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ELECTRON MOBILITY CALCULATIONS OF n-InAs

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Electron mobility calculations of n-type InAs were carried out at temperatures from 10 K up to 400 K and doping concentration from $6x10^{20}$ m^{-3} to $2.5x10^{21}$ m^{-3}. The numerical computations were performed using relaxation time approximation taking into account some elastic scattering mechanisms. The temperature dependence of the electron drift mobility showed a noticeable decrease in the mobility with decreasing of temperature. It was changed, nearly, from the value 40000 $cm^2/V.s$ at room temperature to nearly 1300 $cm^2/V.s$ at 10 K. The decrease of the calculated drift mobility could be attributed to the influence of the ionized impurity scattering at low temperatures.

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1. Introduction

Electron and hole mobilities are two of the important parameters for characterizing the transport of charged carriers and formulating the current in semiconductor devices. A great deal of attention has been paid to these parameters and many authors have measured the carrier mobilities for various III–V compounds by Hall effect measurement technique [1-2]. Efforts have also been focused on theoretical formulation of carrier mobility in semiconductors [3]. In these analyses, a detailed physical formulation of various scattering mechanisms (such as ionized impurity scattering, acoustic phonon scattering, polar and nonpolar optical phonon scatterings, piezoelectric scattering, carrier–carrier scattering, and alloy scattering) has been made to accurately determine the variation of mobility with carrier concentration, temperature and, in some cases the compensation ratio.

The III/V-compound semiconductor indium arsenide (InAs) has attracted interest for application in semiconductor heterostructures and nanostructures because of its small energy gap and high electron mobility. InAs is a direct semiconductor at which the minimum of the conduction band is situated in the center of the Brillouin zone. Near the minimum, the energy is isotropic but non-parabolic [4]. For values of wave vector far from the conduction band minima, the energy deviates from the simple quadratic expressions and nonparabolcity occurs. The vast majority of experimental low-temperature energy gaps fall in the 0.41–0.42 eV range although somewhat higher values have also been reported [5].

In bulk InAs semiconductor there are many scattering centers might be exist. Some of them are elastic in nature and others are inelastic. The elastic scattering mechanisms include ionized impurity scattering, neutral impurity scattering, acoustic phonon deformation mode and piezoelectric acoustic phonon mode. The inelastic types contain polar and non-polar optical phonon scattering [6]. In this paper calculations of the electron mobility of n-type InAs semiconductor were performed. The relaxation time approximation approach was used to investigate some transport phenomena taking into account elastic scattering mechanism types.

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2. Theoretical model

The electrom mobility can be determined by solving Boltzmann equation in the relaxation time approximation as $\mu = \frac{e\langle\tau\rangle}{m^*}$ where μ is the mobility, $\langle\tau\rangle$ is the average relaxation time over the electron energies, *e* is the electronic charge and m^* is the effective mass of the electron.

The scattering due to electrostatic forces between the carrier and the ionized impurity centers depends on the interaction time and the number of impurities. Larger impurity concentrations result in a lower mobility. The mobility associated with the ionized impurity scattering (μ_{ii}) has been calculated as a function of the temperature *(T)* as [7]:

$$\mu_{ii} = \frac{128\sqrt{2}\,\pi^{1/2} \in^2 k^{3/2} T^{3/2}}{N_i\, e^3\, m^{*1/2}\left[\ln(1+y) - \frac{y}{1+y}\right]} \tag{1}$$

where

$$y = \frac{24 \in m^* k^2}{\hbar^2 e^2 n} T^2 \tag{2}$$

Here $\in$ is the static dielectric constant of the semiconductor, k is Boltzmann constant, N_i is the concentration of the ionized impurities, $\hbar$ is the Planck' s constant divided by 2π and n is the concentration of the carriers.

The acoustic mode lattice vibration induced changes in lattice spacing, which change the band gap from point to point. Since the crystal is "deformed" at these points, the potential associated is called the deformation potential. The corresponding relaxation time can be written as [8]

$$\tau_{dp}(\varepsilon) = \frac{\pi \hbar^4 \rho s^2}{\sqrt{2}\, E_1^2\, m^{*3/2}\,(kT)} \varepsilon^{-1/2} \tag{3}$$

where ρ is the crystal mass density, s is the average velocity of sound and E_1 is the deformation potential. The mobility associated with the deformation potential scattering is given by [8]

$$\mu_{dp} = \frac{2\sqrt{2}\pi^{1/2}\hbar^4 \rho s^2 e}{3E_1^2\, m^{*5/2}\, k^{3/2}\, T^{3/2}} \tag{4}$$

The relaxation time due to piezoelectric potential scattering is [8]

$$\tau_{pe}(\varepsilon) = \frac{2\sqrt{2}\pi \hbar^2 \in}{e^2\, P^2\, m^{*1/2}(kT)} \varepsilon^{1/2} \tag{5}$$

where $P = \left(\frac{h_{pe}^2}{\rho s^2 \in}\right)$ is the piezoelectric coupling coefficient and h_{pe} is the piezoelectric constant. The mobility as a result of piezoelectric potential scattering is given by

$$\mu_{pe} = \frac{16\sqrt{2}\pi^{1/2} \in \hbar^2}{3e\, m^{*3/2}\, k^{1/2}\, P^2 T^{1/2}} \tag{6}$$

3. Results and discussions

Indium Arsenide of zincblend crystal structure has a relatively small band gap width, so different scattering mechanisms may be existing in different temperature regimes. The possible elastic scattering types could be the ionized impurity, acoustic phonons deformation potential and piezoelectric acoustic phonons. Calculations of the electron mobility were carried out for n-InAs in a temperature range from 10 K up to 400 K and doping concentrations from $6x10^{20}$ m^{-3} to $25x10^{20}$ m^{-3}. Because of the small band gap of n-InAs, both donors (N_D) and acceptors (N_A) were assumed to be fully ionized and thus electron concentration is given as $n= N_D - N_A$. Values used in the calculation are listed in table 1.

Table 1. Material parameters for InAs [5,9].

Parameter	**Value**
Effective mass (m^*)	0.023 m_o
Static dielectric constant (ϵ)	14.6 ϵ_o
Energy gap (E_g)	0.41 *eV*
Mass density (ρ)	5667 Kg/m^3
Velocity of sound (s)	4280 *m/s*
Acoustic deformation potential (E_1)	4.9 *eV*
Piezoelectric coefficient (h_{pe})	0.027

Fig. 1 shows the temperature dependence of the mobility of n-InAs in a temperature range from 10 K to 400 K. The calculations explored the behavior of the mobility due to elastic scattering processes by ionized impurities and acoustic lattice vibrations. Computations were taken at doping concentration of $6x10^{20}$ m^{-3}. The acoustic phonons include the deformation potential mode and the piezoelectric mode. The resultant mobility due to the both types was calculated by using Matthessen's rule [10].

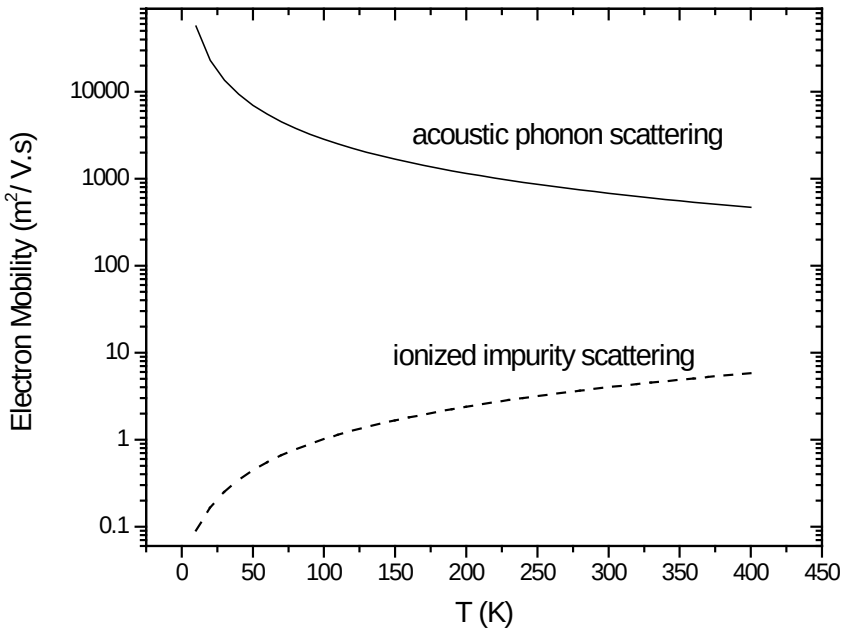

Fig. 1 Mobility versus temperature due to ionized impurities and acoustic phonon scatterings.

Inspection of Fig. 1 reveals that the mobility due to ionized impurities increased by increasing of temperature while that due to acoustic lattice vibrations decreased by raising the temperature. The results agree well with the general concepts recorded in the literatures for this system or other like III-V systems [11,12]. Acoustic phonons at high temperatures represent the more probable elastic scattering centers in the disordered semiconductors and obviously lowering down the temperature decreases the number of phonons and this may lead to more mobility for the electrons. On the other hand (see Fig. 1) the effect of ionized impurities is assumed to be the great factor that influences the mobility of the electrons particularly at low temperatures. The maximum mobility calculated due to ionized impurity scattering was 5 m^2/V.s at 400 K while at the same temperature the mobility due to acoustic phonons was 500 m^2/V.s from which one can understand that the ionized impurity scattering may limits the mobility particularly at low range of temperatures.

To study the behavior of the electron drift mobility in the whole temperature range, Matthessen's rule was utilized to estimate the drift mobility as a result of the ionized impurity and acoustic phonon scatterings. Fig. 2 demonstrates the plot of the electron drift mobility versus the inverse of temperature. The electron drift mobility was calculated at different doping concentration starting from $6x10^{20}$ m^{-3} up to $25x10^{20}$ m^{-3}. At room temperature, the calculated drift mobility recorded approximately the value 4 m^2/V.s at donor concentration of $6x10^{20}$ m^{-3}. By lowering down the temperature starting from 300 K, the calculated mobility decreased regularly till it reached almost 0.13 m^2/V.s at 10 K.

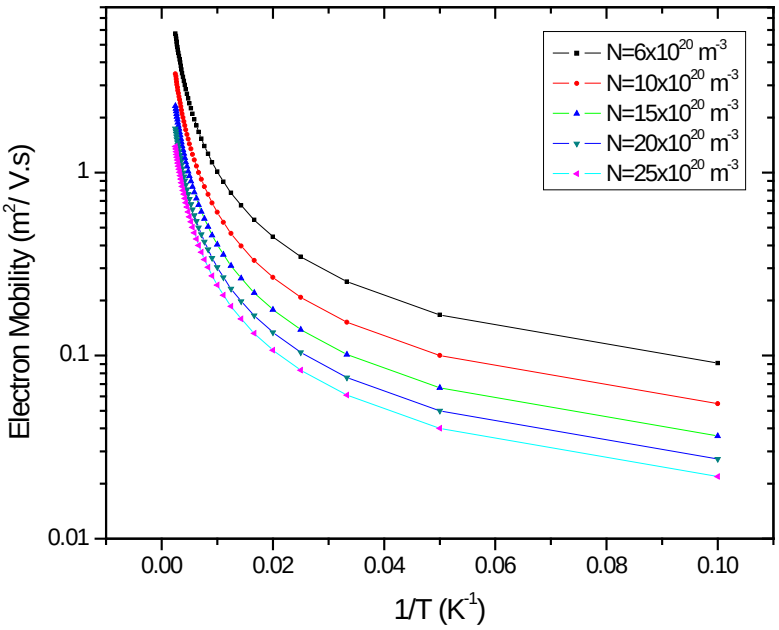

Fig. 2 The electron drift mobility versus inverse of temperature at different donor concentrations.

The results obtained from figures 1 and 2 let one to notice that the ionized impurity scattering probably could be the dominant scattering process that may present in this system. The doping concentration of the order of 10^{20} – 10^{21} m^{-3} at this semiconductor was assumed to be of moderate doping level and thus the impurity ions constitute permanent centers for electron scattering.

The influence of the donor concentration on the electron drift mobility was also analyzed. Fig. 3 depicts the mobility as a function of the donor concentration at selected temperatures of 10 K, 77 K, 300 K and 400 K.

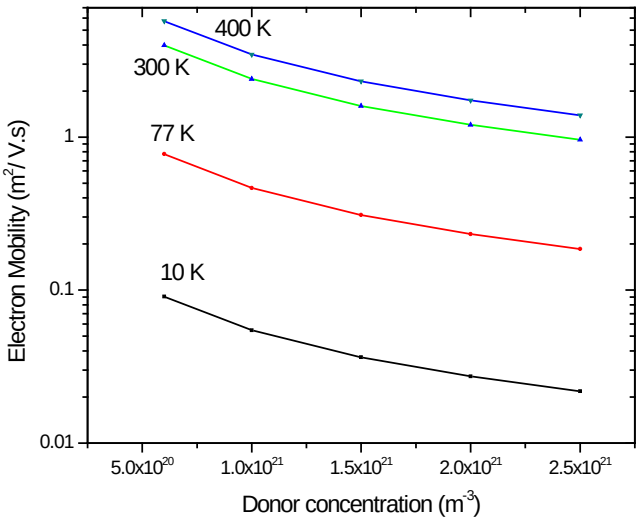

Fig. 3 Drift mobility variation with donor impurity concentration at selected temperatures.

At certain temperature, the electron drift mobility decreases as the material becomes more doped. The decrease of the electron mobility when the material becomes more doped is probably explained due to large ionized impurity scattering which limits the electron mobility particularly at low temperatures.

4. Conclusions

Numerical calculations of the electron mobility as a function of temperature and doping concentration were discussed for n-type InAs semiconductor on the basis of the relaxation time approach. Drift mobility of the electrons in the system was found to be diminished by lowering down the temperature while by decreasing the impurity doping density the drift mobility was noticed to be increased. This may be due to the effect of the ionized impurity scattering with electrons in the material. The ionized impurity scattering probably could be the dominant elastic scattering process that may present in such system. The doping concentration of the order of 10^{20} – 10^{21} m^{-3} at this semiconductor was assumed to be of moderate doping level and thus the impurity ions constitute permanent centers for electron scattering.

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