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ON THE EFFECTIVE ELECTRON MASS IN DEGENERATE II—VI SEMICONDUCTORS UNDER DIFFERENT PHYSICAL CONDITIONS

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An attempt is made to investigate the effective electron mass in degenerate II—VI semiconductors, taking n-CdS as an example, under different physical conditions. We have formulated the effective electron masses in 3D, 2D and 1D configurations, respectively. We have plotted the effective mass with various physical variables. It is found that the effective masses vary with magnetic and size quantum numbers under different conditions due to the splitting of the two spin states by the spin-orbit coupling and the crystalline field. The corresponding results for parabolic semiconductors have also been derived as special cases of the generalized expressions.

I. Introduction

In recent years there has been considerable interest in studying the different electronic properties of degenerate semiconductor because of their importance in device technology[1,2]. The effective mass of the carrier in degenerate materials, which is strongly connected with the mobility, is known to be one of the most important device parameters[3]. It must be mentioned that among the various definition of the effective electron mass[4a], it is the effective momentum mass that should be regarded as the basic quantity[4b]. This is due to the fact that it is the momentum effective mass that appears in the description of transport phenomena

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and all other properties of the electron gas in a band with arbitrary band non-parabolicity[4b]. It can be shown that it is this effective mass which enters in various types of transport coefficients and plays the most dominant role in explaining the experimental results of different types of scattering mechanisms[5,6]. The carrier degeneracy in a semiconductor affects the effective mass when it is energy dependent. Under degenerate conditions, only the carriers at the Fermi surface of semiconductors participate in the conduction process and hence the effective momentum mass of the carriers at the Fermi level (hereafter referred to as EMC) would be of interest in carrier transport under such conditions. The Fermi energy is again determined by the carrier energy spectrum.

In recent years, various dispersion relations for the semiconductors under different physical conditions have been proposed which have created interest of studying the EMC in such semiconductors under different physical conditions[7-16]. Nevertheless, it appears from the literature that EMC in degenerate II—VI semiconductors has yet to be investigated under different physical conditions though the above class of materials have been investigated in Refs. 17—19 for their interesting electronic properties. In what follows in Sect. 2.1 of theoretical background we shall formulate an expression of the EMC in bulk specimens of II—VI semiconductors and study the doping dependence of the same by deriving the appropriate carrier statistics. This will make our analysis a generalized one since we can obtain the corresponding expressions for parabolic energy bands under certain limiting conditions. In Sect. 2.2 we shall study the EMC in III—VI materials under crossed electric and quantizing magnetic fields since the cross-field configuration is fundamental for classical and quantum transport phenomena in solids[20-21].

We wish to note that with the remarkable developments in MBE, MOCVD, fine line lithography and other techniques, various types of 2D structures viz. ultrathin films, inversion layers etc. have been experimentally realized[22-24]. In ultrathin films where the width of the films are comparable to the de-Broglie wavelength of the carriers, the restriction of the motion of the carriers in the direction normal to the film (say, the z-direction) may be view as carrier confinement in an infinitely deep 1D quare potential well, leading to the quantization (known as quantum size effect (QSE)) of the wave vector, allowing 2D electron transport parallel to the film representating new characteristics not exhibited in bulk semiconductors. Heterostructures based on different materials are currently widely investigated because of the enhancement of carrier mobility[25]. These properties make such 2D structures suitable for applications in high speed digital network[26], optical modulators[27], switching systems[28] and other devices.

In Sect. 2.3 we have investigated the EMC in ultrathin films of II—VI semiconductors. If Sect. 2.4 we have further extended calculation under cross-field configuration. In Sect. 2.5 we have formulated the EMC in inversion layers of II—VI semiconductors in the presence of crossed electric and quantizing magnetic fields. Recently a structure based on the confinement of carriers in a wire semiconductors have been proposed to explore the band structure in such materials[29-30]. In these synthetic materials, also known as quantum well wire (QWW), the electron gas is quantized in two transverse direction and the charge carriers can only move in the longitudinal directions[30]. We have studied the EMC in quantum well wires of II—VI materials in Sect. 2.6. We have also plotted the EMC with some of the physical parameters in the aforementioned cases, taking n-CdS as an example.

2. *Theoretical background*

2.1. *Formulation for EMC in bulk specimens for II—VI semiconductors*

The group theoretical analysis shows that based on the symmetry properties of the conduction and valence band wave functions, both the energy bands of II—VI semiconductors should have the general form[17,19],

$$\varepsilon = A\, k_s^2 + B\, k_z^2 + C\, \lambda\, k_s \tag{1}$$

where ε is the energy of the carriers in bulk specimens of semiconductors, $A \equiv \hbar^2/2m_\perp$, $\hbar \equiv h/2\pi$, h is Planck's constant, $k_s^2 \equiv k_x^2 + k_y^2$, $m_\perp$ is the transverse band-edge effective mass of the carriers, $B \equiv \hbar^2/2m_{\|}$, $m_{\|}$ is the longitudinal band-edge effective mass of the carriers, $\lambda = \pm 1$ and C represents the splitting of the two spin states by the spin-orbit coupling and the crystalline field. The use of equation (1) leads, respectively, to the expressions of the transverse and longitudinal EMC's at the Fermi level E_F as

$$m_\perp^*(E_F) = m_\perp\, [1 + \lambda C\, \{C^2 + 4A\, E_F\}^{-1/2}] \tag{2}$$

and

$$m_{\|}^*(E_F) = m_{\|}\,. \tag{3}$$

It appears, then, that the evaluation of equation (2) as a function of carrier concentration leads to an expression of carrier density which, in turn, is determined by the density-of-states function. Using (1), the density-of-states function is given by

$$N(\varepsilon) = (4\pi^2 A^2)^{-1}\, [(C^2/\sqrt{\varepsilon B}) + A\sqrt{\varepsilon/B} \pm \{\{\sqrt{1 - Q^2(\varepsilon)}\} + \\ + \sin^{-1}\{Q(\varepsilon)\}\}\,(AC/\sqrt{2AB}) \pm P(\varepsilon)\,\{1 - Q^2(\varepsilon)\}^{-1/2} \cdot \\ \cdot\, Q(\varepsilon)\,\{1 - Q'(\varepsilon)\}] \tag{4}$$

where

$$P(\varepsilon) \equiv \frac{C}{\sqrt{2AB}}\left(A\varepsilon + \frac{C^2}{4}\right),\quad Q(\varepsilon) \equiv [2A\varepsilon/C^2 + 4A\varepsilon]^{1/2}$$

and $'$ denotes the differentiation w. r. t. ε. Combining Eq. (4) with the Fermi-Dirac occupation probability factor and using the generalized Sommerfeld's lemma[31], the carrier statistics in II—VI semiconductors can be expressed as

$$n_0 = (8\pi^2 A^2)^{-1}\, [R(E_F) + S(E_F)] \tag{5}$$

where

$$R(E_F) \equiv (\pi/A^2)\left[\frac{C^2}{2}\sqrt{E_F/B} + \frac{2}{3} A E_F^{1/2} B^{-1/2} \pm P(E_F)\{\sqrt{1 - Q^2(E_F)} + \right.$$

$$\left. + \sin^{-1} Q(E_F)\}\right],$$

$$S(E_F) \equiv \sum_{r=1}^{t_0} \nabla_r [R(E_F)], \quad \nabla_r \equiv 2(k_B T)^{2r} \cdot (1 - 2^{1-2r})\, \zeta(2r) \frac{d^{2r}}{dE_F^{2r}},$$

k_B is Boltzmann constant, T is temperature and $\zeta(2r)$ is the zeta function of order $2r$[32].

Under the condition $C \to 0$, Eqs. (2), (3), (4) and (5) assume the well-known forms as[33]

$$\varepsilon = A k_s^2 + B k_z^2 \tag{6}$$

$$m_\perp^*(E_F) = m_\perp \tag{7}$$

$$m_\parallel^*(E_F) = m_\parallel \tag{8}$$

$$N(\varepsilon) = 4\pi (2m_D/h^2)^{3/2} \sqrt{\varepsilon} \tag{9}$$

and

$$n_0 = N_C F_{\frac{1}{2}}(\eta) \tag{10}$$

where $m_D \equiv (m_\perp^2 m_\parallel)^{1/3}$, $N_C \equiv 2(2\pi m_D k_B T/h^2)^{3/2}$, $\eta \equiv E_F/k_B T$ and $F_j(\eta)$ is the Fermi-Dirac integral of order j as defined by Blakemore[33].

2.2. *Formulation of EMC in II—VI semiconductors under cross-field configuration*

Following Zawadzki and Lax[34], the carrier energy spectrum in the presence of an electric field E_0 along x-axis and quantizing magnetic field H along z-axis can be expressed as

$$\varepsilon = \left(l + \frac{1}{2}\right)\hbar\omega_0 + \frac{p_z^2}{2m_\parallel} - \frac{E_0}{B} p_y - \frac{E_0^2 m_\perp}{2H^2} + \cdot$$

$$+ D_0\left[\left(l + \frac{1}{2}\right)\hbar\omega_0 + \frac{E_0^2 m_\perp}{2H^2}\right]^{1/2} \pm \frac{1}{2}|g|\,\mu_0 H \tag{11}$$

where l is the Landau quantum number, $\omega_0 \equiv eH/m_\perp$, $D_0 \equiv \frac{\lambda C\sqrt{2m_\perp}}{\hbar}$, g is the band edge g factor and μ_0 is Bohr magneton.

Using (11), the transverse and longitudinal EMC's at the Fermi level E_{FH} can be written as

$$m_{\perp}^{*}(E_{FH}) = (H/E_0)^2 \left[E_{FH} - \left(l + \frac{1}{2}\right)\hbar\omega_0 + \frac{E_0^2 m_{\perp}}{2H^2} + \right.$$

$$\left. + D_0 \left\{ \left(l + \frac{1}{2}\right)\hbar\omega_0 + \frac{E_0^2 m_{\perp}}{2H^2} \right\}^{1/2} \pm \frac{1}{2}|g|\mu_0 H \right] \tag{12}$$

$$m_{\parallel}^{*}(E_{FH}) = m_{\parallel} \tag{13}$$

where E_{FH} is the Fermi energy in the presence of crossed electric and magnetic fields as measured from the edge of band in the absence of any field. The carrier concentration in this case can be written, including spin and broadening, as

$$n_0 = \frac{H\sqrt{2m_{\parallel}}}{6L_x\pi^2\hbar^2 E_0} \sum_{l=0}^{l_{max}} [\delta_1 + \delta_2] \tag{14}$$

where l_x is the sample length along x direction,

$$\delta_1 \equiv \mathrm{Re}\left[\left(E_{FH} + \mathrm{i}\Gamma + \frac{E_0}{H}\hbar x_h - \delta \right)^{3/2} - \right.$$

$$\left. - \left(E_{FH} + \mathrm{i}\Gamma + \frac{E_0}{H}\hbar x_l - \delta \right)^{3/2} \right], \ \mathrm{i} \equiv \sqrt{-1},$$

$$x_h \equiv [eHL_x\hbar + x_l], \quad \varkappa_l \equiv (-H/\hbar E_0)\left[\frac{E_0^2 m_{\perp}}{2H^2} - D_0 (E_0^2 m_{\perp}/2H^2)^{1/2} \right],$$

$$\delta \equiv \left[\left(l + \frac{1}{2}\right)\hbar\omega_0 - \frac{E_0^2 m_{\perp}}{2H^2} + D_0 \left\{ \left(l + \frac{1}{2}\right)\hbar\omega_0 + E_0^2 m_{\perp}(2H^2)^{-1} \pm \right.\right.$$

$$\left.\left. \pm \frac{1}{2}|g|\mu_0 H \right\} \right], \quad \delta_2 \equiv \sum_{r=1}^{l_0} V_r [\delta_1]$$

and Γ is the broadening parameter. Neglecting spin and broadening and under the case of isotropic parabolic energy band i. e. $m_{\parallel} = m_{\perp} = m^*$ together with $C \to 0$, (14) takes the form

$$n_0 = C_0 \sum_{l=0}^{l_{max}} [F_{\frac{1}{2}}(\eta_1) - F_{\frac{1}{2}}(\eta_2)] \tag{15}$$

where

$$C_0 \equiv H\sqrt{2\pi m}\,(k_BT)^{3/2}\,(4L_x E_0 \hbar^2 \pi^2)^{-1},$$

$$\eta_1 \equiv (k_BT)^{-1}\,[E_{FH} - A_0(l) + \frac{1}{2}|g|\,\mu_0 H],\quad A_0(l) \equiv \left[\left(l+\frac{1}{2}\right)\hbar\omega_0 + \right.$$

$$\left. + e^2E_o^2\,(m^*\omega_o^2)^{-1} - eE_0L_\lambda\right],\quad \eta_2 \equiv (k_BT)^{-1}\left[E_{FH} - b_0(l) - \frac{1}{2}|g|\,\mu_0 H\right]$$

and

$$b_0(l) \equiv A_0(l) + eE_0L_x.$$

Under the condition $E_0 \to 0$, (15) assumes the well-known form[33] as

$$n_0 = N_C\,\Theta_0 \sum_{l=0}^{l_{max}} F_{-\frac{1}{2}}(\eta') \tag{16}$$

where

$$\Theta_0 \equiv \hbar\omega_0/k_BT \text{ and } \eta' \equiv (k_BT)^{-1}\left[E_{FH} - \left(1+\frac{1}{2}\right)\hbar\omega_0\right].$$

Under the condition $E_0 \to 0$, $m_\perp^*(E_{FH}) \to \infty$ as it should.

2.3. *Formulation of EMC in ultrathin films of II—VI semiconductors*

The modified carrier energy spectrum in ultrathin films of II—VI semiconductors can be written using (1) and following Zawadzki[35] as

$$\varepsilon = Ak_s^2 + B\,(N\pi/2d_0)^2 + \lambda ck\,k_s \tag{17}$$

where N is the size quantum number and $2d_0$ is the width of the 1D potential.

Using (17), the EMC can be expressed as

$$m_\perp^*(E_{FS}) = m_\perp\left[1 + \frac{\lambda C}{\sqrt{C^2 + 4A\,\{E_{FS} - B(N\pi/2d_0)^2\}}}\right] \tag{18}$$

where E_{FS} is the Fermi energy in the presence of size quantization. The surface electron concentration can be written using (17) as

$$n_0 = (16\pi A^2)^{-1} \sum_{N=1}^{N_{max}} (A_1 + A_2) \tag{19}$$

where

$$A_1 \equiv [\lambda C + \sqrt{C^2 + 4A\,\{E_{FS} - B\,(N\pi/2d_0)^2\}}]^2$$

and

$$A_2 \equiv \sum_{r=1}^{l_0} V_r [A_1].$$

Under the condition $C \to 0$, and $m_{\parallel} = m_{\perp} = m^*$, the Eqs. (18) and (19) assume the well-known form[36] as

$$m_{\perp}^* (E_{FS}) = m^* \tag{20}$$

and

$$n_0 = \frac{m^* k_B T}{\pi \hbar^2} \sum_{N=1}^{N_{max}} F_0 (\eta_N) \tag{21}$$

where

$$\eta_N = (k_B T)^{-1} \left[E_{FS} - \frac{\hbar^2}{2m^*} \left(\frac{N\pi}{2d_0} \right)^2 \right].$$

2.4. *Formulation of EMC in ultrathin films of II—VI semiconductors in the presence of crossed electric and quantizing magnetic field*

The carrier energy spectrum for the present case can be written as

$$\varepsilon = \left(l + \frac{1}{2}\right) \hbar\omega_0 + \frac{\hbar^2}{2m_{\parallel}} (N\pi/2d_0)^2 - \frac{E_0}{H} \hbar k_y - \frac{E_0^2 m_{\perp}}{2H^2} + D_0 \left[\left(l + \frac{1}{2}\right) \hbar\omega_0 + \right.$$

$$\left. + \frac{E_0^2 m_{\perp}}{2H^2} \right]^{1/2} \pm \frac{1}{2} |g| \mu_0 H. \tag{22}$$

Using (22), the EMC can be expressed as

$$m^* (E_{FS}) = (H/E_0)^2 \left[E_{FS} - \left(l + \frac{1}{2}\right) \hbar\omega_0 - \frac{\hbar^2}{2m_{\parallel}} (N\pi/2d_0)^2 + \frac{E_0^2 m_{\perp}}{2H^2} - \right.$$

$$\left. - D_0 \left\{ \left(l + \frac{1}{2}\right) \hbar\omega_0 + \frac{E_0^2 m_{\perp}}{2H^2} \right\}^{1/2} \pm \frac{1}{2} |g| \mu_0 H \right]. \tag{23}$$

The use of Eq. (22), leads to the expression of carrier concentration in ultrathin films of II—VI semiconductors in the presence of crossed electric field and quantizing magnetic fields including spin and broadening as

$$n_0 = \frac{eH}{4\pi\hbar} \sum_{l=0}^{l_{max}} \sum_{N=1}^{N_{max}} \frac{(1 + A_0 \cos \lambda_0)}{1 + A_0^2 + 2A_0 \cos \lambda_0} \tag{24}$$

where

$$A_0 \equiv \exp\left[-\frac{1}{K_BT}(E_{FS}-E')\right], \quad E' \equiv \left(l+\frac{1}{2}\right)\hbar\omega_0 + \frac{\hbar^2}{2m_\perp}\left(\frac{N\pi}{2d_0}\right)^2 -$$

$$-\frac{E_0^2 m_\perp}{2H^2} + D_0\left[\left(l+\frac{1}{2}\right)\hbar\omega_0 + \frac{E_0^2 m_\perp}{2H^2}\right]^{1/2} \pm \frac{1}{2}|g|\mu_0 H$$

and

$$\lambda_0 \equiv \Gamma/k_BT.$$

Neglecting spin and broadening together with $C \to 0$ and $m_{\parallel} = m_\perp = m^*$, (24) assumes the well-known form[37] as

$$n_0 = \frac{eH}{\pi\hbar}\sum_{l=0}^{l_{max}}\sum_{N=1}^{N_{max}} F_{-1}\left[(k_BT)^{-1}\left\{E_{FS}-\left(l+\frac{1}{2}\right)\hbar\omega_0 - \frac{\hbar^2}{2m^*}\left(\frac{N\pi}{2d_0}\right)^2\right\}\right]. \quad (25)$$

2.5. *Formulation of EMC in inversion layers of II—VI semiconductors in the presence of crossed electric and quantizing magnetic fields*

Following the method which is given elsewhere[38], the carrier energy spectrum in n-channel inversion layers of II—VI semiconductors in the presence of electric field E_0 along x-axis and quantizing magnetic field H along z-axis can be written as

$$\varepsilon = \delta - \frac{E_0}{H}\hbar k_y + \left(\frac{\hbar e^2}{\sqrt{2m_{\parallel}}}\cdot\frac{1}{\varepsilon_{sc}}\right)^{2/3} S_i n_0^{2/3} \quad (26)$$

where S_i is the i-th root of Airy function[38], i is the electric subband index and ε_{sc} is the semiconductor permittivity. Using (26), the EMC can be written as

$$m^*(E_{FS}) = (H/E_0)^2\left[E_{FS} - \delta - S_i\left(\frac{\hbar e^2 n_0}{\varepsilon_{sc}\sqrt{2m_{\parallel}}}\right)^{2/3}\right]. \quad (27)$$

The carrier concentration can be expressed as

$$n_0 = \frac{eH}{4\pi\hbar}\sum_{l=0}^{l_{max}}\sum_{i=0}^{i_{max}} F_{-1}(\bar{\Phi}) \quad (28)$$

where

$$\bar{\Phi} \equiv (k_BT)^{-1}\left[E_{FS} - \delta - S_i\left(\frac{\hbar e^2 n_0}{\varepsilon_{sc}\sqrt{2m_{\parallel}}}\right)^{2/3}\right].$$

2.6. *Formulation of EMC in QWW of II—VI semiconductors*

The carrier energy spectrum in QWW of II—VI semiconductors can be written using Eq. (1) and following Brum[39] as

$$k_z^2 = -\left(\frac{n_2\pi}{2d_2}\right)^2 + (4A^2)^{-1}\left[\lambda C + \sqrt{C^2 + 4A\varepsilon - \frac{2A\hbar^2}{m_{\parallel}}\left(\frac{n_1\pi}{2d_1}\right)^2}\right]^2 \tag{29}$$

where $n_1, n_2 = 1, 2, 3, \ldots$ and $2d_1$ and $2d_2$ are the dimensions of the rectangular QWW.

The use of Eq. (29) leads to the expression of EMC as

$$m_{\perp}^*(\varepsilon_F') = m_{\perp}\left[1 + \frac{\lambda C}{\sqrt{C^2 + 4A\varepsilon_F' - \frac{4A\hbar^2}{2m_{\parallel}}\left(\frac{n_1\pi}{2d_1}\right)^2}}\right] \tag{30}$$

where ε_F' is the Fermi energy in the present case.

Thus combining Eq. (29) with the Fermi-Dirac occupation probability factor, the expression of carrier concentration per unit length is given by

$$n_0 = \frac{1}{2\pi}\sum_{n_1=1}^{n_{1max}}\sum_{n_2=1}^{n_{2max}}(a_1 + a_2) \tag{31}$$

where

$$a_1 \equiv \left[-\left(\frac{n_2\pi}{2d_2}\right)^2 + (4A^2)^{-1}\{\lambda C + [C^2 + 4A\varepsilon_F' - 2A\hbar^2 m_{\parallel}^{-1}(n_1\pi/2d_1)^2]^{1/2}\}^2\right]^{1/2}$$

and

$$a_2 \equiv \sum_{r=1}^{l_0} V_r\,[a_1].$$

Under the conditions $C \to 0$, $m_{\parallel} = m_{\perp} = m^*$, (30) and (31) assume the well-known forms[40] as

$$m_{\perp}^*(\varepsilon_F') = m^* \tag{32}$$

and

$$n_0 = \frac{\sqrt{m^*\pi k_B T}}{\hbar\sqrt{2}}\sum_{n_1=1}^{n_{1max}}\sum_{n_2=1}^{n_{2max}}F_{-\frac{1}{2}}(\bar{\eta}) \tag{33}$$

where

$$\bar{\eta} \equiv (k_B T)^{-1} \left[\varepsilon_F' - \frac{\hbar^2 \pi^2}{2m^*} \left\{ \left(\frac{n_1}{2d_1} \right)^2 + \left(\frac{n_2}{2d_2} \right)^2 \right\} \right].$$

3. *Results and discussion*

Using the appropriate equations together with parameters[17-19] $m_\perp = 0.7\, m_0$, $m_{\parallel} = 0.5\, m_0$, $C = 1.2 \times 10^{-10}$ eV · m, $\varepsilon_{sc} = 9.1\, \varepsilon_0$, $E_0 = 10^3$ V/m, $H = 1$ T, $\Gamma = 2 \times 10^{-4}$ eV, $T = 4.2$ K, $L_x = L_y = L_z = 1$ m and $g = 2$ we have plotted the EMC in n-CdS versus various physical parameters as shown, respectively, in Figs. 1 to 6. Some of the significant features which have emerged from these studies can be written very briefly as follows:

1. From Fig. 1 it appears that the transverse EMC increases with increasing carrier degeneracy as expected for degenerate semiconductors. The longitudinal EMC is energy independent since the basic dispersion relation as given by equation (1) is parabolic along k_z direction and exhibits non-parabolicity in the xy plane. For a single value of n_0 the transverse EMC is double valued due to the splitting of the two spin states by the spin orbit coupling and the crystalline field.

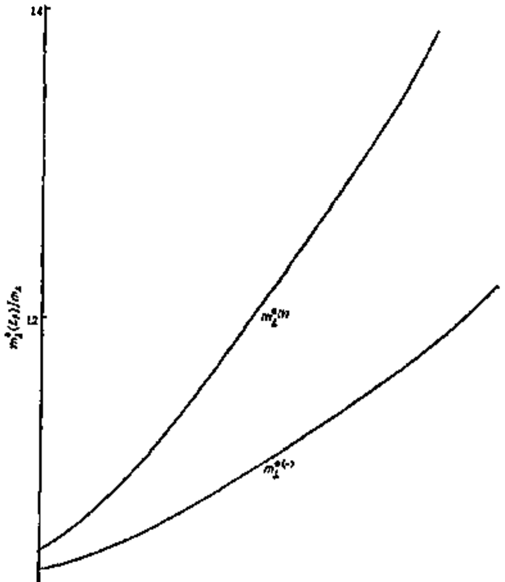

Fig. 1. Plot of $m_\perp^*(E_F)/m_\perp$ as a function of n_0 by using Eqs. (2) and (5) in bulk specimens of n-CdS at 4.2 K.

2. From Fig. 2 it appears that the EMC in the presence of cross field depends both on Fermi energy and the magnetic quantum number which is an inherent property of the cross field. Another important feature is that the various transport coefficients will be sample dimension dependent. This inclusion is valid even for parabolic energy bands and the cross field introduce energy dependent anisotropy in the effective mass. The oscillations are due to the SdH effects.

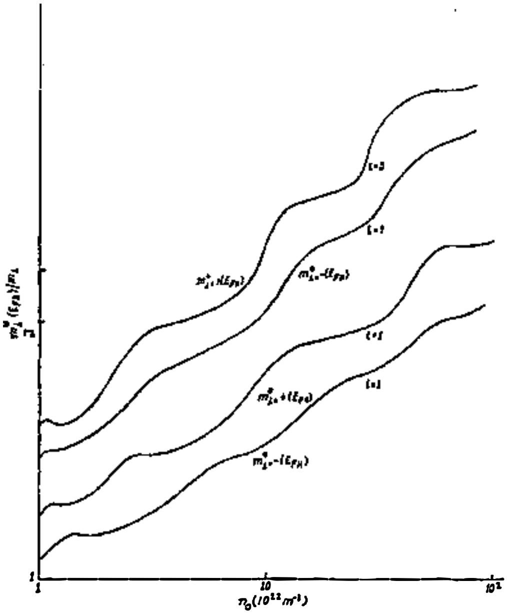

Fig. 2. Plot of $m^*_\perp (E_{FH})/m_\perp$ for the first two magnetic subbands by using Eqs. (12) and (14) as a function of n_0 in n-CdS at 4.2 K in the presence of crossed electric and quantizing magnetic fields.

3. It appears from Fig. 3 that the EMC is significantly influenced by the effects of size quantization. The EMC depends on size quantum number due to the constant C and with increasing film thickness they exhibit converging tendency.
4. It appears from Fig. 4 that the EMC in ultrathin films of II—VI semiconductors under cross field configuration depends on the Fermi energy, size quantum number and the magnetic quantum number resulting in different EMC's corresponding to different subbands. The humps appear due to the change of quantum numbers from one fixed value to another.
5. It appears from Fig. 5 that the EMC in inversion layers on II—VI materials under cross field configuration depends on the Fermi energy, electric subband index and the magnetic quantum number.
6. From Fig. 6 it appears that the EMC in QWW of II—VI semiconductors depends both on the quantum number and the Fermi energy solely due to the constant C. The different EMC's converge to a single value for relatively higher values of carrier degeneracy in the whole range of concentrations considered.

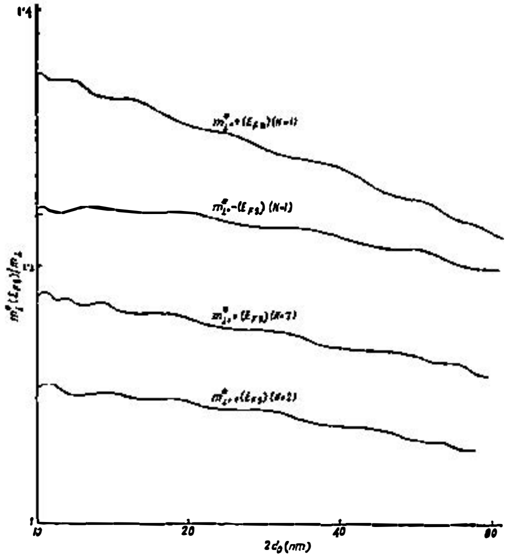

Fig. 3. Plot of $m_{\perp}^{*}(E_{FS})/m_{\perp}$ for the first two subbands by using Eqs. (18) and (19) as functions of $2d$ ($n_0 = 10^{14}\,\mathrm{m}^{-2}$).

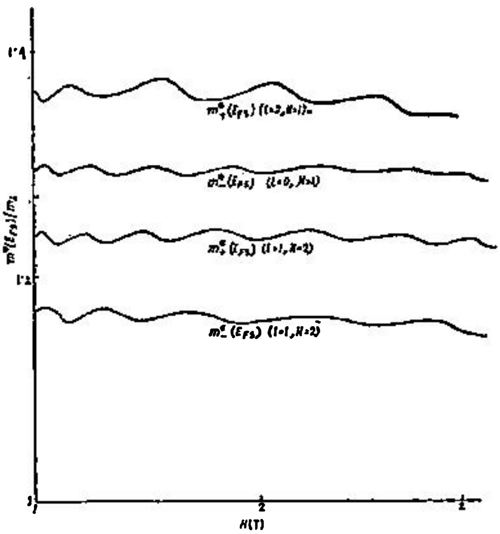

Fig. 4. Plot of $m^{*}(E_{FS})/m_{\perp}$ for few subbands in ultrathin films of n-CdS by using Eqs. (23) and (24) under cross-field configuration ($n_0 = 10^{14}\,\mathrm{m}^{-2}$) as functions of magnetic field.

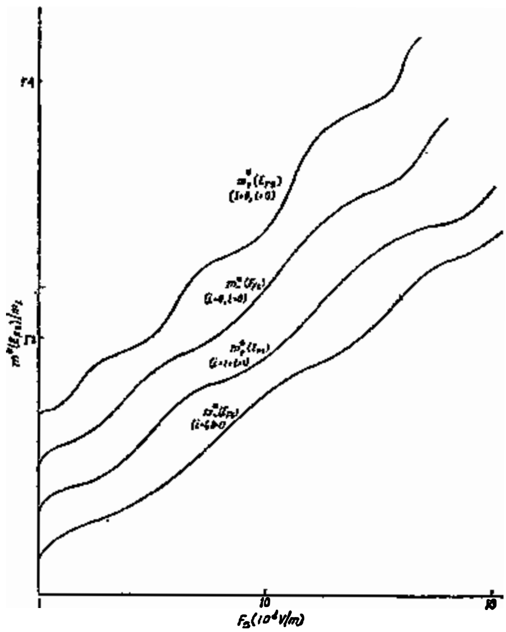

Fig. 5. Plot of $m^* (E_{FS})/m_\perp$ for few subbands in n-channel inversion layers of p-CdS for few subbands by using Eqs. (27) and (28) as functions of surface electric field.

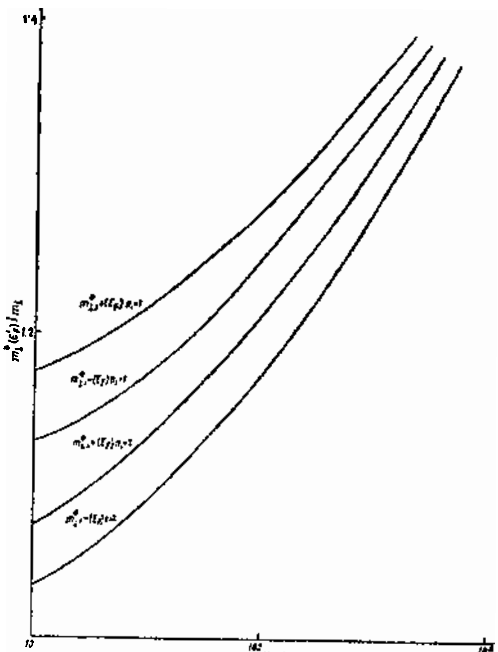

Fig. 6. Plot of $m^*_\perp (\varepsilon'_F)/m_\perp$ for the first two subbands as functions of carrier concentration per unit length ($2d_1 = 40$ nm, $2d_2 = 30$ nm) by using Eqs. (30) and (31).

The oscillations in the various transport coefficients which occur in 3D, 2D and 1D electron gases in II—VI semiconductors under different physical conditions would further be influenced by the index dependent EMC and the contribution of the EMC on the respective mobility would be important. The influences of band tails and the many-body effects have not been considered in this simplified work. Furthermore, though the experimental verification of the basic content of the present paper is not available in the literature to the best of our knowledge, the importance of EMC in semiconductor science has already been stated. Finally, it may be noted that the basic aim of the present paper is not solely to investigate the EMC in II—VI materials under different physical conditions but also to formulate the respective electron concentration since the various transport phenomena and the formulation of different electronic properties are based on the temperature-dependent carrier statistics in such materials.

References

1) F. Stern, J. Appl. Phys. **47** (1976) 5382;

2) R. W. Dixon, Bell. Sys. Tech. J. **55** (1976) 973;

3) S. Adachi, J. Appl. Phys. **58** (1985) R11;

4a) R. Dornhaus and S. Nimtz, Springer Tracts in Mod. Phys. **78** (1976) 1;

4b) W. Zawadzki, in *Handbook of Semiconductors*, **1**, Ed. W. Paul, North-Holland Publ. Co. Amsterdam, 1982 (p. 719);

5) I. M. Tsidilkovskii, Cand. Thesis, Leningrad University, USSR (1955);

6) I. M. Tsidilkovskii, *Band Structure of Semiconductors*, Pergamon Press, Oxford, 1984;

7) D. R. Lovett, *Semimetals and Narrow Gap Semiconductors*, Pion Limited, London, 1977;

8) U. P. Phadke and S. Sharma, J. Phys. Chem. Solids **36** (1975) 1;

9) V. K. Arora and M. Jaafarian, Phys. Rev. **13B** (1976) 4457;

10) J. Kossut and J. Hajdu, Solid State Commun. **27** (1978) 1401;

11) A. N. Chakravarti, A. K. Chowdhury, K. P. Ghatak, S. Ghosh and A. Dhar, J. Appl. Phys. **25** (1981) 105;

12) A. N. Chakravarti, K. P. Ghatak, K. K. Ghosh and H. M. Mukherjee, Phys. Stat. Sol. (b) **116** (1983) 17;

13) M. Mondal and K. P. Ghatak, Phys. Stat. Sol. (b) **123** (1984) K143;

14) M. Mondal and K. P. Ghatak, Acta Phys. Slov. **36** (1986) 325;

15) S. N. Biswas and K. P. Ghatak, Fizika **18** (1986) 121;

16) V. Rossler, Solid State Commun. **49** (1984) 943;

17) S. Wang, *Solid State Electronics*, McGraw-Hill Co., N. Y. (1966), p. 188;

18) B. R. Nag, *Electron Transport in Compound Semiconductors*, Springer Verlag, Springer Series in Solid State Sciences, **11** (1980);

19) J. J. Hopfield, J. Appl. Phys. **32** (1961) 2277;

20) W. Zawadzki, Surface Science **37** (1973) 218;

21) M. Mondal, S. Banik and K. P. Ghatak, Acta. Phys. Slov. **38** (1988) 304;

22) R. Dingle, W. Weigmann and C. H. Henry, Phys. Rev. Letts. **33** (1974) 827;

23) H. L. Stormer, A. C. Gossard and W. Weigmann, Appl. Phys. Letts. **39** (1981) 912;

24) L. L. Chang and L. Esaki, in *Molecular Beam Epitaxy*, Ed. B. R. Pamplin, Pergamon Press, Oxford, 1980;

25) M. T. Linch, Festkörperprobleme, **23** (1983) 227;

26) O. Ania, M. Mattingly, F. Y. Juan and P. K. Bhattacharya, Appl. Phys. Letts. **50** (1987) 43;

27) S. Tarucha and H. Okamoto, Appl. Phys. Letts. **48** (1986) 1;

28) D. A. B. Miller, D. S. Chemla, J. C. Dumen, J. H. Wood, A. C. Burrus, A. C. Gossard and W. Weigmann, IEEE Trans. J. Q. E. **21** (1985) 1462;
29) H. Sasaki, Jap. J. Appl. Phys. **19** (1980) L735;
30) W. J. Skopol, L. D. Jackel, E. L. Hu, R. E. Howard and L. A. Felter, Phys. Rev. Letts. **49** (1982) 951;
31) R. K. Pathria, *Statistical Mechanics*, Pergamon Press, London;
32) M. Abramowitz and I. A. Stegun, *Handbook of Mathematical Functions*, Dover Publication, U. S. A., 1965;
33) J. S. Blakemore, *Semiconductor Statistics*, Pergamon Press, London, 1962;
34) W. Zawadzki and B. Lax, Phys. Rev. Letts. **16** (1966) 1001;
35) W. Zawadzki, Springer Series in Solid State Sciences **53** (1984) 2;
36) A. N. Chakravarti, K. P. Ghatak, A. Dhar, K. K. Ghosh and S. Ghosh, Acta Phys. Polon. **A60** (1981) 151;
37) M. Mondal and K. P. Ghatak, Phys. Stat. Sol. (b) **126** (1984) K41;
38) G. Paasch, T. Fiedler, M. Kolar and I. Bartos, Phys. Stat. Sol. (b) **118** (1983) 641;
39) J. A. Brum, Solid State Commun. **54** (1985) 179;
40) S. N. Biswas and K. P. Ghatak, Phys. Stat. Sol. (b) **137** (1986) K175.

O EFEKTIVNOJ MASI ELEKTRONA U DEGENERIRANIM II—VI POLUVODIČIMA PRI RAZLIČITIM FIZIKALNIM UVJETIMA

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Učinjen je pokušaj razmatranja efektivne mase elektrona u degeneriranim II—VI poluvodičima pri različitim fizikalnim uvjetima. Kao primjer uzet je *n*-CdS. Definirane su efektivne mase u 3D, 2D i 1D konfiguracijama. Nađeno je da efektivna masa varira s magnetskim i veličinskim kvantnim brojevima pri raznim uvjetima kao posljedica razdvajanja dva spinska stanja spin-orbit vezanjem i efektom kristalnog polja.