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Magnetotransport on Two Dimensional Hole Embeded in Carbon Doped Semiconductor Hetero Structure in the Presence of Spin Orbit Intraction

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ABSTRACT We have studied the magnetotransport on two dimensional hole embedded in carbon doped semiconductor hetrojunciton in the presence of spin-orbit interaction. The study of effective masses of spin orbit split subband in p-type two dimensional hole gases grown along the [001] direction was made. The dependence of intrinsic resistance of long disordered single wall carbon nanotubes was also taken into account for study. The disordered single wall nanotubes form a system for one dimensional localization. This was due to coulomb blockade in a series of 10 nm long quantum dots lying along the tube. The activation energy was found to change as the temperature range was changed. The effective masses in the hole systems are different for two spin split subbands and strongly dependent on sample specific properties such as density and spin orbit interaction strength. This resulted the complexity of the valence band of gallium arsenide. The strong spin orbit splitting in two dimensional hole gas was found due to the presence of a beating in the low field Shubnikov-de Hass oscillations. The heavy-heavy hole effective mass shows a strong density dependence due to spin orbit induced non parabolicities in the valence band. The results were confirmed by self-consistent calculations. In p-type two dimensional hole the contribution to spin orbit interaction of Rashba type originated from the structure inversion asymmetry of the host hetero-structure. Rashba spin orbit interaction for holes have a cubic dependence on the inplane momentum. It was found that effective mass was several times larger than electron in the conduction band. The smaller Fermi energy made the carrier-carrier coulomb interaction more relevant, allowing the study of many body related effects. The obtained results were in good agreement with previously obtained results.

KEYWORDS Magnetotransport, Two Dimensional Hole, Carbon Nanotube Semiconductor, Hetero-Structure, Spin-Orbit Interaction, Effective Mass, Disordered, Coulomb Blockade, Activation Energy, Rashba Spin Orbit Interaction.

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INTRODUCTION

Semiconductors such as silicon and gallium arsenide, the electron effective mass has been investigated using temperature dependent transport and cyclotron resonance experimetns [1-7]. Despite of gallium arsenide for fundamental research and technological applications, a detailed study of the effective mass of holes in gallium arsenide two dimensional hole gas grown along the high symmetry direction remains. Two dimensional hole gases required a effective mass value and its dependence on quantities as hole density and spin-orbit interaction strength. Yu and Cardon [8]presented spin and momentum eigen states, leading to a profound difference between the two spin-orbit split bands unlike the case of electron, Rashba spin-orbit interaction for holes is expected to have a cubic dependence on the in-line momentum has been studied by Sinkler [9]. With respect to other materials, gallium arsenide two dimensional hole gases offered the unique opportunity to study pronounced spin orbit interaction effects in a system that can be grown with high control was made by Noh et al. [10] and Hunag et al. [11] and rapidly processed into nano-structures [12-17]. The strong spin orbit splitting in two dimensional hole gases was found from the presence of a beating in the low field Shubnikov-de Hass oscillations [18-23]. The frequency axis *f* can be directly mapped into densities n by $n = \frac{fe}{h}$, since they are coupled by spin orbit and since scattering and charge redistribution between subbands presented various non linear terms [24]. Single wall carbon nanotubes have system to study one dimensional transport. The effect of disorder in one dimensional is very prominent, current lines have to follow the wire. The transmission of impurity centers became low enough, the one dimensional wire as a series of quantum dots. The conduction was then activated $R(T) \approx \exp(T^{-1})$ [25-28]. Gao et al. [29] studied the temperature dependence of the intrinsic of long disordered single wall carbon nanotubes. The intrinsic resistance of disordered nanotube was measured in four point configuration [30]. Zarenba [31] studied that positive magneto resistance visible for a magnetic field smaller than 100mT. Lu et al. [32] studied the spin orbit splitting, quantified as $\frac{\Delta n}{n} = \frac{(n_2 - n_1)}{(n_2 + n_1)}$ varied with gate voltage. An estimation of the spin-orbit energy splitting between subbands has been found in the supplemental material. Andersrion et al. [33] studied binary random compacts with different proportions for small and large volume of magemine nanoparticles for the study of effect of broadening the particle size distribution on the magnetic properties nanoparticles assembled with strong dipolar interaction. The broadened size distribution in the mixed samples glass transition temperature were observed across the series. Their values were increased linearly with weight fraction of large particles. Deng et al. [34] studied that magnetic nanoparticles assemblies are the basis of an ever increasing catalog of applications. The nanoparticles size distribution affected the properties of dense magnetic particle ensemble, e.g. by allowing or forbidding the development of critical slowing down and a super spin glass phase transition. Polozkov et al. [35] presented that energy spectrum for quasi metallic nanotube was described by a strongly hyperbolic dispersion. Dyakov et al. [36] studied experimentally and theoretically the transverse magneto optical Kerr effect in magnetite based magneto plasmonic crystals. It was analysed that spectra from two types of structures where noble metallic stripes were incorporated inside a thin magnetite film. A multiple wideband enhancement of the transverse magneto optical Kerr effect signal in transmission was demonstrated. The results of different parameters were used in coupled wave analysis calculations for the study of optical resonances. Bossini et al. [37] presented that magneto optical effects were used for realization of ultrafast optical switches in nanophotonic circuits, where slowly varying external magnetic field, short radio frequency or optical pulses were applied to govern the magnetization dynamics in magnetic media. Borovkova et al. [38] demonstrated the enhancement of transverse magnetic opto Kerr effect in magneto plasmonic crystals and magneto plasmonic nano antennas [39-41]. Lan et al. [42] developed a model which incorporated intervalley scattering to master equation to explore exciton valley coherence in mono layer subjected to magnetic field. It was found that magnetic field quenched the electron-hole exchange induced pure dephasing and allowed magnetically regulated valley coherence. The recent ab inito calculations delt with valley and atomic intracellular contributions in a unified way associated with the orbital angular momentum [43-45]. It was considered that deal of Vander waals hetro-structures of transverse magneto for two dimensional case was better response.

METHOD

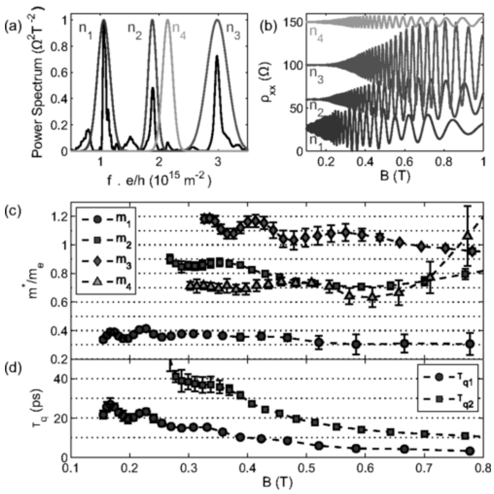
The carriers effective mass in a two dimensional system was estimated from the temperature dependence of the low field Shubnikov-de Hall oscillations. Based on the Ando formula for single subband systems, the relative amplitude decay

$$\frac{\Delta\rho_{xx}}{\rho_{xx}} = i\exp\left(-\frac{\pi}{\omega_c\tau_q}\right)\frac{\dfrac{2\pi^2 k_B}{\hbar\omega_c}}{\dfrac{\sinh\left(2\pi^2 k_B T\right)}{\hbar\omega_c}}$$

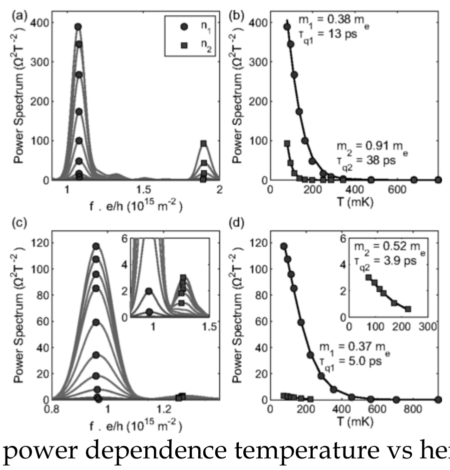
Where T is the temperature, $\omega_c = \frac{eB}{m^v}$ sis the cyclotron frequency, τ_q and $m*$are the fitting parameters. If the magnetic field onsets of the oscillation differ, one of the two effective masses be deduced from the ρ_{xx} oscillations where the contribution of one subband is relevant. The other effective mass be inferred assuming parabolic bands, hence $\frac{m_1}{m_2} = \frac{n_2}{n_1}$ or assuming $\frac{m_1}{m_2} = \left(\frac{\tau_2}{\tau_1}\right)$. A filtering g technique was used to separate the different contributions in Fourier space, yielded the individual masses without assumptions. The low density spin orbit split subband is referred to as heavy-heavy hole subband and the height density one as heavy-heavy hole subband. A linear dependence of the effective masses with respect to magnetic field was observed. We have calculated the effective masses m_1 and $m_2$of the two spin-orbit split $\pm\frac{3}{2}$ subbands in the limit of small magnetic fields. A pronounced difference between m_1 and m_2 upto a factor of 3 and the absence of any field dependence was observed. The Wafer structure used was grown by molecular beam epitaxy on a [001] oriented gallium arsenide substrate. The symmetric doping created a strong structural inversion asymmetry, so the holes wave function resided on the top side of the gallium arsenide quantum well. From the wafer two samples were proceeded, each consisting of two 50 µm × 25µm Hallbars oriented perpendicularly to each other.

RESULTS AND DISCUSSION

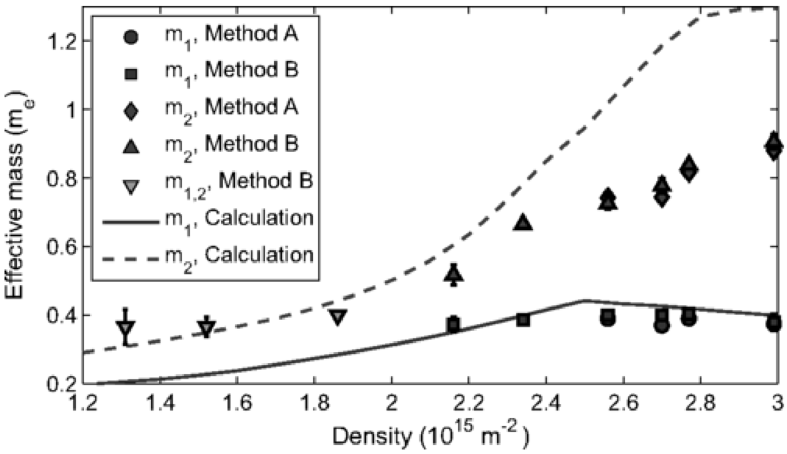
Graph (1)(a) shows the filters used for analyzing data. Graph (1)(b) gives the corresponding Shubnikov-de Hass oscillations. Graph (1)(c) shows the effective masses obtained to the minima of the filtered oscillations and Graph (1) (d) shows the quantum scattering times obtained for n_1 and n_2. The magnetic field in which the amplitude of the $n_2 + n_1$ oscillated became relevant was used as the limit for the validity range of the analysis. The quantum scattering times obtained from the classical positive magneto resistance. The oscillations in m_1 and τ_{q_1} visible at small magnetic field are due to side peaks in the power spectrum as shown in Graph (1)(a). They originated from boundary effects in the Fourier transform and are totally suppressed by windowing the data as, we have studied the temperature dependence of $n_2 + n_1$ and $2n_1$ peaks, assigning them fictitious effective masses m_3 and m_4. The $2n_1$ peak is the second harmonic of n_1. We have found that $n_2 + n_1$ peaks has the strongest temperature dependence, compatible with an effective mass of $m_1 + m_2$. Graph (2) shows the procedure for the two extreme cases where the method was applied. It was found that n_1 and n_2 peaks decayed with temperature which is shown in the left side of Graph (2) on the right the peak amplitudes are fitted to the numerical model. In the limit of small magnetic fields the obtained results do not show any dependence on the specific magnetic field windows chosen for analysis Graph (3) shows the obtained results. The data points were provided only for higher densities. At low density only one peak is visible in the spectrum, hence only one effective mass $m_{1.2}$ was resolved. The heavy-heavy hole effective mass is constant within the density range equal to 0.38 m_e. The heavy-heavy hole effective masses strongly dependent on the carrier density, indicating a spin-orbit interaction induced nanoparabolicity of the valence band with a less than parabolic dependence on K. The Fermi energy in the limit $\beta \to 0$ of the gallium arsenide two dimensional hole grown on the [001] surface. In self consisted calculations we have used the slope of the Hartree potential at the back interface of the quantum well as a fitting parameter to reproduce the spin-orbit splitting found for the density of $3.0 \times 10^{15} m^{-2}$. This slope was then kept fixed when the modeling the different densities tuned via a top gate. The final results is shown in graph (3). The calculated effective masses obtained in the limit $\beta \to 0$ show good agreement with the low field results both in terms of magnitude and trends. Different effective mass gave rise to pronounced differences in the calculated results for material system with strong band nonparabolicities and high anisotropies such as p-type semiconductor or gallium arsenide. It was also found that intrinsic resistance of strongly disordered nanotube was thermally activated. The disordered nanotube formed a system of one-dimensional localization. The results found were compared with previously obtained results of theoretical and experimental works and were found in good agreement.



Graph 1: Plot of Magneto resistance temperature vs filters extract components.



Graph 2: Plot of resistivity power dependence temperature vs heights for unchanged device.



Graph 3: Plot of effective masses as a function of density.

CONCLUSION

The study of magnetotransport on two dimensional hole embedded in carbon doped p-type semiconductor gallium arsenide and aluminium gallium arsenide heerostructure grown on [001] oriented substrates. The beating pattern in the Shubnikov-de Hass oscillations supported the presence of strong spin-orbit interaction in the device. It was found that the obtained effective masses of spin-orbit splitted subbands were dependent at different hole densities. The lighter heavy hole effective mass was not energy dependent. The heavy-heavy hole effective mass has energy dependence indicating a strong spin orbit induced nonparabolicity of the valence band. The obtained results were found in good agreement with previously obtained results of self-consisted calculations.

REFERENCES

[1] Dresselhaus. G, Kip. A. F and Kittel. C., (1955), Phys. Rev. 98, 368.

[2] Smith. J. L. and Stiles. P. J., (1972), Phys. Rev. Lett. 29, 102.

[3] Sheonberg. D, (1984), Magnetic Oscillations in Metals (Cambridge University Press, Cambridge, U. K.).

[4] Coleridge. P. T., Stoner. R and Fletcher. R, (1989), Phys. Rev. B. 39, 1120.

[5] Fletcher. R, Ioriu. M. D, Harris. J. J and Foxon. C.T (1990), Semicond. Sci. Technol. 5, 1136.

[6] Coleridge. P, Hayne. M, Zawadzki. P and Sachrajda. A, (1996), Surf. Sci. 361-362, 560.

[7] Pan. W, Tsui. D.C. and Draper. B. L., (1999), Phys. Rev. B. 59, 10208.

[8] Yu. P and Cardon. M, (2003), Fundamentals of Semiconductors: Physics and Material Properties, (Springer-Verlag, Berlin).

[9] Winkler-R., (2003), Spin-orbit coupling Effect in Two dimensional Electron and Hole Systems, Springer Tracts in Modern Physics, Vol-191, (Springer-Verlog, Berlin).

[10] Noh. H, Lilly. M. P, Tsui. D. C, Simmons. J. A, Hwang. E. H., Sarma. S. Das, Pfeiffer. L. N and West. K. W., (2003), Phys. Rev. B. 68, 165308.

[11] Huang. J, Novikov. D. S., Tsui. D. C., Pfeiffer. L. N and West. K. W, (2006), Phys. Rev. B. 74, 201302.

[12] Grbic. B, Leturcq. R, Ihn. T, Enssi. K, Reutter. D and Wieck. AD, (2007), Phys. Rev. Lett. 99, 176803.

[13] Quay. C. H. L, Hughes. T. L, Sulpizio. J. A., Pfeiffer. L. N., Baldwin. K. W, West K. W., Goldhaber-Gordon. D and Piciotto. R. de, (2010), Nat. Phys. 6, 336.

[14] Komijani.Y, Csontos. M, Shorubalko. I, Ihn. T, Ensslin. K, Meir. Y, Reutter. D and Week. A. D., (2010), Euro Phys. Lett. 91, 67010.

[15] Srinivasna. A, Yeoh. L. A, Klochan. O, Martin. T. P, Chen.J. C. H, Micolich. A. P., Hamilton. A. R, Reutter. D and Wieck. A. D, (2012), Nano. Lett. 13, 48.

[16] Nichele. F, Komijani. Y, Hennel. S, Geir. C, Wegscheider. W, Reutter. D, Wieck. A. D., Ihn. T and Ensslin. K, (2013), New. J. Phys. 15, 33029.

[17] Komijani. Y, Choi. T, Nichele. F, Ensslin. K, Ihn. T, Reutter. D and Wieck. A. D, (2013), Phys. Rev. B. 88, 035417.

[18] Stormer. H. L, Schlesinger. Z, Chang. A, Tsui. D. C, Gossard. A. C. and Wiegmann. W, (1983), Phys. Rev. Lett. 51, 126.

[19] Eisenstein. J. P, Stormer. H. L, Narayana Murit, Gossard. A. C and Wiegmann. W. (1984), Phys. Rev. Lett. 53, 2579.

[20] Grbic. B, Elenberger. C, Ihn. T, Ensslin. K, Reutter. D and Wieck. A. D, (2004), Appl. Phys. Lett. 85, 2277.

[21] Habib. B, Tutuc. E, Melinte. S, Shayengan. M, Wasser Mann. D, Lyon. S. A and Winkler. R, (2004), Phys. Rev. B. 69, 113311.

[22] Grbic. B, Leturcq. R, Ihn. T, Ensslin. K, Reutter. D and Wieck. A. D, (2008), Phys. Rev. B. 77, 125312.

[23] Habib. B, Shayegan. M, and Winkler. R, (2009), Semicond. Sci., Technol. 24, 064002.

[24] Alexandev. A. S and Bratkovsy. A. M,(1996), Phys. Rev. Lett. 76, 1308.

[25] Ruzire. I. M, Chandrashekhar. V, Levin. E. I and Glazman. L. I, (1992), Phys. Rev. B. 45, 13469.

[26] Staring. A. A. M, Van Houten. H, Beenakker. C. W. J and Foxon. C. T. (1992), Phys. Rev. B. 45, 9222.

[27] Chandra Shekhar. V, Ovadyahu. Z and Webb. A, (1991), Phys. Rev. Lett. 67, 2862.

[28] Bezryadin. A, Verschueren. A. R. M, Trans. S. J and Dekker. C, (1998), Phys. Rev. Lett. 80, 4036.

[29] Gao. B, Glattli. D. C, Placais. B and Bachtold. A, (2006), Phys. Rev. B. 74, 085410.

[30] Gao. B, Chen. Y. F., Fuhrer. M. S., Glattli. D. C and Bachtold. A, (2005), Phys. Rev. Lett. 95, 196802.

[31] Zaremba. E, (1992), Phys. Rev. B. 45, 14143.

[32] Lu. J. P., Yau. J. B., Shukla. S. P, Shayegan. M, Wissinger. L, Rossler. U and Winkler. R, (1998), Phys. Rev. Lett. 81, 1282.

[33] Andersson. M. S etal, (2017), Phys. Rev. B. 95, 184431.

[34] Deng. Y, Ediriwickrema. A, Yang. F, Lewis. J, Girardi. M and Slatzman. W. M., (2015), Nat. Mater. 4, 1278.

[35] Polozkov. R. G etal, (2019), Phys. Rev. B. 100, 235401.

[36] Dyakov. S. A etal, (2019), Phys. Rev. B. 100, 214411.

[37] Bossini. D, Belotelov. V. I, Zvezdin. A. K., Kalish. A. N and Kinel. A. V., (2016), ACS Photonics 3, 1385.

[38] Berovkova. O, etal, (2018), Appl. Phys. Lett. 112, 063101.

[39] Maksymov. I. S, (2016), Rev. Phys., 1, 36.

[40] Valente. J, etal, (2015), Nat. Commun. 6, 7021.

[41] Loughran. T, Katley. P, Hendry. E, Barnes. W and Hicken. R, (2018), Opt. Express, 26, 4738.

[42] Lan Kang. Xie. Shijie, Fu. Jiyong and Qu. Fanyao. (2023), Phys. Rev. B. 108, 035419.

[43] Junior. P. E. F, Zollner. K, etal, (2022), New. J. Phys., 24, 083004.

[44] Robert. C, Dery. H, etal, (2021), Phys. Rev. Lett. 126, 067403.

[45] Deilmann. T, Kruger. P etal, (2020), Phys. Rev. Lett. 124, 226402

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