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Evaluating Momentum and Energy Relaxation Times of Electrons, Based on Distribution Functions

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A hydro-dynamic model considering carrier energy transport will be utilized for a next generation device simulator because of its high accuracy and practicality. In a hydro-dynamic model, momentum and energy relaxation times are assumed to be functions of only average carrier energy in steady state, for simplicity. Although these parameters are critical for determining carrier velocity and energy in semiconductor devices, this assumption is not yet verified. This work examines these relaxation times of electrons in silicon by evaluating transient distribution functions.

Momentum and energy relaxation times associated with scattering terms can be defined as follows,

$$\left(\frac{\partial v}{\partial t}\right)_{SCAT.} = -\int \frac{\hbar k_z}{m^*} \frac{f(k,t)}{\tau(k)} d^3k \equiv -\frac{v}{\tau_p(t)} \quad \cdots (1)$$

$$\left(\frac{\partial \varepsilon}{\partial t}\right)_{SCAT.} = -\int \varepsilon(k) \frac{f(k,t)}{\tau(k)} d^3k + \iint \varepsilon(k) P(k',k) f(k',t) d^3k' d^3k \equiv -\frac{\varepsilon - \varepsilon_0}{\tau_e(t)} \quad (2)$$

Here, $f(k,t)$ is distribution function and $P(k,k')$ is scattering probability. Since the transient distribution function can be calculated by using a population transaction (PT) method[1], relaxation times are estimated from Eqs. 1 and 2.

Time dependent relaxation times of electrons in bulk silicon were calculated under various electric field strength conditions. Both turn-on (0->E) and turn-off (E->0) cases were investigated.

Calculated relaxation times under the turn-on conditions are plotted in Fig. 1 where horizontal axis corresponds to average electron energy, instead of time. Both momentum and energy relaxation times were found to be independent of applied field strength ie. they align on each universal curve. Relaxation times can be described as a function of average energy in good approximation. On the other hand, under the turn-off conditions, universality is broken as shown in Fig. 2.

Electron distributions in k-space were analyzed to study an origin of the universality. As shown in Fig. 3, the distribution profile in non-steady state under the turn-on conditions is characterized by "lucky-drift (LD)" component. The LD component travels for distance, which is proportional to field strength and time elapsed. In Fig. 4, the ratios of scattering terms (Eqs. 1 and 2) calculated by using LD component to those calculated by using total distribution functions, are plotted. Regardless of applied field strengths, the ratios are almost unity for all over the energy range except near the steady state. This means scattering phenomena would be characterized mostly by the LD component. Since the LD component is independent of field strength and time, it would be the origin of the universality for relaxation times under turn-on conditions. On the other hand, under turn-off conditions, no LD component exist, which result in non-universality.

Universality for relaxation times holds only when the electric field is turned on. Relaxation time approximation should be re-examined when being used in a hydro-dynamic model

[1]T. Iizuka and M. Fukuma, Solid State Electronics, Jan. 1990

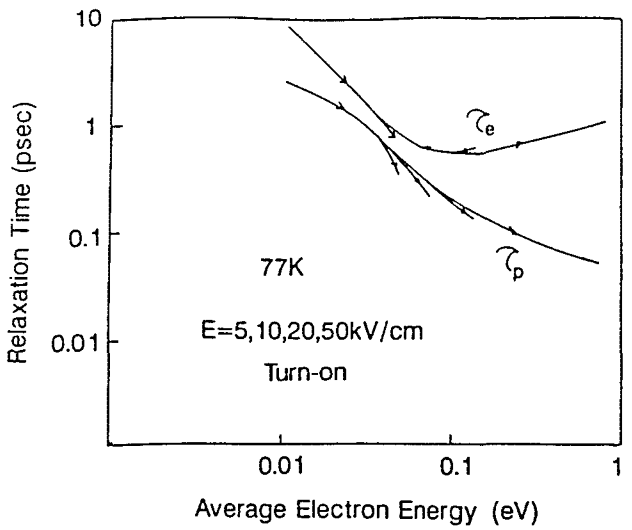

Fig. 1 Average energy dependent relaxation times when E-field is turned on.
Regardless of applied E-field strength, both momentum and energy relaxation times align on each universal curve.

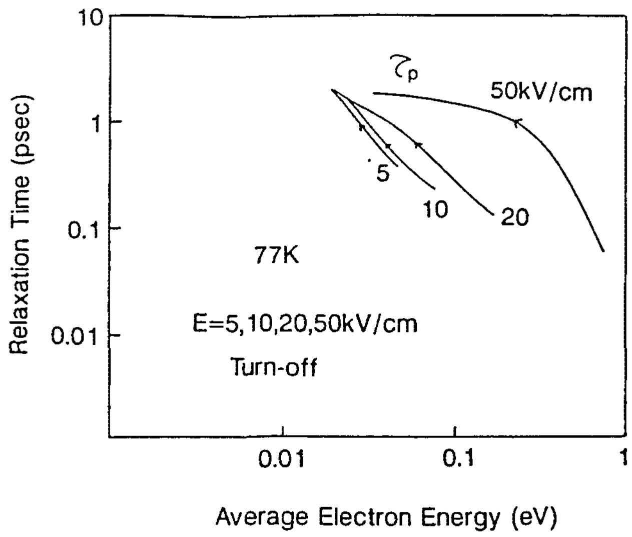

Fig. 2 Average energy dependent momentum relaxation times when E-field is turned off.
Universality does not hold not only for momentum but also for energy relaxation times.

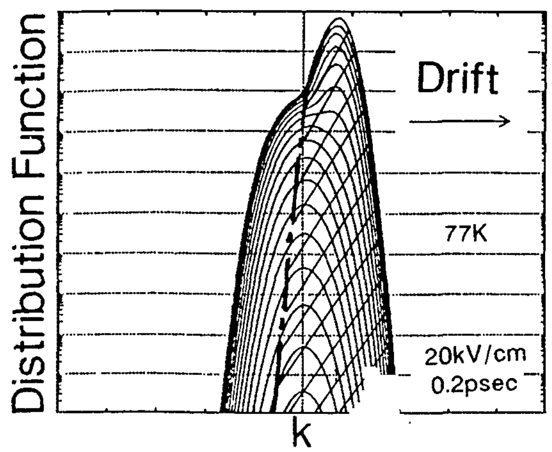

Fig. 3 Distribution function profile in non steady state under the turn-on condition.
The hatched area corresponds to the lucky drift component which is the origin of the universality.

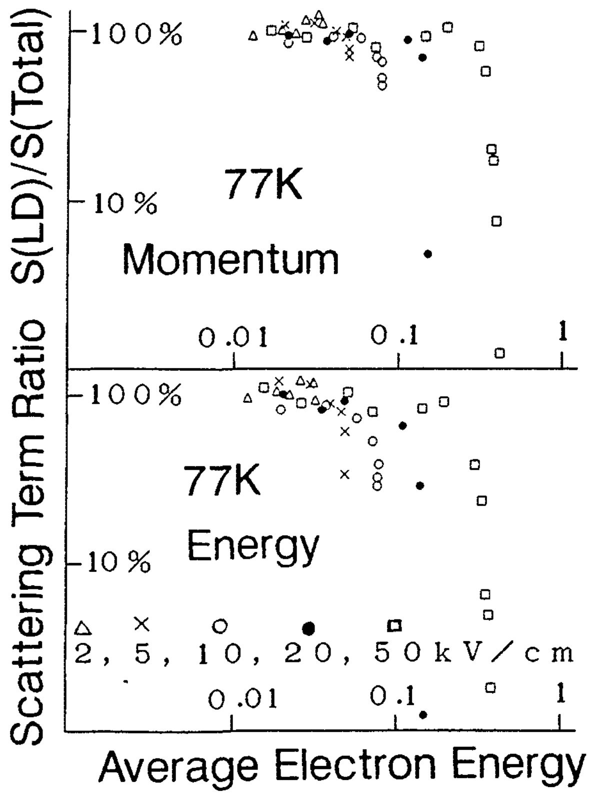

Fig. 4 The ratios of scattering terms calculated from LD components to those calculated from total distribution functions.