TRANSPORT PHENOMENA IN NONDEGENERATE AND DEGENERATE SEMICONDUCTORS

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PREFACE

A study of transport properties of semiconductors is of great importance from the point of view of devices and basic physics. This thesis presents an analytical investigation of drift mobility[1] in nondegenerate germanium at moderate electric fields (warm electron region) using ETM (effective temperature model) and a detailed study[2] of the isotropic part of distribution function and corresponding transport properties of degenerate parabolic semiconductors for various combinations of scattering mechanisms and electric/magnetic fields; the drift and Hall mobility[3] in such semiconductors (at low electric fields) when both acoustic scattering and ionized impurity scattering are appreciable, have also been evaluated. At very low temperatures ($4^{o}K$) and strong electric fields the deviation of phonon distribution function from its equilibrium value (B.E. Distribution) has also been evaluated and used for the calculations of the transport coefficients.

In chapter I of the thesis, the dependence of drift and Hall mobility (at low electric fields) on the degeneracy parameters and the relative preponderance of acoustic mode and ionized impurity scatterings have been investigated, using the standard expressions for mobility applicable to degenerate semiconductors.

Previous investigations of hot electron effects in degenerate semiconductors emanating from groups other than ours suffer from the use of the effective temperature model since a collision integral applicable to degenerate semiconductors was not derived earlier. Sodha and Gupta[4] have recently derived the appropriate expression for the collision integral applicable to parabolic semiconductors when Pauli's exclusion principle (i.e. degeneracy) is taken into account. This collision integral has been used in chapter II of the thesis to evaluate expressions for the isotropic part of the electron velocity distribution function in degenerate parabolic semiconductors for the following combinations of scattering mechanisms:

i) acoustic phonon scattering

ii) acoustic phonon and piezoelectric potential scattering

iii) acoustic phonon and ionized impurity scattering.

The following field configurations have been considered:-

1. $E = i E_x \; ; \quad B = 0$

2. $E = i E_x + j E_y \; ; \quad B = k B_z$

3. $E = (i E_x + j E_y) \exp(i \omega t) \; ; \quad B = k B_z$

In chapter III of the thesis we have calculated drift mobility, Hall mobility, Hall coefficient and magnetoresistance of a degenerate semiconductor when the modified distribution of phonons is taken into account following the work of Paranjape[5]. Electron scattering due to acoustic phonons and ionized impurities have been considered and results compared with those obtained without using modified phonon distribution.

In chapter IV of the thesis the usual equation for drift mobility and the energy equation based on the Maxwellian distribution of velocity corresponding to an elevated electron temperature have been used to derive an expression for the drift mobility at moderate electric fields (warm electron region); the electron scattering due to acoustic phonons and optical phonons have been taken into account. The results are in good agreement with experiments.

The thesis has been divided into four chapters whose titles and summaries are given below:-

Chapter-1: Hall Mobility of Degenerate Semiconductors

In this chapter the dependence of Hall mobility of carriers on impurity concentration has been theoretically investigated for degenerate semiconductors, taking scattering by lattice vibrations as well as ionized impurities into account. The scattering due to optical modes of lattice vibrations has been neglected.

Chapter-2: Hot Electron Transport in Degenerate Parabolic Semiconductors

In this chapter we use kinetic theory techniques to derive the explicit expressions for the velocity distribution function of carriers in a degenerate parabolic semiconductor for arbitrary values of electric and magnetic fields, when the dominant mechanism of scattering are (a) acoustic phonon scattering (b) both acoustic phonon and piezoelectric scattering (c) acoustic phonon and ionized impurity distribution function of carriers in the presence of a strong ac electric field and a dc magnetic field has also been derived. The distribution functions so derived have been employed to calculate drift mobility, Hall coefficient, Hall mobility, coefficient of magnetoresistance (Corbino geometry) and Faraday rotation in degenerate semiconductors under hot electron conditions. Numerical results for the variation of these transport coefficients with electric field, magnetic field and scattering parameters have been presented in the form of graphs.

Chapter-3: Modification of Phonon Distribution in Degenerate Semiconductors by High Electric Fields: Effect on Transport Coefficients

In this chapter, we have evaluated drift mobility, Hall mobility and Hall coefficient of a degenerate semiconductor at very low temperatures and high electric fields. Following Paranjape's[5] approach we have taken into account the modified distribution of phonons in the calculation of their transport coefficients for arbitrary degeneracy of simple model semiconductors. The electron scattering due to ionized impurities as well as due to acoustic phonons have been considered. Our calculations show that the inclusion of the modified phonon distribution in the theory reduces the theoretical values of drift and Hall mobilities of degenerate semiconductors by a factor of two or more; its effect on Hall coefficients is to decrease the theoretical value slightly (20%).

Chapter-4: Low-Field Mobility of Carriers in Non-Degenerate Semiconductors.

Here we extend the Gunn's theory of the low-field variation of carrier mobility using Morgan's analysis to include the effect of scattering by a single optical mode of lattice vibrations. Numerical results obtained for n-germanium show that there is very good agreement between theory and experiment.

The work reported in the thesis has resulted in the following publications by the author:-

1. Hall Mobility of Degenerate Semiconductors, D.B.Agarwal, Z.Physik 163, 207 (1961).

2. Low-Field Mobility of Carriers in Nondegenerate Semiconductors, M.S.Sodha, and D.B.Agarwal, Can.J.Phys. 36, 707 (1958).

3. Hot-Electron Transport in Degenerate Parabolic Semiconductors, D.B.Agarwal, B.P.Pal and S.K.Sharma, 1974 (Communicated).

4. Modification of Phonon Distribution in Degenerate Semiconductors by High Electric Fields: Effect on Transport Coefficients, D.B.Agarwal, S.K.Sharma and M.S.Sodha, 1974 (Communicated).

CONTENTS