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AN EFFICIENT ANALYSIS FOR ABSORPTION AND GAIN COEFFICIENTS IN 'SINGLE STEP-INDEX WAVEGUIDE'S BY USING THE ALPHA METHOD

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ABSTRACT

In this study, some design parameters such as normalized frequency and especially normalized propagation constant have been obtained, depending on some parameters which are functions of energy eigenvalues of the carriers such as electrons and holes confined in a single step-index waveguide laser (SSIWGL) or single step-index waveguide (SSIWG). Some optical expressions about the optical power and probability quantities for the active region and cladding layers of the SSIWG or SSIWGL have been investigated. Investigations have been undertaken in terms of these parameters and also individually the optical even and odd electric field waves with the lowest-modes were theoretically computed. Especially absorption coefficients and loss coefficients addition to some important quantities of the single step-index waveguide lasers for the even and odd electric field waves are evaluated.

Key Words : *Normalized frequency, Normalized propagation constant, Probability, Confinement factor, Gain, Absorption coefficient, Loss.*

ALFA METODU KULLANILARAK 'BASAMAK KIRILMA İNDİSLİ TEKLİ DALGA KILAVUZLARI'NDA SOĞURMA VE KAZANÇ KATSAYILARINA İLİŞKİN KULLANIŞLI BİR ANALİZ

ÖZET

Bu çalışmada, adım kırılma indisli tekli dalga kılavuzlu lazerde veya adım kırılma indisli tekli dalga kılavuzunda hapsedilmiş elektron ve delik gibi taşıyıcılara ait enerji özdeğerlerinin fonksiyonları olan bazı parametrelere bağlı normalize frekans ve özellikle normalize yayılım sabiti gibi tasarım parametreleri elde edilmiştir. Adım kırılma indisli tekli dalga kılavuzunun veya adım kırılma indisli tekli dalga kılavuzlu lazerin aktif ve gömlek bölgeleri için optik güç ve olasılık nicelikleri ile ilgili bazı optik ifadeler, bu parametreler cinsinden incelenmiştir. Araştırmalar bu parametreler cinsinden yapılmıştır ve de teorik olarak en düşük çift ve tek modlu optik elektrik alan dalgaları için ayrı ayrı hesaplanmıştır. Çift ve tek elektrik alan dalgaları için, adım kırılma indisli tekli dalga kılavuzlu lazerlerde bazı önemli büyüklüklere ilave olarak özellikle soğurma ve kayıp katsayıları değerlendirilmiştir.

Anahtar Kelimeler : *Normalize frekans, Normalize yayılım sabiti, Olasılık, Hapsedicilik faktörü, Kazanç, Soğurma katsayısı, Kayıp.*

1. INTRODUCTION

To understand basic principles that govern the operations of the step-index waveguide lasers, we must have a basic comprehension of simple waveguide problem. The step-index waveguide lasers, for example, consist of 20-30 atomic layers (Verdeyen, 1989) and have been increasingly used to read the information stored on the compact disk. A waveguide or waveguide laser has simply three basic regions, as shown, schematically, in Figure 1.

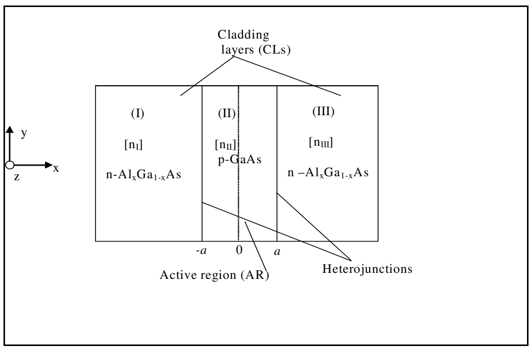

Figure 1. Regions of an ASSIWG or an ASSIWGL.

The step-index waveguide lasers produce light thanks to the unique atomic geometry of the layered crystals. The regions I and III in the waveguide are called cladding layers (CLs) which are high-bandgap layers and the region II is also called active region (AR) which is low-bandgap layer as shown in Figure 1. The CLs constitute two barriers which are erected by energy (Chow and Koch, 1999).The barriers of energy confine the carriers such as electrons and holes with photons in the AR. To confine most of carriers and photons between two CLs, the waveguide is realized by the bandgap engineering. If the width 2*a* of the AR is comparable to the characteristic length such as Broglie wavelength, then the quantum size effect (QSE) occurs (Chow and Koch, 1999).

Heterostructure constructions are formed from the multiple heterojunctions. If the AR with the thin layer is used as a narrower-band material, then it is obtained a double-heterojunction structure, as depicted in Figure-1 which shows the regions of asymmetric single step-index waveguide (ASSIWG) or asymmetric single step-index waveguide laser (ASSIWGL). The regions can be formed from dissimilar materials, such as p-GaAs (p-type Gallium Arsenide) and n-$Al_xGa_{1-x}As$ (n-type Aluminum Gallium Arsenide), with x being the fraction of aluminum being replaced by gallium in the GaAs material.

The semiconductor materials GaAs and AlAs (Aluminum Arsenide) have almost identical lattice constants (Verdeyen, 1989). The notations n_I, n_{II} and n_{III} in Figure-1 are indices of the regions. The usual relationship between the indices in the three regions is $n_{II}>n_I>n_{III}$. For other material compositions of the AR and the CLs, $In_{1-x}Ga_xAs_y P_{1-y}$ (Indium-Gallium-Arsenide-Phosphate) and InP (Indium-Phosphate) can be used, with x and y being the fractions of gallium and arsenide being replaced by indium and phosphate in the InP material respectively (Carroll et al., 1998).

The SSIWG or SSIWGL is a key element for some semiconductor quantum devices. For example, if the waveguide structure repeats itself in a periodic manner, it is known as a multiple quantum well, such as super lattices and quantum cascade lasers whose operation is based on resonant tunneling and the population inversion between subbands. The population inversion can be achieved by using resonant tunneling (Harrison, 2000). Inter subband energy difference and consequently the emission wavelength can be tuned by changing the well and barrier parameters.

There is no any expression in academic works about the absorption coefficients or the gain coefficients which are in terms of the normalized propagation constant (NPC) for even and odd electric field waves in the waveguides (WGs). The ASSIWG in terms of the normalized propagation constant (NPC) and its importance is firstly studied and then some new expressions about the absorption, the loss and the gain coefficients in terms of the NPC in the SSIWG or SSIWGL are obtained for both even and odd electric field waves. The NPC is an important structural parameter and is given by $\alpha=(n_{ef}^2-n_{III}^2)/(n_{II}^2-n_{III}^2)$ for the SSIWG or SSIWGL. Here n_{ef} is effective index.

2. PRELIMINARIES

Electrons or holes fall into the ARs of the waveguides. They are within the same layer of the material of the waveguides. Therefore, both types of charge carriers are localized in the same region of the space in which fast recombination occurs. One-dimensional potential can be generally considered as some of the standard assumptions. But generally, the electric field wave is used in the electrical engineering, instead of the potential. Therefore, to constitute certain confined (bound) states for electrons in the conduction band and holes in the valance band of the AR material of the waveguides, wave functions such as electric field wave can be employed to describe these carriers, since the electric field wave is a special potential per unit length (Verdeyen, 1989).

The confined (bound) states are the states where the carriers are confined in the AR which is highly deep well. These states for carriers in the AR of the SSIWG can be described by the quantized even and odd electric field waves as follows;

$$E_{yII} = A\cos\alpha_{II}x = A\cos\frac{n\pi x}{2a},\ n=1, 3, 5,...,(\text{even}) \quad (1)$$

$$e_{yII} = B\sin\alpha_{II}x = B\sin\frac{n\pi x}{2a},\ n=2, 4, 6,...,(\text{odd}) \quad (2)$$

Eqs.(1) and (2) promptly verify the Schrödinger wave equation* (Pozar, 1998). The particle confining in one-dimensional electric field wave E_y, weather it may be an electron or a hole, can move in a plane layer. The field, which describes the particle (electron or hole), becomes even field E_{yII} as a cosine term or becomes odd field e_{yII} as a sine term. While Schrödinger's equation gives a solution along the axis x, the one-dimensional electric field wave (a special potential wave per unit length) have the energy eigenvalues (EEVs) $E_x=E_n$, n=1, 2, 3,... .

E_{yII} or e_{yII} is an electric wave function, representing the carrier of interest. The amplitudes A an B in Eqs.(1) and (2) can be given expressed as;

$$A = \sqrt{\frac{2\alpha_{II}}{2\zeta + \sin 2\zeta}} \quad (3)$$

$$B = \sqrt{\frac{2\alpha'_{II}}{2\zeta' - \sin 2\zeta'}} \quad (4)$$

which give the probabilities of the AR being unity for both even and odd fields, respectively. The prime shown on the parameters in Eq.(4) symbolize odd field. In the SSIWG with infinitely deep well, the energy eigenvalues (EEVs) E_n for different quantum states (Schiff, 1982) are given by

$$E_n = n^2\pi^2\hbar^2/8m^* a^2,\ n=1, 2, 3, ... \quad (5)$$

where $\hbar$ and m^* are normalized Planck constant as $\hbar = h/2\pi$ and effective mass for a carrier, respectively. For the SSIWG having finitely depth V_o, EEVs E_ν (Gasiorowicz, 1974; Schiff, 1982; Harrison, 2000) are given by

$$E_\nu = V_o - E_n = \frac{\nu^2\hbar^2\pi^2}{8m^* a^2},\ \nu,\ n=1, 2, 3, ... \ . \quad (6)$$

The integers ν and n are mode numbers about the electric field wave. Therefore, the energy eigenvalue (EEV) of a carrier depends on the mode number. In Eq.(6), V_o in the conduction band is a barrier potential which is determined by the construction of the semiconductor material used (Pozar, 1998; Chow and Koch, 1999) and characterizes the depth of the SSIWG. The barrier potential can be also designed by V_c in the valance band as edge potential energy. That is, in any finitely deep SSIWG, the conduction or valance band has appearance of Figure 2b, with the potential energy V(x), representing the discontinuities in the conduction and valance band edges between the different materials. That is, the discontinuity in the conduction (or valance) band can be represented by the constant potential term V_o (or V_v). Here, V_v is the valance band edge potential energy. Hereafter, we shall take the potential barrier V_o into account in the conduction band.

As seen in Eq.(1) or Eq.(2) that $\alpha_{II} = n\pi/2a$. Hence, using this relation in Eq.(5) and Eq.(6), it can really be evaluated (Gasiorowicz, 1974) that

$$\alpha_{II} = \frac{1}{\hbar}\sqrt{2m^*(V_o - E_v)}\ . \quad (7)$$

Thus, in the regions I and III of the SSIWG evanescent fields, which correspond to the even and odd fields in the AR (in region II) (Temiz, 2001; 2002), respectively are given by;

$$E_{yI} = A_I \exp[\alpha_I(x + a)], \quad (8)$$

$$E_{yIII} = A_{III}\exp[-\alpha_{III}(x - a)],$$

$$A_I = A_{III} = A_{I,III} = A\cos\zeta \quad (9)$$

and

*Essentially, each of Eqs.(1) and (2) is phasor. For example $E_{yII}(x,t)$ can be written as $E_{yII}(x,t) = A\cos\alpha_{II}x e^{j(\omega t + z\beta)}$ in the complex form. That is:

$E_{yII}(x,t) = B[\cos(\alpha_{II}x + \omega t + z\beta) + j\sin(\alpha_{II}x + \omega t + z\beta) + \cos[\alpha_{II}x - (\omega t + z\beta)] - j\sin[\alpha_{II}x - (\omega t + z\beta)]$

$\mathrm{Re}\,E_{yII}(x,t) = B[\cos[\alpha_{II}x + (\omega t + z\beta)] + \cos[\alpha_{II}x - (\omega t + z\beta)]$, $A/2 = B$.

$$e_{yI} = B_I \exp\left[\alpha_I (x + a)\right], \tag{10}$$

$$e_{yIII} = B_{III} \exp\left[-\alpha_{III}(x - a)\right],\ B_I = B_{III} = B_{I,III} = B \sin\zeta \tag{11}$$

The parameter ζ and the propagation constants α_I, α_{II} and α_{III} (Gasiorowicz, 1974; Temiz, 2002) in the above equations are given by

$$\zeta = \alpha_{II} a \tag{12}$$

and

$$\alpha_I^{\ 2} = \beta_z^{\ 2} - \left(\frac{\omega n_I}{c}\right)^2 = \beta_z^{\ 2} - k_I^{\ 2}, \tag{13}$$

$$\alpha_{II}^{\ 2} = \left(\frac{\omega n_{II}}{c}\right)^2 - \beta_z^{\ 2} = k_{II}^{\ 2} - \beta_z^{\ 2}, \tag{14}$$

$$\alpha_{III}^{\ 2} = \beta_z^{\ 2} - \left(\frac{\omega n_{III}}{c}\right)^2 = \beta_z^{\ 2} - k_{III}^{\ 2}, \tag{15}$$

$$k_I = \frac{\omega n_I}{c} = k_o n_I, \qquad k_{II} = \frac{\omega n_{II}}{c} = k_o n_{II} \tag{16}$$

$$k_{III} = \frac{\omega n_{III}}{c} = k_o n_{III}, \tag{17}$$

$$k_o = \omega / c = 2\pi/\lambda \tag{18}$$

Where $\mathbf{k}_o$, k_o, λ and ω are the free space wave vector, wave number, the wavelength and angular frequency of the optical field, respectively.

β_z in Eqs.(13)-(15) represents the phase constant. The fields E_{yi} and e_{yi}, i=I,II,III, propagate with phase factor $\exp(-j\beta_z z)$ in the z-direction. We consider the nature of the modes as a function of the phase constant β_z at the angular fixed frequency ω. The conditions $k_I<\beta_z<k_{II}$ and $k_{III}<\beta_z<k_{II}$ are obtained by choosing the refractive indexes as $n_{III}<n_I<n_{II}$. These chosen refraction indexes make the right-hand side of the propagation constants α_I, α_{II} and α_{III} in Eqs.(13)-(15) real. In this case, the right-hand sides of Eqs.(13)-(15) will really become as real quantities.

The mode number of a confined field depends on the values of n_I, n_{II}, n_{III}, the wavelength λ and the thickness of the AR of the SSIWG. The parameters above defined in Eqs.(12)-(18) belong to the ASSIWG shown in Figure 1. Assuming now $n_I=n_{III}=n_{I,III}$, then the ASSIWG becomes single symmetric step-index waveguide (SSSIWG) [or ASSIWG becomes SSSIWGL] as well as $\alpha_I=\alpha_{III}=\alpha_{I,III}$. Therefore, the evanescent electric expressions in Eqs.(8)-(11) can be obtained as given below;

$$E_{yI,III} = A_{I,III} \exp\left[\pm\alpha_{I,III}(x \pm a)\right], \tag{19}$$

$$e_{yI,III} = B_{I,III} \exp\left[\pm\alpha_{I,III}(x \pm a)\right], \tag{20}$$

Where

$$\alpha_{I,III}^{\ 2} = \beta_z^{\ 2} - \left(\frac{\omega n_{I,III}}{c}\right)^2 = \beta_z^{\ 2} - k_{I,III}^{\ 2},\ \ k_{I,III} = \frac{\omega n_{I,III}}{c} = k_o n_{I,III}. \tag{21}$$

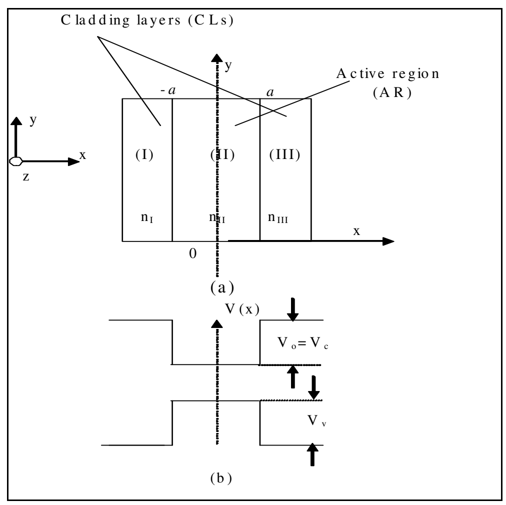

Figure 2a. Three basic regions of the ASSIWG, (b) The variation of one-dimensional potential energy V(x).

The positive and negative signs in Eqs.(19) and (20) correspond hereto region I and III respectively.

In this method if the indices of the regions, the thickness $2a$ of the AR and the wavelength λ for the SSSIQWL are given, the NPC α is obtained. Absorption and gain coefficients, such as a lot of quantities of the waveguide, have obtained in terms of the NPCs α in even and odd fields, directly.

Therefore, we will study the ASSIWG, SSSIWG or SSSIWGL, the properties of the optical threshold absorption coefficients, the absorption coefficients, the threshold gain coefficients, the gain coefficients, the threshold losses of the SSSIWG or SSSIWGL, the threshold power gains and the power gains in terms of the NPC α for even and odd electric field waves in the SSSIWG or SSSIWGL in this given alpha (α) method. Figure 3 shows the electrical field variations in the CLs and AR of the SSSIWGL for $\lambda=1.55\text{x}10^{-6}$ m, a=4000 A° $n_I=n_{I,III}=3.5$, $n_{II}=3.7$.

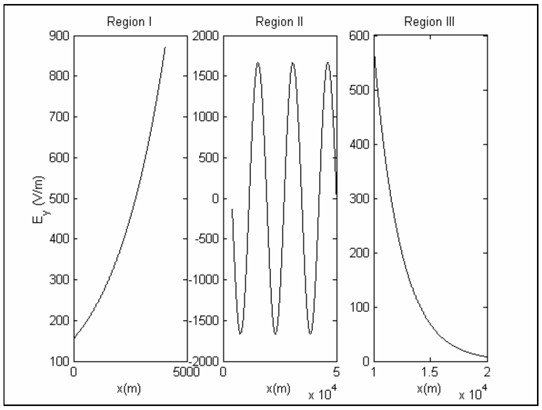

Figure 3. Electrical fields variations in the CLs and AR of the SSSIWGL.

3. SOME KEY PARAMETERS

For even and odd fields in the SSIWG the eigenvalue equations (Temiz, 2001; 2002) is given by,

$$\eta/\zeta = \tan\zeta \,, \tag{22}$$

and

$$\eta'/\zeta' = -\cot\zeta' \tag{23}$$

respectively where ζ, and η are defined by $\zeta = \alpha_{II}a = V\cos\zeta$ and $\eta = \alpha_{I,III}a = V\sin\zeta$ for even field in Eq.(1), and similarly, ζ' and η' are also defined by $\zeta'=\alpha'_{II}a=V'\sin\zeta'$ and $\eta'=\alpha'_{I,III}a=V'\cos\zeta'$ for odd field in Eq.(2). These are parametric variables of the EEVs of the carriers (Iga, 1994; Temiz, 2001) in the SSIWG and therefore can be used as variables for the EEVs in the normalized coordinate systems ζ-η and ζ'-η' for even and odd fields, respectively. The parameters (ζ, η) and (ζ', η') of these normalized coordinate systems form separately circles with the radius V and V' as;

$$V=\sqrt{\zeta^2+\eta^2}\,, \qquad V'=\sqrt{\zeta'^2+\eta'^2} \tag{24}$$

which are called the normalized frequencies (NFs) for even and odd fields respectively. The radii given in Eq.(24) can also be expressed as;

$$V=(a/\hbar)\sqrt{2m^*V_o}\,, \qquad V'=(a/\hbar)\sqrt{2m^*V'_o} \tag{25}$$

in terms of the structural parameters of the used material of the SSIWG (Temiz, 2001; 2002). In Eq.(25), m*, V_o, V_o' and $\hbar$ represent the mass of the carrier, the barrier potentials for even and odd fields and the normalized Planck constant respectively. We must remember that the primes in these formulas represent the odd mode symbolically. Another alternative form (Iga, 1994) of Eq.(25) is given as;

$$V=\frac{2\pi}{\lambda}a\sqrt{n_{II}^{\;2}-n_{I,III}^{\;2}}=\frac{2\pi}{\lambda}an_{II}\sqrt{2\Delta}=\frac{2\pi}{\lambda}a\,\text{NA}, \tag{26}$$

$$\left(\Delta=\frac{n_{II}^2-n_{I,III}^{\;2}}{2n_{II}^2}\cong\frac{n_{II}-n_{I,III}}{n_{II}}\right)$$

as the radius of the circle, as shown in Figure-4 (Temiz, 2001; 2002). The symbol Δ and the abbreviation NA in Eq.(26) are normalized index difference (usually expressed in percent) and numerical aperture respectively. The approximation of Δ arises from the assumption that n_{II} is very close in value to $n_{I,II.}$ as reported elsewhere (Iga, 1994). NF V is calculated from given indices n_I, n_{II}, n_{III} as shown in Eq.(26). The NF V embodies the structural parameters of the SSIWG and is function of the wavelength λ, the length a and the NA, as shown in Eq.(26).

The normalized propagation constants (NPCs) α and α' for even and odd fields are defined by

$$\alpha=\eta^2/V^2=\sin^2\zeta\,, \tag{27}$$

$$\alpha'=\eta'^2/V'^2=\cos^2\zeta' \tag{28}$$

respectively as reported in the literature (Temiz, 2001; 2002).

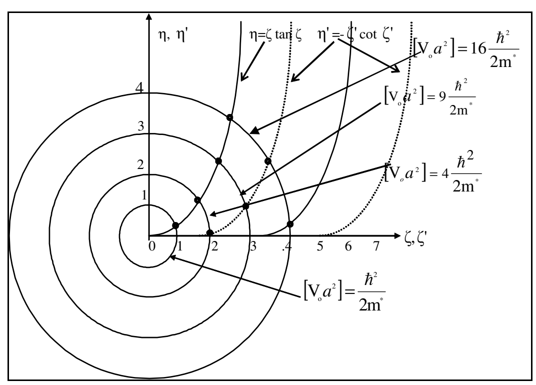

Figure 4. The coordinate points of the EEVs of the charged carriers in the normalized coordinate system ζ-η in a SSSIWG or SSSIWGL (dotted lines belong to odd field).

Eqs(27) and (28) give the other parameters L and L' as

$$L=1-\alpha=\zeta^2/V^2=\cos^2\zeta=\alpha', \tag{29}$$

and

$$L'=1-\alpha'=\zeta'^2/V'^2=\sin^2\zeta=\alpha \tag{30}$$

respectively. The parametric variables ζ, ζ', η and η' can therefore be expressed (Temiz, 2001; 2002) as follows;

$$\zeta = V\sqrt{1-\alpha} = V\sqrt{L}\,, \tag{31}$$

$$\zeta' = V'\sqrt{1-\alpha'} = V'\sqrt{1-L'} = V'\sqrt{\alpha} \tag{32}$$

and

$$\eta = V\sqrt{\alpha}\,, \tag{33}$$

$$\eta' = V'\sqrt{\alpha'} = V'\sqrt{L} \tag{34}$$

The parameters L and L' characterize the depth of the SSSIWG or SSSIWGL for even and odd fields respectively. Eqs.(26)-(34) impose that the NF V is equal to V' in the same SSIWG or SSSIWGL for given indices. Therefore, the NF V=V' yields only one NPC in the same SSSIWG or SSSIWGL. That is, the parameters ζ, ζ' and η, η' for even and odd fields become identical quantities, resulting as ζ=ζ', η=η', since V=V' and α=α' in the same SSSIWG or SSSIWGL.

4. SOME PROBABILITY RATIOS OF EVEN AND ODD FIELDS IN THE REGIONS OF THE ASSIWGL

A field function probability ratio, $\overline{R}$, can be defined as the ratio of the total evanescent field function probability I_l, (I_I+I_{III}), in the region I and III to the active field function probability (I_{II}) in the AR in the ASSIWGL. For even mode, $\overline{R}$ is expressed as;

$$\frac{I_\ell}{I_{II}} = \overline{R} = \frac{\int_{-\infty}^{-a}\left[E_{y_I}(x)E_{y_I}(x)^*\right]dx + \int_{a}^{\infty}\left[E_{yIII}(x)E_{yIII}(x)^*\right]dx}{\int_{-a}^{a}\left[E_{yII}(x)E_{yII}(x)^*\right]dx}$$
$$= \frac{\int_{-\infty}^{-a}\left[\left|E_{y_I}(x)\right|^2\right]dx + \int_{a}^{\infty}\left[\left|E_{yIII}(x)\right|^2\right]dx}{\int_{-a}^{a}\left[\left|E_{yII}(x)\right|^2\right]dx} \tag{35}$$

or

$$\overline{R} = \frac{I_I(x)+I_{III}(x)}{I_{II}(x)} \tag{36}$$

where

$$I_I = \int_{-\infty}^{-a}\left|E_{yI}(x)\right|^2 dx,\quad I_{II} = \int_{-a}^{a}\left|E_{yII}(x)\right|^2 dx, \tag{37}$$

and

$$I_{III} = \int_{a}^{\infty}\left|E_{yIII}(x)\right|^2 dx \tag{38}$$

are field function probabilities in the regions I, II and III respectively in the ASSIWGL. If we consider $E_{yI}=E_{yIII}=E_{yI,III}$ in the ASSIWGL, then we obtain SSSIWGL [See Eq.(19)] and consequently the field function probability ratio $\overline{R}$ as;

$$\overline{R} = \frac{I_\ell}{I_{II}} = \frac{2\int_{a}^{\infty}\left[E_{yI,III}(x)E_{yI,III}(x)^*\right]dx}{2\int_{0}^{a}\left[E_{yII}(x)E_{yII}(x)^*\right]dx} = \frac{\int_{a}^{\infty}\left[E_{yI,III}(x)E_{yI,III}(x)^*\right]dx}{\int_{0}^{a}\left[E_{yII}(x)E_{yII}(x)^*\right]dx} \tag{39}$$

or

$$\overline{R} = \frac{I_\ell}{I_{II}} = \frac{\int_{a}^{\infty}\left|E_{yI,III}(x)\right|^2 dx}{\int_{0}^{a}\left|E_{yII}(x))\right|^2 dx} \tag{40}$$

where

$$I_{I,III} = \int_{a}^{\infty}\left|E_{yI,III}(x)\right|^2 dx,\quad I_{II} = 2\int_{0}^{a}\left|E_{yII}(x)\right|^2 dx \tag{41}$$

are field function probabilities in the regions I or III and II in the SSSIWGL respectively.

By repeating the same procedure and conditions for odd mode, we can have the probability ratio $\overline{r}$ as

$$\overline{r} = \frac{I'_\ell}{I'_{II}} = \frac{\int_{-\infty}^{-a}\left[e_{yI}(x)e_{yI}(x)^*\right]dx + \int_{a}^{\infty}\left[e_{yIII}(x)e_{yIII}(x)^*\right]dx}{\int_{-a}^{a}\left[e_{yII}(x)e_{yII}(x)^*\right]dx}$$
$$= \frac{\int_{-\infty}^{-a}\left[\left|e_{yI}(x)\right|^2\right]dx + \int_{a}^{\infty}\left[\left|e_{yIII}(x)\right|^2\right]dx}{\int_{-a}^{a}\left[\left|e_{yII}(x)\right|^2\right]dx} \tag{42}$$

or

$$\bar{r} = \frac{I'_{I}(x) + I'_{III}(x)}{I'_{II}} \qquad (43)$$

in the ASSIWGL. Similarly, if we get $e_{yI}=e_{yIII}=e_{yI,III}$ in the SSSIWGL [See Eq.(20)], we obtain the field function probability ratio $\bar{r}$ as;

$$r = \frac{I'_{\ell}}{I'_{II}} = \frac{2\int_{a}^{\infty}\left[e_{yI,III}(x)e_{yI,III}(x)^{*}\right]dx}{2\int_{0}^{a}\left[e_{yII}(x)e_{yII}(x)^{*}\right]dx} = \frac{\int_{a}^{\infty}\left|e_{yI,III}(x)\right|^{2}dx}{\int_{0}^{a}\left|e_{yII}(x)\right|^{2}dx} \qquad (44)$$

$$I'_{I,III} = \int_{a}^{\infty} e_{yI,III}(x)e_{yI,III}(x)dx\,, \qquad (45)$$

$$I'_{II} = \int_{-a}^{a} e_{yII}(x)e_{yII}(x)dx = 2\int_{0}^{a} e_{yII}(x)e_{yII}(x)dx\,. \qquad (46)$$

A lot of simple mathematical operations give the probabilities of the some electric field wave components as;

$$I_{I} = \int_{-\infty}^{-a} E_{yI}(x)E_{yI}(x)\,dx = A_{I}^{2}/2\alpha_{I}\,, \qquad (47)$$

$$I'_{I} = \int_{-\infty}^{-a} e_{yI}(x)e_{yI}(x)\,dx = B_{I}^{2}/2\alpha_{I}\,, \qquad (48)$$

$$I_{II} = \int_{-a}^{a} E_{yII}(x)E_{yII}(x)\,dx$$
$$= 2\int_{0}^{a} E_{yII}(x)E_{yII}(x)\,dx = 2\int_{0}^{a}\left|E_{yII}(x)\right|^{2}dx = 1, \qquad (49)$$

$$I'_{II} = \int_{-a}^{a} e_{yII}(x)e_{yII}(x)\,dx$$
$$= 2\int_{0}^{a} e_{yII}(x)e_{yII}(x)dx = 2\int_{0}^{a}\left|e_{yII}(x)\right|^{2}dx = 1, \qquad (50)$$

$$I_{III} = \int_{a}^{\infty} E_{yIII}(x)E_{yIII}(x)\,dx = A_{III}^{2}/2\alpha_{III}\,, \qquad (51)$$

$$I'_{III} = \int_{a}^{\infty} e_{yIII}(x)e_{yIII}(x)\,dx = B_{III}^{2}/2\alpha_{III}\,, \qquad (52)$$

for ASSIWGL and

$$I_{I,III} = \int_{a}^{\infty} E_{yI,III}(x)E_{yI,III}(x)\,dx = A_{I,III}^{2}/2\alpha_{I,III}\,, \qquad (53)$$

$$I'_{I,III} = \int_{a}^{\infty} e_{yI,III}(x)e_{yI,III}(x)\,dx = B_{I,III}^{2}/2\alpha_{I,III}\,, \qquad (54)$$

for the SSSIWGL by reminding the integral $t_j = \int\left|E_{yj}\right|^2 dx$ of even field E_{yj} and $t'_j = \int\left|e_{yj}\right|^2 dx$ for odd field, j=I, II, III. That is, t_j or t'_j represents physically the probability of finding an electron or a hole in dx interval at the jth region of the SSIWL for even or odd field, respectively.

Consequently, using Eqs.(47), (49) and (51) in Eq.(36) yields the field function probability ratio $\bar{R}$ as;

$$\frac{I_{\ell}}{I_{II}} = \bar{R} = \frac{2\zeta_e L}{2\zeta_e + \sin 2\zeta_e}\left(\frac{1}{2\eta_I} + \frac{1}{2\eta_{III}}\right). \qquad (55)$$

for even field in the ASSIWGL, representing abscissa ζ_e and ordinate η_e of the EEV for the carriers. Using Eqs. (48), (50), (52) in Eq.(43) in the same way gives us also the field function probability ratio $\bar{r}$ as;

$$\frac{I'_{\ell}}{I'_{II}} = \bar{r} = \frac{2\zeta'_e L'}{2\zeta'_e - \sin 2\zeta'_e}\left(\frac{1}{2\eta'_I} + \frac{1}{2\eta'_{III}}\right) \qquad (56)$$

for odd field or since V=V', α=α', L=L', η=η' and ζ=ζ' in the same SSSIWGL,

$$\frac{I'_{\ell}}{I'_{II}} = \bar{r} = \frac{2\zeta_e L}{2\zeta_e - \sin 2\zeta_e}\left(\frac{1}{2\eta_I} + \frac{1}{2\eta_{III}}\right). \qquad (57)$$

The optical loss probability function I_l (I'_l) for even (odd) field flows through the CLs (Figure 5) in the ASSIWGL.

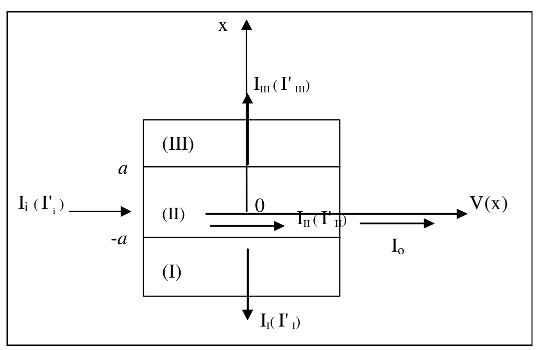

Figure 5. Different field function probabilities in the ASSIWGL in the alpha (α) method.

5. ASYMMETRIC FACTOR AND ITS AFFECTS

After a lot of mathematical manipulations, the variables ζ_e, η_I and η_{III} in Eq.(55) for even field in the ASSIWG are obtained as;

$$\zeta_e = \frac{a k_o NA}{2}\sqrt{(1-\alpha)(1+\sqrt{1+a_p})^2}$$
$$= \frac{V}{2}\sqrt{(1-\alpha)(1+\sqrt{1+a_p})^2}\ , \quad (58)$$

$$\eta_I = a k_o NA\sqrt{1-(1-\alpha)(1/4)(1+\sqrt{1+a_p})^2}\ , \quad (59)$$

$$\eta_{III} = \frac{a k_o NA}{2}\sqrt{4(1+a_p)-(1-\alpha)(1+\sqrt{1+a_p})^2}\ . \quad (60)$$

Where $NA = (n_{II}^2 - n_I^2)^{1/2}$, V=$k_o a$NA. If we get $n_I = n_{III} = n_{I,III}$, then we have a_p=0 [see Eq. (66)] and $V=V_c = k_o a NA_c = k_o a\sqrt{n_{II}^2 - n_{I,III}^2}$ and $NA = NA_{I,III} = (n_{II}^2 - n_{I,III}^2)^{1/2}$. The variables ζ'_e, η'_I and η'_{III} in Eq.(56) for odd field in the ASSIWG are also obtained as:

$$\zeta'_e = \frac{k_o a NA}{2}\sqrt{(1-\alpha')(1+\sqrt{1+a_p})^2}$$
$$= \frac{V}{2}\sqrt{(1-\alpha')(1+\sqrt{1+a_p})^2}\ , \quad (61)$$

$$\eta'_I = a k_o NA\sqrt{1-(1-\alpha')(1/4)(1+\sqrt{1+a_p})^2}\ , \quad (62)$$

$$\eta'_{III} = \frac{a k_o NA}{2}\sqrt{4(1+a_p)-(1-\alpha')(1+\sqrt{1+a_p})^2}\ . \quad (63)$$

Eqs.(48) and (49) can give the geometrical average, i.e. for even field, as

$$\eta_e = \sqrt{(1/2)[\eta_I^2 + \eta_{III}^2]} \quad (64)$$

or a lot of manipulations give

$$\eta_e = V\sqrt{\frac{1}{2}[1-(1-\alpha)(1/4)(1+\sqrt{1+a_p})^2]+\ldots}$$
$$\ldots\frac{1}{8}[4(1+a_p)-(1-\alpha)(1+\sqrt{1+a_p})^2] \quad (65)$$

The asymmetric factor a_p (Bhattacharya, 1998) in Eqs.(58)-(65) is given by

$$a_p = \frac{n_I^2 - n_{III}^2}{n_{II}^2 - n_I^2} \quad (66)$$

Remembering that a_p=0 yields the condition $n_I=n_{III}=n_{I,III}$ for the SSIWGL. It is useful to note that Eq.(64) yields to $\eta_e=\eta_{I,III}=\eta_c$ for $\eta_I=\eta_{III}=\eta_{I,III}=\eta_c$ in the SSIWGL. Also, if it is taken as a_p=0 then Eqs.(58) and (65) give following variables,

$$\zeta_e = \zeta_c = V\sqrt{1-\alpha}\ , \qquad \eta_e = \eta_c = V\sqrt{\alpha} \quad (67)$$

for even field and we have

$$\zeta'_c = V'\sqrt{\alpha'}\ , \qquad \eta'_c = V'\sqrt{1-\alpha'}\ , \quad (68)$$

or taking Eqs.(29)-(34) into account it can be written;

$$\zeta'_c = V'\sqrt{\alpha'} = V'\sqrt{L}\ , \quad (69)$$

$$\eta'_c = V'\sqrt{1-L} = V'\sqrt{L'} = V'\sqrt{\alpha} \quad (70)$$

for odd field in the SSSIWGL. That is, for example, we can take that V=V' and α=α' for even or odd field in the same SSSIWGL. Therefore, for the same SSSIWGL, we can write Eq.(68) as;

$$\zeta'_c = \zeta_c = V\sqrt{L}\ , \quad \eta'_c = \eta_c = V\sqrt{\alpha}\ . \quad (71)$$

Here note that the variables ζ_e, η_e and ζ_c, η_c are parametric coordinates of the EEVs for carriers in the SSSIWGL, respectively. The variables ζ_e and η_e in the ASSIWGL for n_I=3.350, n_{II}=3.351 are plotted in Figure 6. By taking the asymmetric factor a_p in Eq.(66) into account, we see that the larger difference (n_I-n_{III}) is, the larger the variables ζ_e and η_e are, as shown in Figure-6 (also see Figure 7). That is, as the asymmetric factor a_p increases, the two variables ζ_e and η_e increase non-linearly. It is obvious to note that the variables ζ_c=5.6274x10^{-15} and η_c=2.1217x10^{-17} for the SSSIWGL (a_p=0) are constants on the vertical axis, as shown in Figure-6. The constants ζ_c and η_c correspond to the refractive index $n_I=n_{III}=n_{I,III}$.

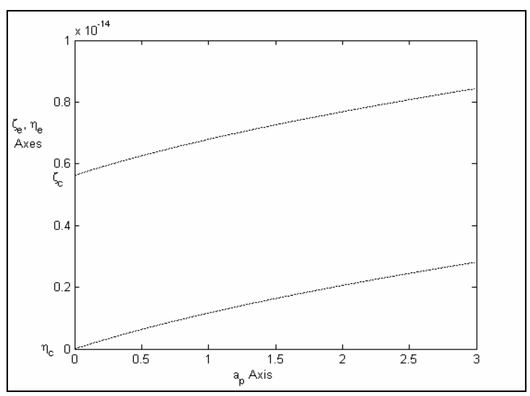

Figure 6. The variations of the parametric coordinates ζ_e an η_e against to the asymmetric factor a_p in the ASSIWGL for n_I=3.350, n_{II}=3.351.

For n_I=4.5, n_{II}=4.8 the variables ζ_e and η_e are also plotted Figure-7. It is obvious to note that the variables $\zeta_c=9.4312\times10^{-15}$ and $\eta_c=9.5530\times10^{-16}$ for the SSSIWGL (a_p=0) on the vertical axis are constants which correspond to the refractive index $n_I=n_{III}=n_{I,III}$, as shown in Figure 7.

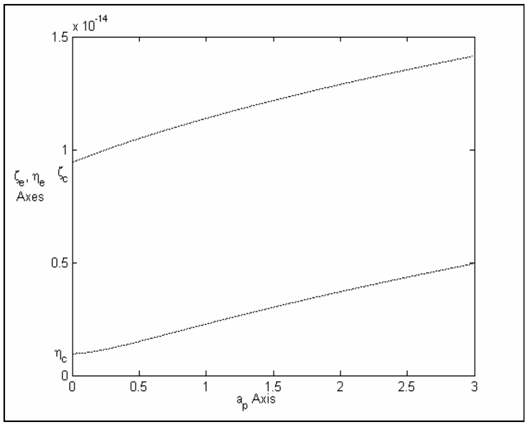

Figure 7. The variations of the parametric coordinates ζ_e and η_e against to the asymmetric factor a_p in the ASSIWGL for a=14 A°, λ=1.55 µm, n_I=4.5, n_{II}=4.8 and convenient constant values $\zeta_c=9.4312\times10^{-15}$ and $\eta_c=9.5530\times10^{-16}$ on the vertical axis.

If it is taken as $\eta_I=\eta_{III}=\eta_{I,III}$ and $\eta'_I=\eta'_{III}=\eta'_{I,III}=\eta'$ in the SSSIWGL, then using Eqs.(49) and (53) in Eq.(40) gives the field function probability ratio $\overline{R}$ as;

$$\overline{R} = \frac{I_\ell}{I_{II}} = \frac{1-\alpha}{\eta+\alpha}. \tag{72}$$

In the same way, using Eqs.(50) and (54) in Eq.(44) yields also the field function probability ratio $\overline{r}$ as;

$$\overline{r} = \frac{I'_\ell(x)}{I'_{II}} = \frac{1-\alpha'}{\eta'-\alpha'}, \tag{73}$$

or in the same SSSIWGL

$$\overline{r} = \frac{I'_\ell(x)}{I'_{II}} = \frac{1-\alpha}{\eta-\alpha}. \tag{74}$$

We desire the optical field function probability I_{II} or I'_{II} being unity for even or odd field, in the AR, respectively. Therefore, in the SSSIWGL for even and odd fields, substituting Eqs.(1) and (2) into Eqs.(49) and (50) yields respectively I_{II} and I'_{II} as

$$I_{II} = A^2\left(a+\frac{\sin 2\zeta}{2\alpha_{II}}\right) = A^2 W_e \tag{75}$$

and

$$I'_{II} = B^2\left(a-\frac{\sin 2\zeta}{2\alpha_{II}}\right) = B^2 W_o \tag{76}$$

giving

$$W_e = a+\frac{\sin 2\zeta}{2\alpha_{II}} \tag{77}$$

$$W_o = a-\frac{\sin 2\zeta}{2\alpha_{II}}. \tag{78}$$

Eqs.(77) and (78) are called the optical effective mode widths for even and odd fields, respectively (Kazarinov and Belenky, 1995). These widths take the leakage of the electric field wave function into account in forbidden regions classically. Note that the comparison of Eqs.(3) and (4) with Eqs.(75)-(76) yields I_{II} and I'_{II} as unity for the same SSSIWGL (obtaining ζ=ζ', η=η', since V=V' and α=α').

The output probabilities I_o and I'_o are given by

$$I_o = I_{II} - (I_I + I_{III}) = I_{II} - I_\ell, \tag{79}$$

where

$$I_\ell = I_I + I_{III} \tag{80}$$

$$I'_o = I'_{II} - (I'_I + I'_{III}) = I'_{II} - I'_\ell, \tag{81}$$

$$I'_\ell = I'_I + I'_{III} \tag{82}$$

in which I_l and I'_l are the loss probabilities (Figure 5). It is important to remind that if these probabilities are divided by electromagnetic impedance of the relevant region then we obtain the optical electromagnetic field power of the relevant region.

6. LOSS PROBABILITIES RELEVANT TO LOSS POWERS OF EVEN AND OLD FIELDS IN THE ASSIWGL AND SSSIWGL

Taking Eq.(49) into account, Eq.(55) yields the loss probability

$$I_\ell = \frac{2\zeta_e L}{2\zeta_e + \sin 2\zeta_e}\left(\frac{1}{2\eta_I} + \frac{1}{2\eta_{III}}\right) \quad (83)$$

for even field, and also taking Eq.(50) into account, Eq.(56) gives the loss probability

$$I'_\ell = \frac{2\zeta'_e L'}{2\zeta'_e - \sin 2\zeta'_e}\left(\frac{1}{2\eta_I} + \frac{1}{2\eta_{III}}\right) \quad (84)$$

for odd field in the ASSIWGL. From Eqs.(83) and (84), we obtain

$$I_\ell = \frac{L}{\eta}\frac{1}{1+\eta/V^2} = \frac{L}{\eta+\alpha} = \frac{1-\alpha}{\eta+\alpha} \quad (85)$$

$$I'_\ell = \frac{L'}{\eta'}\frac{1}{1+\eta'/V'^2} = \frac{L'}{\eta'+\alpha'} = \frac{1-\alpha'}{\eta'+\alpha'} \quad (86)$$

by taking $\eta_I=\eta_{III}=\eta_{I,III}=\eta_c=\eta$ and $\zeta_c=\zeta$ in the SSSIWGL. Eq.(86) becomes

$$I'_\ell = \frac{1-\alpha}{\eta+\alpha} \quad (87)$$

in the same SSSIWGL.

7. INPUT PROBABILITIES IN THE ASSIWGL AND SSSIWGL

The input probabilities I_i and I'_i relevant the input powers (Gasiorowicz, 1974; Temiz, 2002) in the ASSIWGL in Figure-5 are generally defined as

$$I_i = I_{II} + I_I + I_{III} = I_{II} + I_\ell \quad (88)$$

$$= \int_{-a}^{a} E_{yII}(x)E_{yII}(x)dx + \int_{-\infty}^{-a} E_{yI}(x)E_{yI}(x)dx + \int_{a}^{\infty} E_{yIII}(x)E_{yIII}(x)dx, \quad (89)$$

or

$$I_i = 1 + \frac{A_I^2}{2\alpha_I} + \frac{A_{III}^2}{2\alpha_{III}} = 1 + I_\ell \quad (90)$$

for even field and

$$I'_i = I'_{II} + I'_I + I'_{III} = I'_{II} + I'_\ell \quad (91)$$

$$= \int_{-a}^{a} e_{yII}(x)e_{yII}(x)dx + \int_{-\infty}^{-a} e_{yI}(x)e_{yI}(x)dx + \int_{a}^{\infty} e_{yIII}(x)e_{yIII}(x)dx, \quad (92)$$

or

$$I'_i = 1 + \frac{B_I^2}{2\alpha_I} + \frac{B_{III}^2}{2\alpha_{III}} = 1 + I'_i \quad (93)$$

for odd field. In the SSSIWGL I_i and I'_i have become as follows:

$$I_i = 2\int_0^a E_{yII}(x)E_{yII}(x)dx + 2\int_a^\infty E_{yI,III}(x)E_{yI,III}(x)dx \quad (94)$$

or

$$I_i = I_{II} + 2I_{I,III} = I_{II} + I_\ell \quad (95)$$

for even field and

$$I'_i = 2\int_0^a e_{yII}(x)e_{yII}(x)dx + 2\int_a^\infty e_{yI,III}(x)e_{yI,III}(x)dx \quad (96)$$

or

$$I'_i = I'_{II} + 2I'_{I,III} = I'_{II} + I'_\ell \quad (97)$$

for odd field. At the end, referring to Eqs.(49) and (50), we obtain I_i and I'_i as;

$$I_i = 2\int_0^a |E_{yII}(x)|^2 dx + I_\ell = I_{II} + I_\ell = 1 + I_\ell \quad (98)$$

$$I'_i = 2\int_0^a |e_{yII}(x)|^2 dx + I'_\ell = I'_{II} + I'_\ell = 1 + I'_\ell \quad (99)$$

or the probabilities I_{II} and I'_{II}

$$I_{II} = I_i - I_\ell = 2\int_0^a |E_{yII}(x)|^2 dx, \quad (100)$$

$$I'_{II} = I'_i - I'_\ell = 2\int_0^a |e_{yII}(x)|^2 dx. \quad (101)$$

in the AR. Referring to Eqs.(1) and (2), evaluating the integrals in Eqs.(100) and (101) enables us to calculate as;

$$I_{II} = I_i - I_\ell = 2A^2\int_0^a \cos^2(\alpha_{II}x)dx = A^2\left(a + \frac{\sin 2\zeta}{2\alpha_{II}}\right) = 1 \quad (102)$$

$$I'_{II} = I'_i - I'_\ell = 2B^2\int_0^a \sin^2(\alpha_{II}x)dx = B^2\left(a - \frac{\sin 2\zeta'}{2\alpha_{II}}\right) = 1 \quad (103)$$

Which are in agreement with Eqs.(75)-(78). In addition, after from performing the integrals of

Eqs.(94) and (96), we obtain the following equations:

$$I_i = \frac{A_{I,III}^2}{\alpha_{I,III}}[\alpha_{I,III}\frac{2\zeta+\sin 2\zeta}{2\alpha_{II}\cos^2\zeta}+1]$$
$$= \frac{A_{I,III}^2}{\alpha_{I,III}}[\frac{\eta}{\cos^2\zeta}\frac{2\zeta+\sin 2\zeta}{2\zeta}+1] = \frac{\eta+1}{\eta+\alpha} \quad (104)$$

$$I'_i = \frac{B_{I,III}^2}{\alpha_{I,III}}[\alpha_{I,III}\frac{2\zeta-\sin 2\zeta}{2\alpha_{II}\sin^2\zeta}+1]$$
$$= \frac{B_{I,III}^2}{\alpha_{I,III}}[\frac{\eta}{\sin^2\zeta}\frac{2\zeta-\sin 2\zeta}{2\zeta}+1] = \frac{\eta'+1-2\alpha'}{1-\alpha'} \quad (105)$$

or in the same SSSIWGL

$$I'_i = \frac{\eta+1-2\alpha}{1-\alpha}, \quad (106)$$

and

$$I_{II} = A^2[a+\frac{1}{2\alpha_{II}}\sin 2(\alpha_{II}a)] = A^2[a+\frac{a}{2\zeta}\sin 2\zeta, \quad (107)$$

$$I'_{II} = B^2[a-\frac{1}{2\alpha_{II}}\sin(2\alpha_{II}a)] = B^2[a-\frac{a}{2\zeta}\sin(2\zeta. \quad (108)$$

It is seen that using Eqs.(3) and (4) into Eqs.(76) and (76) gives respectively the constants A and B as;

$$A = 1/\sqrt{W_e}, \quad (109)$$

$$B = 1/\sqrt{W_o}. \quad (110)$$

We see from Eqs.(109), (110) that the amplitudes of even and odd fields vary with the optical effective width of the SSSIWGL and indirectly the propagation constant α_{II}.

8. SOME SPECIAL PARAMETERS AND CONFINEMENT FACTORS RELEVANT TO THE REGIONS OF THE ASSIWGL AND SSSIWGL

Probability ratio $\bar{K}$ can be defined as $\bar{K} = \frac{I_\ell}{I_i}$ (Temiz, 2002). Just as, the ratio of the loss probability to the input probability for even field can be obtained as;

$$\frac{I_\ell}{I_i} = \bar{K} = [A_I^2/2\alpha_I + A_{III}^2/2\alpha_{III}]/[1+\frac{A_I^2}{2\alpha_I}+\frac{A_{III}^2}{2\alpha_{III}}] \quad (111)$$

in the ASSIWL. Eq.(111) yields

$$\bar{K} = \frac{1-\alpha}{\eta+1} = \frac{1}{1+1/\bar{R}} \quad (112)$$

for the SSSIWGL. Also the probability ratio $\bar{q}$ for odd field in the ASSIWG (Temiz, 2002) can be defined as;

$$\frac{I'_\ell}{I'_i} = \bar{q} = [B_I^2/2\alpha_I + B_{III}^2/2\alpha_{III}]/[1+B_I^2/2\alpha_I + B_{III}^2/2\alpha_{III}$$
(113)

which gives

$$\frac{I'_\ell}{I'_i} = \bar{q} = \frac{1-\alpha}{1+\eta-2\alpha} = \frac{1}{1+\frac{1}{\bar{r}}} \quad (114)$$

for the SSSIWGL.

For the ASSIWGL, the confinement factor (CF) F_{II} (Temiz, 2002) for even field in the region II is defined and calculated as;

$$\frac{I_{II}}{I_i} = F_{II} = 1/[1+\frac{A_I^2}{2\alpha_I}+\frac{A_{III}^2}{2\alpha_{III}}]. \quad (115)$$

Eq.(115) yields

$$\Gamma_{II} = \frac{\alpha+\eta}{1+\eta} = \frac{\bar{K}}{\bar{R}} = 1-\bar{K} = \frac{1}{\bar{R}} \quad (116)$$

for the SSSIWGL. In the same way, for the confinement factor for odd field (Temiz, 2002) in the region II is also defined and calculated as;

$$\frac{I'_{II}}{I'_i} = F'_{II} = 1/[1+\frac{B_I^2}{2\alpha_I}+\frac{B_{III}^2}{2\alpha_{III}}] \quad (117)$$

for the ASSIWGL and therefore, from Eq.(117) we obtain

$$\Lambda_{II} = \frac{\eta'-\alpha'}{1+\eta'-2\alpha'} = \frac{1}{1+\bar{r}} = 1-\bar{q} = \frac{\bar{q}}{\bar{r}} \quad (118)$$

or

$$\Lambda_{II} = \frac{\eta-\alpha}{1+\eta-2\alpha}. \quad (119)$$

for the SSSIWGL. Thus, we have (Temiz, 2002) the relations

$$\overline{K} + \Gamma_{II} = 1, \qquad \overline{q} + \Lambda_{II} = 1. \tag{120}$$

Here remember again that the prime denote the parameters for odd field symbolically. The parameters $\overline{K}$ in Eq.(112), Γ_{II} in Eq.(116), $\overline{q}$ in Eq.(114), and Λ_{II} in Eq.(1119) have been used to represent the some special probability ratios and the confinement factors for even and odd fields in the SSSIWGL, respectively.

We can generally define the confinement factors for regions of the ASSIWG, representing them by F_I, F_{II} and F_{III}. Just as, the confinement factors for regions I and III of the ASSIWG in Figure-5 can be given as

$$\frac{I_I}{I_i} = F_I = \frac{A_I^2}{2\alpha_I} / [1 + \frac{A_I^2}{2\alpha_I} + \frac{A_{III}^2}{2\alpha_{III}}] = \frac{L}{\frac{\eta_I}{\zeta}(2\zeta + \sin 2\zeta) + L(1 + \eta_I/\eta_{III})} \tag{121}$$

and

$$\frac{I_{III}}{I_i} = F_{III} = \frac{A_{III}^2}{2\alpha_{III}} / [1 + \frac{A_I^2}{2\alpha_I} + \frac{A_{III}^2}{2\alpha_{III}}] = \frac{L}{\frac{\eta_{III}}{\zeta}(2\zeta + \sin 2\zeta) + L(1 + \eta_{III}/\eta_I)} \tag{122}$$

for even field. Also, in the similar way we can obtain respectively

$$\frac{I'_I}{I'_i} = F'_I = \frac{B_I^2}{2\alpha_I} / [1 + \frac{B_I^2}{2\alpha_I} + \frac{B_{III}^2}{2\alpha_{III}}] = \frac{L}{\frac{\eta'_I}{\zeta}(2\zeta' - \sin 2\zeta') + L(1 + \eta'_I/\eta'_{III})} \tag{123}$$

and

$$\frac{I'_{III}}{I'_i} = F'_{III} = \frac{B_{III}^2}{2\alpha_{III}} / [1 + \frac{B_I^2}{2\alpha_I} + \frac{B_{III}^2}{2\alpha_{III}}] = \frac{L}{\frac{\eta'_{III}}{\zeta}(2\zeta' - \sin 2\zeta') + L(1 + \eta'_{III}/\eta'_I)} \tag{124}$$

for odd field. By denoting the confinement factors in the SSSIWGL with Γ_I and Γ_{III} for the regions I and III respectively, if it is taken as $\eta_I = \eta_{III} = \eta_{I,III} = \eta$, then Eqs.(121)-(124) give the relations

$$\Gamma_I = \Gamma_{III} = \Gamma_{I,III} = \frac{1}{2}\overline{K} \tag{125}$$

$$\Lambda_I = \Lambda_{III} = \Lambda_{I,III} = \frac{1}{2}\overline{q} \tag{126}$$

noting that the confinement factors for the regions I and III are equal to each other as $\Gamma_I = \Gamma_{III} = \Gamma_{I,III}$ and $\Lambda_I = \Lambda_{III} = \Lambda_{I,III}$ for even and odd fields in the SSSIWGL, respectively.

It is here important to say that the sums of the confinement factors F_I, F_{II} and F_{III} (F'_I, F'_{II} and F'_{III}) for even (odd) field is equal to unity. Therefore, can be written

$$F_I + F_{III} + F_{II} = 1 \tag{127}$$

$$F'_I + F'_{III} + F'_{II} = 1 \tag{128}$$

in the ASSIWGL (Kazarinov and Belenky, 1995). For the SSSIWGL, we can also obtain (Kazarinov and Belenky, 1995) the relation

$$\Gamma_I + \Gamma_{II} + \Gamma_{III} = \Gamma_{II} + 2\Gamma_{I,III} = 1 \tag{129}$$

or

$$\Gamma_{I,III} = (1 - \Gamma_{II})/2 = \overline{K}/2 \tag{130}$$

and

$$\Lambda_I + \Lambda_{II} + \Lambda_{III} = \Lambda_{II} + 2\Lambda_{I,III} = 1 \tag{131}$$

or

$$\Lambda_{I,III} = (1 - \Lambda_{II})/2 = \overline{q}/2\,. \tag{132}$$

Note that Eqs.(130) and (132) give the confinement factors in the CLs, for the regions I and III in the SSSIWGL, in terms of the confinement factors Γ_{II} and Λ_{II} in the AR or the probability ratios $\overline{K}$ and $\overline{q}$ of related regions for even and odd fields respectively.

9. ABSORPTION COEFFICIENTS AND GAIN COEFFICIENTS

Important parameters for the characterization and simulation of the laser are the threshold absorption coefficient and the threshold gain coefficient. To see the influence of many-body effects in the SSIWG, we can compute the threshold absorption coefficients and absorption coefficients, the threshold loss coefficients, the threshold power gain coefficients and power gain coefficients, the threshold power gains, the power gains for even and odd electric field waves.

Here, k_1, k_3 (k'_1, k'_3) in the ASSIWG or $k_{1,3}$ ($k'_{1,3}$) in the SSSIWGL are defined as absorption coefficients in even (odd field) in the regions I and III for the ASSIWGL or SSSIWGL, respectively. It is generally evident that the total absorption coefficient in the ASSIWGL can be respectively given by

$$k = k_1 F_I + k_2 F_{II} + k_3 F_{III} \tag{133}$$

for even field and

$$k' = k'_1 F'_I + k_2 F'_{II} + k_3 F'_{III} \tag{134}$$

for odd field (Bhattacharya, 1998). Taking k=0 and k'=0 in the SSSIWGL give respectively $k_2=-g_{th}$ and $k'_2=-g'_{th}$ (Bhattacharya, 1998) and therefore we get consequently as;

$$k_1 F_I + k_3 F_{III} = g_{th} F_{II} \tag{135}$$

$$k'_1 F'_I + k'_3 F'_{III} = g'_{th} F'_{II}\,. \tag{136}$$

which give the threshold conditions. Here, $g_{th}F_{II}$ and $g'_{th}F'_{II}$ are called the threshold modal gain for even and odd fields in the ASSIWG respectively. The parameter g_{th} (g'_{th}) is the threshold gain coefficient which is described by the structural properties of the SSSIWGL for even (odd) field (Bhattacharya, 1998). Remembering that, $\bar{q} = 1 - \Lambda_{II}$, $\Gamma_{II} = \frac{\bar{K}}{\bar{R}}$ and $\Lambda_{II} = \frac{\bar{q}}{\bar{r}}$ and taking the equations ζ=ζ', η=η', V=V' and α=α' into account in the same SSSIWGL, we obtain the threshold absorption coefficient from Eq.(135) in even field as;

$$k_{1,3th} = \frac{g_{th}\Gamma_{II}}{2\Gamma_{I,III}} = \frac{g_{th}\Gamma_{II}}{1-\Gamma_{II}} = \frac{g_{th}\Gamma_{II}}{\bar{K}} = \frac{g_{th}}{\bar{R}} = \frac{-k_2}{\bar{R}} \tag{137}$$

and from Eq.(136) in the odd field as

$$k'_{1,3th} = \frac{g'_{th}\Lambda_{II}}{2\Lambda_{I,III}} = \frac{g'_{th}\Lambda_{II}}{1-\Lambda_{II}} = \frac{g'_{th}\Lambda_{II}}{\bar{q}} = \frac{g'_{th}}{\bar{r}} = \frac{-k'_2}{\bar{r}} \tag{138}$$

Note that Eqs.(137) and (138) give threshold absorption coefficients in terms of the confinement factors for even and odd fields in the regions I and III for the SSSIWGL, respectively. Also, the threshold absorption coefficient for even or odd field becomes function of the threshold gain coefficient respectively.

10. GAINS AT THE THRESHOLD CONDITIONS IN SSSIWGL FOR EVEN AND ODD FIELDS

The absorption coefficient k depends on the population difference (N_1-N_2) between the lower energy level E_1 and the upper energy level E_2 in a two-level laser system. N_1 and N_2 are the electron densities in the lower and upper energy levels, respectively. Generally, for $E_2>E_1$ and $N_1>N_2$, the absorption coefficient k is positive. This represents a SSSIWGL with loss. In this case, there is attenuation. At the population inversion, $N_2>N_1$, the absorption coefficient k becomes negative. This case corresponds to the amplification in the SSSIWGL.

The losses in the SSSIWGL can occur due to carrier absorption and scattering at defects and inhomogeneities and other nonradiative transitions. These absorption coefficients (losses) for the regions I and III have been described by α_1 and α_3 ($\alpha_1=\alpha_3$) in the SSSIWGL in ref. (Bhattacharya, 1998) as $\alpha_1+\alpha_3+\Gamma_{II}=1$, in which Γ_{II} represents the confinement factor of the region II of the SSSIWGL. Remember that we have represented the absorption coefficients, the confinement factors with k_i (k'_i), F_i (F'_i), i=I, II, III and with $k_{1,3}$ ($k'_{1,3}$), Γ_{II} (Λ'_{II}) for even (odd) field in the regions in the ASSIWGL and SSSIWGL respectively.

As the rate of stimulated emission increases in the AR, the round-trip gain in the cavity overcomes the losses and the lasing begins. For even (odd) field the gain at which this occurs is called the threshold gain coefficient g_{th} (g'_{th}). The laser modes emerge at the threshold gain. The optical effect width in Eq. (77) or (78) is the thickness where optical mode extends for even or odd field. As it has been seen, the threshold case is an important passing point in the gain profile.

The light intensity or small-signal power gain after traveling on the length $2\ell_g$ of a waveguide is generally given by

$$G = G_o(R_1R_2)e^{2(g-|g_o|)\ell_g} \tag{139}$$

Where G_o is the initial intensity (Verdeyen, 1989), g (g') and g_o (g'_o) are respectively the gain coefficient and the total loss coefficient in the cavity per unit length for even (odd) field. If $g>|g_o|$ ($g'>|g'_o|$), the intensity grows and the SSSIWGL gives net amplification for even (odd) field. Therefore, when the round-trip gain exactly is equal to the loss at the threshold, $G=G_o$, we have

$$1 = R_1R_2e^{2(g_{th}-|g_{oth}|)\ell_g} \tag{140}$$

which yields the relation

$$g_{th} = g_{oth} + \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} \tag{141}$$

for even field (Verdeyen, 1989). In the same way we obtain

$$g'_{th} = g'_{oth} + \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} \tag{142}$$

for odd field. Eq.(141) [Eq.(142)] denotes that the total loss at the right hand side is equal to the threshold gain coefficient g_{th} [g'_{th}] at the left hand side for even (odd) field. The second term on the right hand side of Eq.(141) or Eq.(142) denotes the useful laser output (Bhattacharya, 1998). The $g\Gamma_{II}$ and $g_{th}\Gamma_{II}$ ($g'\Lambda_{II}$ and $g'_{th}\Lambda_{II}$) are respectively called modal gain and threshold modal gain (Kazarinov and Belenky, 1995) for even (odd) field. The threshold modal gains are obtained as;

$$g_{th}\,\Gamma_{II} = (1-\Gamma_{II})k_{1,3th} = \overline{K}k_{1,3th} \quad (143$$

$$g'_{th}\,\Lambda_{II} = (1-\Lambda_{II})k'_{1,3th} = \overline{q}k'_{1,3th} \tag{144}$$

from Eqs.(130), (135) and Eqs.(132), (136) for even and odd fields, respectively. Taking the equations ζ=ζ', η=η', V=V' and α=α' into account in the same SSSIWGL, we can write, (Bhattacharya, 1998),

$$g_{th}\,\Gamma_{II} = (1-\Gamma_{II})k_{1,3th} = \overline{K}k_{1,3th} = g_{oth} + \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} \tag{145}$$

and

$$g'_{th}\,\Lambda_{II} = (1-\Lambda_{II})k'_{1,3th} = \overline{q}k'_{1,3th} = g'_{oth} + \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} \tag{146}$$

or so we have the only threshold gains

$$g_{th} = \frac{1}{\Gamma_{II}}(1-\Gamma_{II})k_{1,3th} = \frac{1}{\Gamma_{II}}\overline{K}k_{1,3th} = \frac{1}{\Gamma_{II}}(g_{oth} + \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2}) \tag{147}$$

and

$$g'_{th} = \frac{1}{\Lambda_{II}}(1-\Lambda_{II})k'_{1,3th} = \frac{1}{\Lambda_{II}}\overline{q}k'_{1,3th} = \frac{1}{\Lambda_{II}}(g'_{oth} + \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2})\,. \tag{148}$$

Using Eqs. (112) and (114) in Eqs.(145) and (146), we have the efficient threshold gain coefficients in terms of absorption coefficients or some parameters of the same SSSIWGL such as g_o (g'_o), ℓ_g, R_1 and R_2 for even (odd) field as;

$$g_{th} = \frac{1}{\Gamma_{II}}\overline{K}k_{1,3th} = \frac{1-\alpha}{\eta+\alpha}k_{1,3th} = \frac{1+\alpha}{\eta+\alpha}(g_{oth} + \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2}) \tag{149}$$

and

$$g'_{th} = \frac{1}{\Lambda_{II}}\overline{q}k'_{1,3th} = \frac{1-\alpha}{\eta-\alpha}k'_{1,3th} = \frac{1-\alpha}{\eta-\alpha}(g'_{oth} + \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2})\,. \tag{150}$$

It is evident that Eqs.(149) and (150) are also functions of the NPC α and/or NF V.

The threshold loss in the SSSIWGL having parameters g_o (g'_o), ℓ_g, R_1 and R_2 is given by

$$g_{oth} = g_{th}\Gamma_{II} - \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} = (1-\Gamma_{II})k_{1,3th} - \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} = \overline{K}k_{1,3th} - \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} \tag{151}$$

or the efficient expressions

$$g_{oth} = \overline{K}k_{1,3th} - \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} = \frac{1-\alpha}{\eta+1}k_{1,3th} - \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} \quad (152)$$

in terms of the NPC α or

$$g_{oth} = \overline{K}k_{1,3th} - \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} = \frac{1-\alpha}{V\sqrt{\alpha}+1}k_{1,3th} - \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} \quad (153)$$

in terms of NPC α and NF V for even field. In the same way for odd field we have

$$g'_{oth} = g_{th}\Lambda_{II} - \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} = (1-\Lambda_{II})k'_{1,3th} - \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} = \overline{q}k'_{1,3th} - \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} \quad (154)$$

or

$$g'_{oth} = \frac{\eta-\alpha}{1+\eta-2\alpha}g'_{th} - \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} = \frac{1-\alpha}{1+\eta-2\alpha}k'_{1,3th} - \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} \quad (155)$$

in terms of the NPC α or

$$g'_{oth} = g'_{th}\Lambda_{II} - \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} = \overline{q}k'_{1,3ht} - \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} = \frac{\eta-\alpha}{1+\eta-2\alpha}g'_{th} - \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} = \frac{1-\alpha}{1+V\sqrt{L}-2\alpha}k'_{1,3th} - \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2} \quad (156)$$

in terms of the NPC α and NF V.

In the SSSIWGL with active length ℓ_g of the AR at the threshold conditions, we get threshold power gain expressions as;

$$G_{th} = e^{g_{th}\Gamma_{II}\ell_g} = e^{\ell_g(1-\Gamma_{II})k_{1,3th}} = e^{\ell_g\overline{K}_{th}} = e^{-k_2\Gamma_{II}\ell_g} \quad (157)$$

for even field and

$$G'_{th} = e^{\ell_g g'_{th}\Lambda_{II}} = e^{\ell_g(1-\Lambda_{II})k_{1,3th}} = e^{\ell_g\overline{q}k_{1,3th}} = e^{-\ell_g k'_2\Lambda_{II}} \quad (158)$$

for odd field (Verdeyen, 1989; Iga, 1994). Now, we obtain the efficient threshold gain expressions

$$G_{th} = e^{\ell_g\overline{K}k_{1,3th}} = e^{\frac{1-\alpha}{\eta+1}\ell_g k_{1,3th}} = e^{\frac{1-\alpha}{V\sqrt{\alpha}+1}\ell_g k_{1,3th}} \quad (159)$$

$$G'_{th} = e^{\ell_g\overline{q}k'_{1,3th}} = e^{\frac{1-\alpha}{1+\eta-2\alpha}\ell_g k'_{1,3th}} = e^{\frac{1-\alpha}{1+V\sqrt{L}-2\alpha}\ell_g k'_{1,3th}} \quad (160)$$

in terms of the NPC α, threshold absorption coefficients $k_{1,3th}$ ($k'_{1,3th}$) and NF V for even and odd fields in the same SSSIWGL. Therefore, we can respectively write for gain expression as;

$$G = e^{\ell_g\overline{K}k_{1,3}} = e^{\frac{1-\alpha}{\eta+1}\ell_g k_{1,3}} = e^{\frac{1-\alpha}{V\sqrt{\alpha}+1}\ell_g k_{1,3}} \quad (161)$$

$$G' = e^{\ell_g\overline{q}k'_{1,3}} = e^{\frac{1-\alpha}{1+\eta-2\alpha}\ell_g k'_{1,3th}} = e^{\frac{1-\alpha}{1+V\sqrt{L}-2\alpha}\ell_g k'_{1,3}} \quad (162)$$

for even and odd fields, in the same way.

In this new approach it has been seen that the threshold gain coefficients in Eqs.(149), (150) which are also in terms of the threshold absorption coefficients, the threshold losses in Eqs.(153), (155) in the same SSSIWGL, threshold power gains in Eqs.(159), (160) and power gains in Eqs.(161), (162) for even and odd fields have been obtained in terms of the NPC α as the efficient expressions in the alpha (α) method.

Just as, now we can give an example for n_{II}=3.351, $n_{I,III}$=3.350, a=50 A°, λ=1.55 x10^{-6} m (ℓ_g=0.05 m). We obtain V=0.00165915890946443 in Eq(26), α=2.75279818295989x10^{6} in Eq(27), L=0.99999724720182 in Eq(29), ζ=0.00165915662579804 in Eq(31), η=2.75280323490291x10^{-6} in Eq(33), $\overline{R}$=1.816326993736504x10^{5} in Eq(72), Γ_{II}=5.505586262067127x10^{-6} in Eq(116), $\overline{K}$=0.99999449441374 in Eq(112). It is seen that there is only single mode since V<1.57 (Iga, 1994).

We obtain the threshold absorption coefficients from using Eqs.(112) and (114) into Eqs.(159) and (160) for even and odd fields respectively as;

$$k_{1,3_{th}} = \frac{\ln G_{th}}{\ell_g \bar{K}} = \frac{(1+\eta)\ln 1}{\ell_g (1-\alpha)} = \frac{(1+V\sqrt{\alpha})\ln 1}{\ell_g (1-\alpha)} \quad (163)$$

$$k'_{1,3_{th}} = \frac{\ln G'_{th}}{\ell_g \bar{q}} = \frac{(1+\eta-2\alpha)\ln 1}{\ell_g (1-\alpha)} = \frac{(1+V\sqrt{\alpha}-2\alpha)\ln 1}{\ell_g (1-\alpha)} \quad (164)$$

for the same SSSIWGL. Also, using Eqs.(163) and Eq.(164) into Eqs.(149) and Eq.(150), gives the threshold gain coefficients for even and odd fields respectively as:

$$g_{th} = \frac{\ln G_{th}}{\ell_g \Gamma_{II}} \quad (165)$$

$$g'_{th} = \frac{\ln G_{th}}{\ell_g \Lambda_{II}} \quad (166)$$

in the SSSIWGL. Note that since logarithm ln1=0 here, for example, we can get the G_{th} and G'_{th} as a double precision (fairly little fraction after decimal point) such as $G_{th}=G'_{th}=1.000000000000001$. The grater this precision is, the grater truths of founded results are also. Just as, if we get G_{th} as $G_{th}=1.000000000000001$, for $\ell_g=0.05$ m, $\Gamma_{II}=3.623281563416194\text{x}10^{-5}$ and $\bar{K}=0.99996376718437$, we have the threshold absorption and gain coefficients as $k_{1,3th}=2.220458274174882\text{x}10^{-14}$ m^{-1} and $-k_2=g_{th}=4.033078301849409\text{x}10^{-9}$ m^{-1} in Eq.(163) and in Eq.(165), respectively. Consequently, we see that the threshold condition in discussed that Eq.(140) is satisfied by Eq.(157) for the absorption coefficient $k_{1,3th}$ and gain coefficient g_{th} as shown that $G_{th} = e^{g_{th}\Gamma_{II}\ell_g} = e^{-k_2\Gamma_{II}\ell_g}$=1.00000000000000 for these found results in even field.

It is obvious that there are not the values of the parameters r, $q_{I,III}$ and Λ_{II} for odd field since V<1.57.

At the threshold, we can obtain the total threshold loss of the material of the SSSIWGL for even field as;

$$g_{oth} = \frac{\ln G_{th}}{\ell_g} - \frac{1}{2\ell_g}\ln\frac{1}{R_1 R_2} \quad (167)$$

by using Eq.(163) into Eq.(153) and for odd field as;

$$g'_{oth} = \frac{\ln G'_{th}}{\ell_g} - \frac{1}{2\ell_g}\ln\frac{1}{R_1 R_2} \quad (168)$$

by using Eq.(164) into Eq.(156). For example, for $G_{th}=1.000000000000001$, $R_1=0.999$ and $R_2=0.995$, $\ell_g=0.05$ m Eqs.(167) gives the threshold losses $g_{oth}=-1.503260539059904\text{x}10^{-4}$ m^{-1} in the SSSIWGL.

$g_{th} = g_{oth} + \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2}$ in Eq(141) gives $g_{th} - g_{oth} = \frac{1}{2\ell_g}\ln\frac{1}{R_1R_2}=1.503300869842922\text{x}10^{-4}$ and $1 = R_1R_2e^{2(g_{th}-|g_{oth}|)\ell_g}$ in Eq(140) yields 0.99401994299813. So, smaller the difference of g_{th}-g_{oth} is, Eq(140) is approaches 1. This case is determined by R_1 and R_2.

The multimode corresponds to the case V>1.57 (Iga, 1994). Therefore, there are more modes in the following example, since V>1.57.

As a matter of fact, now we can give another example for V=2 which gives $\alpha=0.734843732945432$, L=0.26515626705457, $\zeta=1.02986652932226$ and $\eta=1.71446053666503$, $\bar{R}=0.10825778991384$, $\bar{r}=0.27067345726183$, $\Gamma_{II}=0.78698425176433$, $\Lambda_{II}=0.78698425176433$, $\bar{K}=0.09768285943856$, $\bar{q}=0.21301574823567$. There are also the parameters $\bar{r}$, $\bar{q}$ and Λ_{II} for odd field, since V>1.57 with $\bar{R}$, $\bar{K}$ and Γ_{II}. That is, in this example there is only one mode for each of even and odd fields for V=2.

We can give second example for odd field here. For $\ell_g=0.05$ m and $\Lambda_{II}=0.78698425176433$ and $\bar{q}=0.21301574823567$, if we get G_{th} as $G_{th}=1.000000000000001$, we have calculated the threshold absorption coefficient and threshold gain coefficient as $k'_{1,3th}=1.042385864726654\text{x}10^{-13}$ m^{-1} and $-k'_2=g'_{th}=2.821461858064267\text{x}10^{-14}$ m^{-1} in Eqs.(164) and (166), respectively. We see also that the threshold condition in discussed Eq.(140) is satisfied by Eq.(160) for these threshold absorption $k'_{1,3th}$ and threshold gain coefficient g'_{th} coefficient for odd field, as easily shown that $G'_{th} = e^{g'_{th}\Lambda_{II}\ell_g} = e^{-k'_2\Lambda_{II}\ell_g}$=1.00000000000000 for these found results.

Our results of this work are suitable found results in ref. (Popescu, 2005). Because, for values $\lambda=0.5145\text{x}10^{-6}$ m, $n_{I,III}=1.55$, $n_{II}=1.57$, 2*a*=1 μm=10000 A^o in ref. (Popescu, 2005), we have achieved normalized frequency as V=3.0506106640935 in our method. Whereas, V has given by Popescu as 3.05061, as shown in ref. (Popescu, 2005). It is seen that the normalized frequency V found in our method is more sensitive than the normalized frequency in ref (Popescu, 2005).

Thus, we have seen from the samples above that Eq.(140) is numerically satisfied by found results for even and odd fields at the threshold. In fact, to initiate oscillation fast, it is generally pumped by 4 times threshold gain coefficient (Verdeyen, 1989) such as $4g_{th}$ practically and so the modal gain at the beginning becomes bigger than the threshold modal gain $g_{th}\Gamma_{II}$ or $g'_{th}\Lambda_{II}$.

11. GAIN COEFFICIENTS AND LASER GAIN FOR EVEN AND ODD FIELD IN SSSIWGL

Taking Eqs.(137), (138) and Eqs.(149), (150) into account, the absorption coefficients or gain coefficients at the outside of the threshold condition can be in the similar way written as;

$$k_{1,3} = \frac{g\Gamma_{II}}{2\Gamma_{I,III}} = \frac{g\Gamma_{II}}{1-\Gamma_{II}} = \frac{g\Gamma_{II}}{\overline{K}} = \frac{g}{\overline{R}} \tag{169}$$

and

$$k'_{1,3} = \frac{g'\Lambda_{II}}{\Lambda_{I,III}} = \frac{g'\Lambda_{II}}{1-\Lambda_{II}} = \frac{g'_{th}\Lambda_{II}}{\overline{q}} = \frac{g'}{\overline{r}} \tag{170}$$

or for amplification

$$-k_2 = g = \frac{1}{\Gamma_{II}}\overline{K}k_{1,3} \tag{171}$$

and

$$-k'_2 = g' = \frac{1}{\Lambda_{II}}\overline{q}k'_{1,3} \tag{172}$$

for even and odd electric field waves, respectively. On the other hand, using Eqs.(169) and (170) into Eqs.(161) and (162) gives the gain coefficients in terms of the power gains

$$g = \frac{\ln G}{\ell_g\Gamma_{II}} \text{ (=-}k_2\text{ for amplification)} \tag{173}$$

and

$$g' = \frac{\ln G'}{\ell_g\Lambda_{II}} \text{ (=-}k'_2\text{ for amplification)} \tag{174}$$

in the SSSIWGL at any absorption or gain level for even and odd electric field waves, respectively.

Note that Eqs. (171) and (172) give respectively gain coefficient in terms of NPC α and absorption coefficient for related regions I and III for even and odd electric field waves in the same SSSIWGL. Figure 8 and Figure 9 show the ratios of absorption coefficients to the gain coefficients in terms of NPC α for η=1.71446053666503 as $\frac{k_{1,3}}{g} = \frac{\eta+\alpha}{1-\alpha} = \frac{1}{\overline{R}}$ and $\frac{k'_{1,3}}{g'} = \frac{\eta-\alpha}{1-\alpha} = \frac{1}{\overline{r}}$ in even and odd fields, respectively. The relations of absorption coefficients and the gain coefficients for even and odd fields are important two formulas of the efficient results. The ordinate η=1.71446053666503 corresponds to abscissa ζ=1.02986652932226 of the energy eigenvalue of the electrons in the normalized coordinate system ζ-η for V=2, as given above example. Note that the curves in Figure 8 and Figure 9 of the lowest modes for even and odd fields are fairly different in amplitudes of the ratios of absorption coefficients to the gain coefficient.

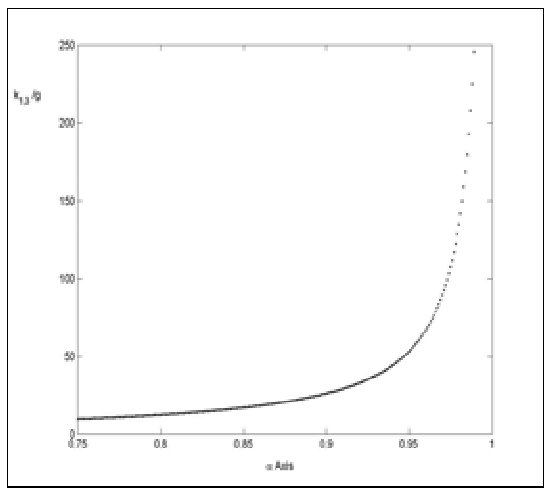

Figure 8. The curve of the ratio of absorption coefficient to the gain coefficient against NPC α in even field.

For ℓ_g=0.05 m, $\overline{K}$=0.09768285943856, $\overline{q}$=0.21301574823567, Γ_{II}=0.78698425176433, Λ_{II}=0.78698425176433, and laser gain G=G'=2000, the absorption coefficients and the gain coefficients for even and odd fields are obtained from Eqs.(161),

(162) and Eqs.(173), (174) as $k_{1,3}$=1.556240778214087x10^3 m^{-1}, $k'_{1,3}$=7.136469976983041x10^2 m^{-1} and $-k_2$=g=1.684751872232560x10^2 m^{-1} and $-k'_2$=g'=1.931653001315258x10^2 m^{-1}, respectively. Just as, we can see that the found these gain coefficients g and g' give the found absorption coefficients $k_{1,3}$ and $k'_{1,3}$, in Eqs.(169), (170) respectively. These calculations confirm accuracy and sensibility of this alpha (α) method.

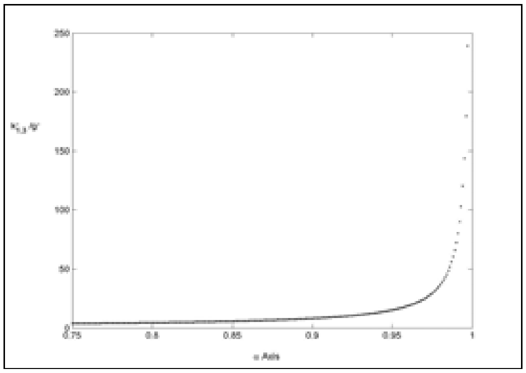

Figure 9. The curve of the ratio of the absorption coefficient to the gain coefficient against NPC α in odd field.

12. RESULTS

In this work, firstly the parametric variables ζ and η of the EEVs for carriers and some probability ratios and the confinement factors in terms of these variables for the ASSIWG have been obtained. Also, we have got some probability ratios and the confinement factors in terms of NPC α or NF V for the SSSIWGL.

It has been shown that these parametric variables ζ and η vary non-linearity for the ASSIWGL. They are constants on the vertical axis for the SSSIWGL as shown in Figure-6 and Figure-7, respectively. Furthermore, as efficient expressions, the threshold absorption coefficients, the threshold gain coefficients, the threshold power gains and the power gains for each of even and odd field have been evaluated in terms of parametric variables ζ and η, the NPC α or NF V, individually. On the other hand, the total loss of the region expressions in threshold conditions in terms of the NPC α for both the even and the odd fields were obtained.

Initially, some special probability ratios, the confinement factors and some special relations of the quantities for the same ASSIWGL and SSSIWGL for both the even and odd fields have particularly been obtained. Besides the threshold absorption coefficients, the threshold gain coefficients, the threshold total losses, the threshold power gains, the power gains expressions, the absorption coefficients, the gain coefficients for the same SSSIWGL have also obtained initially in terms of the NPC α during this theoretical alpha (α) approach. These are all efficient and important expressions and hence it can be argued that the alpha (α) approach presents an efficient method, especially for the design considerations in this field.

It must also noted that the threshold gain coefficients give the threshold power gains almost as a unity (with very precision) in the SSSIWGL.

On the other hand, in case if the length ℓ_g of waveguide, reflection coefficients R_1 and R_2, expected gain G of the waveguide are given, then the absorption coefficients, the gain coefficients, total losses of the device and the ratios of the absorption to the gain coefficients for even and odd fields in the SSSIWGL can theoretically be evaluated efficiently by means of the proposed α approach.

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