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Hole Transport Characteristics of CdSe Single Quantum Wells at Low Temperatures

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Abstract

Hall Mobility and magnetoresistance of the two-dimensional holes in CdSe single quantum wells (SQWs) are calculated in the temperature range of 1K–16K incorporating deformation potential acoustic, piezoelectric, and background and remote ionized impurity scatterings by the iterative solution of the Boltzmann transport equation. The individual contribution to the mobility due to ionized impurity scattering only has also been calculated. The nature of the variation of the Hall mobility with temperature agrees fairly well with that obtained by experimental workers. Hall mobility is found to be mainly governed by the ionized impurity scattering in the temperature range considered. The oscillatory nature of the magnetoresistance coefficient variation with the temperature points towards the magnetophonon oscillations.

Keywords: Hall Mobility, Magnetoresistance, Single Quantum Wells.

I. INTRODUCTION

The emerging research interest in ZnTe/CdSe single quantum wells (SQWs) has been aroused in recent years due to their scientific importance and technological applications [1-3]. In particular, such quantum wells are used in optoelectronic devices like lasers [3]. Theoretical studies of the 2D hole transport in SQWs are scarce in the literature although some experimental data are available [4].

In this paper, we calculate the Hall Mobility and magnetoresistance of the two-dimensional holes in CdSe single quantum wells (SQWs) incorporating Fermi-Dirac statistics and the relevant lattice scattering mechanisms in the temperature range of 1K–16K. The individual contribution to the Hall mobility due to impurity scattering only has also been calculated. The variation of the magnetoresistance coefficient with temperature has been investigated taking into account all the relevant scattering mechanisms.

II. ANALYTICAL DETAILS

The band gaps of ZnTe and CdSe are taken as 2.34 eV and 1.75 eV, respecvely [5]. Resembling AlAs/GaAs QWs, the conduction band offset in the ZnTe/CdSe single QWs is taken to be 60% of the difference of the band gaps. The conduction band offset for the ZnTe/CdSe QWs is much higher than the Fermi energy E_f, so the CdSe square well can be assumed to be infinite.

We consider a rectangular Cartesian coordinate system with z-axis perpendicular to the interfacial planes so that the 2D transport occurs parallel to the xy plane. The electric field ε is assumed to be along x-axis and the non-quantizing magnetic field B along z-axis. The carrier distribution function can be written as.

$$f(\mathbf{k}) = f_0(E) - \left(\frac{e\hbar}{m^*}\varepsilon\right)\frac{\partial f_0}{\partial E}\left[k_x\xi_x(E) - \omega_B k_y \xi_y(E)\right] \tag{1}$$

where $\boldsymbol{k}$ is the 2D wave vector of holes with energy E, $f_0(E)$ is the equilibrium Fermi- Dirac function, e is the carrier charge, is Planck's constant divided by 2π, m^*

is the electron effective mass, k_x and k_y are the x- and y-components of $\boldsymbol{k}$, $\omega_B = \frac{eB}{m^*}$ is the cyclotron resonance frequency, and ξ_x and ξ_y are the perturbation functions.

The perturbation functions obtained from the Boltzmann transport equation are

$$\xi_x(E) = \frac{\tau(E)}{1+\omega_B^2\tau^2(E)} \quad (2)$$

$$\xi_y(E) = \frac{\tau^2(E)}{1+\omega_B^2\tau^2(E)} \quad (3)$$

Here, $\tau(E)$ is the combined relaxation time for all the scatterings:

We have calculated Hall Mobility and magnetoresistance coefficient taking into account elastic scattering processes, viz., acoustic scattering via deformation potential and piezoelectric couplings and screened Coulomb scattering for both background and remote ionized impurities. The expressions for the scattering rates have been taken from the reference [6]. The expressions remain unaltered in the case of hole transport considered here because electrons and holes differ only in charge sign and effective mass value which we have incorporated in our numerical computations.

The Hall mobility μ_H and magnetoresistance coefficient R_m are given by following [5] :

$$\mu_H = \mu_{xx}(0) |\mu_{xy}| / [B(\mu^2_{xx} + \mu^2_{xy})] \quad (4)$$

and $$R_m = \mu_H B \mu_{xx} / |\mu_{xy}| - 1 \quad (5)$$

where

$$\mu_{xx} = \frac{e}{\pi N_{2D}\hbar^2}\int_0^{\alpha}\left(-\frac{\partial f_0}{\partial E}\right)\times\xi_x(E)E\,dE$$

and the drift mobility $\mu_{xx}(0)$ is the value of μ_{xx} for B=0.

III. RESULTS

The effective mass of the holes for CdSe is taken as $m^* = 0.45m_0$, where m_0 is the electron rest mass [7]. The

$$\mu_{xy} = \frac{e\omega_B}{\pi N_{2D}\hbar^2}\times\int_0^{\alpha}\left(-\frac{\partial f_0}{\partial E}\right)\xi y\,E\,dE,$$

other parameter values related to CdSe and used in our calculations are taken from Rode [8] and given in table 1. We take the 2D carrier concentration $N_{2D} = 4.8 \times 10^{15}/\text{m}^2$.

Table 1. Materical parameters of CdSe used in the calculations

Parameters	Values
Static dielectric constant	9.4
Optic dielectric constant	6.1
Longitudinal elastic constant	$7.37\text{x}10^{10}$ Nm^{-2}
Transverse elastic constant	$2.459\text{x}10^{10}$ Nm^{-2}
Acoustic deformation potential constant	3.7 eV
Piezoelectric tensor component for parallel mode scattering	$3.37\text{x}10^{9}$ Vm^{-1}
Piezoelectric tensor component for perpendicular mode scattering	$2.36\text{x}10^{9}$ Vm^{-1}
Polar LO phonon temperature	303 K

In figure 1 the variation of Hall mobility with temperature is displayed, the mobility is limited by ionized impurity scattering (μ_{im}) only. The widths of the QWs are taken as 10nm, 8nm and 5nm respectively. Figure 2 displays the variation of overall mobility (μ) with temperature, the mobility is limited by the combined scattering mechanisms, namely, deformation potential acoustic phonon scattering, piezoelectric parallel mode and perpendicular mode scatterings and ionized impurity (both background and remote) scattering . The variation of the overall mobility is displayed over the temperature range 1 to 16K for channel widths 10nm, 8nm and 5nm respectively, with magnetic field B=0.2T. The ionized impurity concentration is taken as N_I =8.6×10^{22}/m^3 in our calculations. Figures 1 and 2 show the same trend of mobility variation with temperature; in both the figures the Hall mobility almost remains constant up to 4.2K. The same feature has been obtained by experimental workers for SiGe SQWs [4].The theoretical explanation for this is that none of the scattering processes dominate in such low temperature range so the mobility almost remain constant up to 4.2K.

In figure 1, the mobilities limited by ionized impurity scattering for all well widths, namely, 5nm, 8nm, 10nm respectively, increase from 4.2K onwards, and then they attain a peak at 8K and finally drop off as temperature increases further. This is due to the fact that μ_{im} increases with increasing temperature owing to its Coulombic nature and then fall off as temperature increases. In figure 2, the temperature variation of the overall mobility due to combined effect of all scattering mechanisms exhibit the same nature as in figure 1 but the only difference is that the mobility peaks are reached at a temperature lower than 8K. This may be attributed to the combined effect of deformation potential acoustic and piezoelectric scatterings besides the impurity scattering

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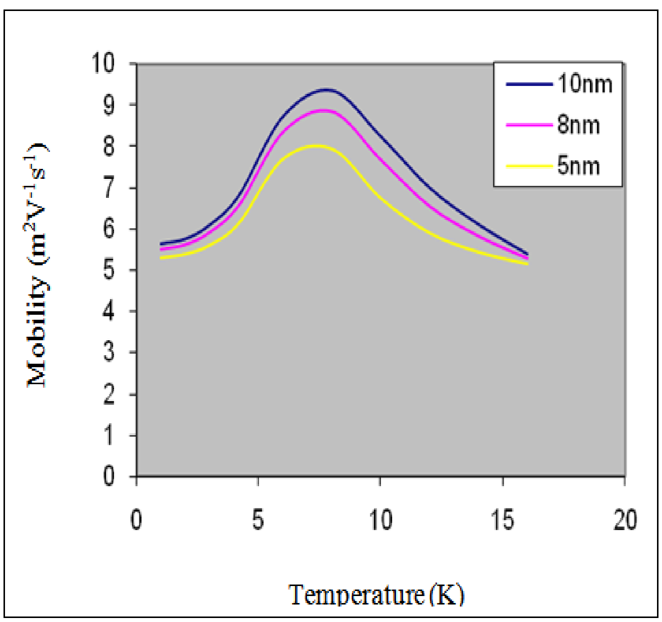

Figure 1. 2D Hall mobility *vs*. Temperature in CdSe SQW for Lz=10nm, 8nm, 5nm, N_{2D}=4.8×10^{15}/m^2, and N_I=8.6×10^{22}/m^3 for ionized impurity Scattering.

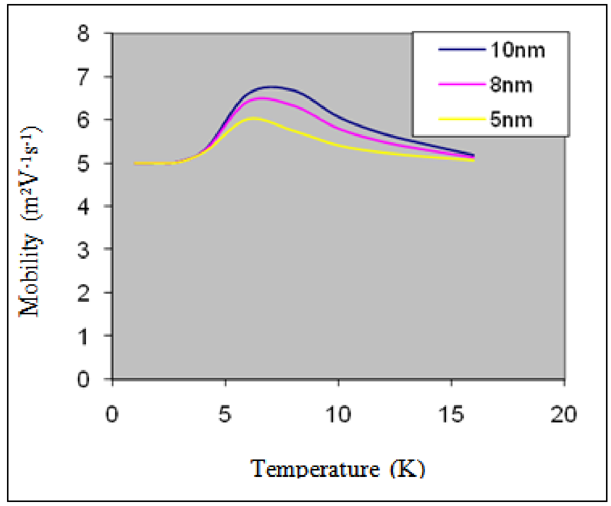

Figure 2. 2D Hall mobility *vs*. Temperature in CdSe SQW for L_z=10nm, 8nm, 5nm, N_{2D}=4.8×10^{15}/m^2, and N_I=8.6×10^{22}/m^3 for combined scattering.

Figure 3 shows the variation of magnetoresistance (R_m) with temperature for channel widths 10nm, 8nm and 5nm respectively, *with* magnetic field B = 0.02T, impurity concentration N_I=8.6×10^{22}/m^3 and 2D carrier concentration N_{2D}=4.8×10^{15}/m^2 .The magnetoresistance is found to have an oscillatory nature which arises due to magnetophonon oscillations of the deformation potential scattering [9].

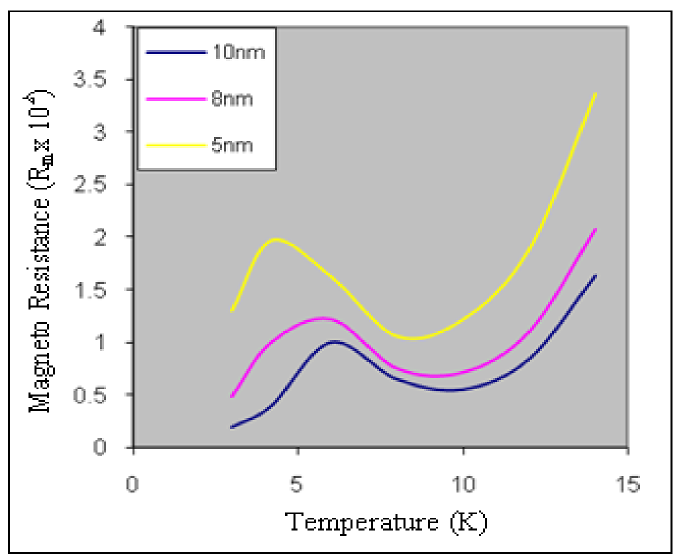

Figure 3. Variation of Temperature and R_m for different for L_z=10nm, 8nm, 5nm, N_{2D}=4.8×10^{15}/m^2, and N_I=8.6×10^{22}/m^3 for combined scattering.

IV. CONCLUSION

In the present paper we have presented some new calculations of the Hall mobility and magnetoresistance coefficient for the two-dimensional hole transport in CdSe SQWs. The nature of the mobility variation agrees fairly well with that obtained by the experimental workers for SiGe SQWs [4]. The overall Hall mobility is found to be mainly governed by the ionized impurity scattering. The contributions from other scattering processes, namely deformation potential acoustic and piezoelectric scatterings cause a negative temperature gradient in the mobility variation as evident from figure 2. The variation of magnetoresistance coefficient with temperature has an oscillatory nature due to magnetophonon oscillations. These results will throw new light in understanding the hole transport mechanism in CdSe quantum wells.

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