 2 and 4 layers of thin nonlinear films, and The dispersion equation in five layers waveguide shows a very flexible and general expression because it can be applied to the waveguides multilayer having symmetric or asymmetric structures.

References

[1]. T. Bischofberger and Y. R. Shen,(1979) Theoretical and experimental study of the dynamic behavior of a nonlinear Fabry-Perot interferrometer, Phys. Rev. A19,p.1169.

[2]. H.M. Gibbs, S.L. McCall and T.N.C. Venkatesan, (1976), Differential Gain and Bistability Using a Sodium-Filled Fabry-Perot Interferometer, Phys. Rev. Lett. 36, p.1135.

[3]. N.N. Akhmediev and A. Ankiewicz, (1997)Solitons: Nonlinear pulses and beams,(Chap man & Hall, London).

[4]. A.D.Boardman and P.Egan, (1985)"S-polarized Waves In a Thin Dielectrik Film Asymmetrically Bounded by Optically Nonlinear Media" IEEEJ, Quantum Electron, pp 1701-1713.

[5]. Jong-Sool Jeong,(1996) Seok Ho Song, A Novel Generalized Nonlinear Dispersi Equation for Five-Layer Waveguides With Kerr-Like Nonlinearity, Seol, Korea.

[6]. Rohedi, A.Y.,dkk., August 2003, Analytical Formulation of Normal Modes in Symmetrical Directional-coupler, International Symposium of Modern Optics and Its Applications (ISMOA) Department of Physics ITB, Bandung-Indonesia.

[7]. Rohedi, A.Y, Yudoyono G, Sawitri, Sekartejo (2007), Simplified Calculation of Guided Nonlinear Boundary-Wave Parameter Using Optimization Procedur, Solo-Indonesia.

[8]. J. Danckaert, K. Fobelets, I. Veretennicoff, G. Vitrant and R. Reinisch,(1991) Dispersive optical bistability in stratified structures, Phys. Rev. B44, p. 8214.

[9]. T.B. Benjamin and J.F. Feir,(1996) The disintegration of wave trains on deep water, J.Fluid Mech. 27, p. 417.

[10]. T. Tamir, (1990), Integrated Optics, Springer – Verlag Berlin Hidelberg New York.

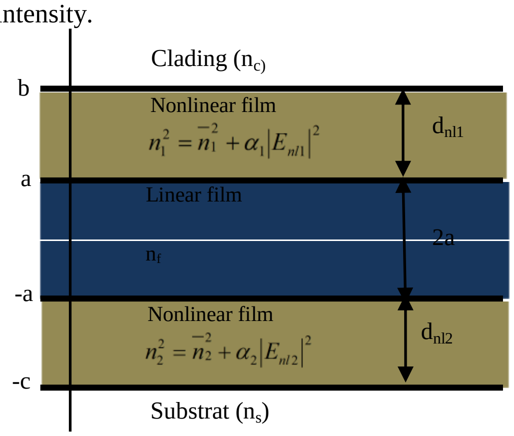

Figure 1. Scheme Five Layer Waveguides Nonlinear

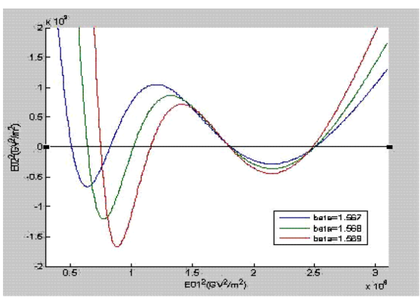

Figure 2. The relationship between field intensity E_{01}^2 and E_{02}^2

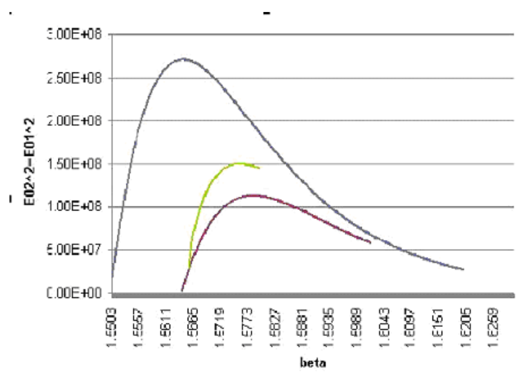

Figure 3. The relationship between the effective refractive index with field intensity $E_{01}^2 = E_{02}^2$

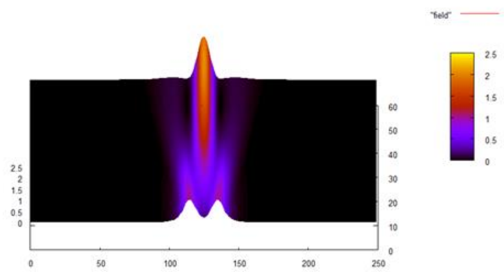

Figure 4. Field distribution pattern with the power input on the nonlinear layer film (0,1mWatt)

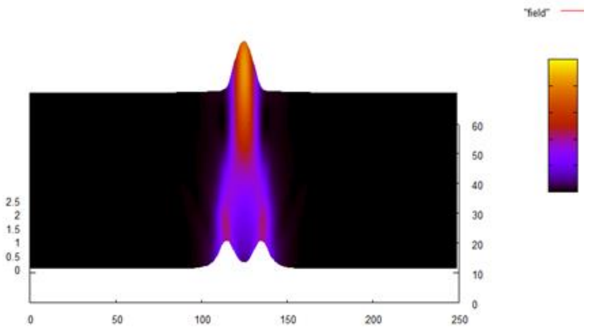

Figure 5. Field distribution pattern with the power input on the nonlinear layer film (5mWatt)

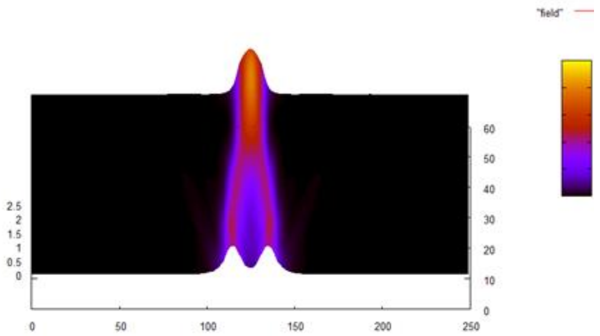

Figure 6. Field distribution pattern with the power input on the nonlinear layer film (7mWatt)

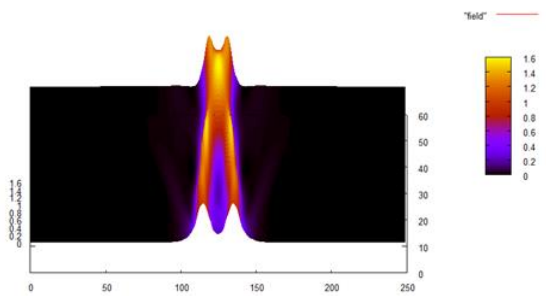

Figure 7. Field distribution pattern with the power input on the nonlinear layer film (10mWatt)

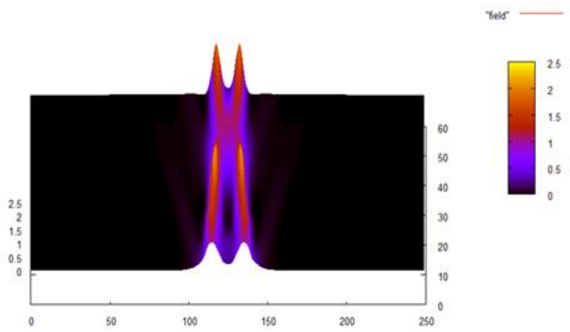

Figure 8. Field distribution pattern with the power input on the nonlinear layer film (13mWatt)

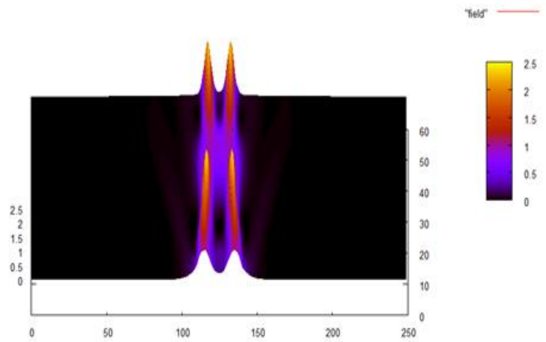

Figure 9. Field distribution pattern with the power input on the nonlinear layer film (15mWatt)

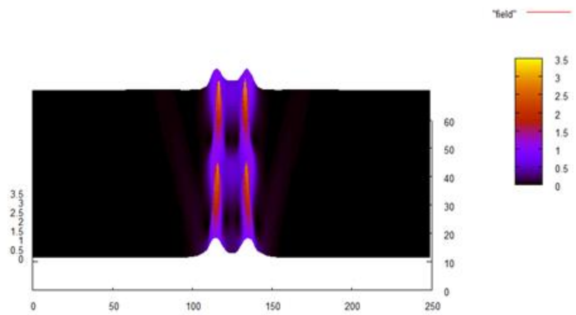

Figure 10. Field distribution pattern with the power input on the nonlinear layer film (20mWatt)