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Modeling the transport of charge carriers in the active devices diode submicron n^+-n- n^+, based upon $Ga_{0.49}In_{0.51}P$ by the Monte Carlo method

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ABSTRACT
A Monte Carlo simulation program was developed to simulate the movement of electrons in a submicron GaInP diode three dimensional (3D) with 0.1 microns-long active layer. The algorithm couples a standard Monte Carlo particle simulator for the Boltzmann equation with a 3D Poisson solver. Thus a series of hits for a specific MC submicron diode (GaInP), with an active layer (n = $2x10^{15}cm^{-3}$) of length 0.1µm surrounded by two regions doped with n = $5x10^{17}cm^{-3}$, are presented. The lattice temperature is 300K and the anode voltage V_a is 1V. The analysis also showed that the average drift velocity to the electrons in the channel is about $5x10^6$ cm/sec
Keywords -Monte Carlo simulation, active layer, drift velocity, Diode device,

I. INTRODUCTION

The main advantage of III-V's over GaInP is their high intrinsic mobility, which amounts to high speed and lower delay [1]. The effective mass of electrons is much lower in III-V's as compared to Si, which results in a high injection velocity. This low effective mass, however, also results in a low density-of-states, which affects the semiconductor capacitance and drive current. This is frequently referred to as the density of-states bottleneck [2]. The stochastic model is used to study the role of phonon scattering on the state of diodes devices. Finally, the role of the Surface roughness scattering and its implementation within Monte Carlo discussed [3]. Simulating these structures is simple in the sense that it can be reduced to a description of a dimension. However, the simulation can bring us a lot of useful information on the transport properties of more complex structures. The general structure of a diode n + -n- n + is shown in Figure1.

In this study, we describe how the device characteristics of sub-100 nm GaInP are affected by the length of active region, by velocity overshoot due to near ballistic electrons, and by
overshoot degradation due to short-channel tunneling of carriers[4]

II. MATHEMATICAL MODEL

Several simulations of Semiconductor's devices have been presented after the work of Hockney's et al. [5]. From the physical point of view, the various simulations can be divided into two groups, depending on the GaInP model used (two or three valley model, or the full band diagram). The scattering mechanisms are also taken from these models, and include non-equivalent intervalley (Γ↔X or L for the two valley model, Γ↔L, L↔X, Γ↔X for the three valley model), equivalent intervalley (L↔L in the first case, L↔L, and X↔X in the second), polar optic and acoustic phonon scatterings [6]. For traditional semiconductor device modeling, the predominant model corresponds to solutions of the so-called drift-diffusion equations, which are 'local' in terms of the driving forces (electric fields and spatial gradients in the carrier density), i.e. the current at a particular point in space only depends on the instantaneous electric fields and concentration gradient at that point. The complete drift-diffusion model is based on the following set of equations [7]:

Current equations:

$$J_n = qn(x)\mu_n E(x) + qD_n\, dn/dx$$

$$J_p = qn(x)\mu_p E(x) - qD_p\, dn/dx$$

Continuity equations:

$$\frac{\partial n}{\partial t} = \frac{1}{q}\nabla.J_n + U_n$$

$$\frac{\partial p}{\partial t} = \frac{1}{q}\nabla.J_p + U_p$$

Poisson's equation:

$$\nabla.(\varepsilon\nabla V) = -(p - n + N_D^+ + N_A^-)$$

Where U_n and U_p are the generation-recombination rates.
The continuity equations are the conservation laws for the carriers. A numerical scheme which solves the continuity equations should

• Conserve the total number of particles inside the device being simulated [8].

• Respect local positive definite nature of carrier density. Negative density is unphysical.

• Respect monotony of the solution (i.e. it should not introduce spurious space oscillations) [9].

III. RESULTATS AND DISCUSSIONS

We start the presentation of specific examples MC simulation of semiconductor devices from a structure (diode).
The general structure of a diode n + -n- n + is shown in Fig 1. Heavily doped regions act as cathode and anode, abrupt homojunctions are assumed for more simplicity.
So a series of specific MC results for submicron diode (GaInP), with an active layer (ND = $2x10^{15}cm^{-3}$) length 100 nm surrounded by regions doped ND = $5x10^{17}cm^{-3}$ are presented in the figure below. The lattice temperature is 300K and the anode voltage Va is 1V. Several observations are observed.

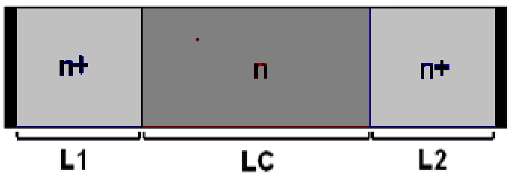


Figure 1 -: Diode structure (GaInP) n^+-n- n^+.

The density of free electrons Fig 2 shows that the electrons diffuse from the doped regions in the intrinsic layer. The dipole of the load on both interfaces induces a field that opposes to this trend [10]. When voltage is applied to the structure, the potential decreases within the intrinsic layer Fig 3.

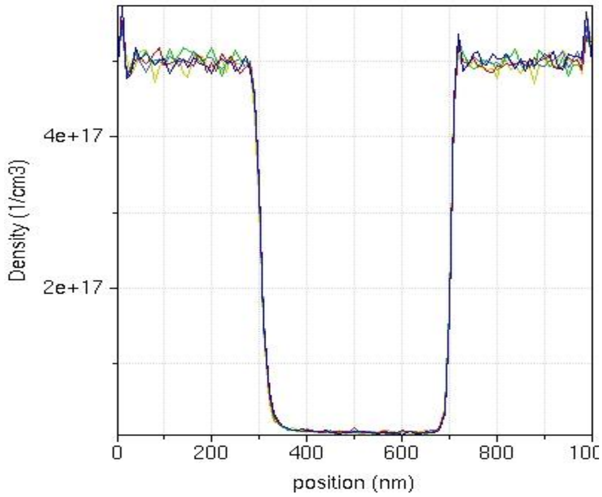


Figure 2 - electron density versus distance profiles for diode device

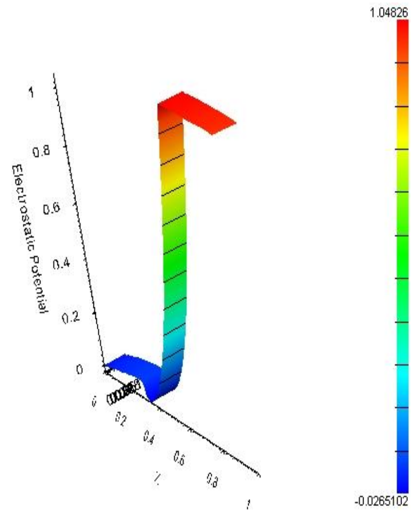


Figure 3 - electrostatic potential along the axis

A very high electric field is found Fig 4, near the anode. The carriers entering the active layer overcomes the small potential barrier to the cathode are accelerated almost ballistically to about half of the intrinsic region. As a result, the average speed of electrons (in the x direction) increases to a value of about 10^7cm / sec [11].

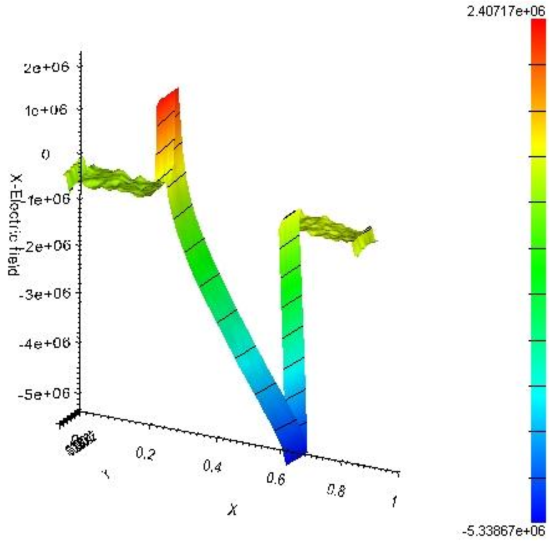
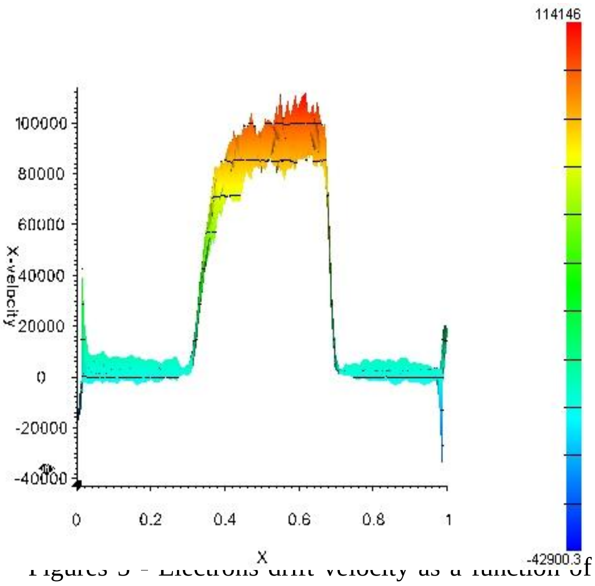


Figure 4 – field Electric as a function of distance

For the decrease following Fig 5 is due to electron transfer in satellite valleys, and the backscattering of anode layer n + (caused by the diffusion of impurities). Raising the temperature to 400 K, it produces even a speed reduction in the active layer (up to a value of $5x10^6$ cm / sec), due to enhanced diffusion [12].



Figures 5 - Electrons drift velocity as a function of time for various field values

In the active region Fig 6, the electrons are accelerated by the strong electric fields and gain energy [13], leading its electrons to the n-n$^+$ interface at maximum power. Then the average energy continues to decline, this is caused by the fact that the electrons lose their energies due to several phenomena of diffusion.

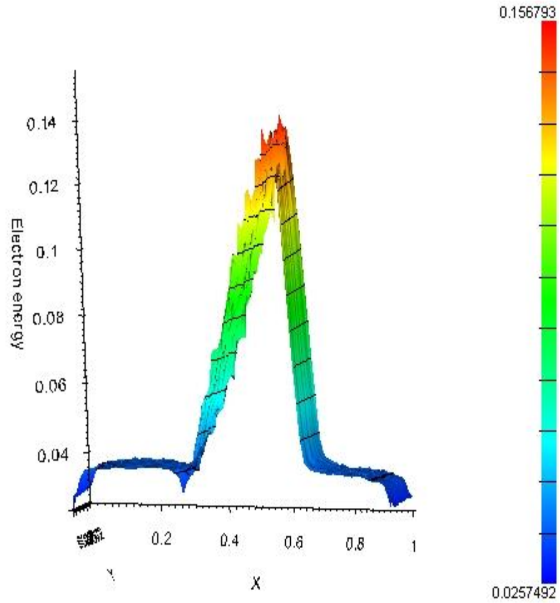


Figure 6 – Electron energy as a function of the distance x.

IV. Conclusion

Increasing the length of the active layer also reduces the velocities of the electrons [14], since the movement of the carrier moves from quasi-ballistic to conditions dominated by collisions.

One of the important points in the MC simulation of submicron structures on the role of boundary conditions [15]. In the situation presented in the previous figures, the electric field decreases rapidly (within a distance of a few hundred angstroms) that we are entering the doped region. The carriers are then in thermal equilibrium at both ends of the field of simulation [16].

In conclusion, we have shown that the Monte Carlo simulation of semiconductor devices has made considerable progress in recent years, and today is a very valuable tool in the field of modeling of the devices [17]. In addition, the Monte Carlo Method is the best technique to study situations where non-stationary effects are important (e.g. in submicron devices). It's safe to expect that the trend toward miniaturization of devices will continue in the future, and simulators MC gradually extend their applicability [18].

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