Electronic Transport in Bulk and Quantized Low Dimensional Semiconductor Systems

A Thesis Submitted to

Central Department of Physics
Institute of Science and Technology
Tribhuvan University
Kathmandu, Nepal

For the degree of

Doctor of Philosophy (Physics)

by

Sanju Shrestha

June, 2005

Supervisor's Certificate

This is to certify that the thesis entitled "***Electronic Transport in Bulk and Quantized Low Dimensional Semiconductor Systems***" described the original work done by ***Mrs. Sanju Shrestha*** of the degree of ***Doctor of Philosophy*** in the ***Central Department of Physics, Institute of Science and Technology, Tribhuvan University, Kirtipur, Kathmandu, Nepal*** under our supervision. The thesis has in our opinion reached the standard fulfilling of the requirements for the Ph. D. Degree. She has done her work in the period of Oct, 2000 to June, 2005 in **the *Central Department of Physics, Tribhuvan University, Nepal*** as well as in the ***Department of Electronics and Tele-Communication Engineering, Jadavpur University, Kolkata, India.***

……

(***Prof. C. K. Sarkar***)
Dept. of E. T. C. E.
Jadavpur University
Kolkata 700 032, India

……

(***Dr. P. K. Bhattarai***)
Padma Kanya Multiple Campus
Tribhuvan University
Kathmandu, Nepal

June, 2005

Acknowledgements

I would like to express my sincere gratitude to my supervisors Prof. C. K. Sarkar, Dept. of Electronics and Tele-Communication Engineering, Jadavpur University, Kolkata, India & Dr. P. K. Bhattarai, Padma Kanya Multiple Campus, Tribhuvan Univeristy, Kathmandu, Nepal for their valuable guidance, instruction and support throughout the course of the research. I not only learned specialized knowledge from them, but also learned working attitude and skill. This work would not have been completed possibly without their patient guidance and persistent encouragement.

I would like to express my cordial thanks to Prof. D. R. Mishra, Prof. L. N. Jha, Prof. D. D. Paudyal, Prof. S. Gurung, Dr. S. R. Buyahut and Dr. N. B. Maharjan, Central Dept. of Physics, Tribhuvan University, Kathmandu for their valuable suggestion and kind cooperation.

I am grateful to Prof. D. C. Sarkar, Mrs. Sarkar, Mrs. Mala Sarkar and Master Arghyadeep Sarkar for their care and providing me homely atmosphere during my stay in Kolkata, far away from my home town.

I would like to express my very special thanks to Dr. C. Bose, Mr. K. K. Mallik, Dept. of E. T. C. E., J. U. for their assistance and helpful discussions for my work. I am sincerely grateful to Late Prof. M. N. Roy, Prof. R. Nandi, Prof. H. Saha, Prof. A. K. Bandhopadhya, Ramda, faculties and staffs of Jadavpur University for providing me excellent research facilities and cooperation. All of my experiences and interactions with them have shaped my work efficiently.

I would like to thank all of my departmental friends and JU ladies hostel mates, Ms. Arpi Majumder, Mrs. Aparna Chakraborty, Ms. Gargi Chakraborty, Mr. Partha Sarkar, Mrs. Madhabi Ganguly, Mr. Srimanta Baishya, Ms. Sangita Behera and Mr. Surya Shankar Dan.

I would also like to acknowledge Third World Academy of Sciences (TWAS), Trieste, Italy for awarding me Third World Organization for Women in Science (TWOWS) fellowship to carry out my research and their frequent kind cooperation.

Finally, I would like to thank my family, especially to my dear son Sashit Shrestha, husband Dr. S. R. Shrestha and our parents Mrs. B. Maya Shrestha, Mr. Banshi Shrestha and Mrs. Shyama Shrestha for teaching me to understand the value of education and hard work and giving me moral support in my educational life as well as personal life. Their infinite love and strong support are always the greatest inspiration to me on my every step of life.

Abstract of thesis entitled

Electronic Transport in Bulk and Quantized Low Dimensional Semiconductor Systems

Submitted by
Sanju Shrestha
for the degree of **Ph. D. (Physics)**
in **Tribuvan University, Kathmandu, Nepal**

It is very interesting and important to study electronic transport parameters of bulk and low dimensional systems. Bulk material, such as GaN, a III+V compound semiconductor is a very useful material for electronic device applications due to its direct and wide band gap and also due to the strong bond strength. However, a non availability of single crystalline form of GaN and perfectly matched substrates are always problems for GaN. Hence, GaN, grown by various chemical vapor deposition techniques on a substrate such as sapphire is having large dislocations at the interface, the layer between the bulk layer of GaN and the sapphire due to the mismatch in the lattice constants. Such interfacial layer significantly affects the transport parameters of the material, where the transport properties are high dominated by scattering due to dislocations.

The author calculated various transport parameters such as ac/dc mobilities, Seebeck coefficient, thermal conductivity and the thermoelectric figure of merit considering two layer model formulated by Look and the results are also found to be agreement with the experimental values.

In a junction between high and low band gap semiconductors, the carriers are transferred from higher band gap to the lower band gap due to which a space charge is generated in the higher band gap. At the same time, charge gets accumulated at the lower band gap forming an accumulation of charges. It causes the band bending and the formation of a triangular quantum well. The carriers accumulated at the interface of the junction get quantized into various energy levels. Such system behaves as quantum-two dimension (Q2D) because the carriers are free to move on a plane, perpendicular to the junction. The mobility of such a system is very high due to reduction of the

scattering mechanisms as well as due to charge getting separated from the parent donors.

Further, by confining the one more dimension of the heterojunction by taking an infinite potential well causes the carriers to move only on one dimension and the system is called quasi-one dimensional (Q1D) system. Such Q1D system is also called quantum well wire (QWW) because; the carries are restricted to move on only one dimension instead of a plane, which was in the case of Q2D system. The author has carried out comparative studies on Q2D and Q1D ac/dc mobilities in the heterojunctions of AlGaAs/GaAs and GaInAs/InP. The effect of various low temperature phonon and nonphonon scattering mechanisms on the systems are also observed.

In addition, the Q1D system formed by magnetically confined system is also attracting attention of researchers in device application because it is capable of over looking the various techniques of fabrication difficulties and defects created by such fabrication techniques.

In the presence of a high magnetic field, the transverse component of the energy dispersion relation gets quantized into various equally spaced energy levels called Landau levels and the motion of the carriers is completely restricted. However, the longitudinal component along the field is still free to move. The mobility of such system is enhanced when a low effective mass semiconductors n-HgCdTe (Mercury Cadmium Telluride) is used. The band structure of n-HgCdTe is found to be nonparabolic due to its low band gap according to Kane [Phadke and Sharma, 1975]. Recent publications, based on experimental verifications of transport coefficient of n-HgCdTe of Chen and Sher [Chen and Sher, 1982] show that the band structure of MCT (Mercury Cadmium Telluride) is more hyperbolic in nature rather than nonparabolic. The author has compared the effect of band structures on the various transport properties of MCT such as mobility, Seebeck coefficient, thermal conductivity, figure of merit (Z) etc. The figure of merit is a very important property of a material to be used in thermoelectric devices, such as cooler, refrigerator etc.

Emission of photoelectron takes place when a monochromatic photon of energy $h\omega$ is incident on a sample. These photoelectrons will have the information about the quantized states they left. Depending upon the

strength of the application of the photon energy, the transverse components of the energy dispersion relation with various quantized energy levels in the case of magnetic confinement take part in the photoemission process. Hence, the photoemission causing photo electric current density is found to be step like nature due to the participation of various energy levels. Comparative study of the photo emission due to geometrically confined system of dimension exactly as that of the magnetically confined structure is another interesting study presented in the thesis.

When such a magnetically confined Q1D system be replaced by a thin film of thickness equal to that of the deBroglie wave length, the longitudinal component of the energy dispersion relation also gets quantized and the system behaves as quantum-zero dimensional (Q0D) system. The comparative studies of such magnetically and geometrically confined systems have also been formulated in the thesis.

Due to the presence of impurities in semiconductors quantized energy levels get broadened. Hence, the photoelectric current density gets modified due to broadening. The author has observed and compared the effect of broadening of the quantized energy levels on the photoelectric emission due to magnetically and geometrically confined systems. It is found that the characteristic nature of the photoelectric current density remains the same but the values of the current density decreases with the inclusion of the broadening parameter.

Phadke U. P. and Sharma S., J. Phys. Chem. Sol. 36, 1 (1975).
Chen A.B. and Sher A ,J. Vac. Sci. Technol. 21, 138 (1982).

Contents

Chapter III

Low field Electrical and Thermal Transport Properties of lattice mismatched n-GaN grown on Sapphire

Chapter IV

Comparative studies of Reduced Dimensionality on electron transport at the heterojunctions of GaAs/$Al_xGa_{(1-x)}As$ & $Ga_xIn_{(1-x)}As$/InP Systems at Low Temperatures

Chapter V

Band structure effects on Electrical and Thermal properties of Mercury Cadmium Telluride (n-$Hg_{0.8}Cd_{0.2}Te$) under Magnetic Quantization in Longitudinal Configuration

Chapter VI

Effect of Energy Level Broadening on Photoelectric Emission from sub-two-dimensional Systems

List of publications

Low field AC conductivity for GaN with two layer model
S. Shrestha, A. Chakraborty, B. Sen & C. K. Sarkar
pg. 377, *Proceeding of International conference on Communications, Devices and intelligent Systems (CODIS 2004)*

The effect of band structure on the thermoelectric figure of merit of n-HgCdTe (MCT) under magnetic quantization at low temperatures
S. Shrestha, A. Chakraborty & C. K. Sarkar
pg.324, *Proceeding of International conference on Communications, Devices and intelligent Systems (CODIS 2004)*

Effect of carrier confinement on photoelectric emission from magnetically and geometrically confined sub-two-dimensional semiconductor systems
P. K. Das, C. Bose, S. Shrestha & C. K. Sarkar
pg.381, *Proceeding of International conference on Communications, Devices and intelligent Systems (CODIS 2004)*

The effect of reduced dimensionality on low field transport at low temperatures
S. Shrestha, P. Samanta & C. K. Sarkar
pg.1074, *Proceedings of the XIIth International Workshop on the Physics of Semiconductor Devices (IWPSD 2003)*

Study of thermoelectric power of GaN grown on sapphire using two layer model
Chakraborty, S. Shrestha & C. K. Sarkar
pg.1071, *Proceedings of the XIIth International Workshop on the Physics of Semiconductor Devices (IWPSD 2003)*

Effect of reduced dimensionality on low field AC Mobility at low temperatures
S. Shrestha, P. Samanta & C. K. Sarkar
pg.133, *IEEE Conference on Electron Devices and Solid-State Circuits (EDSSC'2003)*

Hot-phonon effect on hot electron transport in narrow gap semiconductors under a quantizing magnetic field at low temperature *

S. Shrestha & C. K. Sarkar

pg. 409, *Phonons in Condensed Materials editors: S P Sanyal and R K Singh (2002)*

Low field AC mobility in one dimensional electron gas at low temperatures

S. Shrestha, P. Samanta & C. K. Sarkar

pg. 414, *Phonons in Condensed Materials editors: S P Sanyal and R K Singh (2002)*

Breakdown of Gate Dielectrics of EEPROM Devices in VLSI Circuit during High-field Stress*

P. Samanta, S. Shrestha & C. K. Sarkar

Pg. 110, *28th Annual Convention and Exhibition of IEEE India Council (ACE-200)*

Longitudinal Magneto-Seebeck coefficient in degenerate and nondegenerate n-HgCdTe in the Extreme Quantum Limit at low temperatures

S. Shrestha, K. Santra, P. K. Bhattarai & C. K. Sarkar

pg.1367, *XIth International Workshop on the Physics of Semiconductor Devices (IWPSD 2001)*

Study of magneto-millimeter and microwave hot electron conductivities in narrow band gap n-HgCdTe

S. Shrestha, P. K. Bhattarai, A. Chakraborty & C. K. Sarkar

Communicated for Proceeding of IVth National Conference on Science & Technology, Royal Nepal Academy of Science and Technology (RONAST)

Combined figure of merit for GN: grown on sapphire

S. Shrestha, A. Chakraborty, C. K. Sarkar & P. K. Bhattarai

Communicated for Proceeding of IVth National Conference on Science & Technology, Royal Nepal Academy of Science and Technology (RONAST)

*Not related to the thesis.

List of papers communicated for Journal publication:

- Comparative studies on electronic transport due to the reduced dimensionality at the heterojunctions of $GaAs/Al_xGa_{(1-x)}As$ and $Ga_xIn_{(1-x)}As/InP$ systems at low temperatures

S. Shrestha & C. K. Sarkar
Microelectronics Journal, ELSEVIER (2006)

- Low-field electrical and thermal transport in lattice-mismatched n-GaN grown on sapphire: Two-layer model calculations

S. Shrestha, C. K. Sarkar & A. Chakraborty
Journal of Applied Physics, an American Physical Society journal 100, 013705 (2006).

- Effect of Energy Level Broadening on Photoelectric Emission from sub-two-dimensional Systems

C. Bose, P. K. Das, S. Shrestha & C. K. Sarkar
(to International Journal of Nanoscience, World Scientific Publishing)

- Studies on thermal transport properties of Mercury Cadmium Telluride (n-$Hg_{0.8}Cd_{0.2}Te$) with hyperbolic band structure under magnetic quantization
  (to be communicated)

- Effect of band structures of Mercury Cadmium Telluride (n-$Hg_{0.8}Cd_{0.2}Te$) on the thermoelectric figure of merit in the presence of high magnetic field
  (to be communicated)