TRANSIENT RESPONSE OF HOT ELECTRONS IN NARROW-GAP SEMICONDUCTORS AT LOW TEMPERATURES IN THE PRESENCE OF A LONGITUDINAL QUANTIZING MAGNETIC FIELD

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Transient response of hot electrons in narrow-gap semiconductors to a step electric field in the presence of a longitudinal quantizing magnetic field has been studied at low temperatures using displaced Maxwellian distribution. The energy and momentum balance equations are used assuming acoustic phonon scattering via deformation potential responsible for the energy relaxation and elastic acoustic phonon scattering together with ionized impurity scattering for momentum relaxation. The calculations for the variation of drift velocity and electron temperature as functions of time are made for n-Hg0.8Cd0.2Te in the extreme quantum limit at 1.5 K and 4.2 K. The momentum and energy relaxation times are found to be of the same order of magnitudes as with the experimental values. The magnetic field and lattice temperature dependences of the relaxation rates have been investigated.

1. Introduction

In recent years there has been a considerable interest in the study of hot electron transport in semiconductors under magnetic quantization [1-3]. The velocity-field characteristics in narrow band gap semiconductors like n-Hg0.8Cd0.2Te in the presence of a large longitudinal magnetic field have been investigated by many authors [2,4]. The interest in such materials has grown because of infrared applications and dramatic quantum effects due to low effective masses. The transient response of hot electrons is important when the behaviour of the electron gas is sought in a short time scale. It provides information on the relaxation processes of hot electrons.

Recently, Nimtz and Stadler have made time resolved hot carrier transport experiments to study the hot electron specific heat [2]. They have made an estimation of energy and momentum relaxation rates in n-HgCdTe from the measurements of electric field dependence of the current density.

A theoretical model is proposed to investigate transient response of hot electrons in a narrow gap semiconductor such as n-HgCdTe and will be used to analyse the experimental results of relaxation times obtained by Nimtz and Stadler [2].

In the model, the magnetic field is assumed to be strong enough to cause the carriers to occupy the lowest Landau subband, i.e. extreme magnetic quantum limit. The effect of band nonparabolicity, non-equipartition of phonons and Landau-level broadening due to electron impurity interactions have also been considered. The present model also includes the free carrier screening. The carrier distribution is assumed to be drifted Maxwellian distribution. In the presence of a quantizing
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magnetic field, electron-electron interaction is stronger than in a bulk material without magnetic field due to quantum confinement effect and the weakness of ionized impurity scattering in high magnetic fields. It can be assumed that the electron-electron interaction in momentum and energy exchanges is strong enough to maintain a drifted Maxwellian distribution. The physical condition required for the distribution to be a drifted Maxwellian means the sample should have a critical electron concentration of about \( n \approx 10^{15} \text{ cm}^{-3} \) [5].

The energy and momentum balance equations are set up by assuming inelastic acoustic phonon scattering via deformation potential which is the dominant energy relaxation mechanism at low temperatures while the elastic acoustic phonon and ionised impurity scattering contribute to the momentum relaxation. The effect of piezoelectric scattering on the energy loss rate at low temperatures is not found to be important [6] and it has been neglected in the present work. Due to low temperatures, the contribution to energy loss rate by L.O. phonons will not be significant and it is not considered in the analysis.

The theoretical formulation and results are presented in Sect. 2 and 3, respectively.

2. Theory

The quantized energy of electrons in a semiconductor with a spherical and non-parabolic conduction band as a function of wave-vector along the \( z \)-direction parallel to the applied quantizing magnetic field \( B \) can be expressed as [7].

\[
E = - \frac{E_g}{2} + \frac{E_g a_0}{2} + \frac{h^2 k^2}{2 m^* a_0},
\]

where \( \hbar \) is the Planck's constant divided by \( 2\pi \), \( k \) is the \( z \)-component of electronic wave vector, \( m^* \) is the band edge effective mass, \( E_g \) is the band gap energy and \( a_0 \) is the non-parabolicity factor being given by

\[
a_0 = \sqrt{1 + \frac{2\hbar \omega_c}{E_g} \left( 1 - |g| \frac{m^*}{2m_0} \right)},
\]

where \( g \) is the Lande's \( g \)-factor, \( m_0 \) is the electron rest mass, and \( \omega_c = eB/m^* \) is the cyclotron frequency, \( e \) being the electronic charge.

When an electric field is applied parallel to the applied magnetic field \( B \), the electrons gain energy from the electric field and the temperature of the electron system increases. The difference between the electron temperature and the lattice temperature becomes large causing the electrons to emit more phonons than they absorb at higher electric fields. A balance is needed for the achievement of a steady state where the power input into the electronic system for the applied field and the power loss from the carriers are equal.