Particle Simulation of Relaxation of Energy and Momentum in GaAs MESFETs

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We have observed the relaxation of energy and momentum GaAs MESFET with 0.5 micron gate length by means of Monte Carlo particle simulation. The result is compared with ones obtained by using the steady state data in a single-particle Monte Carlo simulation for an uniform electric-field case.

RELAXATION OF ENERGY AND MOMENTUM IN THE DEVICE

The drain voltage in Fig.1 is suddenly changed from 1V to 0V in order to simulate the relaxation process. Fig.2 shows the time response of energy and population of Γ-valley. The time response at the two points with almost same energy in the ON state are shown together in the figure. The difference between the relaxation times for the solid and dotted lines is not so large. Fig.3 shows the time response of momentum at the source side of the energy peak. The circles in Fig.4 shows the relaxation times. The solid line in Fig.4 shows the same results obtained from the steady state data in a single-particle Monte Carlo simulation for an uniform electric-field case. Although the circles are fairly scattered, it has been found that the circles are fairly less than the solid line for energy greater than 0.25 eV.

TRANSPORT EQUATIONS WITH RELAXATION TIMES OF ENERGY AND MOMENTUM

Using the transport equations with the relaxation times, T_p and T_ε are able to be evaluated from the steady state distributions of electric field, average energy, carrer concentration and average velocity in the ON-state, if the influence of the boundaries of the device is negligible. Fig.5 shows the results on T_p and T_ε obtained by using the data on the drain side of the energy peak. Although the present results are fairly scattered, the closed circles for T_ε agree with the solid line. On the other hand, the open circles for T_p are considerably small compared with the dotted line. It is obvious that the thermal equilibrium condition in the drain electrode is responsible for the small T_p. The influence of the drain electrode on the T_ε is not so large. The situation changes drastically in the source side of the energy peak, namely underneath the gate. Fig.6 shows the values for α_ε and α_p which are defined by $\alpha_\varepsilon = 1-5/3\times(\mathbb{W}\cdot\nabla\varepsilon)/(\mathbb{W}\cdot\mathbb{F})$, $\alpha_p = 1-2/3(\partial\varepsilon/\partial z+(\varepsilon/n)\partial n/\partial z)/(q\cdot Fz)$, respectively. It is obvious that the negative values of them are physicaly meaningless. This means that the equations underestimate ε and overestimate V underneath the gate in comparison with the multi-particles simulator. Consequently it is considered that the equations are not valid or less accurate in the region of near ballistic transports. In Fig.7 the difference between the thermal kinetic energy (dotted line) and the total energy (solid line) is the kinetic energy of electron drift. Neglecting the kinetic energy of electron drift underneath the gate may cause further inaccuracy.

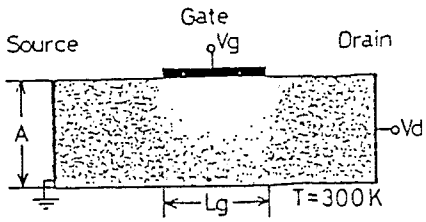

Fig.1 A schenatic device structure of GaAs MESFET and particles distribution of the ON steady state : Lg=0.5μm, A=0.1μm, Vg=-0.3V, T=300K, $n=10^{17}cm^{-3}$.

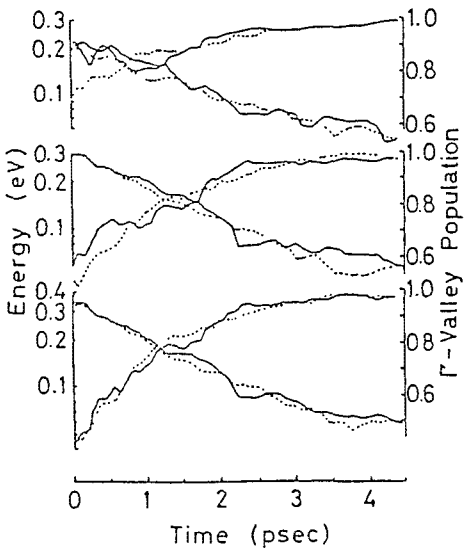

Fig.2 Response of energy and population of Γ-valley at six points in the channel. Solid and dotted lines denote them at the source and drain sides of the energy peak, respectively.

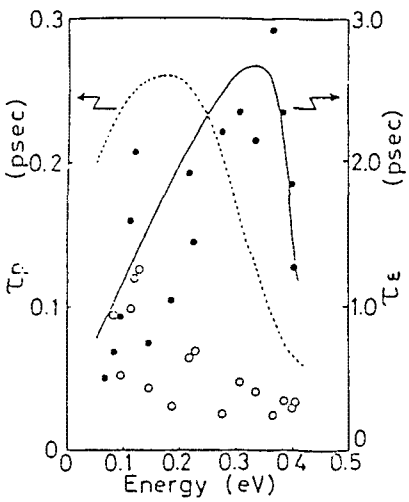

Fig.5 Relaxation times of energy (closed circles) and momentum (open circles) calculated from the equations proposed by Cook and Frey using the data of the steady state in the device. Solid and dotted lines show the energy and momentum relaxation times, respectively, obtained by using the single-particle Monte-Carlo simulation for an uniform electric-field case.

REFERENCE
Cook,R. and Frey,J.,IEEE Trans.Electron Devices,Vol. ED-29,No.6(1982)970

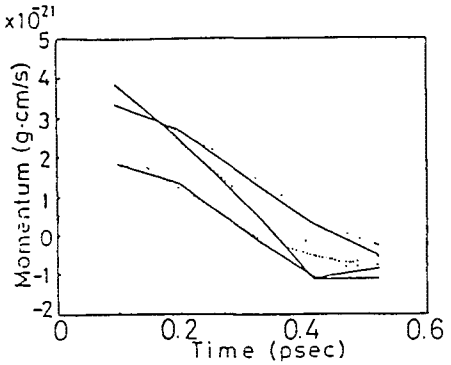

Fig.3 Response of momentum (solid line) and the solution (dotted line) of the differential equation $dP/dt=m^*V-P/\tau p$ at τp=constant.

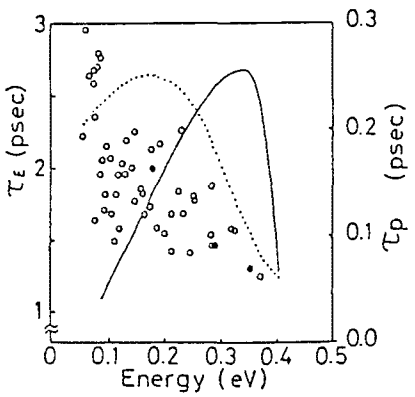

Fig.4 Relaxation times of energy (open circles) and momentum (closed circles) evaluated from the time responses. Solid and dotted lines show the relaxation times of energy and momentum, respectively, obtained by using the single-particle Monte-Carlo simulation for an uniform electric-field case.

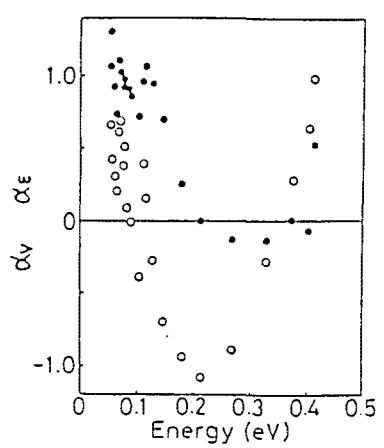

Fig.6 α_ε and α_p defined by $\alpha_\varepsilon=1-5/3(V\cdot\nabla\varepsilon)/(V\cdot F)$, $\alpha_p=1-2/3(\partial\varepsilon/\partial z+(\varepsilon/n)\partial n/\partial z)/(q\cdot Fz)$, respectively.

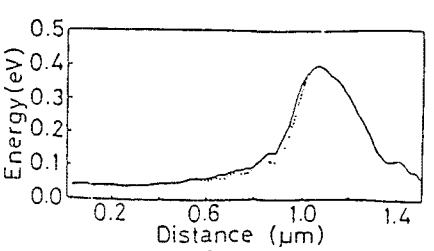

Fig.7 The distribution of the thermal kinetic energy (dotted line) and the total energy (solid line).