MONTE CARLO SIMULATION OF 1D SEMICONDUCTOR DEVICES

Hasan Sarwar[1,2], Dr. Shahida Rafique[2]

[1]Department of Computer Science, Institute of Science and Technology, Hs 54 (New), Rd 15/A (New), Dhanmondi, Dhaka 1209, Bangladesh.

Email : mdhasan70@hotmail.com

[2]Department of Applied Physics and Engineering, University of Dhaka, Dhaka 1000, Bangladesh

E:Mail : rim@bdcom.com

Electron transport through semiconductor devices has been observed using Monte Carlo Simulation. The parameters that have been observed are number of electrons in the Γ valley, L valley, and the *X* valley, current density, kinetic energy, transit time. Effect of different scattering mechanisms has been considered during simulation. The scattering methods are polar optical phonon scattering, heavy hole scattering, ionized impurity scattering nonpolar acoustics optical phonon scattering. Emphasis has been given on ternary AlxGa1−xAs, GaxIn1−xAs and AlxIn1−xAs systems. Influence of scattering mechanisms on electron velocity has been shown. Input parameters were temperature, dimension of the device, impurity concentration (donor and acceptors).

INTRODUCTION

Semiconductor material selection plays a vital role in developing semiconductor devices. Extensive research in material has produced a number of compound semiconductors. Since the introduction of Monte Carlo Technique in the application of high field transport in semiconductor devices by Kurosawa[1], only recently it has received great attention[2]. Now a days semiconductor devices can be simulated using Monte Carlo Tool. As usual in semiclassical transport, the dynamics of the electron interactions is assumed to be independent of the applied field and the collisions are assumed to occur instantaneously. The electronic transitions of interest for charge transport in semiconductors can be classified as intravalley or intervalley and in case of holes it would be intraband or interband. [3]

THEORY

The interaction of phonons with charge carriers is due to the deformation of the otherwise perfect crystal produced by phonons through the deformation potential mechanism or through electrostatic forces produced by the polarization waves that accompany the phonons. The first kind of interaction is typical of covalent semiconductors; the electrostatic interaction, typical of polar materials, is called piezoelectric interaction for acoustic phonons, and polar interaction for optical phonons. The most important scattering sources are phonons, impurities and other carriers. Furthermore, impurities can be neutral or ionized. In the latter case the interaction is of coulomb type, whereas in the former the interaction is of much shorter range and the overall effect of such impurities is in general much weaker. The phenomena involving trapping and de-trapping of charges that can occur in semiconductors, such as ionization and generation-recombination, are important to be considered.

RESULT

Monte Carlo simulation has been performed [4] on devices of size .5 micron. For alloy composition of x = 0.4, $Al_xGa_{1-x}As$ Al_xIn_{1-x} As and $Ga_xIn_{1-x}As$ drift velocity, current density, kinetic energy, percentage of electron in G, X, L valleys, transition time have been measured. In all the cases impurity concentration were taken as 2.9e15cm-3. Measurements have been collected for temperature T = 300k. For evaluating ensemble averages all valleys have been treated. Polar optical phonon scattering, intervalley scattering, non-polar acoustic phonon scattering and ionized impurity scattering were considered. Fig. 1 displays the drift velocity as a function of electric field strength. It is found that AlGaAs has the least electron velocity compared to AlInAs and GaInAs.

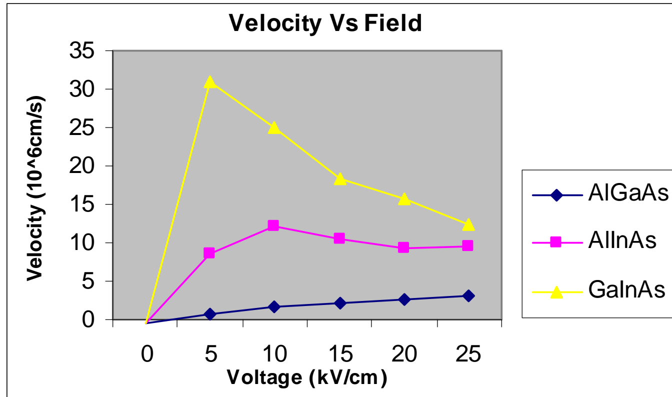

Fig 1 Drift Velocity of electrons for $Al_xGa_{1-x}As$ Al_xIn_{1-x} As and Ga_xIn_{1-x} As as a function of field strength. For all compounds alloy composition x = .4 at 300K for and donor impurity concentration at 2.9e15cm-3, device length = .5 micron.

Fig. 2 shows the current density for all the semiconductors as a function of electric field strength.

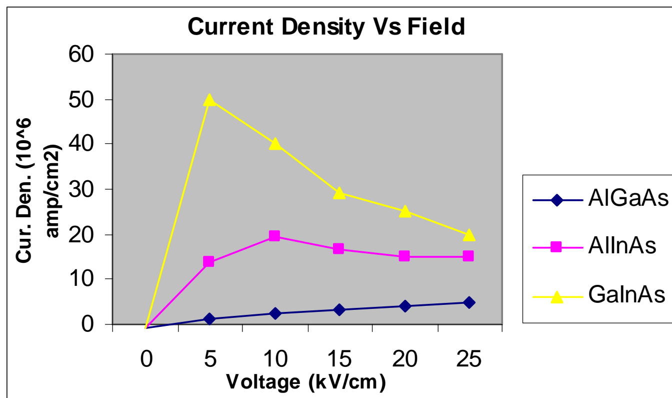

Fig 2 Drift Velocity of electrons for Al_xGa_{1-x} As Al_xIn_{1-x} As and Ga_xIn_{1-x} As as a function of field strength. Alloy composition x = .4 at 300K and donor impurity concentration at 2.9e15cm-3, device length = .5 micron.

Fig. 3 shows electron kinetic energy for all the semiconductors as a function of electric field strength.

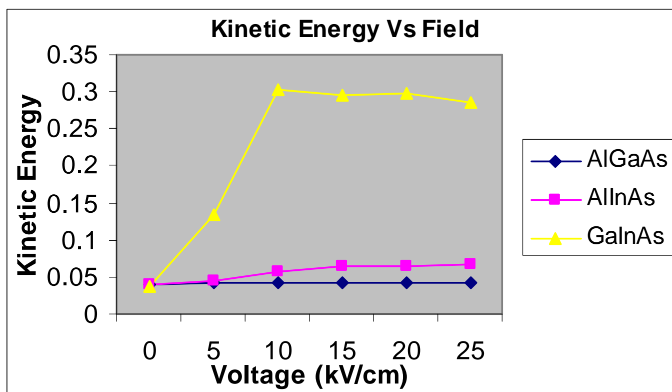

Fig 3 Kinetic Energy of electrons for AlxGa1-x As AlxIn1-x As and GaxIn1-x As as a function of field strength. Alloy composition x = .4 at 300K and donor impurity concentration at 2.9e15cm-3, device length = .5 micron.

Fig. 4 shows the transient time for all the semiconductors as a function of electric field strength.

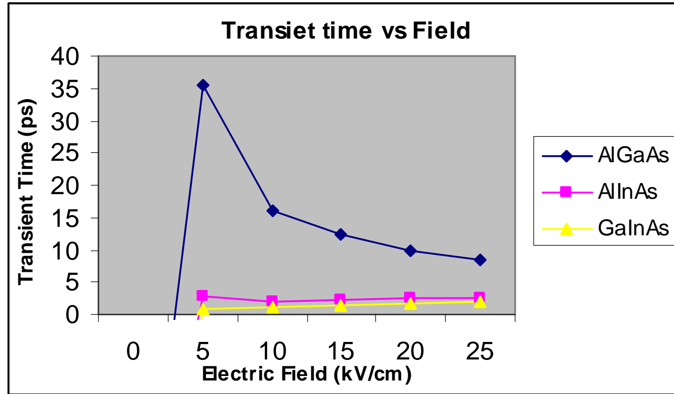

Fig 4 Transient time of electrons for AlxGa1-x As AlxIn1-x As and GaxIn1-x As as a function of field strength. Alloy composition x = .4 at 300K and donor impurity concentration at 2.9e15cm-3, device length = .5 micron.

Fig. 5 shows the percentage of electron density for all the semiconductors as a function of electric field strength.

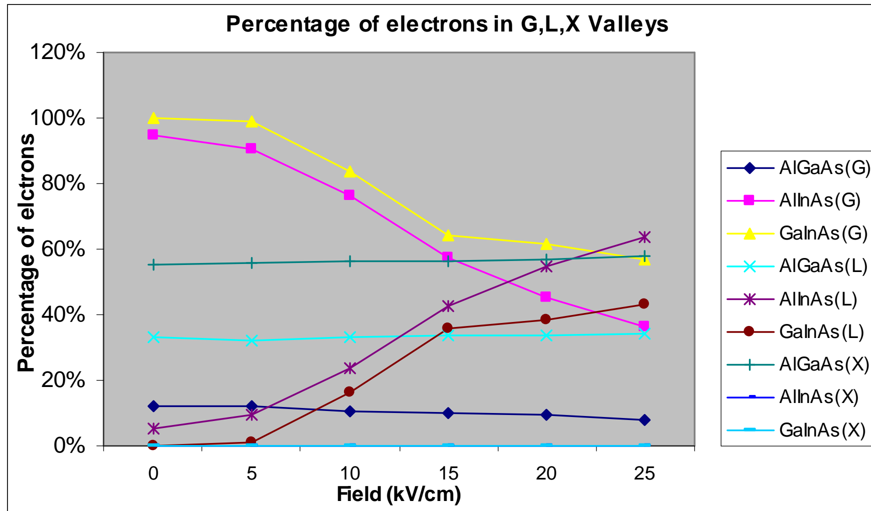

Fig 5 Percentage of electrons N_G/N, N_L/N, N_X/N respectively in G, L and X valleys for AlxGa1-x As AlxIn1-x As and GaxIn1-x As as a function of field strength. Alloy composition x = .4 at 300K and donor impurity concentration at 2.9e15cm-3, device length = .5 micron.

CONCLUSION

For alloy composition of x = 0.4, AlGaAs shows the least electron drift velocity while GaInAs has highest velocity specially in low field. At high field drift velocity starts to converge. Current density also follows the same pattern. Kinetic energy of electrons in AlGaAs and AlInAs are very low compared to GaInAs. On the other hand, transient time in AlGaAs is higher than the other two semiconductors. Here also, transient time converges at high field. In AlGaAs, lowest number of electrons reside in G valley, and highest number of electrons reside in X valley. In AlInAs, highest number of electrons reside in G valley and lowest

number of electrons reside in X valley, and in GaInAs highest number of electrons reside in G valley and lowest number of electrons reside in X valley.

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