Preface

The merging of the concept of introduction of asymmetry of the wave vector space of the charge carriers in semiconductors with the modern techniques of fabricating nanostructured materials such as MBE, MOCVD, and FLL in one, two, and three dimensions (such as UFs, nipi structures, inversion, and accumulation layers, quantum wire superlattices, carbon nanotubes, nanowires, quantum dots, magneto inversion and accumulation layers, quantum dot superlattices, etc.) spawns not only useful quantum effect devices but also unearths new concepts in the realm of low-dimensional materials science and related disciplines. It is worth remarking that these semiconductor nanostructures occupy a paramount position in the entire arena of nanoscience and technology by their own right and find extensive applications in quantum registers, resonant tunneling diodes and transistors, quantum switches, quantum sensors, quantum logic gates, hetero-junction field-effect transistors, quantum well and nanowire transistors, high-speed digital networks, high-frequency microwave circuits, quantum cascade lasers, high-resolution terahertz spectroscopy, superlattice photo-oscillator, advanced integrated circuits, superlattice photocathodes, thermoelectric devices, superlattice coolers, intermediate-band solar cells, micro-optical systems, high performance infrared imaging systems, band-pass filters, thermal sensors, optical modulators, optical switching systems, single electron/molecule electronics, nanotube-based diodes, and other nano-electronic devices. Knowledge regarding these quantized structures may be gained from original research contributions in scientific journals, proceedings of various international conferences, and different review articles respectively. Mathematician Simmons rightfully tells us [1] that the mathematical knowledge is said to be doubling in every 10 years and in this context we can also envision the extrapolation of the Moore's law by projecting it in the perspective of the advancement of new research and analyses, in turn, generating novel concepts particularly in the area of nanoscience and technology [2]. In this context, it may be noted that the available books on solid-state and allied sciences cannot afford to cover even an entire chapter excluding few pages on the Effective Electron Mass (EEM) in Low-Dimensional Semiconductors.

The effective mass of the carriers in semiconductors, being connected with the mobility, is known to be one of the most important physical quantities, used for the analysis of electron devices under different operating conditions [3]. The carrier degeneracy in semiconductors influences the effective mass when it is energy dependent. Under degenerate conditions, only the electrons at the Fermi surface of n-type semiconductors participate in the conduction process and hence, the effective mass of the electrons corresponding to the Fermi level would be of interest in electron transport under such conditions. The Fermi energy is again determined by the electron energy spectrum and the carrier statistics and therefore, these two features would determine the dependence of the EEM in degenerate n-type semiconductors under the degree of carrier degeneracy. In recent years, various energy wave vector dispersion relations have been proposed [4–10] which have created the interest in studying the effective mass in such materials under external conditions. It has, therefore, different values in different materials and varies with electron concentration, with the magnitude of the reciprocal quantising magnetic field under magnetic quantization, with the quantizing electric field as in inversion layers, with the nano-thickness as in UFs and nanowires and with superlattice period as in the quantum confined superlattices of small gap semiconductors with graded interfaces having various carrier energy spectra [11–57].

This book, divided into three parts which contain nine chapters and three Appendices, is partially based on our ongoing researches on the effective mass from 1980 and an attempt has been made to present a cross section of the effective mass for a wide range of low-dimensional semiconductors with varying carrier energy spectra under various physical conditions. The first part deals with the influence of quantum confinement on the EEM in non-parabolic semiconductors. Chapter 1 investigates the EEM in UFs of nonlinear optical materials on the basis of a generalized electron dispersion law introducing the anisotropies of the effective electron masses and the spin orbit splitting constants respectively together with the inclusion of the crystal field splitting within the framework of the *k.p* formalism. The results of III–V (e.g. InAs, InSb, GaAs, etc.), ternary (e.g. $Hg_{1-x}Cd_xTe$), quaternary (e.g. $In_{1-x}Ga_xAs_{1-y}P_y$ lattice matched to InP) compounds form a special case of our generalized analysis under certain limiting conditions. The EEM in UFs of II–VI, Bi, IV–VI, stressed Kane-type semiconductors, Te, GaP, $PtSb_2$, Bi_2Te_3, Ge and GaSb compounds have also been investigated by using the appropriate energy band structures for these materials. The importance of the aforementioned semiconductors has also been described in the same chapter. It is well known that the semiconductor superlattices find extensive applications in avalanche photodiodes, photo-detectors, electro-optic modulators, etc. In Chap. 2 the EEM in nipi structures of nonlinear optical, III–V, II–VI, IV–VI, and stressed Kane-type semiconductors has been studied.

In recent years, there has been considerable interest in the study of the inversion layers which are formed at the surfaces of semiconductors in metal–oxide–semiconductor field-effect transistors (MOSFET) under the influence of a sufficiently strong electric field applied perpendicular to the surface by means of a large gate bias. In such layers, the carriers form a two-dimensional gas and are free to move parallel to the surface while their motion is quantized perpendicular to it leading to the formation of electric subbands [58]. In Chap. 3, the EEM in *n*-channel inversion layers of nonlinear optical, III–V, II–VI, IV–VI stressed Kane-type semiconductors, Ge and GaSb has been investigated.

The effects of quantizing magnetic field on the band structures of compound semiconductors are more striking than that of the parabolic one and are easily observed in experiments. A number of interesting physical features originate from the significant changes in the basic energy wave vector relation of the carriers caused by the magnetic field. The valuable information could also be obtained from experiments under magnetic quantization regarding the important physical properties such as Fermi energy and effective masses of the carriers, which affect almost all the transport properties of the electron devices [59–63] of various materials having different carrier dispersion relations [64]. In Chap. 4, the EEM in nonlinear optical, III–V. II–VI, Bi. IV–VI, stressed Kane-type semiconductors, Te, GaP, $PtSb_2$, Bi_2Te_3, Ge, GaSb and II–V compounds have also been studied under magnetic quantization. Since Iijima's discovery [65], carbon nanotubes (CNTs) have been recognized as fascinating materials with nanometer dimensions uncovering new phenomena in different areas of nanoscience and technology. The remarkable physical properties of these quantum materials make them ideal candidates to reveal new phenomena in nano-electronics. Chapter 5 contains the study of the EEM in nanowires of the nonlinear optical, III–V, II–VI, Bi, IV–VI, stressed Kane-type semiconductors, Te, GaP, $PtSb_2$, Bi_2Te_3, Ge, GaSb and II–V semiconductors together with CNTs respectively.

With the advent of nanophotonics, there has been considerable interest in studying the optical processes in semiconductors and their nanostructures [66–67]. It appears from the literature that investigations have been carried out on the assumption that the carrier energy spectra are invariant quantities in the presence of intense light waves, which is not fundamentally true. The physical properties of semiconductors in the presence of light waves which change the basic dispersion relation have been relatively less investigated in the literature [68, 69]. The second part of this book studies the influence of light waves of the EEM in opto-electronic semiconductors and Chap. 6 investigates the influence of light waves on the EEM in quantum confined III–V, ternary, and quaternary semiconductors. Under external photo excitation the electron dispersion relation changes profoundly and the EEM has been studied by formulating a new electron dispersion law on the basis of *k.p* formalism. In the same chapter the influence of magnetic quantization on the EEM has been investigated. The same chapter also explores the effect of light waves on the EEM for 2D systems (e.g. UFs, nipi structures, and inversion layers), 1D systems (such as quantum wire effective mass superlattices, and quantum wire superlattices with graded interfaces) and the influence of quantizing magnetic field on the EEM for effective mass superlattices, and superlattices with graded interfaces respectively.

With the advent of nanodevices, the inbuilt electric field becomes so large that the electron energy spectrum changes fundamentally and the single Chap. 7 of the third part investigates the influence of intense electric field on the EEM in II–V, ternary and quaternary semiconductors. The same chapter also explores the influence of electric field on the 2D systems (e.g. UFs, nipi structures and inversion layers) and 1D systems (such as, nano wire effective mass superlattices, and nano wire superlattices with graded interfaces) in this context. Chapter 8 contains the applications and brief review of experimental results. Chapter 9 contains the conclusion and the scope for future research.

It may be noted that the influence of crossed electric and quantizing magnetic fields on the transport properties of semiconductors having various band structures are relatively less investigated as compared with the corresponding magnetic quantization, although, the cross-fields are fundamental with respect to the addition of new physics and the related experimental findings. It is well known that in the presence of electric field (E_o) along x-axis and the quantizing magnetic field (B) along z-axis, the dispersion relations of the conduction electrons in semiconductors become modified and for which the electron moves in both the z and y directions. The motion along y-direction is purely due to the presence of E_0 along x-axis and in the absence of electric field, the EEM along y-axis tends to infinity which indicates the fact that the electron motion along y-axis is forbidden. The EEM of the isotropic, bulk semiconductors having parabolic energy bands exhibits mass anisotropy in the presence of cross fields and this anisotropy depends on the electron energy, the magnetic quantum number, the electric and the magnetic fields respectively, although, the EEM along z-axis is a constant quantity. In 1966, Zawadzki and Lax [70] formulated the electron dispersion law for III-V semiconductors in accordance with the two-band model of Kane under cross fields configuration which generates the interest to study this particular topic of solid state science in general [71–77].

Appendix A investigates the EEM under cross field configuration in nonlinear optical, III–V, II–VI, Bi, IV–VI, and stressed Kane-type semiconductors and ultra thin films of the aforementioned materials. It is an amazing fact that though heavily doped semiconductors have been deeply studied in the literature but the study of the carrier transport in heavily doped materials through proper formulation of the Boltzmann transport equation which needs in turn, the corresponding heavily doped carrier energy spectra is still one of the open research problems [78–81]. Appendix B attempts to touch the enormous field of active research with respect to EEM of heavily doped compound semiconductors in a nutshell. Appendix C deals with the EEM in III–V, II–VI, IV–VI, HgTe/CdTe, and strained layer heavily doped superlattices with graded interfaces and effective mass superlattices of the said constituent materials. In these appendices no graphs together with results and discussions are being presented since we feel that the readers will enjoy the complex computer algorithm to investigate the EEM in the respective case generating new physics and thereby transforming each appendix into a short monograph by considering various materials having different dispersion relations. Since there is no existing book devoted totally to the EEM in low-dimensional semiconductors to the best of our knowledge, we hope that this book will be a useful reference source for the present and the next generation of readers and researchers of materials and allied sciences in general. In spite of our joint efforts, the production of error-free first edition of any book from every point of view enjoys permanently the domain of impossibility theorems and the same stands very true for this monograph also. Various expressions of this book have been appearing for the first time in printed form. The suggestions of the readers for the development of this book will be highly appreciated for the purpose of future edition, if any.

In this book, from Chap. 1 till the end, we have presented **250 open research problems** in this particular topic. The problems presented here are the integral part of this book and will be useful for the readers to initiate their own contributions on the effective mass. This aspect is also important for Ph.D. aspirants and researchers. Each chapter ends with a table containing the main results excluding the last two and the Appendices.

In this monograph, we have investigated various dispersion relations of different quantized structures and the corresponding electron statistics to study effective mass. Our theoretical formulation of the density-of-states effective mass of tetragonal materials based on our generalized electron dispersion relation agrees well with the available experimental data as given elsewhere [82]. Thus, in this book, the readers will get a lot of information regarding quantum confined low-dimensional materials having different band structures. Although the name of the book is extremely specific, from the content, one can infer that it should be useful in graduate courses on materials science, nanoscience and technology, solid-state science, semiconductor physics, and nanostructured devices in many universities and institutes. Last but not the least, we do hope that our humble effort will kindle the desire to delve deeper into this fascinating topic by anyone engaged in materials research and device development either in academics or in industries.

Acknowledgments

Acknowledgment by Sitangshu Bhattacharya

In spite of many hurdles, the completion of this monograph is owed to my teacher S. Mahapatra, in the Department of Electronic Systems Engineering at the Indian Institute of Science, Bangalore, with whom I have learned to perform quality research. My sincere gratitude is also to my friend R. C. Mallik of Thermoelectric Materials and Device Laboratory, Department of Physics of the same Institute for his constant inspiration. I offer special thanks to all my friends at my department and institute for standing by my side at difficult times of my research life. I am indebted to the Department of Science and Technology, India, for sanctioning the project and the fellowship under "SERC Fast Track Proposal of Young Scientist" scheme-2008-2009 (SR/FTP/ETA-37/08) under which this monograph has been completed. As forever, I am immensely grateful to the second author, my friend, mentor, and Ph.D. thesis advisor.

Acknowledgment by Kamakhya Prasad Ghatak

Like the first author, I am ever grateful to Professor A. N. Chakravarti, my Ph.D. thesis advisor and mentor who convinced a 21-year-old Circuit theorist that theoretical semiconductor science is the hidden dual dance of quantum mechanics and statistical mechanics, and even to appreciate the incredible beauty, he placed a stiff note for me to understand deeply the Course of Theoretical Physics, the Classics of Landau–Lifshitz together with the two-volume classics of Morse-Feshbach 35 years ago. I am grateful to Professor P. K. Bose, Director, National Institute of Technology, Agartala, Tripura my present mentor at the last phase of my academic life and a very pivotal person in my academic career, for instigating me to carry out extensive research by ignoring all the difficulties. I express my gratitude to Professors R. K. Poddar and R. N. Basu, Ex-Vice Chancellors of the University of Calcutta, Professors S. K. Sen and A. N. Basu, Ex-Vice Chancellors of Jadavpur University, and Professor D. K. Basu, Ex-Vice Chancellor of Burdwan and Tripura Universities, the five pivotal persons in the research growth of my career. I am grateful to Professors S. C. Dasgupta, P. K. Choudhury, M. Mitra and S. Sarkar of the Department of Mathematics of the then Bengal Engineering College (presently Bengal Engineering and Science University), Shibpur, Howrah for creating the interest in various topics of Engineering Mathematics when I was pursuing the bachelor degree in the branch of Electronics and Telecommunication Engineering 40 years ago. I am indebted to Late Professor C. K. Majumdar of the Department of Physics of the University of Calcutta for lighting the fire for Theoretical Physics. I express my gratitude to Professors H. L. Hartnagel, D. Bimberg, W. L. Freeman, and W. Schommers for various academic interactions spanning the last two decades. The well-known scientist Late Professor P. N. Butcher has been a steady hidden force since 1987, before his demise, with respect to our scripting the series in band structure-dependent properties of nanostructured materials. He insisted to me repeatedly regarding it and to tune with his high rigorous academic standard, my colleagues and I wrote the Einstein Relation in Compound Semiconductors and their Nanostructures, Springer Series in Materials Science, Vol. 116, 2009 as the first one, Photoemission from Optoelectronic Materials and their Nanostructures, Springer Series in Nanostructure Science and Technology, 2009 as the second one, "Thermoelectric Power in Nano-Structured Materials Under Strong Magnetic Fields", Springer Series in Materials Science, Vol. 137, 2010 as the third one, "Fowler-Nordheim Field Emission :Effects in Semiconductor Nanostructures", Springer Series in Solid State Sciences, Vol 170, 2012 as the fourth one, and the present monograph as the fifth one.

I offer special thanks to Late Mr. N. Guhachoudhury of Jadavpur University for instilling in me the thought that the *academic output* = ((*desire* χ *determination* χ *dedication*) − (*false enhanced self-ego pretending like a true friend although a real unrecognizable foe*)). I must not allow even a thank you to my beloved better half for really forming the backbone of my long unperturbed research career, since in accordance with Sanatan Hindu Dharma, the fusion of marriage has transformed us to form a single entity, where the individuality is being lost. I am grateful to all the members of my research team for not only quantum confining me in the infinitely deep quantum wells of Ramanujan and Rabindranath but also inspiring me in the real sense of the term to teach quantum mechanics and related topics from eight volume classics of Greiner et. al. I must express my gratitude to Mr. N. Paitya, one of the strong member of my research group, for critically reading the manuscript and offering important suggestions for the betterment of the book. I offered my special thanks to the Assistant Professors and Ph.D. scholars of my present Department for overall supervision of the book in its last phase before sending it to Dr. C. Ascheron, Executive Editor Physics, Springer Verlag. Myself and Dr. D. De of the Department of Computer Science and Engineering, West Bengal University of Technology are grateful to the University Grant Commission for sanctioning the research project No-F 40-469/2011(SR) and Department of Science and Technology for further sanctioning the project SERC/ET-0213/2011 respectively, under which this book has been completed. Last but not the least, I offer special thanks to my life long time tested friend Mr. B. Nag of Applied Physics Department for motivating me during rather turbulent moments of my academic career.

Joint acknowledgments

As always. we are grateful to Dr. C. Ascheron in the real sense of the term for his inspiration and priceless technical assistance from the very start of our first book from Springer. We owe a lot to Ms. A. Duhm, Associate Editor Physics, Springer and Mrs. E. Suer, assistant to Dr. Ascheron. Naturally, the authors are responsible for non-imaginative shortcomings. We firmly believe that our Mother Nature has propelled this joint collaboration in her own unseen way in spite of several insurmountable obstacles.

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http://www.springer.com/978-3-642-31247-2

Effective Electron Mass in Low-Dimensional Semiconductors

Bhattacharya, S.; Ghatak, K.P.
2013, XXIV, 536 p., Hardcover
ISBN: 978-3-642-31247-2