International Journal of Science, Environment
and Technology, Vol. 1, No 2, 80 - 87, 2012

NUMERICAL CALCULATION OF THE ELECTRON MOBILITY IN GaAs SEMICONDUCTOR UNDER WEAK ELECTRIC FIELD APPLICATION

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Abstract: In this study, electrons mobility of GaAs semiconductor with using the iterative method in the temperature range of 100-600 K at low field range is calculated .We have considered the polar optic phonons, ionized impurity scattering and acoustic phonon scattering mechanisms. Temperature and doping dependencies of electron mobility in GaAs crystal structure have been calculated using an iterative technique. It is found that the electron mobility decreases monotonically as the temperature increases from 100K to 500K which is depended to the band structure characteristics of GaAs. The low temperature value of electron mobility increases significantly with increasing doping concentration.
Keywords: Electron Mobility; Ionized impurity scattering; Polar optic phonons, Doping.

1. Introduction

GaAs is a semiconductor that is used for manufacturing of high-frequency microwave and Integrated circuits and diodes in the light (LED) and semiconductor laser diodes, and solar batteries. Knowing the electron transport in this material is important for In order to better design pieces that are based on a GaAs. This work shows the results of numerical calculations of the reversible electron transport in the GaAs. High pure GaAs semiconductor is one of the best semiconductor detectors, which can be made in large size with a very suitable high energy resolution. Although, high pure GaAs is very costly and must be kept at low temperature, it is widely used for gamma and x-ray spectroscopy[1]. When this crystal is located in a combined neutron-gamma field, neutron interactions with GaAs element induce main crystal damages and distort its energy resolution[2]. Depending

on the energy, neutron interactions with matter may undergo a variety of nuclear processes. The main interactions of fast neutrons are elastic scattering and inelastic scattering, but neutron capture is an important interaction for thermal neutrons[3]. Improved electron transport properties are one of the main targets in the ongoing study of semiconductor like GaAs. The iterative technique has proved valuable for studying non-equilibrium carrier transport in a range of semiconductor materials and devices. However, carrier transport modeling of GaAs material has only recently begun to receive sustained attention, now that the growth of compounds and alloys is able to produce valuable material for the electronics industry. In this communication we present iterative calculations of electron drift mobility in low electric field application[4]. We demonstrate the effect of low electric field on the electron transport properties in these materials. The differences in transport properties are analyzed in terms of important material parameters. Most of the calculations have been carried out using a non-parabolic ellipsoidal valley model to describe transport in the conduction band. In this calculation we have used the model of non-parabolic ellipsoidal valley to describe transport in the conduction band.

2. Method

In principle the iterative technique give exact numerical prediction of electron mobility in bulk semiconductors. To calculate mobility, we have to solve the Boltzmann equation to get the modified probability distribution function under the action of a steady electric field. Here, we have adopted the iterative technique for solving the Boltzmann transport equation. Under application of a uniform electric field the Boltzmann equation can be written as[5]

$$(\frac{e}{\hbar})E.\nabla_k f = \int [s' f'(1-f) - sf(1-f')]dk \qquad (1)$$

where $f=f(k)$ and $f'=f(k')$ are the probability distribution functions and $s=s(k,k')$ and $s'=s(k',k)$ are the differential scattering rates. If the electric field is small, we can treat the change from the equilibrium distribution function as a perturbation which is first order in the electric field. The distribution in the presence of a sufficiently small field can be written quite generally as

$$f(k) = f_0(k) + g(k)\cos\theta \qquad (2)$$

where $f_0(k)$ is the equilibrium distribution function, θ is the angle between k and E and $g(k)$ is an isotropic function of k, which is proportional to the magnitude of the electric field. In general, contributions to the differential scattering rates come from two types of scattering processes, elastic scattering s_{el}, due to acoustic, impurity, plasmon and piezoelectric phonons, and inelastic scattering s_{inel}, due to polar optic phonons

$$s(k,k') = s_{el}(k,k') + s_{inel}(k,k') \tag{3}$$

Generally this scattering process can not be treated within the framework of the relaxation time approximation because of the possibility of the significant energy exchange between the electron and the polar optic modes. In this case, s_{inel} represents transitions from the state characterized by k to k' either by emission $[s_{em}(k,k')]$ or by absorption $[s_{ab}(k,k')]$ of a phonon. The total elastic scattering rate will be the sum of all the different scattering rates which are considered as elastic processes, i.e. acoustic, piezoelectric and ionized impurity. In the case of polar optic phonon scattering, we have to consider scattering-in rates by phonon emission and absorption as well as scattering-out rates by phonon absorption and emission. Using Boltzmann equation and considering all differential scattering rates, the factor $g(k)$ in the perturbed part of the distribution function $f(k)$ can be given by[6]

$$g(k) = \frac{\frac{-eE}{\hbar}\frac{\partial f_0}{\partial k} + \sum\int g'\cos\varphi[s_{inel}'(1-f) + s_{inel}f)]dk}{\sum\int(1-\cos\varphi)s_{el}dk + \sum\int[s_{inel}(1-f') + s_{inel}'f']dk} \tag{4}$$

Note, the first term in the denominator is simply the momentum relaxation rate for elastic scattering. It is interesting to note that if the initial distribution is chosen to be the equilibrium distribution, for which $g(k)$ is equal zero, we get the relaxation time approximation result after the first iteration. We have found that convergence can normally be achieved after only a few iterations for small electric fields. Once $g(k)$ has been evaluated to the required accuracy, it is possible to calculate quantities such as the drift mobility which is given by

$$\mu_d = \frac{\hbar}{3m} \frac{\int_0^\infty k^3 \frac{g(k)}{Ed} dk}{\int_0^\infty k^2 f(k) dk} \tag{5}$$

Where d is defined as $1/d = m\nabla_k E/\hbar^2 k$.

3. Discussion of results

Figure 1 shows the calculated electron drift mobility in bulk GaAs material as a function of temperature with free electron concentration of 10^{21} to 10^{23} m^{-3} and with the electric field applied along one of the cubic axes. It can be seen from the figure that the electron drift mobilities at room temperature that we find for GaAs is 3000 cm^2/V-s at 10^{23} m^{-3} donor concentration. The results plotted in figure 1 indicate that the electron drift mobility of GaAs is lower at donor concentration of 10^{23} m^{-3} at all temperatures. This is largely due to the higher electron scattering rate. Also it can be seen that below 100 K, ionized impurity scattering is the dominant forms of lattice scattering.

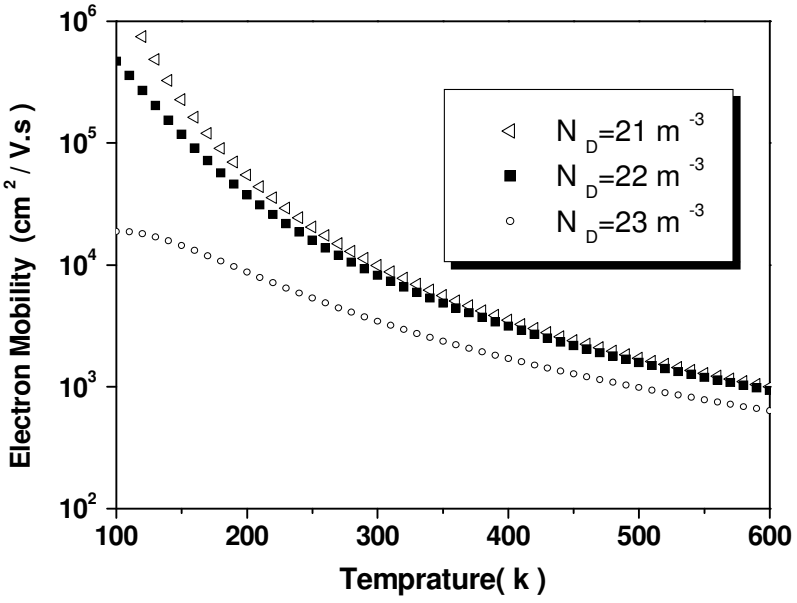

Fig 1. Electron mobility in terms of temperature in GaAs fordifferent electron density.

Figure 2 shows the piezoelectric scattering rate in term of energy in GaAs for different temperatures. It is observed that with increasing energy of the external electric field the scattering rate is decreased. The piezoelectric scattering process at higher temperatures and low energy electron energy is important.

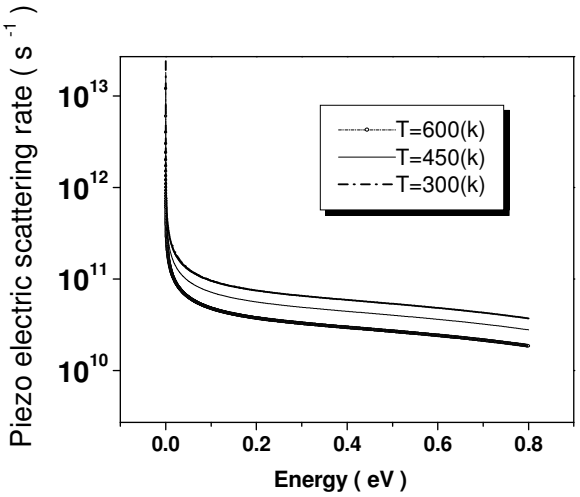

Fig 2. Piezoelectric electron scattering rate in terms of energy for different temperature in GaAs.

Figure 3 shows the deformation potential electron scattering rate in GaAs at different temperatures. The scattering rate of electrons at higher temperatures is higher also it can be seen that the amplitude of oscillations of atoms increases with increasing temperature.

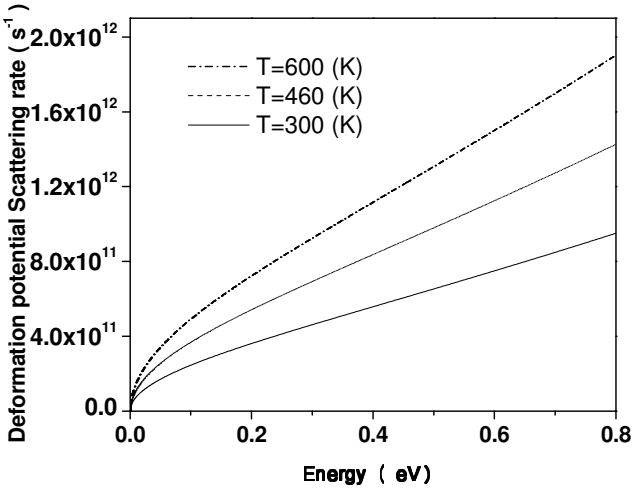

Fig. 3. Deformation electron scattering rate in terms of energy at Γ valley in different temperature in GaAs.

Figures 4 and 5 show the change of polar optical scattering rate in GaAs in the state of absorption and emission. Figure 4 is for the absorption of phonons in terms of electron energy. It can be seen that with increasing the energy, electron scattering does not change. But at higher temperatures it increase.

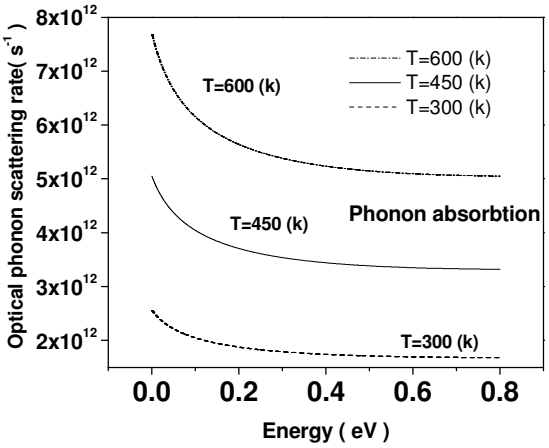

Fig. 4. Electron scattering rate by polar optical phonons of energy at different temperature for absorption of phonons.

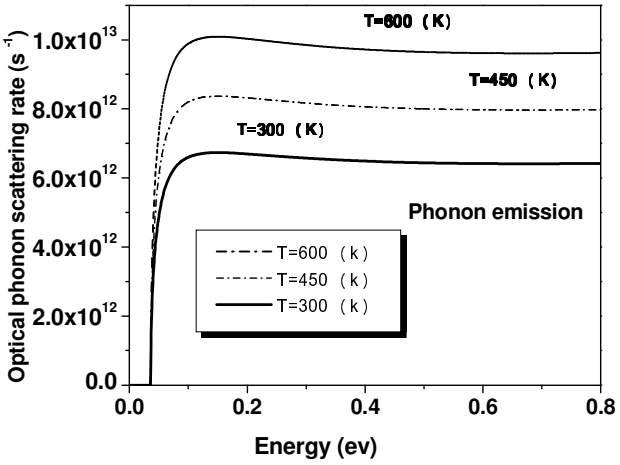

Fig. 5. Electron scattering rate by polar optical phonons of energy at different temperature for emission of phonons.

Figure 5 shows the electron scattering rate due to optical phonons at emission state. The energy gained by the vibration of optical phonons in the crystal structure is released. The energy of electrons with optical phonons to the energy dispersion of the GaAs is suddenly goes up. In other words, emission of optical phonons only occurs when the energy of

primary electron energy of optical phonons in GaAs exceeds 0.35 eV. Then slowly decreases with increasing energy dispersion of the electrons. In this case, higher temperatures are more scattered.
Finally, figure 6 show the ionized impurity scattering rate of electrons in GaAs. It can be seen that at high electric fields the electron scattering from impurity atoms is much higher.

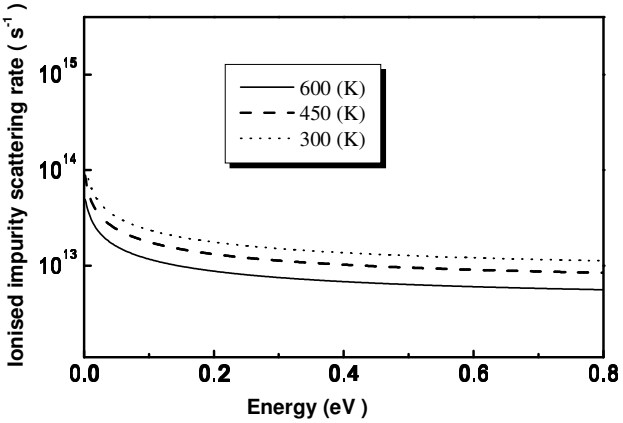

Fig. 6. Electron scattering rate by ionized impurity atoms at different temperatures in GaAs.

4. Conclusion

In conclusion, we have quantitatively obtained temperature-dependent and electron concentration-dependent electron mobility in GaAs using an iterative technique. The theoretical values show good agreement with recently obtained experimental data. Several scattering mechanisms have been included in the calculation. Ionized impurities have been treated beyond the Born approximation using a phase shift analysis. Screening of ionized impurities has been treated more realistically using a multi-ion screening formalism, which is more relevant in the case of highly compensated III-V semiconductors like GaAs.

References

[1] Arabshahi H (2009). Comparison of SiC and ZnO field effect transistors for high power applications, *Modern Phys. Lett. B*, 23, 2533-2539.

[2] Bertazzi F, Goano M and Bellotti E (2007). Electron and hole transport in bulk ZnO: A full band monte carlo study, *J. Elec. Mat.* 36, 857-863.

[3] Furno E, Bertazzi F, Goano M, Ghione G and Bellotti E (2008). Hydrodynamic transport parameters of wurtzite ZnO from analytic- and full-band Monte Carlo simulation, *Solid-State Elecronics* 52, 1796-1802.

[4] Farahmand M, Garetto C, Bellotti E, Brennan K F, Goano M, Ghillino E, Ghione G, and Ruden P (2001). Monte Carlo simulation of electron transport in the III-nitride wurtzite phase materials system: binaries and ternaries, *IEEE Transactions on Electron Devices, 48, 535-539.*

[5] Jacoboni C and Lugli P (1989): The Monte Carlo method for semiconductor and device simulation, *Springer- Verlag*, 3, 221-234.

[6] Moglestue C(1993). Monte Carlo simulation of semiconductor devices, *Chapman & Hall*, 4, 190-198.

Received May 5, 2012