2.3. Relaxation Time

-2.3.1 Relaxation time associated with 0th momentum (minority carrier life time)
-2.3.2 Relaxation time associated with 1st momentum (mobility)
-2.3.3. Relaxation time associated with 2nd momentum(energy relaxation time)

Goal;

To understand the relaxation time constants characterizing the each moment equation in the HD framework.

1. Minority carrier life time

Objective To understand the generation and recombination model to describe the 'time increase rate' of n and p.
To understand the concept of the 'minority carrier life time' .

A. Model for generation and recombination

-The increase rate of n, p in the semiconductor can be written as,

$$\frac{\partial n}{\partial t} = -\frac{\partial}{\partial x_j}(n\langle v_j\rangle) + \frac{1}{4\pi^3}\int \left.\frac{\partial f}{\partial t}\right)_{coll} d^3\underline{k} \qquad (2a)$$

where $\frac{1}{4\pi^3}\int \left.\frac{\partial f}{\partial t}\right)_{coll} d^3\underline{k}$ term is only nonzero when $\left.\frac{\partial f}{\partial t}\right)_{coll}$ term is associated with the 'intervalley scattering'.

- $\frac{1}{4\pi^3}\int \left.\frac{\partial f}{\partial t}\right)_{coll} d^3\underline{k}$ term includes all the possible physical mechanisms contributing to the 'intervalley scattering'.
They are generation and recombination through traps, tunneling and enhancement of the tunneling by traps and the impact ionization.

- General equation including $\frac{1}{4\pi^3}\int \left.\frac{\partial f}{\partial t}\right)_{coll} d^3\underline{k}$ is

Gth : generation rate
GL: generation rate due to illumination
Gii: generation rate due to impact ionization
GT: Generation and recombination of n and p through traps;
Rn, Rp, Gn, Gp

- In the chapter, only the Rn, Rp, Gn, Gp will be considered.

Rn: Electron Capture rate by the trap
= Cn *n* Nt(1-ft)
Rp; Hole capture rate by the trap
= Cp* p* Nt ft
Gn: Electron Generation rate from the trap
= en * Nt * ft
Gp: Hole Generation rate from the trap
= ep *Nt*(1-ft)

----(1)

where Cn, Cp: Capture cross section of the traps
en, ep : emission probability of electrons and holes.

B. SRH (Shockley Read Hall) model for generation and recombination through traps

In the uniform sample ;

dn/dt = Gn - Rn + GL

dp/dt = Gp - Rp + GL- -

d{Nt *ft} /dt = Rn + Gp - Gn- Rp

and the Poisson Effect

- = q(p - n + Nd+ - Na- + NTd(1-ft))

NTd; Concentration of the net donor like states

f_t ; occupancy probability of the trap with the energy level in E_t.

In the steady state where d{Nt*ft} =0,

d{Nt *ft} /dt = Rn + Gp - Gn- Rp =0,

so that

Gn -Rn = Gp -Rp -----(2)

-Now the trick to arrive at the SRH model is that first we find the en and ep in the thermal equilibrium(where $f_t = \frac{1}{1 + e^{(Ef - Et)/kT}}$) and use the en and epp values in the non equilibrium as well.

If you plug the (2) to (1) using the en and ep values obtained in thermal equilibrium nd solve for ft(the occupation probability of electrons in the trap),

ft =

Also, the general equation for U can be obtained as,

U(net recombination rate in the steady state)

= --------(3)

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1. When Cn = Cp,

-----(4)

2. The driving force of net U is np - n^2_{i}.

<reading material> Grove, pp 127-146.

C. The Minority carrier life time

In the case when the concentration of the minority carrier is much smaller than the majority carrier in non equilibrium case (n >>p c+³ p in the n type : the case is called the 'low level injection'),

U can be written as,

U C (p - p_o)/ ¯p.

Here ¯p. is called the minority carrier life time.

2. Momentum relaxation time

In the derivation of the 1st moment of the BTE, the increase rate of the momentum due to scattering can be written as,

Let $\phi = mv_i$

$$\frac{1}{4\pi^3}\int\frac{\partial f}{\partial t}\bigg)_{coll} mvid^3\underline{k} = -\frac{nV_j}{\tau_m} \qquad (5)$$

where ¯rr is the momentum relaxation time.

Averge velocity in j direction can be written as the function of the electric field (drift term) and the gradient of n and Tn(electron temperature) in the 'tensor form'.

$$V_i = -\frac{q\tau}{\langle m^* \rangle_{ij}}\varepsilon_j - \frac{\tau}{n\langle m^* \rangle_{ij}}\frac{\partial}{\partial x_j}(nk_B T_{ij})$$
$$= -\mu_{ij}\varepsilon_j - \frac{\mu_{ij}}{qn}\frac{\partial}{\partial x_j}(nk_B T_{ij})$$

- Meaning of ¯$_{rr}$.

Consider the continuity equaion for momentum in the uniform sample with -Ex is applied,

d(mVx)/dt = qE - mVx)/¯$_{rr}$.

In the steady state,

Vx0= (q¯$_{rr}$/m) E so that the mobility in the 'uniform field' is related with ¯$_{rr}$ as,

u = (q¯$_{rr}$/m).

If E =0 when t=0^{+},

Vx = Vx0 exp (-t/¯$_{rr}$) meaning that ¯$_{rr}$ is the parameter indicating how fast the average velocity returns to zero after the field is switched off.

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- ¯$_{rr}$ can be obtained as the function of electric field from the relationship between mobility and ¯$_{rr}$.

¯$_{rr}$ = (m/q) *u(E). Notice that u(E) is known from the measurements, we can safely find ¯$_{rr}$ vs. E relationship.

- However, the relationship is only valid for the steady state and the uniform case. For the case when E varies abruptly in space (and/or time), ¯$_{rr}$(so the mobility) is not only the function of E as obtained in the steady state and the uniform case. This phenomenon is called the 'nonlocal effect' for the carrier mobility.

*There are two approaches to handle this problem.
¯ rr (E), ¯ rr(Tn) and others to

See the more detailed discussion on this issue can be found from T. Grassera, 'Review of Hydrodynamic and Energy-Transport Models for Semiconductor Device Simulation,' PROCEEDINGS OF THE IEEE, VOL. 91, NO. 2, FEBRUARY 2003

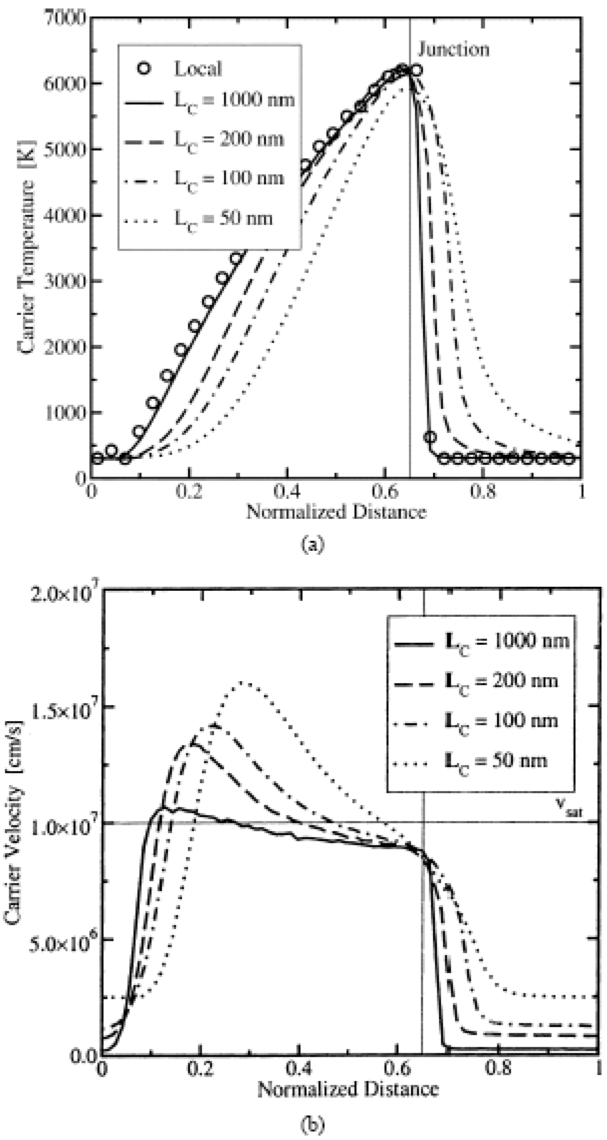

Fig. 1 (a) The carrier temperature of comparable n^+- n - n^+ structures with varying channel lengths where the spatial coordinates have been normalized to get an overlapping electric field. (b) The average carrier velocity where the velocity overshoot is caused by the nonlocality of the carrier temperature.

In the figure above, the 1D n+nn+ silicon bar is considered with Lc as the

length of n region to resemble the channel region of NMOSFET.
Notice that the electron temperature and the carrier velocity are much higher than the local counterpart.

C. Energy Relaxation time

In the 2nd of moment of the BTE,is

$$\frac{\partial(nW)}{\partial t} = -q\varepsilon_j F_j - \frac{\partial}{\partial x_j} S_j + \frac{1}{4\pi^3}\int \frac{\partial f}{\partial t}\Big)_{coll} E d^3\underline{k}$$

, 3nd term of RHS: energy loss by heating lattice (by way of generating phonon) can be written as

$$\frac{1}{4\pi^3}\int \frac{\partial f}{\partial t}\Big)_{coll} E d^3\underline{k} = -n(W - W0)/\bar{\ }_e$$

where ¯$_e$ is the 'energy relaxation time'.
In the uniform sample where E is constant in the space and time, electron energy can obtained from

q u E^2 = (W - W0)/¯$_e$.

¯$_e$ is usually know from the photo measurement or the Monte C미개 simulation. ¯$_e$ in silicon is in the order of 0.4e-12 second.

- The empirical relationship for the energy relaxation time as the function of carrier temperature can be found as,

$$\tau_w = \tau_{w,0} + \tau_{w,1} \times \exp\left[C_1 \times \left(\frac{T_n}{300\ \mathrm{K}} + C_0\right)^2 + C_2 \times \left(\frac{T_n}{300\ \mathrm{K}} + C_0\right) + C_3 \times \left(\frac{T_L}{300\ ]}\right.\right.$$

For the nonalloy material,

Material	$\tau_{w,0}$ [ps]	$\tau_{w,1}$ [ps]	C_0	C_1	C_2	C_3
Si	1.0	−0.538	0	0.0015	−0.09	0.17
Ge	0.26	1.49	0	−0.434	1.322	0
GaAs	0.48	0.025	0	−0.053	0.853	0.5
AlAs	0.17	0.025	61	−0.053	0.853	0.5
InAs	0.08	0.025	3	−0.053	0.853	0.5

For alloy material,

Material	$\tau_{w,0}$* [ps]	$\tau_{w,1}$ [ps]	C_0*	C_1	C_2	C_3
AlGaAs	−0.35	0.025	−61	−0.053	0.853	0.5
InGaAs	1.8	0.025	−34	−0.053	0.853	0.5

ref.

B. Gonzalez et.al, An energy relaxation time model for device simulation

[i]http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TY5-3XH3J36-M&_user=198559&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000013398&_version=1&_urlVersion=0&_userid=198559&md5=91d62178c6e79b320489925ebe7ad710

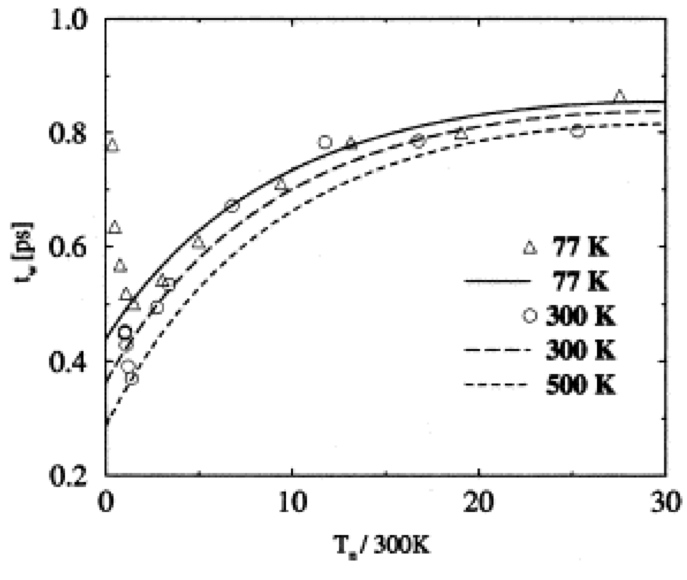

Fig. 1. Energy relaxation time as a function of electron temperature. Comparison of the model and MC data for Si at several lattice temperatures.