CHAPTER 1
INTRODUCTION AND SCOPE OF THE THESIS

The present day sophistication in both theoretical and experimental investigations of semiconductor electronics is due to the rapid expansion of scientific research in the physics and technology of the crystalline materials. In recent years, the developments were made extending studies to non-parabolic compounds having different energy band structures leading to the inventions of various classes of semiconductor devices. Before the last two decades, the investigations of semiconductors were mainly confined to the non-degenerate limit. The emphasis then gradually shifted to studies under conditions of carrier degeneracy since many semiconductor devices were developed which operate under such conditions. Moreover, in devices using non-parabolic semiconductors, the level of degeneracy is often very high. It is well-known from the pioneer work of Kane (E.O Kane, *J. Phys. Chem. Solids*, 1, 249(1957)) that the influence of energy band gap is a special feature of non-parabolic compounds affecting their physical properties particularly under the condition of carrier degeneracy and has widely been investigated for the last three decades. Nevertheless, there still remain scopes in the investigations made which the interest for further researches of the various other aspects of such non-parabolic semiconductors having different band structures is becoming increasingly important.

The effects of quantizing magnetic field on the band structures of non-parabolic materials are more striking than that of the parabolic one and a number of interesting physical features originate from the significant changes in the basic band structures caused by the magnetic fields, e.g. i) de Hass- van Alphen oscillations in magnetic susceptibility; ii) Shubnikov-de Hass oscillations in magneto resistance; iii) the magneto phonon oscillations in magneto resistance and thermoelectric power; iv) the oscillations in the optical infrared absorption coefficients; v) the cyclotron resonance absorption etc. Besides, valuable information could also be obtained from experiments under magnetic quantization about other important physical properties such as the Fermi energy and the effective mass of the carriers which affect almost all the transport coefficients.

The effective mass of the carriers in semiconductors, being connected with the mobility, is used for the analysis of electron devices under different operating conditions. 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 effective electron mass in degenerate n-type semiconductors under the degree of carrier degeneracy.

With the advent of modern technological techniques, it has become possible to fabricate semiconductor superlattices composed of alternate layers of two different degenerate materials with controlled thickness, many of which are currently under study due to their interesting properties such as negative resistance, information of minibands etc. The superlattices, originally proposed by Esaki and Tsu (IBM. Res. Develop, 61, 14(1970)), have found wide applications in many device structures such as photo-detectors, avalanche photodiodes, transistors, tunneling devices, light emitters, electro-optic modulators etc. The most extensively studied superlattices is the one consisting of alternate layers of GaAs and the Ga_{1-x}Al_xAs. The GaAs layers form the quantum wells and the Ga_{1-x}Al_xAs layers form the potential barriers.

Semiconductor nanostructures (SNs) exhibit increased oscillator strength due to electron hole wave function overlap, and bandgap engineering due to the effect of quantum confinement (QC). QC is defined as the modification in the free particle dispersion relation as a function of a system's spatial dimension. If a free electron is confined within a potential barrier, a shift in the bandgap energy is observed, which is inversely proportional to the system size squared, in the effective mass approximation. For practical applications, utilizing QC effects in NSs requires an understanding of the band structure of a low dimensional material.

Recently, various energy wave vector dispersion relations have been proposed 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 quantizing magnetic field under magnetic quantization, with the quantizing electric field as in inversion layers, with the nano-thickness as in quantum wells and nano wires and with superlattice period as in the quantum confined superlattices of small gap semiconductors with graded interfaces having various carrier energy spectra.
With these points in view, the author undertook investigation on electronic properties in quantum confined non-parabolic semiconductors where the concept of effective mass of the carriers (EMME) in semiconductors is one of the basic pillars in the realm of computational and theoretical nanoscience and technology.

In chapter two, the author has studied EMME in different quantum confined non-parabolic compounds by considering all types of anisotropies of the energy band constants within the framework of \( kp \) formalism in the presence of magnetic quantization, size quantization, nipi structures, inversion layers and nanowires respectively. In the same chapter we further investigate the influence of light waves on the EMME in III-V, ternary and quaternary materials by formulating the electron dispersion laws. Under certain limiting conditions all the results for all the cases get simplified into the well-known results for parabolic energy bands and thus confirming the compatibility test. The content of this chapter finds ten applications in the realm of quantum science and technology.

It is well known that the magneto thermoelectric power is a very important quantity (J. Hajdu, G. Landwehr, In: *Strong and Ultrastrong Magnetic Fields and Their Applications*, Topics in Applied Physics, F. Herlach (ed.) Vol. 57, p. 97 (Springer-Verlag, Germany, 1985)), since the change in entropy (a vital concept in thermodynamics) can be known from this relation by determining the experimental values of the change of electron concentration. The analysis of magneto thermoelectric power generates information regarding the effective mass of the carriers in materials which occupies a central position in the whole field of materials science in general (I. M. Tsidilkovskii, *Band Structures of Semiconductors* (Pergamon Press, London, (1982)). The classical magneto thermoelectric power \( G_0 \) equation is valid only under the non-degenerate carrier concentration and the magnitude of the magneto thermoelectric power is given by \( G_0 = \left( \pi^2 k_B / 3e \right) \); \( k_B \) and \( e \) are Boltzmann’s constant and the magnitude of the carrier charge, respectively (K. P. Ghatak and S. Bhattacharya, *Thermoelectric Power in Nanostructured Materials: Strong Magnetic Fields*, Springer Series in Materials Science, *vol 137*, (2010)). From this equation, it is readily inferred that this conventional form is a function of three fundamental constants only, being independent of the signature of the charge carriers in materials. The significant work of Zawadzki (W. Zawadzki, 11th *Internat. Conf. Phys. of Semicond.* Vol. 1 (Elsevier Publishing Company, Netherlands, 1972)) reflects the fact that the magneto thermoelectric power for materials
having degenerate electron concentration is independent of scattering mechanisms and is exclusively determined by the dispersion laws of the respective carriers. It will, therefore, assume different values for different systems and varies with the doping, the magnitude of the reciprocal quantizing magnetic field under magnetic quantization, the nano thickness in ultrathin films, quantum wires and dots, the quantizing electric field as in inversion layers, the carrier statistics in various types of quantum confined superlattices having different carrier energy spectra and other types of low-dimensional field assisted systems.

The chapter three investigates the magneto thermoelectric power ($S$) in quantum dots of heavily doped nonlinear optical semiconductors on the basis of newly formulated carrier dispersion laws by considering all types of anisotropies within the framework of $kp$ formalism.

In chapter four, the magneto thermoelectric power ($S$) for heavily doped III–V, II–VI, IV–VI, HgTe/CdTe and strained layer Quantum Dot Superlattices (QDSLs) with graded interfaces together with the effective mass superlattices of the aforementioned materials has been investigated by formulating new carrier energy spectra.

The thesis is concluded with chapter five which contains a summary of the present work and a discussion on the future scopes of the investigation reported in this thesis.

The present dissertation for the Ph.D. degree is mainly based on the above investigations carried out by the author. Though considerable care has been taken in preparing the thesis, there may remain errors along with incomplete bibliography for which the author may be excused, particularly because of the fact that he had to prepare the thesis in the midst of heavy teaching and project assignments for both UG and PG students together with within very limited time and facilities, furthermore, there are many unavoidable repetitions in the thesis since the present dissertation is based only on the published papers in scientific referred journals.