THEORETICAL PROBLEMS OF HOT ELECTRONS IN SEMICONDUCTORS

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رسالة

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SUMMARY (In Arabic).

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S U M M A R Y

To study the behaviour of hot electrons, to analyze electric conductivity and other transport effects in semiconductors, it is necessary, to know the distribution function of free current carriers in the conduction and valence bands.

The Boltzmann's equation has been investigated for the analysis of high electric fields transport phenomena. The distribution function has been derived for a wide range of impurity concentrations in n-Ge of about $10^{13} - 10^{16}$ cm^{-3} at low temperatures. At this conditions the scattering of electrons by acoustic phonons and impurities are predominant. The distribution function was simplified by considering the following cases,

1- The probability of impurity scattering was considered to be small compared with acoustic phonons. In this case the distribution function was found to follow the form of Davydov function. The variation of the obtained distribution function with the applied electric field has been studied. It was found that, at high electric fields, the distribution function was the same as that obtained by

Dryvestien for hot electrons in an ionized gas and the electric current density proportional to the square root of electric field ($J \propto E^{1/2}$).

2- The probability of impurity scattering was considered larger than the acoustic phonons. In this case the distribution function has been derived for high electric fields and the following results were obtained:

a) The distribution function has an additional term, which tends to zero for large concentrations of impurities.

b) The electric conductivity has been calculated using the obtained distribution function. Accordingly it was found that the scattering by impurities minimize the electric conductivity.

The optical properties of hot electrons in semiconductors has been investigated, where the absorption coefficient of light has been studied. The free carriers were considered to be under the effect of static electric and an alternating fields. The distribution function has been derived under this condition. The absorption coefficient has been calculated, taking in consideration the acoustic phonons and impurities scattering. The results achieved are as follows :

1- The impurity scattering increases the absorption at high frequencies.

2- It decreases the absorption at low frequencies.

Finally the Hall coefficient has been calculated for hot electrons by considering the effect of acoustic and impurities scattering. It was found that, the impurities scattering minimize the Hall coefficient. For small magnetic field and large concentration of impurities the obtained results was coincident with the results obtained before.

I N T R O D U C T I O N

INTRODUCTION

In 1951 it was pointed out by W. Shockly that departures from Ohm's law in high electric fields would be much more readily produced in semiconductors than in metals. This is due to the fact that in semiconductor a change in the mean energy of electrons represents a large change in the mean energy of the electrons. The change in the mean energy of the electrons of the order of (K_oT) represents a large change in their effective temperature. In this case the electrons is said to be hot and is out of the thermal equilibrium within the lattice. For electrons having nearly a Maxwellian distribution with an effective temperature T_e, mean velocity $(2 K_oT_e/m)^{1/2}$ and mean energy $(3/2 K_oT_e)$, the nonohmic behavier has been shown to arise from the generation of acoustic flux. Acoustic flux is generated by the carriers which take place when the drift velocity exceeds the sound velocity (A.R. Hutsen, 1961).

It has been shown by V.L. Bonch (1969) that in semiconductors, the charge carriers may be heated not only by an external electric field, but also by pressures. The latter is produced if the distribution function is artificially made inhomogenous. This inhomogeneity may be for example, due to the gradient of the local average energy or to the concentration gradient of carriers. Some properties of such inhomogeneous systems were studied by V.L. Bonch Bruevich (1969).

Application of high field to a metal is not expected to produce a significant electron heating at any rate, due to the large value of the average electron energy. Hot electrons were introduced into a metal by tunnelling from another metal or semiconductor biased appropriately with respect to the first (Mead, 1962 - Spitzer, 1962 - Spratt, 1961).

In this situation, the properties which should be studied are the rate of energy loss and the mean free path of the electrons.

Although the fundamental laws governing the electric conductivity at high electric field strengths were theoretically developed more than thirty years ago, investigations on a large scale have been accomplished only in the last ten years. There are several reasons for increasing the interest in this subject. Heating of the carriers by high field has been found to produce new effects i.e. effects not present in the material in low fields. The change of conductivity as a function of field strength and the anisotropy of the materials even in cubic crystals, the instability of current at high electric fields, the electron emission from cold cathodes, some effects connected with the surface and the birefringence of electromagnetic radiation by free carriers are examples of this type.

On the other hand, the carriers investigations in high electric fields appear as a methodically new possibility to get information about the properties characterizing the semiconductor indepently of the presence of external fields. The energy transfer to the lattice, the energy dependance of the recombination cross-section excited carriers and the valence bands examination by infrared absorption belong to these types of investigations.

Finally the hot electron effects have and will lead to important consequences in practical applications as; an emission from a new type of cathodes (W.M. Feist, 1963); a new method to measure high frequency power and generators for ultra high frequency (P.M. Butcher, 1957).

In semiconductors, it is necessary to know the distribution of free current carriers in the conduction and valence bands in order to analyze many effects in this field.

In semiconductor of moderate doping, the thermal equilibrium energy distribution of the carriers is the Maxwell-Boltzmann distribution function itself. For low electric fields it is assumed that the kinetic energy and momentum of the carriers have Maxwell-Boltzmann distribution.

For high electric fields the carriers distribution has another electric shape.

Usually the current carriers in the absence or the presence of the electric field interact with the lattice vibration in the sample, and consequently the absorption and emission phonons are produced.

In the absence of the electric field, when the carriers have the Maxwell distribution function and the phonons are in equilibrium, absorption and emission are balanced. In this case the number of phonons with wave vector $\vec{q}$ will be

$$\bar{N}_{\vec{q}} = 1/\left[\exp\left(\hbar\omega_{\vec{q}}/K_oT\right)\right]$$

where $\hbar$ is plank's constant (h) divided by 2π, and K_o is Boltzmann's constant.

When an electric field (E) applied to semiconductor the carriers gained energy at the rate eME^2. Where M is the mobility of the carriers and e is the magnitude of electronic charge.

This energy raises the average energy of the carriers and the average rate of emission of phonon. At the steady state, the average loss of energy due to collisions would be equal the rate of gain of energy from the field (M.S. Sodha and B.K. Sowhney, 1968)

i.e. $$eME^2 = \left\langle \frac{d\mathcal{E}}{dt} \right\rangle$$

where $\frac{d\mathcal{E}}{dt}$ is energy loss.

In the existance of a small electric field, the steady state requires a little change in the distribution function. The essential change can be described as the superposition of a small drift term on the thermal equilibrium distribution, such as ; $$f = f_o(\mathcal{E}, T) + f_1$$

where $f_1 \ll f_o$. $f_o(\mathcal{E}, T)$ is Maxwell-Boltzmann distribution at lattice temperature T. f_1 depends on band structure and scattering.

In the high electric field, it is no longer possible to wirte f in the form given above. Here we are concerned with the case in which a steady state of the carriers is always attainable in high fields. This is due to the rate of phonon emission or other energy loss that are increased as the average energy of the carriers increases.
In the steady, the average loss of energy in collisions must equal the average energy gain from the field between collisions If the collisions are elastic, energy gained from the field will be small. In addition if the collisions are not predominantly forward, or at small angle, the energy gained from the field will be random.

Then in the existance of high fields, the distribution function will take the form of a small drift term superimposed on the energy function only. So that;

$$f(\mathcal{E}, \vec{E}) = f_o(\mathcal{E}, \vec{E}) + f_1(\mathcal{E}, \vec{E})$$

where $f_1 \ll f_o$.

At high enough carrier concentrations, we must consider also the collisions of the carriers with each other.