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The Study of the Distribution Function of Electrons by Ensemble Monte-Carlo Simulation of the Heterojunction Bipolar Transistor in Large Current Mode

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The bipolar heterojunction transistor (HBT) is an important device for VLSI submicron technology. Simulation of submicron devices with operating frequencies ~100 GHz demands to take into account nonstationary and nonequilibrium phenomena. Operating modes of HBT have been investigated in large number of papers, e.g., [1,2]. As a rule the dynamics of charge transport was investigated in base and collector regions of the device. Velocity distribution in emitter area was assumed as an equilibrium Maxwell on the heterobarrier emitter-base.

We have investigated the dynamics of charge transport in large current mode of HBT. Kinetic Boltzman equations for electrons were numerically solved by macroparticle's method with Monte-Carlo algorithms for electron scattering. Electron scattering on charged impurities, acoustic and optical phonons and alloy scattering in AlGaAs emitter area have been taken into account when the electron component of semiconductor plasma was simulated by ensemble Monte-Carlo method. The holes were simulated by stochastic dynamic method with Monte-Carlo algorithms for modeling the hole's reflection from the abrupt base-emitter heterojunction. Self-consistent electrical field and built-in quasi-electrical field near the emitter-base bound were taking into account.

The results of the simulation are shown in Fig. 1-7. Space distribution of the electrons and potentials on the electrodes are shown in the Fig.1. Distributions $dN(V_y)/dV_y$ for electrons in different valleys are shown in Fig.2-5. These distributions correspond to the rectangle areas 1-2 on Fig.1. for base potential +0.1V (Fig.2,3) and -0.1V (fig.4,5). It may be seen from the figures that the velocity distribution of electrons is non-Maxwell. It can be explained by some reasons. Energy gap between Γ- and L-valley in AlGaAs is of the order of emitter-base voltage. Besides energy barrier does not allow X-electrons to cross the heterojunction from emitter to base that's why the number of X- and L- electrons in emitter (see Fig.2) is more greater than in equilibrium case.

Inter-valley electron scattering of high energy electrons started from the heterobarrier and moving through base leads to increasing of the number of electrons with random velocity direction (the central peak in fig. 3) and decreases the number of electrons with the large V_y component in the electron beam (noncentral peak in Fig.3). The phase plane V_y (y) for all electrons in the structure is shown in the Fig.6 for base potential +0.1V and in the Fig.7 for -0.1V. It may be seen that the number of electrons in Γ-electron beam in the base is small enough in comparison with the number of electrons with random velocity direction due to the scattering on inter-valley optical phonons in case of $\varphi_b = +0.1$ V. When the base potential was changed to -0.1 V , L-electrons beam appeared. The change of the potential distribution increases the number of L-electrons in the emitter region due to influence of "virtual emitter" region. Γ-electrons have enough time to scatter in L-valley and then to cross the heterojunction due to the form of the potential distribution.

The results of the simulation show that taking into account the emitter region, including "virtual emitter," is very important for correct simulation of the device in large current mode. The including of the emitter region in the area under consideration allows to take into account non-Maxwell character of electron velocity distribution on the boundary between emitter and base.

References

1.S.Kartashov, V.Ryzhii, G.Khrenov "Investigation of the collector structure influence on the high-frequency characteristics of the AlGaAs/GaAs heterostructure bipolar transistor" Sov.Microelectronics 1992, V.21

2.G.Khrenov, V.Ryzhii, S.Kartashov "Monte Carlo simulation of AlGaAs/GaAs HBTs with different collector structure' Proc. of Intern.Conf.of Microelectronics, Warsaw, Poland, 1992.

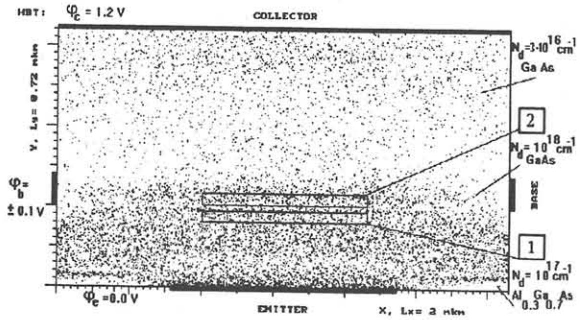

Fig.1

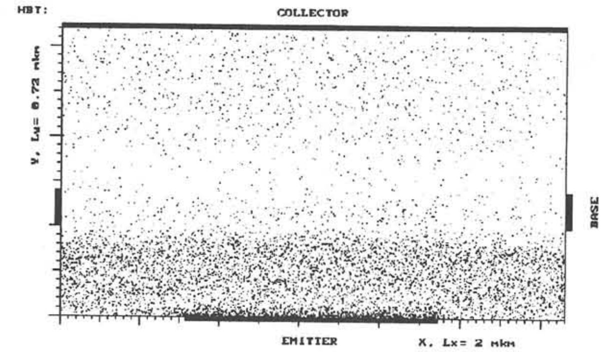

Fig.2

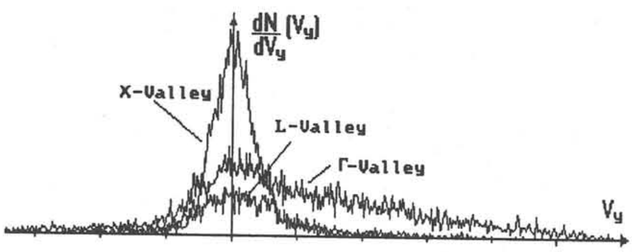

Fig.3

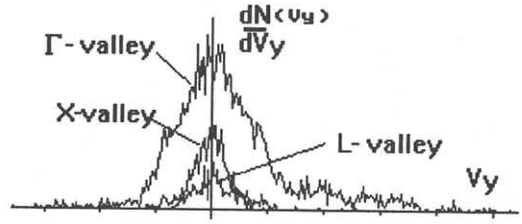

Fig.4

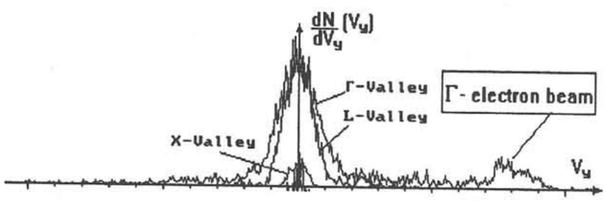

Fig.5

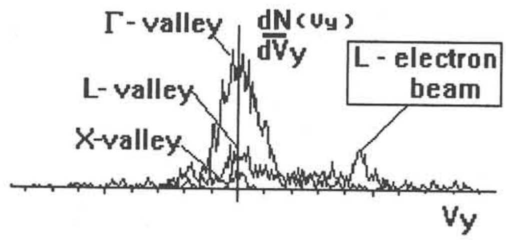

Fig.6

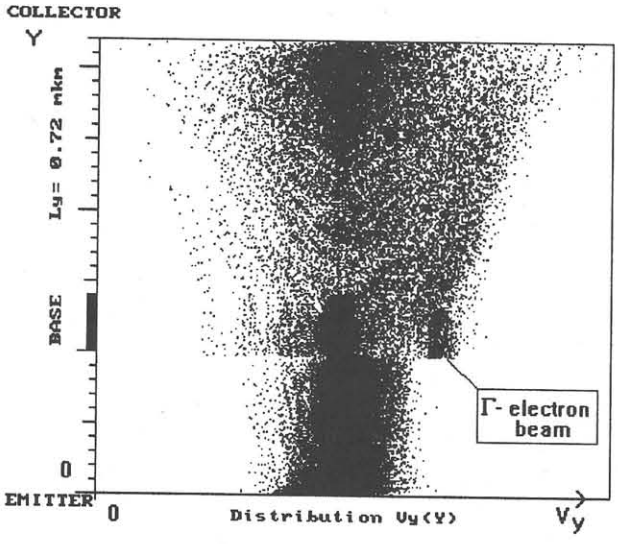

Fig.7

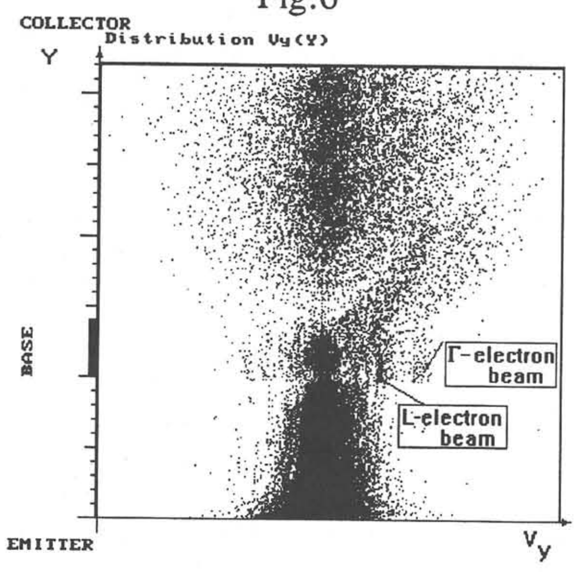

Fig.8