CHAPTER 3

ELECTRON IRRADIATION EFFECTS
Electron irradiation effects in GaAs thin wafers.

Introduction:

The effects produced in crystalline solids by bombardment with radiation able to displace atoms from their normal crystals lattices are of increasing technological importance. Wigner (1964) realised prior to the construction of the first nuclear reactor that the intense bombardment suffered by the structural materials would lead to the deleterious changes in their physical properties. The early work on graphite used as a reactor moderator showed that very large physical changes do occur. Since then the effects of the irradiation have been investigated in many solids at both a fundamental and technological level using all types of incident nuclear radiations viz -rays, electrons, protons, \( \times \)-particles etc. The studies of the radiation induced defects in the solids has now become the active area of interest for the researchers. The radiation damage caused by the higher energy particles is obviously a function of their energy. As far as \( \gamma \)-rays are concerned, they produce most damage as simple displacements in the form of vacancies and interstitials.

The study of the electron irradiated displacements is considered to be easier in view of the easy availability of the electron source in the laboratory. Further electron irradiation has the additional advantage that it results mainly in intrinsic point defects which are readily annealable. However, the major advantage of using the standard source is that other radiations like protons and \( \times \) particles can be easily
converted into equivalent fluences using simple equivalence laws (Solar radiation Handbook, 1982). Besides this, the standard value of the energy fixed in the case of electrons is 1 MEV, which enables the easy theoretical computation of the numerous parameters undergoing changes as a result of the electron irradiation. Moreover, the energy levels introduced in the electron-irradiated material when studied at 1 MEV fluences are almost known from various experimental measurements.

**Damage due to Electrons**

Energetic particles with energies ≥ 1 MEV are able to produce the displacements by direct interaction through the Coulomb potential with the nuclei of the solids. Electrons of this energy must be treated using relativistic mechanics to describe their motion. The nuclear masses are so much greater than that of the electrons that the collision essentially alters only the direction of the electron momentum. If the electron is deflected through an angle \( \theta \) in the centre of mass coordinate system (which because of the large mass ratio essentially coincides with the laboratory system of coordinates) by interaction with a particular nucleus, then the energy transferred to the nucleus is

\[
T = \frac{2p^2}{\mu} \sin^2 \frac{\theta}{2} \quad \text{<3.1>}
\]

\[
= \frac{2me}{M} \left( E + \frac{1}{2m_e c^2} \right) E \sin^2 \frac{\theta}{2}
\]

where \( p \) is the electron momentum, \( m_e \) the electron mass, \( c \) the velocity of light and \( M \) the nuclear mass. \( E \) is the kinetic energy of the electron given by

\[
E = m_e c^2 \left[ \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} - 1 \right] \quad \text{<3.2>}
\]
Following the Seitz and Koehler (1956) method, we rewrite (3.1) as

\[ T = T_m \sin^2 \theta \]  

where \( T_m \) is the maximum possible energy which could be transferred to the nucleus by an electron of energy \( E \). For practical purposes the equation for \( T_m \) may be put as

\[ A T_m \text{(ev)} = 560.8 x (x^2) \]  

where

\[ x = \frac{E}{me^2} \]

Similarly if we define \( E_d \) as the minimum electron energy to produce displacements, then this is given by

\[ E_d = 2 \left( \frac{m_0}{m} \right) \frac{E_t}{me^2} (E_t + 2me^2) \]

or in practical units of ev

\[ E_d \text{(ev)} = \frac{E_t (E_t + 1.012 \times 10^6)}{470 \times 10^6} \]

In order to calculate the number of atoms displaced by an electron bombardment, we require the scattering crosssection of the nucleus for the incident electrons. The electron nucleus interaction is through the Coloumb potential and for such high electron energies, the atomic electrons may be neglected. The Coloumb interaction produces Rutherford scattering of the electrons. The differential crosssection for the Rutherford scattering of the relativistic electrons is according to Mckinley and Feshbach (1948)

\[ d\sigma(B) = \beta^2 \csc^2 \theta \left[ \sin^2 \theta + \frac{K \alpha \beta \sin \theta \left( 1 - \sin \theta \right)}{4 \alpha \beta \cos \theta \csc^2 \theta} \right] \]

where \( \alpha = \frac{e^2}{4\pi \epsilon_0} \), \( \beta = \frac{v}{c} \) and \( \theta = \frac{2 \gamma e^2}{mc^2} \).

We are interested however in the differential crosssection for
the energy transfer and equation (3.9) may be rewritten in terms of the energy transferred \( T \) using

\[
T = T_{\text{m}} \sin^2 \theta/2 \quad \text{--- (3.10)}
\]

\[
\phi = b' = \frac{b}{\delta}
\]

where \( \delta = (1 - \beta^2)^{-1/2} \) and \( \delta \) yields

\[
\sigma \in (T) = \frac{\pi \delta^2}{4} \frac{T_{\text{m}}}{T} \left\{ 1 - \beta^2 \frac{T}{T_{\text{m}}} + \frac{\alpha \beta}{T_{\text{m}}} \left[ \left( \frac{T}{T_{\text{m}}} \right)^{1/2} - \left( \frac{T}{T_{\text{m}}} \right) \right] \right\} \, dT \quad \text{--- (3.11)}
\]

The crosssection for the production of primary displacements is obtained by integrating equation (3.10) over \( T \), from \( E_d \) to \( T_{\text{m}} \)

\[
\sigma_d = \int_{T = E_d}^{T = T_{\text{m}}} \sigma \in (T) \, dT \quad \text{--- (3.12)}
\]

where \( E_d \) is the minimum energy required for the displacement and \( T_{\text{m}} \) is the maximum energy transferred by the electron to the atom. Thus we obtain

\[
\sigma_d = \frac{\pi \delta^2}{4} \left[ \left( \frac{T_{\text{m}}}{E_d} - 1 \right) - \beta^2 \ln \left( \frac{T_{\text{m}}}{E_d} \right) + \frac{\alpha \beta}{T_{\text{m}}} \left[ \left( \frac{T_{\text{m}}}{E_d} \right)^{1/2} - 1 \right] \right] \quad \text{--- (3.13)}
\]

Seitz and Koehler (1956) show that this expression has the following properties. When \( T_{\text{m}} \) is only slightly greater than \( E_d \) \((T_{\text{m}} \gg E_d)\) so that only atoms displaced are the primary atoms, then this expression reduces to

\[
\sigma_d \sim \pi \beta^2 \left( \frac{e^2}{m_{\text{e}} c^2} \right) \frac{1}{\beta^4 \delta^2} \left( \frac{T_{\text{m}}}{E_d} - 1 \right) \quad \text{--- (3.14)}
\]

In the equation (3.14) we may write

\[
\frac{\pi \delta^2}{4} = \pi \beta^2 \left( \frac{e^2}{m_{\text{e}} c^2} \right)^2 \frac{1}{\beta^4 \delta^2} \quad \text{--- (3.15)}
\]

\[
= 2.450 \times 10^2 S \frac{Z^2}{\beta \delta^2}
\]
Experimentally electron bombardment is used because of the close control, which is possible because of the electron energy. The precise control of the energy also allows the control of the type of the damage produced. If \( \frac{T_m}{E_d} \) is maintained only slightly above unity, each collision displacing an atom produces only the primary displacements and the equation (3.13) may be used.

If the bombarding electron energies are in the range

\[
M c^2 >> E >> m_e c^2
\]

then the displacement crosssection tends to a saturation level given by

\[
\sigma_d \sim \frac{\pi \hbar^2}{4} \left( \frac{T_m}{E_d} \right) = \frac{8 \pi \hbar^2 a R_i^2}{N c^2 E_d}
\]

\[
= 5.55 \times \left( \frac{Z^2}{A} \right) \times 10^{-14} \text{ cm}^2
\]

As usual in this equation, \( R_H \) is the Rydberg energy and \( a \) is the Bohr radius.

In both the aforementioned cases the displacement crosssection which may be either be primary and total, the number of defects produced by one electron in passing through a sample of thickness \( t \) (Vook, 1968) is

\[
N_d = \tilde{c} \tau N = N_0 \int_{E_{in}}^{E_0} \frac{\sigma(E, E_d)}{-dE/dz} \ dE
\]

Where \( N_0 \) is the atom density, \( E_0 \) is the initial energy of the electron, and \( -dE/dz \) is the average stopping power of the sample. The lower limit of the integral is determined by two distinct cases stated here as under.

**Case 1:** When the thickness of the material is lesser than the range
of the incident electrons R. In this case the electron escapes the
length of the material without being absorbed in it thus causing only
the uniform damage and the energy of the escaping electron will be reduced.
This will be the lower limit of the integral (3.18).

Case 2: When the thickness of the material under study is larger than
the incident electron range R. In this case the electrons get
completely absorbed in the material, till its incident energy is
reduced to almost zero because now the electron faces the problem of
travelling much larger distances than in the first case before being
brought to rest in the material itself. However the electron starting
with $E_0$ attains the value of $E_{\text{th}}$ after travelling some distance in
the material. This threshold energy is necessary for producing primary
displacements. However, below the value of $E_{\text{th}}$ the production of $\beta$-
rays results, which can cause damage to the material in its own way. As
we are interested in studying the defects caused as a result of the
energetic electrons, the lower limit in the integral (3.18) is $E_{\text{th}}$.
That is there is no damage due to the electrons, when the energy falls
below $E_{\text{th}}$. In the present programme multiple scattering has not been
considered due to two reasons (1) the sample is quite thin in
comparison to the electron range (multiple scattering usually occurs at
the end of the electron track). (2) Multiple scattering normally
occurs in case of the secondary and territory electrons which we have
not taken into consideration.

Therefore in order to calculate $N_d$
one should compute $\sigma_d(E,E_d)$ (displacement crosssection) and $-\frac{dE}{dx}$
(stopping power).
3.2.1 Computation of $\sigma_d(E, E_d)$

The displacement cross section can be computed from the equation

$$
\sigma_d = \frac{\kappa_0^2}{q} \left( \frac{T_m}{E_d} - 1 \right) - \beta^2 \ln \left( \frac{T_m}{E_d} \right) + \frac{\kappa_0 \beta}{2} \left( \frac{T_m}{E_d} \right)^{1/2} - \frac{1}{2} \left( \frac{T_m}{E_d} \right) \ln \left( \frac{T_m}{E_d} \right) \frac{\kappa_0}{q} \beta
$$

Where \( T_m \) is obtained from

$$
T_m = \frac{5.60 \times \varepsilon (\varepsilon + 1)}{A} \tag{3.19}
$$

3.2.2 Computation of energy loss (\( \frac{dE}{dx} \))

Energy loss by the electrons also known as the stopping power can be calculated from Bethe and Ashkin (1953) modified by Den and Holmes (1959) for the relativistic treatment.

$$
-\frac{dE}{dx} = \frac{2 \pi \kappa_0 e^2 \varepsilon^2}{m_e c^2 \beta} \left\{ \ln \left[ \frac{m e c^2 \beta^2 E}{2 I (1-\beta^2)} \right] - \left[ 2 (1-\beta^2)^{1/2} - 1 + \beta^2 \right] \varepsilon \right\}
$$

Where \( I \) is the mean excitation potential of the atoms of the solid. Its value is known mostly for the elements and for some compounds. However Stephense et al. (1982) have compiled the data for a number of elements and compounds. According to them, \( I \) for a compound can be calculated by using the equation.

$$
\langle I \rangle = \exp \left\{ \left[ \sum \frac{w_j \left[ Z_j^2 \right]}{A_j} \ln Z_j \right] / \langle Z^2 \rangle \right\} \tag{3.21}
$$

Where \( \langle Z^2 \rangle = \sum \frac{w_j Z_j^2}{A_j} \)

Where \( w_j, Z_j, A_j \) are the fraction by weight, atomic number.
atomic weight and the mean excitation energy respectively of the constituent. By using the numerical values of $Z_{Ga}$ and $Z_{As}$ etc., the value of $I$ as calculated turns out to be $384.9 \text{eV}$.

3.3 Displacement effects:

The defect density ($N_d$) calculated from equation (3.18) gives a measure of the total number of displaced atoms in a material due to the passage of electrons. This defect density arises due to the displacement of the atoms from a crystal lattice. However, in case of elemental semiconductors like silicon, one can easily say that most of the radiation induced defects are produced due to the displacement of the silicon atom, whereas in the case of compound semiconductors like GaAs, nothing concrete can be said about the displacement of a particular atom such as Ga or As. It may result on account of the displacement of either a Ga atom or an As atom. Therefore computation of the defect density does not provide us any clue regarding the displacement of either of the two atoms i.e. Ga and As from its crystal lattice. However, it has been observed experimentally that 1 Mev electrons produce only Ga vacancies (Mooney et al., 1980).

Permanent damage in the semiconductors like GaAs is the result of the displacement of Ga and As atoms from their lattice also caused by the electrons. These displacements produce stable defects that result in the changes in the electronic, mechanical and thermal properties. In case of pure silicon only two types of defects namely a vacancy and an interstitial are produced. However, in sharp contrast to the defects produced in silicon, the highly energetic electrons cause considerable lattice damage not only in the form of
vacancy, interstials and impurity complexes but antisites like $Ga_A^{+}, As^+Ga^-$ and divacancies like $V_{Ga}, V_{As}^-$. These multiple defects cause a cumulative degradation in the structural, electrical and optical properties of GaAs. As each defects produces one energy level in the bandgap, there will be a number of different defects in the form of degradation in the minority carrier lifetime, carrier removal rate etc (Loualiche et al., 1982). For a energy level lying near $E_{c}$ (middle of the gap) the effect on physical and electronic properties is maximum. If one assumed that each displacement contributes to one energy level in the bandgap and each level removes one charge carrier, one can calculate the defect density and also the carrier removal rate using the incident radiation flux. A number of energy levels are introduced in the electron irradiated n-GaAs.

Table 3.1 shows the values of capture crosssection for holes and electrons corresponding to different energy levels identified in case of electron irradiated n-GaAs material.

3.4 Influence on physical/electronic properties.

Irradiation of the solid material by fast moving electrons produces deep energy levels, which consequently reduce the conductivity, carrier concentration and mobility. However the conductivity is doubly reduced as can be seen from the equation $\sigma = n e \mu$ showing its dependence on both $n$ and $\mu$. However it has been experimentally observed that influence of radiation on mobility is not significant in comparision to its effect on carrier concentration. Besides the theoretical computations of these parameters because of the defects produced cannot be performed owing to the lack of any established theoretical model. Further the decrease in carrier concentration, minority carrier
life time /diffusion length have been computed. Also the irradiation of the MIS configuration results in the charge build up in the thin intervening oxide layer thus providing the accumulation of the fixed negative charges in the oxidised layer of n-GaAs material. However in this section we shall be discussing the effect of irradiation on two main radiation sensitive parameters namely the minority carrier life time $\gamma_e$ and minority carrier diffusion length $L_D$, which affect the performance of the electron devices particularly the solar cells. Let us first define these life times /diffusion lengths.

Radiation controlled life time ($\gamma_d$)

The defect density ($N_d$) introduced on account of the electron irradiation will change the life time of the minority carriers in n-type semiconductors. The radiation controlled life time is defined as the life time of the minority carriers having some radiation flux/energy dependence. It also depends on the carrier capture cross-section, carrier thermal velocity, and defect density in the material. It is abbreviated as $\gamma_d$ and is given by (Horne and Wilkinson, 1974)

$$\gamma_d = \frac{1}{N_d <p> ^{\gamma_d}} <3.23>$$

Where $\gamma_d$ is the capture cross-section of the holes because we are referring to the life time of the minority carriers in the n-GaAs material and $<p>$ is the thermal velocity of holes.

Effective lifetime ($\gamma_e$)

The minority carrier life times are inversely proportional to the
recombination rates of results due to the presence of various defects in the material. As the recombination rates add up, the net minority carrier lifetime would be obtained by adding the inverse of the lifetime results due to each defect. Therefore the effective lifetime would be given by

\[
\frac{1}{\gamma_{E}} = \frac{1}{\gamma_{0}} + \sum_{l=1}^{N_d} \frac{1}{\gamma_{dl}} \quad <3.24>
\]

Where \( \gamma_{dl} \) is the lifetime due to a particular level called the \( l \) level.

Minority carrier diffusion length (\( L_{E} \))

It is defined as the resultant minority carrier diffusion length after electron irradiation. It is abbreviated as \( L_{E} \) and has the units of \( \mu m\). It can be defined by using the equation (Conway et al., 1981)

\[
L_{E} = (D_{p} \gamma_{E})^{1/2} \quad <3.25>
\]

Where \( D_{p} \) is the diffusion coefficient for holes.

Minority carrier diffusion length damage coefficient (\( k_{L} \))

Starting with the expression (3.16) for minority carrier lifetime degradation constant \( k_{Y} \), one can arrive at the minority carrier diffusion length damage coefficient by making certain substitutions as shown here,

\[
\frac{1}{\gamma_{E}} - \frac{1}{\gamma_{0}} = k_{Y} \phi \quad <3.26>
\]

Where \( k_{Y} = k_{L} D_{p} \) and \( \gamma_{E} \).

Yields from (3.16), the expression for \( k_{L} \) as

\[
\frac{1}{L_{E}^{2}} - \frac{1}{L_{p0}^{2}} = k_{L} \phi \quad <3.27>
\]

Where \( k_{L} \) is the damage coefficient and in most of the experimental measurements this very parameter has been computed.
Computation of energy loss ($\frac{dE}{dx}$) and photoelectronic properties in electron irradiated GaAs.

Using equations (3.11) and (3.19) for energy loss $\frac{dE}{dx}$ and displacement crosssection $\sigma_d$, we have computed the defect density introduced on account of electron irradiation. Consequently the carrier removal rate $N_d$ has been determined. Subsequently the minority carrier lifetime and diffusion length have been computed.

Energy loss ($\frac{dE}{dx}$) calculations.

First of all we have computed the energy loss using electron energies in the range of (0.1-5) Mev. Energy loss values have been obtained in units of Kev / micron. Figure (3.1) shows the plot of energy loss suffered in the material as a function of the electron energy. As can be seen from the figure (3.1) that almost uniform energy loss is observed for values of $E$ lying between (0.5-5) Mev followed by a sharp rise in $dE$ value for $E=0.1$ Mev. It is well known that Bremstrahling mechanism become dominant at higher energies, so due to this reason the energy loss calculations have been restricted to the above described energy range only.

Displacement crosssection ($\sigma_d$)

This parameter has been computed in the same energy range as above. The scattering crosssection has been evaluated by using three different values of the displacement energy ($E_d$) as 9.45 (Von-Bauerlein, 1960), 17.5 (Pons et al., 1979), 17.5 (Grimshaw and...
FIG 3.1 PLOT OF ENERGY LOSS IN $\pi$-Ga-As AS A FUNCTION OF ELECTRON ENERGY
Variation of $\sigma_4$ with energy

1. $E_d = 9.45\, \text{eV}$
2. $E_d = 17.5\, \text{eV}$
3. $E_d = 25\, \text{eV}$
As there is no consensus on any one value of $E_d$ in GaAs, we have taken all the three possible values as have been reported in the literature from time to time.

Figure (3.1) shows the variation of $\frac{d\sigma}{dE}$ as the function of the electron energy. The calculated value of $\frac{d\sigma}{dE}$ at a typical electron energy of 1 Mev as seen from the plot comes out to be $1.6 \times 10^{-22}$ cm$^2$, which is quite close to that computed by Grimshaw and Banbury (1964). It is evident from the figure that the displacement cross-section rises steadily in the energy range ($0.1\) Mev and from $E=(2.5\) Mev, this value stays almost constant. It can also be seen from the figure (3.1) that $\frac{d\sigma}{dE}$ values show a remarkable decrease with the increase of the displacement energy values to 17.5 and 25 evs. This may be on account of the fact that $E_d$ and $E_g$ bear an inverse relation to each other.

If we assume that each displaced atom introduced one defect level in the forbidden energy bandgap, then we get the value of the carrier removal rate in units of cm. According to the theoretical estimates made by (Lang, 1977) the values of the carrier removal rate also found in case of 1 Mev electron irradiated GaAs have been found to lie in the range of $(0.5-5.0)$ cm$^{-1}$. This set of values vary well with $\frac{3.75}{4.39-0.61}$ cm$^{-1}$ and accommodates our three computed values of $(\frac{Nd}{\phi})_T$ at an electron energy of 1 Mev.

Radiation controlled lifetime ($\tau_{rd}$).

This parameter has been computed using the expression (3.13). For its computation we need values of defect density ($Nd$), capture cross-section for holes ($\sigma_p$) maintaining $\phi$ at a constant
Three different values of $\Phi$, i.e. 3.75, 1.34 and 0.61 cm have been introduced in our calculations corresponding to three different values of $E_d$ as 9.45, 17.5 and 25 respectively. The electron fluence range is chosen in this case to be $(10^{-5} - 10^{-8} \text{cm})$. We know that different energy levels as a result of 1MeV electron irradiation are introduced in the material under study and also that the capture crosssection ($\Sigma$) is dependent on the inclusion of such energy levels in the case of GaAs. It has been observed by different workers (Li et al., 1982, Li et al., 1983, Pons et al., 1980) that corresponding to each energy level identified in GaAs at 1MeV electron irradiation, there is a corresponding value of capture crosssection measured in units of cm. In particular (Pons et al., 1980) has identified the values of capture crosssection for holes in case of $n$-GaAs to lie in the range of $(10^{-5} - 10^{-6} \text{cm})$. In our present calculations employed for the computation of ($\tau_w$), we have selected three different values of ($\Sigma$) to be equal to $10^{-15}$, $5 \times 10^{-16}$ and $1 \times 10^{-16}$, which represent the average values of the capture crosssection for holes found in case of $n$-GaAs. For a level lying closer to the conduction band identified by (Li et al., 1982) the value of $\Sigma$ is found to be equal to $1 \times 10^{-16} \text{cm}^{-2}$.

Minority carrier lifetime after irradiation ($\tau_E$).

The computation of this parameter is based on the expression ($3.14$), which require the knowledge of the different values of the radiation controlled lifetime ($\tau_d$) and also a constant value of the minority carrier lifetime before irradiation ($\tau_0$). Various values of obtained earlier have been introduced in the equation for ($\tau_E$) to obtain its different values. A value has been taken to be equal to $3 \times 10^{-9}$ sec.
Final minority carrier diffusion length \( (L_E) \).

Using the well known formulae (3.25) for the computation of \( (L_E) \), we have obtained different values of \( (L_E) \) by introducing various values of \( \gamma_E \) as computed earlier. Keeping the values of diffusion coefficient for holes \( (D_p) \) to be a constant and equal to 3.885 as determined by Sze, 1969.

Figures (2.3-3.8) show the variation of \( \gamma_E \) and \( L_E \) as a function of the electron fluence. As can be seen from different plots, these values exhibit a sharp decrease particularly for higher electron fluences. Such a trend observed may be on account of the introduction of a very large number of radiation induced defect density \( (N_d) \). Further as a result of the influence of the radiation on the highly sensitive parameters i.e. effective minority carrier lifetime \( (\gamma_E) \) and final minority carrier diffusion length \( (L_E) \) it is obvious to expect a decreasing trend in the values of these two parameters, when plotted against the electron fluence. The reduced values of \( \gamma_E \) and \( L_E \) as a consequence of the electron irradiation brings about a considerable degradation of the photosensitive properties of the material under study.

Damage coefficient \( (k_L) \).

From the calculated values of \( (L_E) \) we have found the values of the minority carrier diffusion length damage coefficient from the equation (3.26) using the computed values of \( (L_E) \). This damage coefficient represents the degree of damage introduced into the sample as a result of its being irradiated by 1 Mev electrons. In case of these
$\gamma E \text{ in units of } 10^{-8} \text{ sec}$

1. $N_d = 0.61 \text{ Cm}^{-1}$
2. $N_d = 1.34 \text{ Cm}^{-1}$
3. $N_d = 3.75 \text{ Cm}^{-1}$

FIG. 3: Variation of $\gamma E$ with fluence.
FIG 3.4 VARIATION OF $T_E$ WITH FLUENCE

1. $N_d = 0.61 \text{ cm}^{-1}$
2. $N_d = 1.34 \text{ cm}^{-1}$
3. $N_d = 3.75 \text{ cm}^{-1}$

FOR $\phi = 5 \times 10^{-15}$

$T_E$ in units of $10^{-9}$ seconds

Fluence in $\text{cm}^{-2}$
FIG. 3:5 VARIATION OF $\gamma E$ WITH FLUENCE
FIG. 3.6 VARIATION OF \( L_E \) WITH FLUENCE

1. \( \frac{N_d}{\phi} = 0.61 \text{ Cm}^{-1} \)
2. \( \frac{N_d}{\phi} = 1.34 \text{ Cm}^{-1} \)
3. \( \frac{N_d}{\phi} = 3.75 \text{ Cm}^{-1} \)
FIG. 8.7 VARIATION OF $L_E$ WITH FLUENCE
1. $\frac{Nd}{\phi} = 0.61 \text{ cm}^{-1}$
2. $\frac{Nd}{\phi} = 1.34 \text{ cm}^{-1}$
3. $\frac{Nd}{\phi} = 3.75 \text{ cm}^{-1}$

For $\sigma_p = 5E-15 \text{ cm}^2$

**Fig. 3** Variation of LE with Fluence
calculations we have introduced the mean value of the minority carrier hole diffusion length \( (L_{p0}) \) before irradiation. Again there is no unique value of \( (L_{p0}) \) reported in the literature, so have taken its mean value to be 3.3 \( \mu m \) for the purpose of the present computation.

The value of the damage coefficient computed by us is equal to \( 7.6 \times 10^2 \) \( E_d \) = 9.45 ev which is incidently in close conformity with values reported by (Loo et al, 1979) in case of electron irradiated n-GaAs. The values of \( (k_L) \) for \( (E_d) \) of 17.5 and 25 ev are roughly of the same order as that obtained for \( (E_d) = 9.45 \). However due to the scarcity of the values of \( (k_L) \) corresponding to the latter values of \( E_d \), it is not possible to correlate them with those obtained by others.

Conclusions.

In this chapter we have tried to gain some insight into the understanding of the radiation damaged mechanism observed in thin wafers of the electron irradiated GaAs mainly through the computation of the various energy dependent parameters such as energy loss, displacement cross section, defect density, minority carrier lifetimes / diffusion lengths. A close survey of the computed values obtained by us for \( (E_d) = 9.45 \) ev in respect of the above stated parameters in particular are found to be in good conformity with their corresponding values obtained for the similar value of \( (E_d) \) by others. Therefore it can be safely said that in our case the \( (E_d) \) value of 9.45 ev is most suitable, so far the question of knowing the value of \( (E_d) \) necessary for producing a displacement is concerned.
Electron Energy = 1 Mev
Dopant for GaAs: Sn

**TABLE NO. 31**

<table>
<thead>
<tr>
<th>Energy Level</th>
<th>$S_p$ (cm$^2$)</th>
<th>$S_n$ (cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E2 = Ec - 0.20</td>
<td>4.01*10$^{-14}$</td>
<td>1*10$^{-14}$</td>
</tr>
<tr>
<td>E3 = Ec - 0.30</td>
<td>1.1*10$^{-15}$</td>
<td>1.8*10$^{-15}$</td>
</tr>
<tr>
<td>E4 = Ec - 0.71</td>
<td>-</td>
<td>5.1*10$^{-14}$ (Li, 1982)</td>
</tr>
<tr>
<td>E5 = Ec - 0.91</td>
<td>-</td>
<td>5.8*10$^{-14}$</td>
</tr>
<tr>
<td>E2 = Ec - 0.36</td>
<td>6.9*10$^{-15}$</td>
<td>---</td>
</tr>
<tr>
<td>E3 = Ec - 0.50</td>
<td>1.4*10$^{-16}$</td>
<td>--- (Pons, 1965)</td>
</tr>
<tr>
<td>E4 = Ec - 0.72</td>
<td>1.4*10$^{-15}$</td>
<td>---</td>
</tr>
<tr>
<td>E2 = Ec - 0.14</td>
<td>1*10$^{-16}$</td>
<td>1.1*10$^{-16}$</td>
</tr>
<tr>
<td>E3 = Ec - 0.35</td>
<td>1*10$^{-15}$</td>
<td>6.2*10$^{-15}$</td>
</tr>
<tr>
<td>E4 = Ec - 0.62</td>
<td>-</td>
<td>5.1*10$^{-14}$ (Li, 1980)</td>
</tr>
<tr>
<td>E5 = Ec - 0.83</td>
<td>-</td>
<td>1.9*10$^{-14}$</td>
</tr>
</tbody>
</table>
REFERENCES.