TEMPERATURE, ACCEPTOR CONCENTRATION AND DONOR CONCENTRATION DEPENDENCY OF ELECTRONIC MOBILITY IN BULK GaN AND GaP

Md. Rabiul Islam[1*] and Md. Zahid Hasan Mahmood[2]

[1,2]Department of Applied Physics Electronics and Communication Engineering, University of Dhaka, Bangladesh

ABSTRACT

Mobility is an important factor to determine the speed of an electronic device. Devices composed of electronic materials with higher mobility are able to achieve higher speed. It is therefore favourable to maximize the mobility. In this paper, we have chosen GaN and GaP as semiconductor material and Low-field electron mobility has been calculated in bulk and wurzite phase GaN and GaP. The dependency of mobility upon temperature is shown. Beside this, dependency of mobility upon acceptor concentration and donor concentration are also shown.

KEYWORDS

Mobility, Scattering, GaN, GaP, Donor, Acceptor

1. INTRODUCTION

The tremendous theoretical enrichment and technological development in the field of semiconductor has made it possible of wide scale application in wireless communication, high power devices, optoelectronic and high speed devices. High-speed devices like gunn diode, microwave transistor, impact-ionization avalanche transit-time (IMPATT) diode, resonant-tunneling diode (RTD) are ultimate result of this rapid development in semiconductor research field. The key requirement of these high speed devices is high electron mobility. Therefore to achieve better and better performance from high-speed devices continuation of research to achieve further high mobility is required [1, 2].

However, till the last decade primary semiconductor were Silicon (Si) and Group III-V materials such as Gallium Arsenide (GaAs) and Aluminium Arsenide (AlAs). Although these materials had extensive application in various fields, those materials have a major limitation of narrow band gaps (1.1 eV for Si and 1.4 eV for GaAs). These limitations have made their usage limited. It is because of the fact that electrons can easily travel from the valence band to the conduction band in a material with a narrow band gap. Those materials are therefore not suitable for high temperature and high speed applications [3]. The GaN and GaP have band gap of 3.4 eV and 2.25 eV respectively at 300 K. This wide band gap and other properties have made those materials specially applicable for exciting applications [4].

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2. MOBILITY

Mobility is a measure of how well charge carriers are able to move through a substance. Electrons are able to flow more quickly in materials with higher mobility [5]. Bulk mobility measures how well charge carriers move through bulk semiconductors and it is important to study electrical properties of semiconductor. The mobility is determined by the rate at which electrons are scattered by impurities and defects within the crystal structure of the semiconductor. This rate is the reciprocal of the relaxation time τ, the average time between collisions. The relaxation time can be adjusted to account for the varying degrees of scattering on any given collision. This is called the momentum relaxation time τ_m. The mobility is dependent upon τ_m by the equation [6],

$$\mu = \frac{e\tau_m}{m^*} \tag{1}$$

Where,

- e is the charge of the electron.
- m^* is the effective mass of the electron.

3. SCATTERINGS

As free charge carriers traverse through a semiconductor, they encounter various scatterings [7]. Scatterings influence the bulk electronic mobility. The important mechanisms of electron scattering considered are:

3.1. Ionized Impurity Scattering

Carriers, electrons or holes, are scattered from impurities and defects. Some of these scatterers are charged and some are neutral. Defects, if charged, can be considered as ionized impurities for mobility calculation purposes. The ionized impurity scattering is dominant at low temperatures because, as the thermal velocity of the carriers goes down, the effect of long-range Coulombic interactions on their motion is increased [7, 9]. Now the momentum relaxation time for ionized impurity scattering is given as [8],

$$\tau_{ii} = \frac{0.414\epsilon_r{}^2(0)T^{3/2}}{Z^2N_i\left[\ln(1+b)-\frac{b}{1+b}\right]} \tag{2}$$

Here,

$$b = 4.31 \times 10^{13}\left[\frac{\epsilon_r{}^2(0)T^2}{n^*}\right]\left(\frac{m^*}{m}\right)x \tag{3}$$

Where,

- $\epsilon_r(0)$ is static dielectric constant.
- N_i is the concentration of ionized impurities.
- m is the mass of electron.
- T is the temperature in Kelvin.

3.2. Neutral Impurity Scattering

If the scatterers are neutral, they can be handled using the neutral impurity scattering theory. When an electron approaches close to a neutral atom it exchanges momentum with the bound electron. Note that, the scattering cross section for this process is not nearly as large as in the case of the ionized impurity scattering [7]. Considering neutral impurities scattering momentum relaxation time equation is written as [8],

$$\tau_{in} = \frac{8.16\times10^{6}}{\epsilon_r(0)N_n}\left(\frac{m^*}{m}\right)^2 \quad (4)$$

Where

- N_n represents the concentration of neutral impurities.

3.3. Acoustic Deformation Potential Scattering

Beginning at about 5 K, acoustic phonon scattering becomes the main mechanism limiting the mobility through both deformation potential and piezoelectric scattering. Unless explicitly specified, acoustic phonon scattering is generally assumed to be only because of the deformation potential as the nomenclature was developed for semiconductors with no or negligible piezoelectric behavior. Because the nitrides are highly piezoelectric, both components must be taken into consideration [8, 9].

For temperatures below about 200 K, the deformation potential induced acoustic scattering dominates over the piezoelectric components. For high temperatures, the piezoelectric component is relatively stronger [7]. Considering acoustic deformation potential scattering momentum relaxation time equation is written as [8],

$$\tau_{dp} = \frac{2.4\times10^{-20}C_L}{D_{ap}{}^2T^{3/2}}\left(\frac{m}{m^*}\right)^{1/2} \quad (5)$$

$$C_L = \frac{1}{5}(3C_{11} + 2C_{12} + 4C_{44}) \quad (6)$$

Where,

- D_{ap} is the deformation potential.
- C_L elastic constant (Logarithmic component).

3.4. Piezoelectric Scattering

In non-centrosymmetric crystals, a polarization field is induced when stress is applied. Carriers then interact with the electric field induced by strain. In a sense, the carriers can be scattered by a TA phonon in addition to LA phonons through the piezoelectric coupling, as is the case in the deformation potential acoustic phonon scattering [7, 9]. For piezoelectric scattering the momentum relaxation time equation is given as [8]

$$\tau_{ip} = \frac{9.54\times10^{-8}}{h_{14}{}^2\left(\frac{3}{c_L}+\frac{3}{c_T}\right)T^{3/2}}\left(\frac{m}{m^*}\right)^{1/2} \quad (7)$$

Here,

$$C_L = \frac{1}{5}(3C_{11} + 2C_{12} + 4C_{44}) \quad (8)$$

$$C_T = \frac{1}{5}(3C_{11} - C_{12} + 3C_{44}) \quad (9)$$

Where,

- h_{14} is the piezoelectric stress tensor.
- c_T is the elastic constant (Transverse component).

3.5. Optical Deformation Potential Scattering

Optical phonons in semiconductors have energies in the tens of mill-electron volts with the figure for LO phonons to be about 92 meV [7]. This implies that at low temperatures, such as 100 K, most electrons do not have sufficient thermal energy to emit optical phonons. Moreover, the thermal occupation number for phonons is very small and therefore the probability of an electron

absorbing an optical phonon is very low. This basically indicates that optical phonon scattering at low temperatures is negligible [10, 11].

At higher temperature the picture is very different in the sense that electrons have sufficient energy to emit optical phonons and overtake LA acoustic phonon scattering. This statement is particularly applicable to polar semiconductors where the Frohlich electron-phonon coupling is very strong scattering by LA phonons relaxes primarily the electron momentum with negligible energy change; however, scattering by optical phonons relaxes both electron momentum and energy [7]. The momentum relaxation time for optical phonon scattering by deformation potential is given by [8],

$$\tau_{op} = \frac{4.83\times10^{-20} C_L [e^{\frac{\theta}{T}} - 1]}{\xi_A{}^2 T^{1/2} \theta} \left(\frac{m}{m^*}\right)^{3/2} \quad (10)$$

Here,

$$\theta = \frac{h\omega_{LO}}{k} \quad (11)$$

Where,

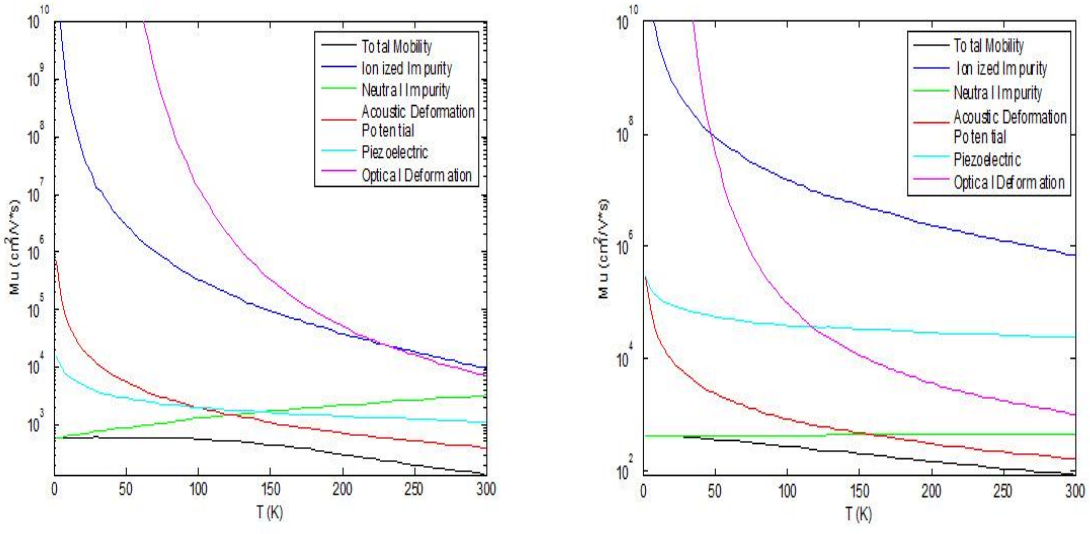
- ξ_A denotes the optical phonon deformation potential.
- $h\omega_{LO}$ is the optical phonon energy.
- ω_{LO} is the optical phonon frequency.
- k is the Boltzmann constant.
- *h* is the Plank constant.

4. RESULTS

The results obtained are shown in the following subsections. A comparison between results obtained in the case of GaN and GaP is also done.

4.1. Temperature Dependency of Electronic Mobility

Figure 1 depicts the variation of low field electronic mobility as a function of temperature for GaN and GaP, which also includes the contribution of individual scattering mechanism in mobility.

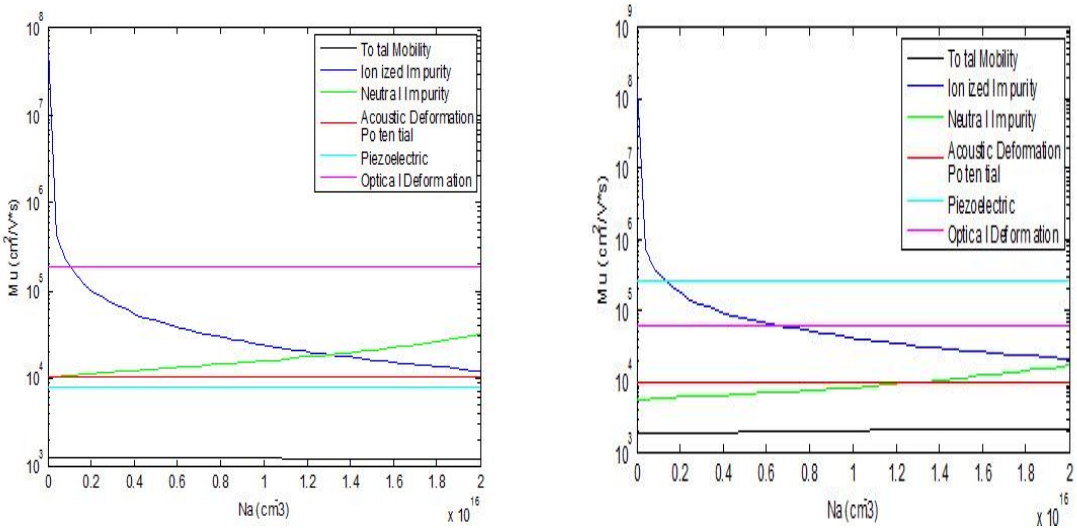


(a) (b)

Figure 1. Temperature dependency of mobility, (a) for GaN and (b) for GaP.

4.2. Acceptor Concentration Dependency of Electronic Mobility

Variation of low field electronic mobility as a function of acceptor concentration is shown in figure 2 for both GaN and GaP, which also include the contribution of individual scattering mechanism in mobility.

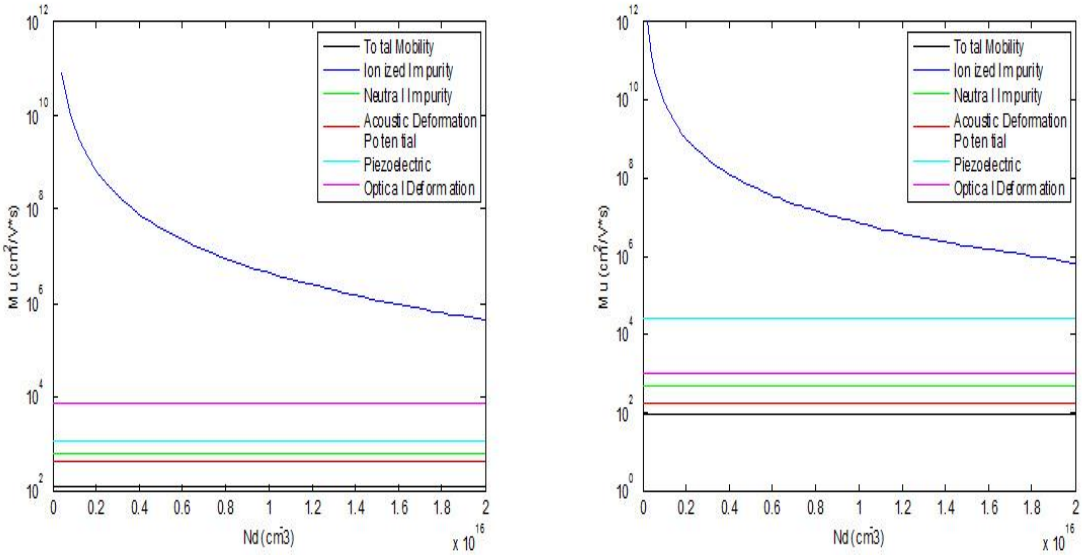


(a) (b)

Figure 2. Acceptor concentration dependency of mobility, (a) for GaN and (b) for GaP.

4.3. Donor Concentration Dependency of Electronic Mobility

Variation of low field electronic mobility as a function of donor concentration is shown in figure 3 for both GaN and GaP, which also include the contribution of individual scattering mechanism in mobility.



(a) (b)

Figure 3. Donor concentration dependency of mobility, (a) for GaN and (b) for GaP.

5. CONCLUSION

In summary, low field electron mobility has been calculated considering five different scattering mechanisms for GaN and InN. A number of scatterings have been omitted for simplicity. Calculation can be improved by considering all scatterings. Dependency of mobility upon temperature, donor concentration and acceptor concentration has been studied for both GaN and GaP. The total electronic mobility decreases with increasing temperature for both GaN and GaP. The total electronic mobility is almost independent of acceptor and donor concentration for both GaN and GaP.

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