

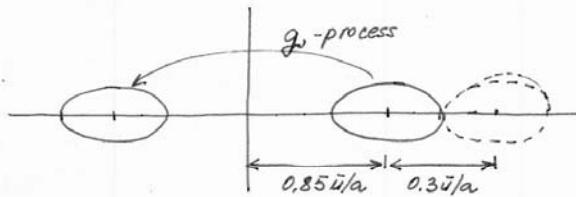
(E) INTERVALLEY SCATTERING :

Si : For Silicon, the six valleys are energetically equivalent and lie along the $\langle 100 \rangle$ direction, near the zone boundary. Two types of intervalley scattering are possible:

g-type process moves a carrier from a given valley to one on the opposite side of the same axis (for example from a valley along $\langle 100 \rangle$ to a valley along $\langle \bar{1}00 \rangle$ direction)

f-type process moves a carrier to one of the remaining valleys.

In both cases, intervalley scattering requires phonons with wavevectors near the zone boundary. Such phonons are called intervalley phonons. Note also that g-type process is an umklapp process and has a net phonon wavevector $0.3\bar{u}/a$. The wavevector involved in the f-process is on the order of $\sqrt{2} 0.85\bar{u}/a \approx 1.2\bar{u}/a$.



$$k - k' \pm q + G = 0 \Rightarrow k' = k \pm q + G = k - 1.7\bar{u}/a + 2\bar{u}/a = k + 0.3\bar{u}/a$$

GaAs : Intervalley scattering in GaAs is somewhat different because the valleys Γ , L and X are not energetically equivalent. For example, Γ valley is about 0.3 eV below the ellipsoidal L-valley located along $\langle 111 \rangle$ direction. Because carriers must acquire ≈ 0.3 eV of energy, intervalley scattering does not occur unless a high electric field is present to accelerate the carriers to high energy. For electrons in GaAs, besides Γ -L, L-L, L-X and X-X scattering is possible.

The mathematical treatment of intervalley scattering is done in a very simple, phenomenological way. The interaction potential is defined as:

$$H_{ep} = Dif U(r, t)$$

where Dif , the intervalley deformation potential, characterizes the strength of the scattering from the initial valley "i" to the final valley "j". This interaction potential has electronic component : $H_{ev} = Dif$

- Therefore, the matrix element squared for intervalley scattering is:

$$|M(\vec{k}, \vec{q})|^2 = \frac{\hbar}{2\mu V w_0} D_{if}^2 \left(N_0 + \frac{1}{2} \mp \frac{1}{2} \right) \delta(\vec{k} - \vec{k}' \pm \vec{q} + \vec{G})$$



→ The matrix element is independent of \vec{q} , which means that intervalley scattering is ISOTROPIC scattering process ($\frac{1}{2} \mp \frac{1}{2}$)

→ The crystal momentum conservation (for normal processes) requires: $\pm \vec{q} = \vec{k}' - \vec{k} \approx \Delta \vec{k}$

where $\Delta \vec{k}$ is the vector joining the two valley minima. Since $\Delta \vec{k}$ is large compared to the additional wavevector change due to phonon absorption or emission, we can say:

$$w_{\vec{q}} \approx w_{\Delta \vec{k}}$$

and the scattering is treated as non-polar optical phonon scattering with $w_0 = w_{\Delta \vec{k}}$.

- The total scattering rate out of initial state \vec{k} can be calculated using the previously derived result for constant matrix element. The energy conservation in the scattering process requires:

$$\pm \hbar w_0 + E_k + E_{ci} = E_{k'} + E_{cf} \Rightarrow E_{k'} = E_k \pm \hbar w_0 + E_{ci} - E_{cf}$$

↑ ↑
abs/emission potential energies $E_{k'} = E_k \pm \hbar w_0 - \underbrace{(E_{cf} - E_{ci})}_{\Delta E_{fi}}$

If the number of final valleys to which carrier scatters is Z_f , we have:

$$\frac{1}{I(\vec{k})} = \frac{\bar{n}}{\hbar} \frac{\hbar}{2\mu w_{if}} D_{if}^2 Z_f \left(N_{if} + \frac{1}{2} \mp \frac{1}{2} \right) \frac{1}{2} g_c (E_k \pm \hbar w_{if} - \Delta E_{fi})$$

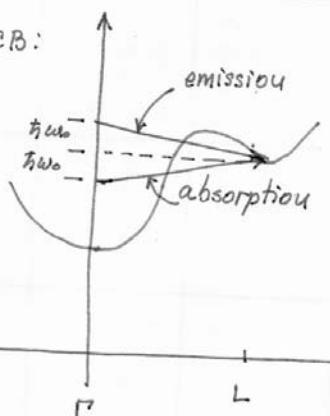
$\frac{1}{2}$ total DOS

where: Z_f = # of final valleys for scattering
 ΔE_{fi} = difference between the bottoms of the conduction bands in the final and the initial valley
 $(\Delta E_{fi} = 0 \text{ for equivalent intervalley scattering})$

To summarize:

$$\frac{1}{I(\vec{k})} = \frac{\bar{n} Z_f D_{if}^2}{2\mu w_{if}} \left[N_{if} g_c (E_k + \hbar w_{if} - \Delta E_{fi}) + (N_{if} + 1) g_c (E_k - \hbar w_{if} - \Delta E_{fi}) \right]$$

GaAs CB:



The intervalley scattering
is important in elucidating
the NDR observed in the
so-called Gunn effect

(GaAs, InP nonequivalent
intervalley scattering)

Si CB:

