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CURRENT- VOLTAGE CHARACTERISTICS OF CDSE 2D FETS AT LOW TEMPERATURES

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ABSTRACT:
Current- voltage characteristics of CdSe 2D FETs are calculated at low temperatures namely, 5 K and 15 K, incorporating deformation potential acoustic, piezoelectric, and background and remote ionized impurity scatterings in the framework of Fermi-Dirac statistics. The nature of the I-V characteristics obtained by the authors agrees fairly well with those obtained by other researchers for CdSe FETs [1]. The current is higher at smaller channel widths compared to those at higher widths. Drain current is found to be mainly limited by impurity scattering and its value is closer to that due to combined scattering while piezoelectric and acoustic scatterings have negligible effects at low temperature of interest here.

I. INTRODUCTION:

Research works on CdSe FETs already exist in the literature [1, 2]. Electronic transports in CdSe single quantum wells have received considerable attention in recent years due to wide spectrum technological applications [3-5]. Such quantum wells are used in optoelectronics devices like lasers [4].

The width of the quantum wells being comparable to the de Broglie wavelength, electron motion is quantized in the direction perpendicular to the layers. Electron energy levels are split in sub bands resulting in the two dimensional (2D) electronic transport parallel to the interface.

In the present communication, we have investigated theoretically the transport properties of 2D electrons in CdSe single quantum wells in the low temperature range incorporating Fermi-Dirac statistics and the relevant scattering mechanisms.

II. ANALYTICAL MODEL:

In our model we consider a rectangular Cartesian co-ordinate 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 non-quantizing magnetic field B along z- axis. The carrier distribution function can be written as

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

Where *k* is the 2D wave vector of electrons with energy, f_0 (E) is the equilibrium Fermi-Dirac function, e is the electronic charge, ħ is Planck's constant divided by 2π, m^* is the electron effective mass.k_x and k_y are the x and y component of 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 equations are,

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

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

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

$$\tau^{-1}(E) = \tau_{ac}^{-1}(E) + \tau_p^{-1} + \tau_{im}^{-1}(E) \qquad (4)$$

Where $\tau_{ac}(E)$ is the relaxation time for deformation potential acoustic scattering, $\tau_p(E)$ is those for the piezoelectric scattering, respectively. $\tau_{im}(E)$ is the relaxation time for background and remote impurity scatterings. The expression for $\tau_{ac}(E)$ is taken from Ref.[6], while that for $\tau_{im}(E)$ is taken from Ref.[7]. The expression for relaxation time of piezoelectric scattering is given in Ref.[6].

The Hall mobility μ_H and magnetoresistance is given by [8]

$$\mu_H = \frac{\mu_{xx}(0)\,|\mu_{xy}|}{B(\mu_{xx}^2 + \mu_{xy}^2)} \qquad (5)$$

Where,

$$\mu_{xx} = \frac{e}{\pi N_{2D}\hbar^2}\int_0^{\alpha}\left(-\frac{\partial f_0}{\partial E}\right)\times\frac{\tau(E)}{1+\omega_B^2\tau^2(E)}\,E\,dE\,, \qquad (6)$$

$$\mu_{xy} = \frac{e\omega_B}{\pi N_{2D}\hbar^2}\times\int_0^{\alpha}\left(-\frac{\partial f_0}{\partial E}\right)\frac{\tau^2(E)}{1+\omega_B^2\tau^2(E)}\,E\,dE \qquad (7)$$

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

Next, we calculate the drain current in 2D FET Channel as

$$J=N_{2D}\,ev= N_{2D}\, e\mu E= N_{2D}\, e\mu V/d \qquad (8)$$

Where ,N_{2D} = 2D electron Concentration,.
e= electron Charge,
μ= mobility,
d=channel width,
and V= applied drain voltage.

We have computed mobility for deformation potential acoustic scattering (μ_{ac}), piezoelectric mode scattering ($\mu_{\perp p}$), ionized impurity scattering (μ_{im}) respectively, and the overall mobility (μ) due to combined scatterings by solving the Boltzmann transport equation numerically with the help of the iterative technique. Next the drain currents are calculated for the corresponding drain voltages using the expression (8).

III. RESULTS:

The effective mass of the electrons for CdSe including polaronic correction is taken as m^*= 0.12m_0, where m_0 is the electron rest mass [5]. The other parameter values related to CdSe which are used in our calculations are taken from Rode [9] and given in table 1.

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

The variation of current with voltage is displayed in Figure 1, for three different channel widths, namely, 10nm, 20 nm and 30 nm at the temperature 5K. The nature of the I-V characteristics obtained by the authors agrees fairly well with those obtained by other workers [1]. The current is higher at smaller channel widths compared to that at higher widths.

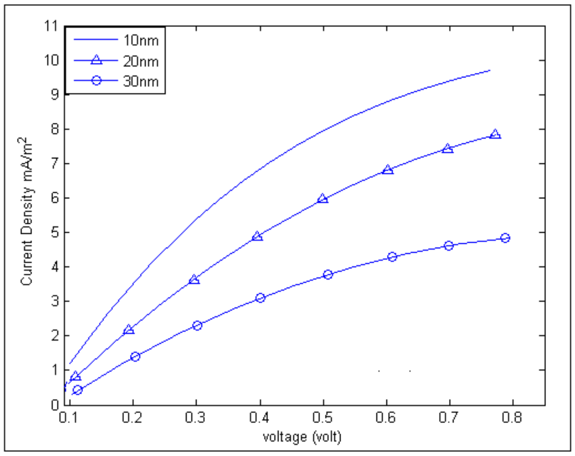

Figure 2. Drain current Drain voltage characterstics of CdSe FETs at different channel widths

Figure 2 shows the variations of current density with voltage for the mobility due to deformation potential acoustic scattering (μ_{ac}), piezoelectric mode scattering (μ_p) and ionized impurity scattering (μ_{im}). The variation of the current against voltage for overall mobility (μ) combining all these scattering mechanisms is also calculated for the width of the QW = 10.5nm. We have taken the value of the background ionized impurity concentration as N_I = $8.6 \times 10^{22}/m^3$ at 15K. The other parameter values for CdSe are taken from above Table 1.

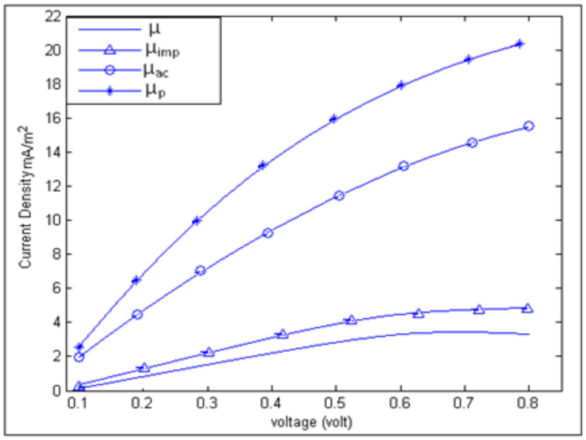

Figure 3. Drain current vs.drain voltage plot in CdSe FETs for L_z=10.5nm, $N_{2D}=4.8\times10^{15}/m^2$, and $N_I=8.6\times10^{22}/m^3$. μ_{ac}, $\mu_{\perp p}$, and μ_{im} represent respectively mobility for deformation potential acoustic scattering, piezoelectric mode scattering, and ionized impurity scattering. μ is the overall mobility at 15 K due to combined scatterings.

Current density is found to be more sensitive for impurity and acoustic scatterings than that due to combined scattering and piezoelectric scattering.

IV. CONCLUSION:

We have shown the variation of the drain current with the drain voltages for CdSe 2D FETS at different channel widths in the nanoscale dimensions at the low temperature of 5K, which is preferred for low noise. Drain current is found to be higher at smaller channel widths compared to those at higher widths showing the promise for narrow channel FETS in device applications. It is evident from Figure 3 that drain current is mainly limited by the impurity scattering and its value is closer to that due to combined scattering while piezoelectric scattering and acoustic scatterings have insignificant effects in the low temperature range of interest here. Thus our study will provide a deeper insight in understanding the electronic transport in nanoscale FETs.

REFERENCES:

[1] Anubhav Khandelwal, Debdeep Jena, James W. Grebinski, Katherine Leigh Hull, Masaru K Kuno, Journal of Electronics Material. , 35, 170-172(2006) (Springer).

[2] H. Koelmans , H.C. De Graaff, Solid-State Electronics, 10,997-1000 (1967).

[3] N.Samarth, H.Luc, J.K.Furdyna, R.G.Alonso, Y.R.Lee, A.K.Ramdas, S.B.Qaon and N.Otsuk, Appl.Phy.Lett. **56** 1163 (1990).

[4] G.Landwehr, A.Waag, F.Fischer, H.J.Lugauer, and K.Schull, Physica E **3** 158 (1998).

[5] H.K.Ng, Y.A.Leem, R.Knobel, I.P.Smorchkova, A.A.Sirenko, N.Samarth, Appl. Phy. Lett. **75** 3662(1999).

[6] D.Chattopadhyay, Phys. Stat. Sol. (b) **135** 409 (1986).

[7] J.Lee, H.N.Spector, V.K.Arora, J.Appl.Phys. **54** 6995 (1983).

[8] P K Ghosh, D. Chattopadhyay, A. Ghosal and B. G. Mulimani, Phys. Stat. Sol. (b), 176, 451 (1993).

[9] D.l.Rode,: Low Field Electron Transport, in Semiconductors and Semimetals, (eds) R.K.Willardson and A.C.Beer (Academic, New York) **Vol.10**,Ch1. (1975).