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Comparison of Dispersion Relations and Effect of Magnetic Field on Different Nano-structures

Rakhi Bhattacharjee* and Ajoykumar Chakraborty**

ABSTRACT

The main focus is to formulate the Dispersion Relations (DR) in low dimensional semiconductor materials like Bulk Semiconductors, Quantum Wells (QWs), Nano-Wires (NWs) and Quantum Box (QBs) of Heavily Doped (HD) III-V and IV-VI materials in the presence of magnetic field on the basis of k.pformalism. Experimental results show that the Fermi Energy Vs Inverse magnetic Field curve is maintaining a constant part and Dispersion Relations (DRs) in Accumulation and Inversion Layers of Non-Linear Optical Semiconductors is comparable.

Keywords: Dispersion Relations(DRs), Quantum Wells(QWs), Nanowires(NWs), Quantum Box(QBs).

1. INTRODUCTION

In the recent years, the Dispersion Relations(DRs)depending on the different properties of low dimensional nano structured devices are widely used. A dispersion relation relates the wavelength or wave number of a wave to its frequency. From this relation the phase velocity and group velocity of the wave have convenient expressions which then determine the refractive index of the medium. Dispersion Relaton (DRs) is the most fundamentals among all properties. If we know DR, we can get the Density Of State Functions (DOS)[1-3] and integrating the DOS functions, we can get the electron concentration. So, we can study all the properties since the study of the properties depends on the electron concentration.

The rest of the paper is organized as follows. Theoretical Background are explained in section II. Results and Discussions are presented in section III. Concluding remarks are given in section IV.

2. THEORETICAL BACKGROUND

2.1. The DR in Bulk Semiconductor materials in the Presence of Magnetic Field

The DR of the conduction electrons in bulk samples of III-Vternary and quaternary materials[4-5] can be written as $\left(g\frac{eB}{\pi\wedge 2h*}\right)\sum_{n=0}^{n=n\max}\left(\left(2m*E/h*\wedge 2\right)-\left(2eB\left(n+-0.5\right)/h*\right)\right)\wedge 0.5,$

$$E\left(1+\alpha E\right)=\frac{\hbar^2k^2}{2m_c},\alpha=\frac{1}{E_g}\ (2.1a)$$

where, E is the electron energy as measured from the edge of the conduction band in the vertically upward direction in the absence of any quantization, E_g is the band gap and m_c is the effective electron mass at the edge of the conduction band.

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* Department of Electronics and Communication Engineering National Institute of Technology, Agartala, Tripura 799046, India, *Email: rakhibhatta@gmail.com*

** Departtment of Electrical Engineering National Institute of Technology, Agartala, Tripura 799046, India, *Email:akcalll@yahoo.co.in* *n*0 =10^23(assumed),1/B=0.1 to 3(steps 0.01),e = 1.6 × 10^-19, h* = 1.05 × 10^-34. Let us consider aultra-thin III-V semiconductor layer of rectangular cross-section. In such a structure the electron motion is quantized along the z-direction, (a being the nano thickness along z-direction) resulting in formation of electric sub-bands corresponding to different quantum numbers. The electrons motion is free along in the x-y plane and the magnetic field B is applied along the y-direction.

In the absence of magnetic field, dispersion relation of the electrons in quasi 2D structures [4-5] can be expressed as

$$E(1+\alpha E)=\frac{\hbar^2}{2m_c}\left(\frac{n\pi}{a}\right)^2+\frac{\hbar^2k_x^2}{2m_c}+\frac{\hbar^2k_y^2}{2m_c} \tag{2.1b}$$

In this case, the potential function assumes the form

$$V(z) = 0,\ 0 < z < a$$

and $V(z) = \alpha$, $0 < z$ and for $z > a$

2.2. The DR in Accumulation and Inversion Layers of Non-Linear Optical Semiconductors

In the presence of a surface electric field F_s along z direction and perpendicular to the surface[6-12] assumes the form

$$\frac{\hbar^2k_z^2}{2m_{\parallel}^*}+\frac{\hbar^2k_s^2}{2m_{\perp}^*}\frac{T_{21}(E-|e|F_sz,\eta_g)}{T_{22}(E-|e|F_sz,\eta_g)}=T_{21}(E-|e|F_sz,\eta_g) \tag{2.1}$$

where, for this section, E represents the electron energy as measured from the edge of the conduction band at the surface in the vertically upward direction.

The quantization rule for 2D carriers in this case, is given by [13-15]

$$\int_0^{z_t} k_z dz=\frac{2}{3}(S_i)^{3/2} \tag{2.2}$$

where, z_t is the classical turning point and S_i is the zeros of the Airy function $\left(Ai(-S_i)=0\right)$.

$$\frac{\hbar^2k_s^2}{2m_{\parallel}^*}=L_6(E,i,\eta_g) \tag{2.3}$$

$$L_6(E,i,\eta_g)=\frac{T_{21}(E,\eta_g)-L_3(E,i,\eta_g)}{L_4(E,i,\eta_g)},$$

wh

$$L_3(E,i,\eta_g)=S_i\left[T'_{21}(E,\eta_g)\right]^{2/3}\left[\frac{\hbar|e|F_s}{\sqrt{2m_{\parallel}^*}}\right]^{2/3}$$

and

$$L_4(E,i,\eta_g)[\frac{T_{21}(E,\eta_g)}{T_{22}(E,\eta_g)}+L_3(E,\mathrm{i},\eta_g)$$

$$\frac{T_{21}(E,\eta_g)}{T'_{21}(E,\eta_g)T_{22}(E,\eta_g)}.$$

$$\frac{2}{3}\left\{\frac{T'_{21}(E,\eta_g)}{T_{21}(E,\eta_g)}-\frac{T'_{22}(E,\eta_g)}{T_{22}(E,\eta_g)}\right\}]$$

The EM in this case can be written as

$$m^*\left(E_f', i, \eta_g\right) = m_{\|}^*$$

$$\text{Real part of } \left[L_6'\left(E_f', i, \eta_g\right)\right] \tag{2.4}$$

where $E_f' = eV_g - \frac{e^2 n_s d_{ex}}{\varepsilon_{ox}} + E_{FB}$, V_g is the gate voltage, n_s is the surface electron concentration, d_{ox} is the thickness of the oxide layer, ε_{ox} is the permittivity of the oxide layer, $F_s = \frac{en_s}{\varepsilon_{sc}}$, ε_{sc} is the semiconductor permittivity and E_{FB} should be determined from the

$$n_B = \frac{2g_v}{(2\pi)^3} \frac{2m_{\perp}^* \sqrt{2m_{\|}^*}}{\hbar^3}$$

$$\text{Real Part of } \left[T_{22}\left(E_{FB}, \eta_g\right)\sqrt{T_{21}\left(E_{FB}, \eta_g\right)}\right] \tag{2.5}$$

and n_B is the bulk electron concentration.

3. RESULTS AND DISCUSSIONS

The DR in Bulk Semiconductor Materials in the presence of Magnetic Field is plotted in Fig. 1.1.Here we plotted Fermi Energy Ef is along X axis and Magnetic Field 1/B is along Y axis. With the increasing Inverse Magnetic Field the Fermi Energy is decreasing.

Fig.1.2 Plot shows the EM under weak electric field limit as the function of surface electric field for accumulation layers of Cd_3As_2 in accordance with the generalized theory.Here we have taken Generalized model, Three Band Model and Two Band Model. The value is increasing in case of Generalized Model compared to the other Models.

Fig. 1.3 Shows the plot of the EM at strong electric field limit as function of surface electric field for accumulation layers of Cd_3As_2 for all cases of Fig. 1.2. Here we have taken Generalized model, Three Band

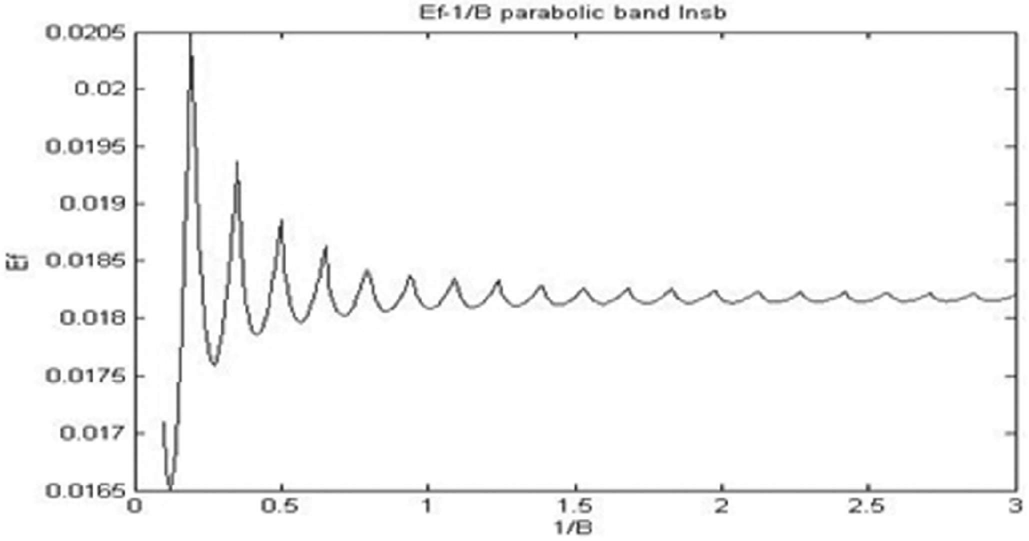

Figure 1.1: plot of fermi energy Vs magnetic field in bulk semiconductors.

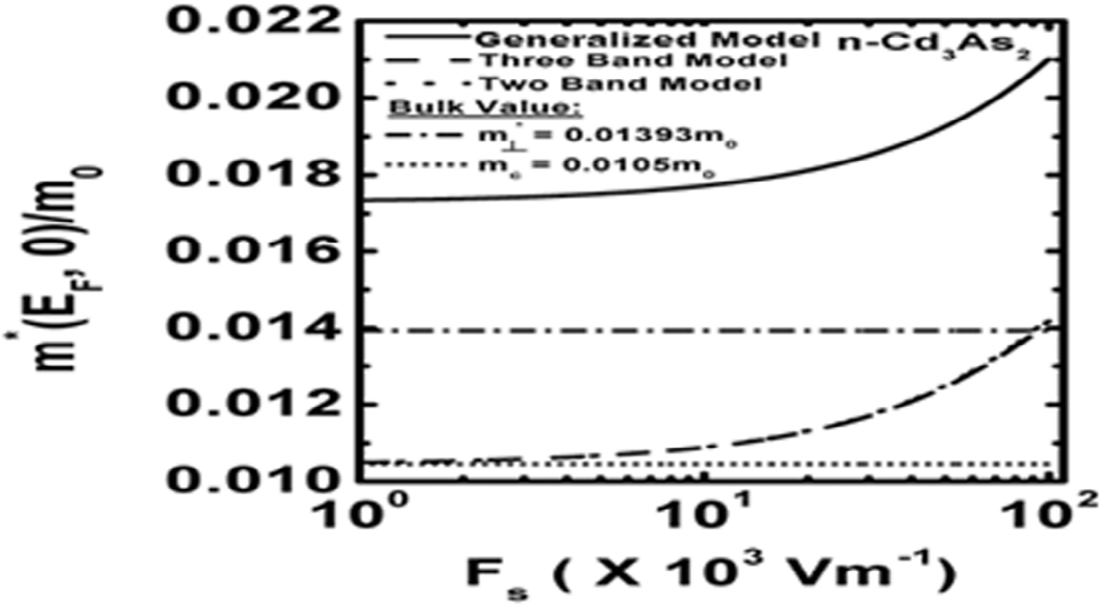

Figure 1.2: Plot of the EM under weak electric field limit

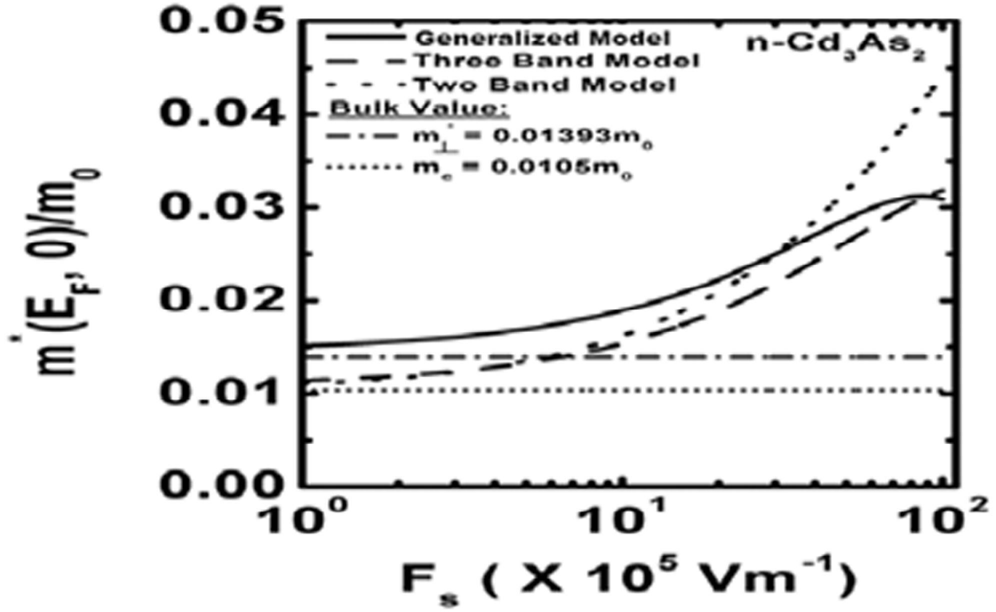

Figure 1.3: Plot of the EM at strong electric field

Model and Two Band Model. The value is increasing in case of Generalized Model compared to the other Models.

Fig. 1.4Shows theplot of the EM at strong electric filed limit as function of surface electric field for accumulation layers of CdGeAs$_2$ for all cases of Fig. 1.3. Here we have taken Generalized model, Three Band Model and Two Band Model. The value is decreasing beyond the Negative Y axis in case of Generalized Model compared to the other Models.

Fig. 1.5 Shows the plot of the EM at low electric field limit as function of surface electric field for accumulation layers of n-InAs Here we have taken Three Band Model and Two Band Model. The value is increasing slightly in case of Three Band Model compared to the Two Band Model.

Fig. 1.6 Shows Plot of the EM at high electric field limit as function of surface electric field for accumulation layers of n-InAs. Here we have taken Three Band Model and Two Band Model. The value is increasing in case of Two Band Model compared to the Three Band Model.

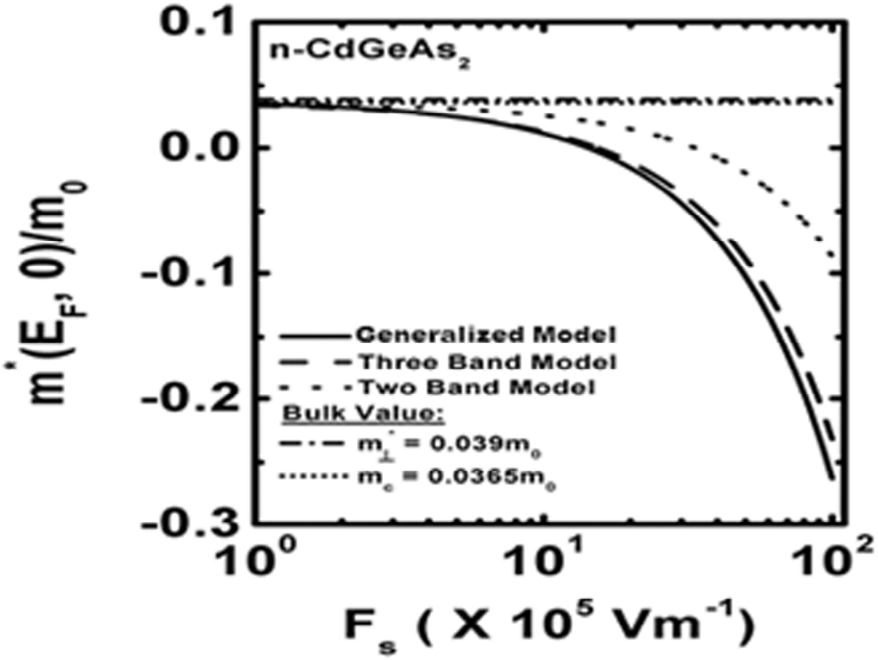

Figure 1.4: Plot of the EM at strong electric filed

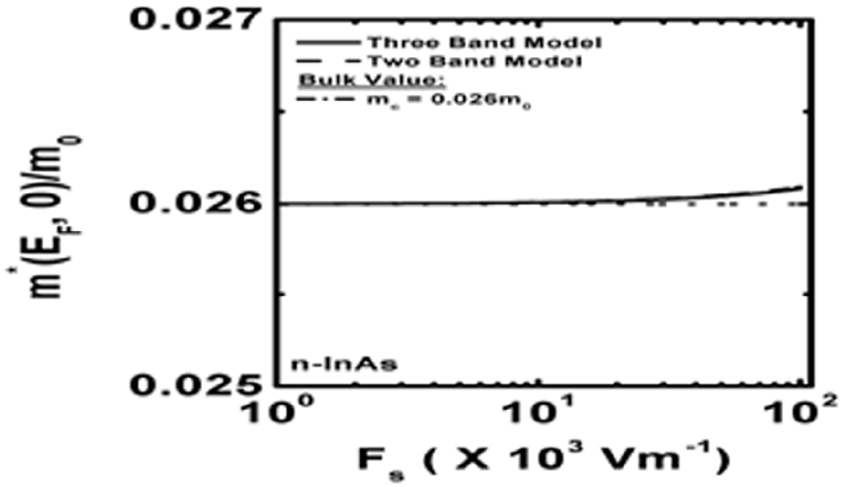

Figure 1.5: Plot of the EM at low electric field

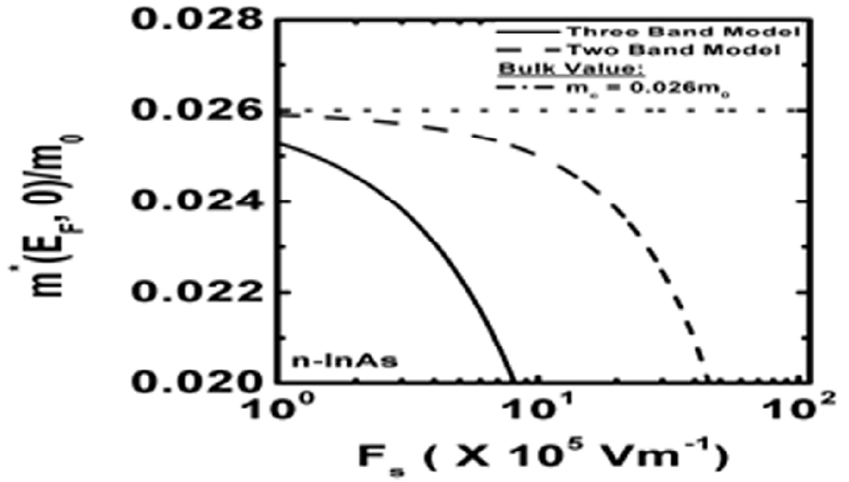

Figure 1.6: Plot of the EM at high electric field

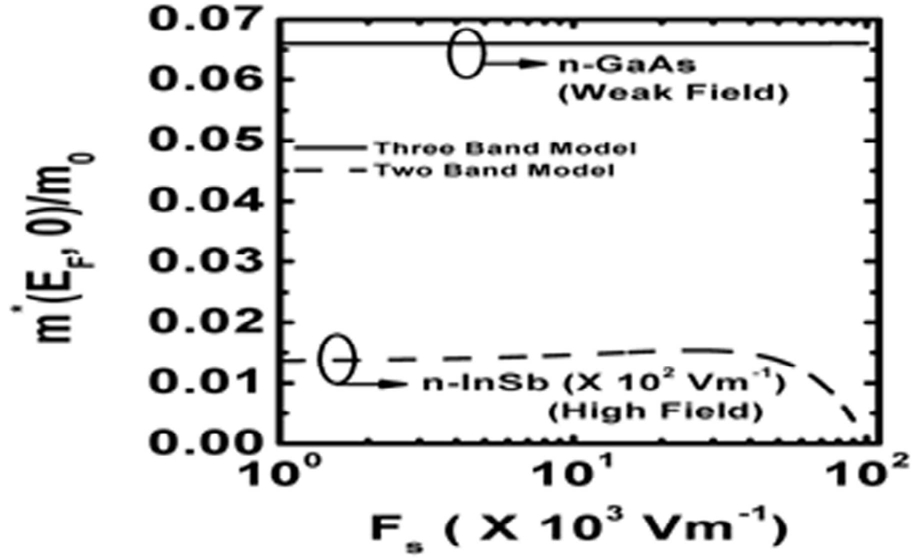

Figure 1.7: Plot of the EM at low and high electric field

Fig. 1.7 Shows the plot of the EM at low and high electric field limits as function of surface electric field for accumulation layers of GaAs and InSb respectively. Here we have taken Three Band Model and Two Band Model. The value is different for two different types of materials.

4. CONCLUSION

The effective mass in Bulk Semiconductors, Accumulation and Inversion Layers of Non-Linear Optical Semiconductors has been studied and their different characteristics curves are compared by taking various technologically important heavily doped materials. This is done by formulating the corresponding dispersion relations, the carrier statistics and the effective mass in details within the formalism and considering all types of anisotropies of the energy band constants. In many cases the effective Fermi level mass depends on the size quantum numbers, and the sub band indices in the afford mentioned cases. The well-known expressions of the said quantities have also been obtained in all the cases from our generalized formulations which exhibit the compatibility of the results.

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