Theoretical analysis of the incremental band gap and effective electron mass in n-$In_{1-x}Ga_xAs_yP_{1-y}$ in accordance with the perturbed Two and Three band model of Kane

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Abstract— We are going to demonstrate a simple theoretical analysis of the effective electron mass (EEM)in the presence of light waves at the Fermi level for n-$In_{1-x}Ga_xAs_yP_{1-y}$materials whose unperturbed energy bands are defined by the two-band and three-band model of Kane. The conduction band moves vertically upward and the band gap increases with the intensity, wavelength of light in the presence of light i.e. the unperturbed isotropic energy spectrum changes into an anisotropic dispersion relation in the presence of light. We have also observed that the EEM varies proportionally with electron concentration, intensity and wavelength in different manners. The effective momentum mass (EMM) at the Fermi level is dependent on both the wavelength and light intensity. The nature of change is totally dependent on the band-structure and is affected by the different energy band constants.

Index Terms— Effective Momentum Mass, Kane Two & Three band model, Perturbation.

I. INTRODUCTION

Among the numerous definitions of the effective electron mass (EEM), we havenoted that it is the effective momentum mass (EMM) that should be considered as the basic quantity since it is the mass that appears in the description of transport phenomena and all other properties of the conduction electrons in a band with arbitrary band non-parabolicity[4].Various variations of EMM with quantizing electric and magnetic field are available.An interest in analyzing the EMM for ternary materials have been created because of the availability of various energy wave vector dispersion relations. Sometime it varies with electron concentration or sometimes with heavily doped materials with band tails. Due to SdH effect,EMM oscillates with inverse quantizing magnetic fields. The EMM in quantum wells and quantum wires is dependent on Fermi Energy and quantum numbers. However some moderate discussion about EMM for ternary materials is required.

We have made us ofn-$In_{1-x}Ga_xAs_yP_{1-y}$ lattice matched to InP as an example of III-V quaternary compound semiconductor. It is an important material for optoelectronic applications and a classic narrow gap compound and an important material for optoelectronic applications whose band gap can be varied to cover a spectral range from 0.8μm-30 μm, just by adjusting the alloy composition[40].In this paper we have made the calculation of the dispersion relation of conduction electron of III-V quaternary materials in presence of light-wave whose unperturbed electron energy spectrum is described in three bandmodel of Kane. The two band model of Kane has been used to study the dispersion relation for the said material in presence of external photo excitation for the purpose of the relative comparison. The expression for EMM is calculated for all the above mentioned cases.

II. THEORETICAL BACKGROUND

Electron Dispersion Law in presence of light wave in n-$In_{1-x}Ga_xAs_yP_{1-y}$

With the application of electro magnetic field (characterizing a light wave with vector potential $(\vec{X})$ the Hamiltonian for conduction electron is given by [27]

$$\bar{H}=\frac{(\vec{s}+e\vec{X})^2}{2m_c}+V(\vec{r})$$

(1)

Where $\vec{s}$ is the momentum vector, $\vec{X}$is the vector potential, $V(\vec{r})$ is the crystal potential and m_c is the EMM in absence of any field. With reference to the standard theory of radiation, we assume $(\nabla.\vec{A})$ =0 and $[\vec{s},\vec{X}]$ =0 and therefore equation (1) can be modified as

$$\frac{(\vec{s}+e\vec{X})^2}{2m_c}=\frac{(s^2+e(\vec{s}\cdot\vec{X}+\vec{X}.\vec{s})+X^2)}{2m_c}$$

With $|\vec{X}|^2$ =0 and $\vec{s}\cdot\vec{X}$ =0

$$\frac{(\vec{s}+e\vec{X})^2}{2mc}=\frac{s^2}{2mc}+\frac{e.\vec{X}\vec{s}}{2mc}$$

Therefore equation (1) can be rewritten as

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$\overline{H}=\overline{H}_0+\overline{H'}$,

where $\overline{H}_0=\frac{s\ 2}{2m_c}+V(\vec{r})$ (2)

and $\overline{H'}=\frac{e}{2m_c}.\vec{X}.\vec{s}$

(3)

Here $\overline{H'}$ represents perturbation to the unperturbed Hamiltonian $\overline{H}_0$. We can rewrite equation (3) as

$$\overline{H'}=\left(\frac{-i\hbar e}{2mc}\right)(\vec{X}.\nabla) \quad (4)$$

The vector potential ($\vec{X}$) of a plane wave can be written as

$$\vec{X}=X_0\vec{\varepsilon}_s\cos(\vec{b}_0.\vec{r}-\omega t)$$

(5)

Where X_0 is the amplitude of the light wave, $\bar{\varepsilon}_s$ is the polarization vector, $\bar{b}_0$ is the momentum vector of the incident photon, $\vec{r}$ is the position vector and ω is the angular frequency of light wave. From equation (4) and (5), considering initial and final state [16]

$$\overline{H'}_{nl}=\frac{e}{2m}<n\vec{k}|\vec{A}.\vec{p}|l\vec{q}> \quad (6)$$

This in turn gives,

$$\overline{H'}_{nl}=\left(\frac{-A0i\hbar e}{4mc}\right).\vec{\varepsilon}_s.$$
$$\{<n\vec{k}|\exp(i\vec{b}0.\vec{r})\nabla|l\vec{q}>e^{-i\omega t}\}+\{<n\vec{k}|\exp(-i\vec{b}0.\vec{r})\nabla|l\vec{q}>e^{i\omega t}\} \quad (7)$$

The first matrix element of equation (7) can be written as[27]

$$<n\vec{k}|\exp(i\vec{b}0.\vec{r})\nabla|l\vec{q}>$$
$$=\int\exp(i[\vec{q}+\vec{b}0-\vec{k}].\vec{r})i\vec{q}u_n{}^*(\vec{k},\vec{r})u_1(\vec{q},\vec{r})d^3r$$
$$+\int\exp(i[\vec{q}+\vec{b}0-\vec{k}].\vec{r})u_n{}^*(\vec{k},\vec{r})\nabla u_1(\vec{q},\vec{r})d^3r$$

(8)

The functions (u_n^* u1) and($u_n^*\nabla$ u_1)are periodic .The electromagnetic wavelength is sufficiently large so that $\vec{k}$ and $\vec{q}$ are within the Brilloun zone. The integral over all space is separated into a sum over unit cells times an integral over a single unit cell[34].

Therefore equation (8) can be written as

$$<n\vec{k}|\exp(i\vec{b}0.\vec{r})\nabla|l\vec{q}>=\left[\frac{(2\pi)3}{\Omega}\right]\times$$
$$\{i\vec{q}\delta(\vec{q}+\vec{b}0-\vec{k})\,\delta_{nl}(\vec{q}+\vec{b}0-\vec{k}).$$
$$\int_{cell}u_n^*(\vec{k},\vec{r})\nabla u1(\vec{q},\vec{r})d^3r\}$$
$$=\left[\frac{(2\pi)3}{\Omega}\right]\{\delta(\vec{q}+\vec{b}0-\vec{k})$$
$$\int_{cell}u_n^*(\vec{k},\vec{r})\nabla u1(\vec{q},\vec{r})d^3r\} \quad (9)$$

Here Ω is the volume of the unit cell and $\int u_n^*(\vec{k},\vec{r})u1(\vec{q},\vec{r})d^3r=\delta(\vec{q}-\vec{k})\delta_{nl}=0$, since n and l are not equal. From equation (6) and (9) we can write

$$\overline{H'}_{nl}=\frac{eA_0}{2m_c}\vec{\varepsilon}_s.\overrightarrow{s_{nl}}(\vec{k})\,\delta(\vec{q}-\vec{k})\cos(\omega t)$$

(10)

Where $\bar{p}_{nl}(\vec{k})=-i\hbar\int u_n^*\nabla u_l d^3r=\int u_n^*(\vec{k},\vec{r})\vec{p}u_1(\vec{k},\vec{r})d^3r$

Therefore we have

$$\overline{H'}_{nl}=\frac{eA_0}{2m_c}\vec{\varepsilon}_s.\overrightarrow{p_{nl}}(\vec{k}) \quad (11)$$

We can neglect the transition of the electrons in the same band because of recombination process. So we may have, $<n\vec{k}|H'|n\vec{k}>=0$

The second order perturbed energy now can be written as

$$E_n^{(2)}(\vec{k})=E_n(\vec{k})+$$
$$<n\vec{k}|\overline{H'}|n\vec{k}>+\frac{|<n\vec{k}|\overline{H'}|l\vec{k}>|^2}{E_n(\vec{k})-E_l(\vec{k})}$$

(12)

With n=c (conduction band) and l=v (valance band), the energy equation for conduction electrons assumes the form

$$E_c^{(2)}(\vec{k})=E_c(\vec{k})+\frac{\left(\frac{eA_0}{2m_c}\right)^2|\overrightarrow{\varepsilon_s}.\overrightarrow{s_{cv}}(\vec{k})|^2}{E_c(\vec{k})-E_v(\vec{k})} \quad (13)$$

Where $|\overrightarrow{\varepsilon_s}.\overrightarrow{s_{cv}}(\vec{k})|^2$ represents square of OME. According to three band model of Kane,

$$\xi\ 1k=E_c(\vec{k})-E_v(\vec{k})=\left(E_{g0}^2+E_{g0}\overline{h^2}\frac{k^2}{m_x}\right)^{\frac{1}{2}}$$

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(14)

$$\gamma(E)=\frac{\overline{h^2}k^2}{2m_c}$$

(15)

and

$$\left(\frac{eA_0}{2m_c}\right)^2 \cdot \frac{\left|\overrightarrow{\varepsilon_s}.\overrightarrow{S_{cv}}(\vec{k})\right|^2}{E_c(\vec{k})-E_v(\vec{k})}=$$

$$\left(\frac{eA_0}{2m_c}\right)^2\frac{2\pi}{3}\left|\overrightarrow{\varepsilon_s}.\overrightarrow{S_{cv}}(0)\right|^2\frac{\beta^2}{4}\left(t+\frac{\rho}{\sqrt{2}}\right)^2 x$$

$$\frac{1}{\xi_{1k}}\{(1+\frac{E_g-\delta'}{\xi_{1k}+\delta'})+(E_g-\delta')$$

$$\left[\frac{1}{\xi_{1k}+\delta'}-\frac{1}{E_g+\delta'}\right]^{\frac{1}{2}} x \left[\frac{1}{\xi_{1k}+\delta'}-\frac{E_g+\delta'}{(E_g-\delta')^2}\right]^{\frac{1}{2}}\}^2$$

(16)

In which E_{g0} is the unperturbed band gap, m_r is the reduced mass given by $m_r^{-1}=m_c^{-1}+m_v^{-1}$, m_v is the effective mass of heavy hole, $\gamma(E)=E(aE+1)(bE+1)/(cE+1)$, $a=E_{g0}^{-1}$, $b=(E_{g0}+\Delta)^{-1}$, Δ is the spin orbit splitting factor and $c=(E_{g0}+2\Delta/3)^{-1}$.

Following the perturbation theory and using appropriate equations we can write

$$\gamma(E)=\frac{\overline{h^2}k^2}{2m_c}+\left(\frac{eA_0}{2m_c}\right)^2\frac{2\pi}{3}\left|\overrightarrow{\varepsilon_s}.\overrightarrow{S_{cv}}(0)\right|^2\frac{\beta^2}{4}\left(t+\frac{\rho}{\sqrt{2}}\right)^2 x$$

$$\frac{1}{\xi_{1k}}\{(1+\frac{E_g-\delta'}{\xi_{1k}+\delta'})+(E_g-\delta')$$

$$\left[\frac{1}{\xi_{1k}+\delta'}-\frac{1}{E_g+\delta'}\right]^{\frac{1}{2}} x \left[\frac{1}{\xi_{1k}+\delta'}-\frac{E_g+\delta'}{(E_g-\delta')^2}\right]^{\frac{1}{2}}\}^2$$

It can be shown that[30],

$$X_0^2=\frac{I\lambda^2}{2\pi^2c^3\sqrt{\epsilon\epsilon_0}} \qquad (17)$$

Where I is the light intensity of wavelength λ, c is the velocity of light, ϵ is the permittivity of semiconductor and ϵ_0 is the permittivity of vacuum. Thus the simplified electron energy spectrum in III-V, quaternary materials like *n-*$In_{1-x}Ga_xAs_yP_{1-y}$ in the presence of light waves can be expressed as

$$\frac{\overline{h^2}k^2}{2m_c}=\beta_0(E,\lambda) \qquad (18)$$

Where, $\beta_0(E,\lambda)=\gamma(E)-\theta_0(E,\lambda)$ (19)

$$\theta_0(E,\lambda)=\frac{e^2}{48m_x\pi c^3}\frac{I\lambda^2}{\sqrt{\epsilon\epsilon_0}}\frac{E_{g0}\,(E_{g0}+\Delta)}{\left(E_{g0}+\left(\frac{2}{3}\right)\Delta\right)}\frac{\beta^2}{4}\ x$$

$$\left(t+\frac{\rho}{\sqrt{2}}\right)^2\frac{1}{\emptyset_0(E)}\{(1+\frac{E_{g0}-\delta'}{\emptyset_0(E)+\delta'})$$

$$+(E_{g0}-\delta')[\frac{1}{\emptyset_0(E)+\delta'}-\frac{1}{E_{g0}+\delta'}]^{1/2}\ x$$

$$[\frac{1}{\emptyset_0(E)+\delta'}-\frac{E_{g0}+\delta'}{(E_{g0}-\delta')^2}]^{1/2}\}^2 \qquad (20)$$

And

$$\emptyset_0(E)=E_{g0}(1+2(1+\frac{m_c}{m_v})\frac{\gamma(E)}{E_{g0}})^{1/2} \qquad (21)$$

Thus under the limiting condition $\vec{k}\rightarrow 0$, from equation (18), we observe that $E\neq 0$ and is positive. Therefore , the energy of the electron does not tend to zero when $\vec{k}\rightarrow 0$, whereas for the un-perturbed three-band model of Kane, $\gamma(E)=\frac{\overline{h^2}k^2}{2m_c}$ in which $E\rightarrow 0$ for $\vec{k}\rightarrow 0$. Therefore this will provide the increased band gap(ΔE_g) of the semiconductor due to photon excitation. The values of the increased band gap can be obtained for various values of I and λ. This implies that when a semiconductor is exposed to a light wave, band gap gets perturbed with an increased band gap depending on the intensity of light and the color of light wave.

Special cases

For the two-band model of Kane, we have $\Delta\rightarrow 0$. Under this case, $\gamma(E)\rightarrow E(1+\alpha E)=\frac{\overline{h^2}k^2}{2m_c}$ with $\alpha=1/E_{g0}$. Since $\beta\rightarrow 1$, $t\rightarrow 1$, $\rho\rightarrow 0$, $\delta'\rightarrow 0$ for $\Delta\rightarrow 0$, from equation (18), we can write the energy spectrum for n-$In_{1-x}Ga_xAs_yP_{1-y}$materials in the presence of external photo-excitation whose unperturbed conduction electrons obey the two-band model of Kane as

$$\frac{\overline{h^2}k^2}{2m_c}=\omega_0(E,\lambda) \qquad (22)$$

Where$\omega_0(E,\lambda)=E(1+\alpha E)-B_0(E,\lambda)$

$$B_0(E,\lambda)=\frac{e^2I\lambda^2E_{g0}}{192\pi c^3m_x\sqrt{\epsilon\epsilon_0}}\frac{1}{\emptyset_1(E)}$$

$$\{(1+\frac{E_{g0}}{\emptyset_1(E)})+E_{g0}[\frac{1}{\emptyset_1(E)}-\frac{1}{E_{g0}}]\}^2$$

$$\emptyset_1(E)=E_{g0}\left\{1+\frac{2m_c}{m_x}\frac{E(1+\alpha E)}{E_{g0}}\right\}^{1/2}$$

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*When the unperturbed conduction band is approximated by the parabolic electron energy spectrum, we can write $a \rightarrow 0$, $b \rightarrow 0$, $c \rightarrow 0$ and $\gamma(E) \rightarrow E$. Thus , again from equation (18),

$$\frac{\bar{h}^2 k^2}{2m_c} = \rho_0(E,\lambda) \quad (23)$$

$$\rho_0(E) = E - \frac{e^2 I \lambda^2}{48\pi c^3 m_x \sqrt{\epsilon\epsilon_0}} \quad (24)$$

EMM in the presence of light wave in n-$In_{1-x}Ga_xAs_yP_{1-y}$

The effective momentum mass can be written as[3]

$$m^*(E_F) = [(\bar{h}k)/(\frac{1}{\bar{h}}\frac{\delta E}{\delta k})]|_{E=E_F} = \bar{h}^2 k \frac{\delta k}{\delta E}|_{E=E_F} \quad (25)$$

Using (18) & (25) we have

$$m^*(E_F) = m_c[\gamma'(E_F) - \theta_0'(E_F,\lambda)] \quad (26)$$

Where symbols with prime indicate differentiation with respect to E_F. Thus EMM requires electron statistics which comes from density of states function. Using (18) the DOS for *n-$In_{1-x}Ga_xAs_yP_{1-y}$* in presence of light wave can be expressed as

$$D_0(E) = 4\pi\left(\frac{2mc}{h^2}\right)^{\frac{3}{2}}\sqrt{\beta 0(E,\lambda)}\,\beta_0'(E,\lambda) \quad (27)$$

Where $\beta_0'(E,\lambda) = \frac{\delta}{\delta E}[\beta 0(E,\lambda)]$

Applying Fermi-Dirac occupancy probability on (27) and using the concept of generalized Somerfield's lemma [30], the electron concentration is expressed as

$$n_0 = (3\pi^2)^{-1}\left(\frac{2mc}{h^2}\right)^{\frac{3}{2}}[M_1(E_F,\lambda) + N_1(E_F,\lambda)] \quad (28)$$

where,

$$M_1(E_F,\lambda) \equiv [\beta_0(E_F,\lambda)]^{3/2}$$

$$N_1(E_F,\lambda) = \sum_{r=1}^{s'} L(r,0) M1(E_F,\lambda)$$

$$L(r,J) \equiv [2(k_B T)^{2r}(1-2^{1-2r})\xi(2r)]\left[\frac{\partial^{2r+J}}{\partial E_F^{2r+J}}\right]$$

Again r, J is the sets of real positive integers and ξ (2r) is the ξ function of order 2r[52].

Now expression of EMM and n_0 for n-$In_{1-x}Ga_xAs_yP_{1-y}$in presence of light wave whose unperturbed conduction electrons obey the two band model of Kane can be expressed as

$$m^*(E_F) = m_c[(1+2\alpha E_F) - B_0'(E_F,\lambda)] \quad (29)$$

$$n_0 = (3\pi^2)^{-1}\left(\frac{2mc}{h^2}\right)^{\frac{3}{2}}[M_2(E_F,\lambda) + N_2(E_F,\lambda)] \quad (30)$$

where $M_2(E_F,\lambda) \equiv [\omega_0(E_F,\lambda)]^{3/2}$ and $N_2(E_F,\lambda) = \sum_{r=1}^{b'} L(r,0) M_2(E_F,\lambda)$

EMM in the absence of light wave in n-$In_{1-x}Ga_xAs_yP_{1-y}$

(A) According to the three band model of Kane the EMM and n_0 can be expressed as

$$m^*(E_{F_0}) = m_c[\gamma'(E_{F_0})] \quad (31)$$

$$n_0 = (3\pi^2)^{-1}\left(\frac{2mc}{h^2}\right)^{\frac{3}{2}}[M_4(E_{F_0}) + N_4(E_{F_0})] \quad (32)$$

Where $M_4(E_{F_0}) \equiv [\gamma(E_{F_0})]^{3/2}$ and $N_4(E_{F_0}) = \sum_{r=1}^{S'} L(r,0) M_4(E_{F_0})$

(B) With reference two band model of Kane thee expressions for EMM and n_0 are given by

$$m^*(E_{F_0}) = m_c[(1+2\alpha E_{F_0})] \quad (33)$$

$$n_0 = (3\pi^2)^{-1}\left(\frac{2mc}{h^2}\right)^{\frac{3}{2}}[M_5(E_{F_0}) + N_5(E_{F_0})] \quad (34)$$

where $M_5(E_{F_0}) \equiv [E_{F_0}(1+2E_{F_0})]^{3/2}$ and

$$N_5(E_{F_0})] = \sum_{r=1}^{b'} L(r,0) M_5(E_{F_0})$$

(c) As a special case with $\Delta >> E_{g0}$ or $\Delta << E_{g0}$ together with the condition $\alpha E_{F_0} << 1$, equation(34) reduced to the form

$$n_0 = N_c\left[F_{\frac{1}{2}}(\eta) + \left(\frac{15\alpha k_B T}{4}\right)F_{\frac{3}{2}}(\eta)\right] \quad (35)$$

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where $N_c=2(2\pi m_c k_B T/h^2)^{3/2}$, $\eta=E_{F_0}/k_B T$ and $F_t(\eta)$ is the one parameter Fermi-Dirac integral of order t_0 which can be written as [31]

$$F_{t0}(\eta)=\left(\frac{1}{\Gamma(t_0+1)}\right)\int_0^{\infty} y^{t0}\,(1+\exp\,(y-\eta))^{-1}\,dy \quad , \; y>-1 \qquad (36)$$

The Gamma function is complex here and continued as a complex contour integral towards the negative axis. So,

$$F_{t0}(\eta)=A_{t0}\int_{-\infty}^{0+} y^{t0}\,(1+\exp-y-\eta))^{-1}\,dy \qquad (37)$$

In which $A_{t0} = \Gamma(-t_0)/2\pi\sqrt{-1}$

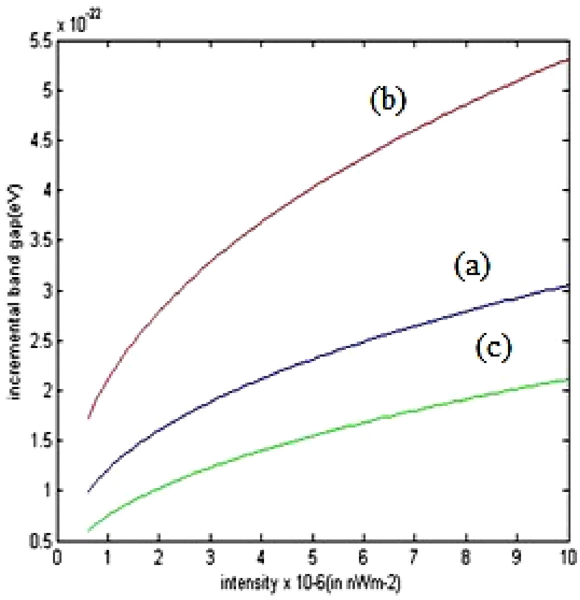
(D) Under the condition $E_g \rightarrow \infty$, we have the simplified results [31],given as

$$m^*(E_F)= m_c\;,\; n_0=N_c F_{\frac{1}{2}}(\eta) \qquad (38)$$

III. Results and Discussions

Using the appropriate equations, we have plotted (figure 1) incremental band gap (ΔEg) of $n\text{-}In_{1-x}Ga_xAs_yP_{1-y}$ as a function of I (for a given wavelength λ= 660 nm) at T = 4.2K in figure 1 using $x = 0.2$, $m_v= 0.4m0$, $\varepsilon r = 12.642$, $\Delta = (0.063 + 0.24x + 0.27x2)$eV, $Eg_0 = [-0.302 + 1.93x + 5.25\times10^{-4} T(1-2x)-0.810x^2 + 0.832x^3]$ eV. In figure 2, we have plotted the increased band gap for the same semiconductors as a function of λ assuming I =10nWm $^{-2}$ for the purpose of numerical computations. In figure 3, and also in figure 4 we have plotted the EMM as functions of wavelength and electron concentration respectively.

The ΔEg increases with increasing I for both perturbed three and two band models of Kane and as well as with perturbed parabolic energy band models. We observed that for a given value of the intensity of light, when a semiconductor is exposed to different colors of light, the band gap of the semiconductor also increases with the wavelength of light although the rate of change is totally different as compared with the curves of figure 1. The influence of light is apparent from the plots in figures 3,since the EMM depends strongly on $I$and $\lambda$for the three- and the two-band model of Kane which is in direct contrast with that for the bulk specimens of said compounds in the absence of external photo-excitation. The variations of the EMM in figure 4 reflect the direct signature of the light wave on the band-structure dependent physical properties of semiconductors in general in the presence of external photo-excitation and the photon assisted transport for the corresponding photonic devices. The numerical values of the EMM in the presence of the light waves are larger than that of the same in the absence of light waves for both the three- and the two-band model of Kane. Although the EMM tends to increase with the intensity and the wavelength, the rate of increase is totally band-structure dependent. It appears that the numerical values of the EMM are greatest for ternary materials and least for quaternary compounds.



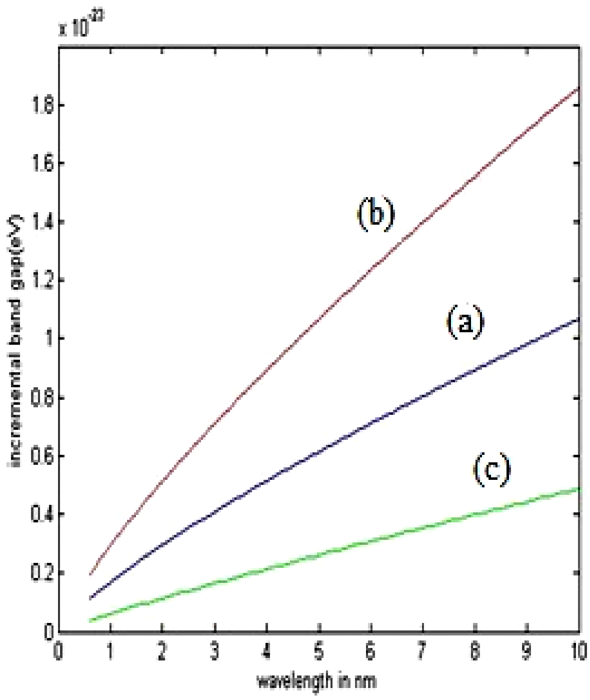


Figure 1 & 2 :(a) and (b) represent the variations according to perturbed three- and two-band models of Kane respectively. The curve (c) represents the same variation in $n\text{-}In_{1-x}Ga_xAs_yP_{1-y}$ in accordance with the perturbed parabolic energy bands

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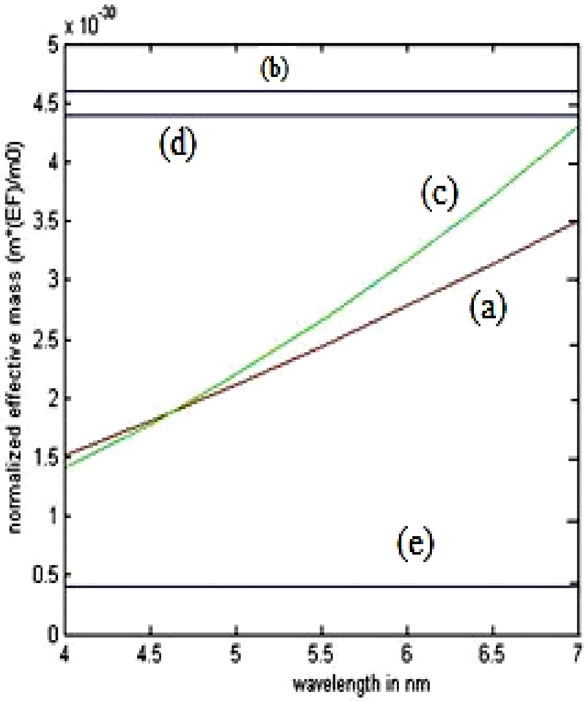

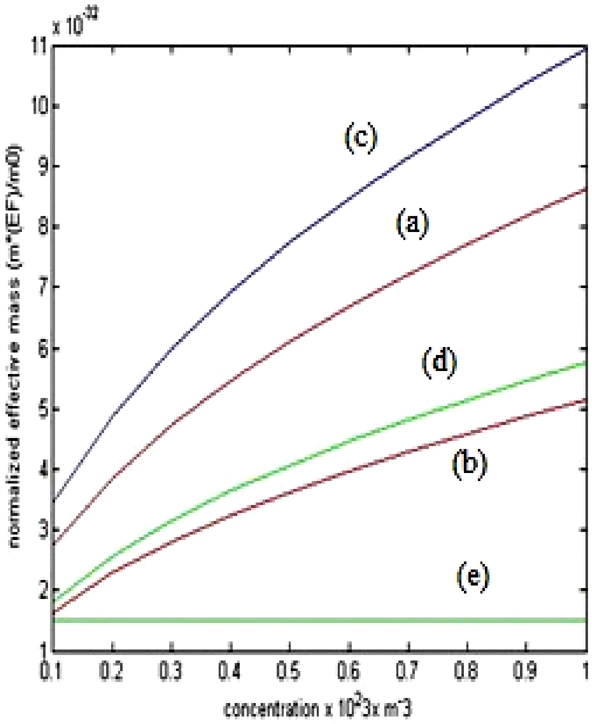

Figure 3 &4:EMMn-$In_{1-x}Ga_xAs_yP_{1-y}$ in the presence of light waves in which the curves (a) and (c) represent the three- and two-band models of Kane respectively. The curves (b) and (d) exhibit the same variation in the absence of external photo-excitation. The curve (e) represents the parabolic energy band model both in the presence and in the absence of the external photo-excitation.

The theoretical results of our paper will be useful in determining the mobility, even for relatively wide gap compounds whose energy band structures can be approximated by the parabolic energy bands, both in the presence and absence of light waves. It is worth remarking that our basic equations (20-24), cover various materials with different energy band structures. In this paper, the concentration, alloy composition, light intensity and the wavelength dependences of the EMM for $n\text{-}In_{1-x}Ga_xAs_yP_{1-y}$ lattice matched to InP have been studied. Thus, we have covered a class of optoelectronic and allied compounds whose energy band structures are defined by the three- and two-band models of Kane in the absence of photon field. This analysis not only shows the mathematical compatibility of our formulation but also shows the fact that our discussion is a more generalized one, since one can obtain the corresponding results for the relatively wide gap materials having parabolic energy bands under certain limiting conditions from our present derivation.

REFERENCES

[1] Adachi S J 1985 *Appl. Phys.* **58** R11
[2] Zawadzki W 1982 *Handbook of Semiconductor*
[3]Tsidilkovski I M 1955 *Cand. Thesis* (Leningrad UniversitySSR)i
[4] Mitra B and Ghatak K P 1989 *Phys. Scr.* **40** 776Biswas S .K, Ghatak A R, Neogi A, Sharma A, Bhattacharya S and Ghatak K P 2007 *Physica*E **36** 163
[5] Mondal M, Banik S and Ghatak K P 1989 *J. Low Temp. Phys.***74** 423
[6] Ghatak K P, Bhattacharya S, Saikia H and Sinha A 2006 *J. Comput. Theor. Nanosci.* **3** 1
[7] Ghatak K P and Biswas S N 1989 *J. Vac. Sci. Technol.* B **7** 104 Chakraborty P K, Choudhury S and Ghatak K P 2007 *Physica*B**387** 33
[8] Bhattacharya S, Pahari S, Basu D K and Ghatak K P 2006 *J.Comput. Theor. Nanosci.* **3** 280
Sinha A, Sharma A K, Barui R, Ghatak A R, Bhattacharya Sand Ghatak K P 2007 *Physica*B **391** 141
[9] Chakraborty P K, Nag B and Ghatak K P 2003 *J. Phys. Chem. Solids* **64** 2191
[10] Ghatak K P, Basu D K and Nag B 1997 *J. Phys. Chem. Solids* **58** 133Nag B and Ghatak K P 1998 *Nonlinear Opt. Quantum Opt.* **19**1Ghatak K P and Nag B 1998 *Nanostruct. Mater* **10** 923
[11] Charkaborty P K, Dutta G C and Ghatak K P 2003 *Phys. Scr.* **68** 368
[12] Chakravarti A N, Choudhury A K, Ghatak K P, Ghosh S and Dhar A 1981 *Appl. Phys.* **25** 105
[20] Ghatak K P and Mondal M 1988 *Z. Phys.* B **69** 471 Ghatak K P and Biswas S N 1995 *Nonlinear Opt. QuantumOpt.* **12** 83Dhar A Z 1982 *Physik*B **47** 149
[13] Arora V K and Jeafarian H 1976 *Phys. Rev.* B **13** 4457
[14] Singh M, Wallace P R, Jog S D and Erushanov J 1984*J. Phys. Chem. Solids* **45** 409
[15] Zawadski W 1974 *Adv. Phys.* **23** 435
[16]Tsidilkovski I M 1982 *Band Struct. Semicond.* (London:Pergamon)
[17] Ando T, Fowler A H and Stern F 1982 *Rev. Mod. Phys.* **54** 437

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[18] Bisaro R, Laurencin G, Friederich A and Razeghi A 1982 *Appl. Phys. Lett.* **40** 978Dingle R, Stormer H L, Gossard A C and Weigmann W 1978 *Appl. Phys. Lett.* **33** 665
[19] Alferness R C, Joyner C H, Divino M D, Martyak M J R andBuhl L L 1986 *Appl. Phys. Lett.* **49** 125
[20] Bell T E 1983 *IEEE Spectrum* **20** 38
[21] Lu P Y, Wang C H, Williams C M, Chu S N G and Stiles C M 1986 *Appl. Phys. Lett.* **49** 1372
[22] Taskar N R, Bhat I B, Parat K K, Terry D H, Ehsani E andGandhi S K 1989 *J. Vac. Sci. Technol.* A **7** 281
[23] Weiss E and Mainzer N 1989 *J. Vac. Sci. Technol.* A **7** 391
[24]Koch F 1984 *Two Dimensional Systems, Heterostructures and Superlattices*, ed G Bauer, F Kuchar and H Heinrich(*Springer Series in Solid State Sciences* vol 53) seriesed M Cardona, P Flude, K V Klitzing and H J Queisser (Berlin: Springer) p 20
[25] Daw D H, Kao D S and Stringfellow G B 1991 *J. Appl. Phys.* **69** 2552
[26] Timmons M L, Bedair S, Markunas M R J and Hutchby J A 1982 *Proc. 16th IEEE Photovoltaic Specialists Conferences(IEEE: San Diego, CA)* p 666
[27] Tomasetta L R, Law H D, Eden R C, Reyhimy I and Nakano K 1978 *IEEE Quantum Electron.* **14** 800 Lee M K, Wu D S and Tung H H 1987 *J. Appl. Phys.* **62** 3209
[28] Hansen G L, Schmit J L and Casselman T N 1982 *J. Appl. Phys.* **63** 7079Kim R S and Narita S 1976 *Phys. Status Solidi* b **73** 741Sredin V A, Savitskii G, Danilyuk Y V, Miliyanchuk M V andPetrovich I V 1981 *Sov. Phys.—Semicond.* **15** 249
[29] Adachi S 1982 *J. Appl. Phys.* **53** 8775 Sutradhar S K, Chattopadhyay D and Nag B R 1982 *Phys. Rev.*B**25** 4069 Levimson M, Benton J L, Temkin H and Kimerling L C 1982 *Appl. Phys. Lett.* **40** 990
[30] Seeger K 1997 *Semiconductor Physics* (*Springer Series in Solid State Sciences* vol 40) 6th edn, series ed Cardona M,Flud P, Klitzing K V and Queisser H J (Berlin: Springer)
[31] Nag B R 2000 *Physics of Quantum Well Devices* (Dordrecht: Kluwer)
[32] Pathria R K 1996 *Statistical Mechanics* 2nd edition (Oxford: Butterworth-Heinmann)
[33] Abramowitz M and Stegun I A 1965 *Handbook of Mathematical Functions* (New York: Dover)
[34] Schulman J N and Chang Y C 1981 *Phys. Rev.* B**24** 4445
[35] A.Dey, A.Neogi, B.Maity, D.Chanda (Sarkar),Journal of Optoelectronics and Advanced materials ,Vol. 14, No. 3-4, March – April 2012, p.
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