CHAPTER IV

RESULTS AND DISCUSSION

4.1 Introduction

In this Chapter, we present results of electrical and optical properties of vacuum evaporated and hydrogenated a-Si films. The results are discussed in the framework of Davis-Hrott model. Finally, we give our comments on the possible role of hydrogen in these films.

4.2 Transport Properties of V-a-Si Films

4.2A. D.C. conductivity: D.C. conductivity results for a-Si films prepared in vacuum at $10^{-6}$ torr pressure are reported here. The room temperature conductivity lies between $10^{-3}$ and $10^{-5}$ cm$^{-1}$. The conductivity data plotted as a function of $10^3/T$ is shown in Fig. 6. Annealing is found to reduce the room temperature conductivity by three orders of magnitude. Below room temperature, the conductivity activation energy changes discontinuously as a function of temperature and hence no single activation energy could be assigned. The high temperature activation energy for the fully annealed film is found to be 0.14 eV. This is in agreement with the results of Bahl et al. The same data plotted as a function of $1/T^2$ is shown in Fig. 7. A straight line fit in the temperature range below 260$^0$K is obtained. According to Mott's theory, the conduction mechanism in this temperature range is by variable range hopping in the localised states near the Fermi-level. An estimate of these states can be made from the slope $T_o = \frac{x^3}{N(E_F)}$ of the conductivity $\sigma$ vs $\frac{1}{T^2}$ plot.
Fig. 6 Temperature dependence of conductivity ($\delta$) of a vacuum evaporated a-Si film, for various anneals.
Fig. 7 Conductivity as a function of $T^{-1/4}$ of a $\text{V-a-Si}$ film.

The slope $T_0$ can be used to calculate the density of states, $N(E_F)$. 
The graph shows the conductivity ($\sigma$) of V-a-Si materials as a function of temperature ($T^{-1/4}$) expressed in Kelvin ($K^{-1/4}$). The data is represented for different conditions:

- **Virgin** represented by dots.
- **250°C, 6 hrs.** represented by crosses.
- **350°C, 6 hrs.** represented by circles.
In the as-deposited films the data gives $T_o = 5 \times 10^7 \text{K}$, on annealing the films at $350^\circ \text{C}$ for 6 hours, the value of $T_o$ increases to $1 \times 10^8 \text{K}$. Assuming the decay function $\kappa$ to be equal to $10^7 \text{cm}^{-1}$, $N(E_F)$, the density of localised states has been calculated. Table I shows the density of states in the as-deposited and annealed films. It is seen that even after annealing at high temperatures these films contain a large density of localised states of the order of $2 \times 10^{18} \text{cm}^{-3} \text{eV}^{-1}$. The localised states are due to the presence of the dangling bonds at void surfaces. On annealing, the density of defect states is reduced, which can be understood considering that annealing causes some structural re-arrangement, which causes some of the dangling bonds to pair up forming a bonding orbital.

Similar results have been obtained on evaporated and sputtered films of a-Si by other workers$^2$-$^4$.

4.2B. Optical absorption: The optical absorption coefficient ($\kappa$) for V-a-Si films is measured in the range 0.6 eV to 3 eV. The absorption data is plotted as $(\kappa \cdot h \nu)^{1/2}$ vs $(h \nu - E_o)$ where $E_o$ can be interpreted as the minimum distance between localised states in one band and extended states in the other. It represents transitions from extended (localised) states in the valence band to localised (extended) states in the conduction band$^5$. Fig. 8 shows a straight line fit for the above data. Extrapolating this to $\kappa = 0$ gives the value for $E_o$. The optical gap $E_o$ in as-deposited films is found to be 1.35 eV and on annealing at $300^\circ \text{C}$, it increases to 1.42 eV. The optical gap $E_o = 1.42 \text{eV}$ defined as above in a-Si films
Table I
Annealing Behaviour of a Vacuum Evaporated a-Si Films Deposited at Room Temperature

\[ T_A = \text{Annealing Temperature.} \]

<table>
<thead>
<tr>
<th></th>
<th>As-deposited</th>
<th>( T_A = 250^\circ\text{C} ) (6 hr)</th>
<th>( T_A = 350^\circ\text{C} ) (6 hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho ) (( \Omega \cdot \text{cm}^{-1} ))</td>
<td>2.15 \times 10^{-3}</td>
<td>6.15 \times 10^{-5}</td>
<td>1.5 \times 10^{-6}</td>
</tr>
<tr>
<td>( T_0 ) (K)</td>
<td>5 \times 10^7</td>
<td>7 \times 10^7</td>
<td>1 \times 10^8</td>
</tr>
<tr>
<td>( N(E_F) ) (( \text{cm}^{-3} \text{ev}^{-1} ))</td>
<td>4 \times 10^{18}</td>
<td>3 \times 10^{18}</td>
<td>2 \times 10^{18}</td>
</tr>
</tbody>
</table>
Fig.8 The optical absorption coefficient \( \kappa \), plotted

as \( (\kappa h\nu)^2 \) vs \( h\nu \). The intercept on

x-axis gives value of \( E_o \), the optical gap.
\[(\alpha h\nu)^{V/2} \times 10^2 (\text{cm}^2(\text{eV})^{V/2}\]

\[h\nu (\text{eV})\]

- **Virgin**
- **150°C, 6 hrs.**
- **300°C, 6 hrs**
is, therefore, much larger than the indirect gap \( E_0 = 1.1 \text{ eV} \) in crystalline Silicon\(^1\). The absorption in amorphous materials is sensitive to the structure and defects in the amorphous network. The increase in \( E_0 \) as a result of annealing can be explained by considering that the tail of localized states at the band edges reduces on annealing.

4.3 \textbf{Transport Properties of Hydrogenated Amorphous Silicon}

4.3A. \textbf{Introduction:} In the earlier section we have reported the conductivity and optical absorption results for V-a-Si films. In this section we report results of a-Si films prepared under partial pressure of hydrogen and oxygen. Hydrogen or oxygen is expected to compensate the dangling bonds in the amorphous structure and thereby reduce the density of states within the gap.

4.3B. \textbf{D.C. conductivity and optical absorption:} The room temperature conductivity (\( \sigma \)) of a-Si films is found to change by 5 to 6 orders in magnitude, when prepared under partial pressures of hydrogen. The typical values of \( \sigma \) vary between \( 10^{-3} \) and \( 10^{-11} \, \Omega^{-1} \, \text{cm}^{-1} \). Table II shows the annealing history of a typical sample evaporated at \( 1 \times 10^{-4} \, \text{Torr} \) of partial pressure of hydrogen on to a substrate kept at room temperature. The room temperature conductivity decreases on annealing up to \( 250^\circ \text{C} \), and annealing above \( 300^\circ \text{C} \) causes \( \sigma \) to increase. The conductivity as a function of temperature has been investigated in the temperature range \( 500^\circ \text{K} \) to \( 110^\circ \text{K} \). The conductivity data, for a film deposited at room temperature and at a partial pressure of hydrogen \( p_H = 1 \times 10^{-4} \, \text{Torr} \),
### Table II

**Variation of Conductivity at Various Annealing Temperatures ($T_A$).**

<table>
<thead>
<tr>
<th>$P_H = 1 \times 10^{-4}$ torr</th>
<th>As-deposited</th>
<th>$T_A = 150^\circ$C (6 hr)</th>
<th>$T_A = 220^\circ$C (6 hr)</th>
<th>$T_A = 300^\circ$C (6 hr)</th>
<th>$T_A = 400^\circ$C (6 hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{R,T} (\Omega^{-1} \text{ cm}^{-1})$</td>
<td>$1.5 \times 10^{-8}$</td>
<td>$3.3 \times 10^{-10}$</td>
<td>$2.5 \times 10^{-10}$</td>
<td>$2.5 \times 10^{-9}$</td>
<td>$2 \times 10^{-9}$ (\Omega^{-1} \text{ cm}^{-1})</td>
</tr>
</tbody>
</table>
with a typical rate of deposition being $0.2^\circ A$/sec, is plotted in Fig. 9 as a function of $10^3/T$. A single activation energy could be assigned for the annealed film, at high temperature. The activation energy is found to be $0.7$ eV. The value of activation energy decreases at lower temperatures. The conductivity below room temperature is plotted in Fig. 10 as a function of $T^{-1}$. A good straight-line fit is obtained, which can be interpreted by the variable range hopping theory. From the slope $T_o = \alpha^3/N(E_F)$ of the above plot, the density of states $N(E_F)$ can be calculated, assuming $\alpha = 10^7$ cm$^{-1}$. The $T_o$ value for as-deposited films is $6 \times 10^8$ K and on annealing at $300^\circ C$ for 6 hrs, it changes to $T_o = 8 \times 10^8$ K. The value of $N(E_F)$ for as-deposited films comes out to be of the order of $3.5 \times 10^{17}$ cm$^{-3}$ eV$^{-1}$, and in annealed samples $N(E_F) = 2.5 \times 10^{17}$ cm$^{-3}$ eV$^{-1}$. The optical gap $E_o$ for hydrogenated films is obtained by plotting $(\alpha h\nu)^{1/2}$ vs $h\nu$ in the range 0.6 eV to 3 eV. Results are shown in Fig. 11. It is observed that $E_o = 1.75$ eV in as-deposited films, which increases to $E_o = 1.83$ eV on annealing at $300^\circ C$.

The increase in $\theta$ and $E_o$ of the hydrogenated films with respect to the vacuum evaporated films indicates that the dangling bonds are saturated by hydrogen incorporated in the film, and as a result the number of states in the gap decreases. These results, therefore, are in agreement with the reports on the glow discharge deposited$^9,10$ and hydrogenated sputtered a-Si films$^7,8$. We would like to add that an estimate of $N(E_F)$, the density of states near
Fig. 9 Temperature dependance of conductivity ($\sigma$) of a hydrogenated a-Si (H-a-Si) film, deposited at room temperature and at a partial pressure of hydrogen of the order of $1 \times 10^{-4}$ torr, for different annealing temperatures.
$\Delta E_\sigma = 0.7 \text{ eV}$

H-a-Si

$\times$ - Virgin

$\bigcirc$ - 300°C, 2hrs.
Fig. 10  Conductivity as a function of $T^{-1}$ of a H- a-Si film, for different annealing temperatures. From the slope $T_o$ of the plot, $N(E_F)$, the density of states can be calculated.
Fig. 11 The optical absorption coefficient $\kappa$ plotted as $(\alpha \nu)^{1/2}$ vs $h\nu$. The intercept on $x$-axis gives the value of $E_o$, the optical gap.
the Fermi-level, from the $T_0$ data may not be unambiguous. Annealing of V-a-Si films shows a change of $N(E_F)$ only by a factor of 2, although ESR experiments indicate a much larger change$^{11,12}$. The hydrogenated films also show a change only by a factor of 3 even though the conductivity changes by several orders of magnitude. The applicability of the hopping theory to the conduction mechanism has been questioned by various authors$^{13,14}$ and at this stage, therefore, we cannot give with confidence any definite number for $N(E_F)$ in the V-a-Si and H-a-Si films based on the $T^{-4}$ plots. We have investigated the dependence of hydrogen partial pressure $p_H$ and substrate temperature $T_s$ on the room temperature conductivity of the H-a-Si films. We find that the results depend critically on the deposition rate. Table III shows the room temperature conductivity of films deposited at three different partial pressures of hydrogen. We find that up to a temperature of about 250°C, annealing of the defects results in a lowering of the conductivity. At a higher temperature, however, the conductivity increases. This could be attributed to the removal of hydrogen at a high temperature from the H-a-Si film, as has been observed by Brodsky et al$^{16}$ and others$^{15}$ on glow discharge films. These results are also in agreement with the observations of Anderson et al$^{17}$ on H-sputtered a-Si films. They find that at $T_s > 250°C$ hydrogen incorporation is not efficient and the films are more conducting. The resistivity of the films did not show any systematic dependence on partial pressure of hydrogen because slight change in the deposition rate can result
**Table III**

Conductivity of Hydrogenated a-Si Films for Different Deposition Conditions,

\[ P_H = \text{Hydrogen Partial Pressure}, \quad T_d = \text{Substrate Temperature}. \]

<table>
<thead>
<tr>
<th>Partial Pressure of hydrogen</th>
<th>Room Temperature Conductivity ((\Omega^{-1} \text{ cm}^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(T_d = 350^\circ\text{C})</td>
</tr>
<tr>
<td>(P_H = 1 \times 10^{-5} \text{ torr})</td>
<td>-</td>
</tr>
<tr>
<td>(P_H = 1 \times 10^{-4} \text{ torr})</td>
<td>(2.5 \times 10^{-7})</td>
</tr>
<tr>
<td>(P_H = 5 \times 10^{-6} \text{ torr})</td>
<td>-</td>
</tr>
</tbody>
</table>
in a significant change in the hydrogen incorporation in the films.

We have also measured the conductivity and optical absorption of films deposited at a partial pressure $p_H = 10^{-5}$ torr, of dry oxygen. Deposition rates are typically $0.5\, \text{A sec}$ to $2\, \text{A sec}$. These oxygenated films have room temperature conductivity ($\sigma$) and optical gap ($E_g$) similar to the hydrogenated films. This indicates that oxygen is also effective in removing the dangling bonds from the amorphous films.

In view of the similarity in properties of the a-Si films deposited in a partial pressure of oxygen or hydrogen to those of the glow discharge deposited films and hydrogen sputtered films, we have carried out experiments on the effect of electron irradiation and doping on the properties of these films. The first experiment is important in view of the possible use of these films for solar-cell applications. The second experiment will tell unambiguously if the incorporation of hydrogen automatically ensures removal of gap states under which condition only doping will be efficient. The results are presented in the next two sections.

4.4 Electron Irradiation

The effect of electron irradiation on the conductivity of $N$-a-Si films and on O-a-Si films have been studied along with that on V-a-Si films. The conductivity of V-a-Si and H.a.Si films remains unaltered for an irradiation time of 30 mins. The O-a-Si films, on
the other hand, show an increase in conductivity by a factor of 2, which is found to recover in an hour or so at room temperature. The typical anneal curve of conductivity as a function of time is shown in Fig. 12. The increase in the conductivity on irradiation is related to the number of defects produced due to radiation damage. An estimate of these defects can be made by knowing the electron dose and the cross section for damage. The total number of electrons incident on the sample is about \(10^{16}\) cm\(^{-2}\). A typical estimate for the cross section \(\sigma_d\) is about 10 barns. The density of defects is then of the order of \(10^{16}\) cm\(^{-3}\). Assuming conduction at room temperature to take place at the band edges, we can write for the conductivity,

\[
\sigma = \sigma_0 \exp \left( \frac{E - E_p}{kT} \right),
\]

where \(E_p\) is the location of the Fermi-level. For a change in the conductivity by a factor 2, the Fermi-level is to be shifted by about \(kT\). Since this is caused by the creation of \(10^{16}\) cm\(^{-3}\) defects, the density of states at the Fermi-level can be estimated to be of the order of \(5 \times 10^{17}\) cm\(^{-3}\) eV\(^{-1}\). This is in good agreement with the results of Nadan et al.\(^{19}\), who find \(N(E_F)\) to be \(10^{18}\) cm\(^{-3}\) eV\(^{-1}\) for oxygenated films. The absence of irradiation effect in H-a-Si films may be because the defects created are annealing out fast, as they are formed. The difference in the annealing behaviour of H-a-Si and C-a-Si films can be understood by considering the irradiation studies in crystalline Si. It is known in this case that oxygen vacancy
Fig. 12  Annealing behaviour of the conductivity of an irradiated C-$a$-Si film as a function of time at room temperature. Arrow indicates the conductivity before electron irradiation.
defects created due to irradiation are stable up to about 500°C. Attempts were made to freeze the defects in hydrogenated samples and irradiations were carried out at 125°C. But the conductivity was below the range of measurement both before and after irradiation.

In conclusion, we find that hydrogenated films are hard to radiations, whereas the irradiation produces some electrically active centres in the oxygenated films, which can be correlated with the oxygen vacancy complexes in crystalline Silicon. The defects anneal out fast at room temperature.

4.5 Doping of Hydrogenated a-Si Films

We have tried to dope the hydrogenated a-Si films by evaporating Si doped with 0.5% Al and 0.1% Sb. The resistivity of the films is found to be the same as that of the undoped hydrogenated samples. Experiments were performed for various values of partial pressure of hydrogen and at various temperatures but no doping effect as manifested in a large change in conductivity could be observed.

The absence of the doping effect indicates that the films may still have a considerable number of states within the gap. It may be mentioned that apart from the vacuum deposited films, doping effect has not been observed even in glow discharge silane films deposited at room temperature. Although the latter films contain hydrogen, a large number of states still exists in the gap and that accounts for
the insensitivity to doping. It is possible that our hydrogenated films can also have similar properties. In order to find out if these films contain a large number of states within the gap, we have carried out photoconductivity experiments, the results of which are reported in the next section.

4.6 Photoconductivity

Typical results for photoconductivity of a film deposited at a partial pressure $p_H = 5 \times 10^{-6}$ torr of hydrogen on to a substrate kept at room temperature is shown in Table IV. The photoconductivity $\sigma_{ph}$ is found to be of the order of $4 \times 10^{-11} \Omega^{-1} \text{ cm}^{-1}$, which increases by one order of magnitude, when the film is annealed at $250^\circ \text{C}$ for four hours in hydrogen. Subsequent annealing does not increase the photoconductivity any further. Since the photon intensity is $4 \times 10^{18}$ photons/cm$^2$.sec, in our case, the photoconductivity observed is much smaller than that observed in glow discharge or r.f. sputtered hydrogenated films. In the former case the best results show $\sigma_{ph}$ to be of the order of $10^{-5} \Omega^{-1} \text{ cm}^{-1}$ for a photon intensity of $1 \times 10^{15}$/cm$^2$.sec. In the sputtered hydrogenated films, the best results give $\sigma_{ph} = 10^{-7} \Omega^{-1} \text{ cm}^{-1}$ for the same photon intensity. We have done experiments at various values of $T_S$ and the results are shown in Table V. In none of the cases, $\sigma_{ph}$ is found to be high. Similar results are obtained for films deposited at different pressures. This indicates that our films, perhaps, still contain a large number of trapping centres, which
Table IV

Photoconductivity of Hydrogenated a-Si Films Deposited at $P_H = 5 \times 10^{-6}$ torr
and Substrate at Room Temperature, after Successive Annealing Cycles

<table>
<thead>
<tr>
<th>Conductivity</th>
<th>As-deposited</th>
<th>$T_A = 250^\circ C$ (4 hr)</th>
<th>$T_A = 250^\circ C$ (8 hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>dark ($\Omega^{-1} \text{ cm}^{-1}$)</td>
<td>$3.5 \times 10^{-11}$</td>
<td>$1.5 \times 10^{-10}$</td>
<td>$2.5 \times 10^{-10}$ ($\Omega^{-1} \text{ cm}^{-1}$)</td>
</tr>
<tr>
<td>ph ($\Omega^{-1} \text{ cm}^{-1}$)</td>
<td>$4.0 \times 10^{-11}$</td>
<td>$4.0 \times 10^{-10}$</td>
<td>$2.5 \times 10^{-10}$ ($\Omega^{-1} \text{ cm}^{-1}$)</td>
</tr>
</tbody>
</table>
Table V

Photoconductivity and Dark Conductivity at H-a-Si Films at Different Substrate Temperatures ($T_d$) and After Successive Annealing Stages

$P_r = 5 \times 10^{-4}$ torr

<table>
<thead>
<tr>
<th>Anneal History</th>
<th>$T_d = 300^\circ C$</th>
<th>$T_d = 250^\circ C$</th>
<th>$T_d = 200^\circ C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma (\Omega^{-1} cm^{-1})$</td>
<td>6 dark</td>
<td>6 ph</td>
<td>6 dark</td>
</tr>
<tr>
<td>As-deposited</td>
<td>$3.5 \times 10^{-8}$</td>
<td>$6.5 \times 10^{-10}$</td>
<td>$1.5 \times 10^{-9}$</td>
</tr>
<tr>
<td>$T_A = 250^\circ C$</td>
<td>$3 \times 10^{-8}$</td>
<td>$5 \times 10^{-9}$</td>
<td>$2.5 \times 10^{-8}$</td>
</tr>
<tr>
<td>(4 hr)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_A = 250^\circ C$</td>
<td>$1.5 \times 10^{-7}$</td>
<td>$1.5 \times 10^{-8}$</td>
<td>$3.5 \times 10^{-8}$</td>
</tr>
<tr>
<td>(8 hr)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
reduce the lifetime of the photogenerated carriers.

One may argue that the difference in behaviour in the hydrogenated films prepared by us and those obtained by silane deposition or sputtering could be due to the presence of atomic hydrogen during deposition by the latter method. We have done experiments to deposit films by evaporating in a partial pressure of atomic hydrogen. Hydrogen was atomised by bleeding the gas on to a hot tungsten filament, heated to 2000°C, kept in close proximity to the graphite boat within the vacuum chamber. The results are found to be similar to what has been observed by using molecular hydrogen. One thus concludes that mere incorporation of hydrogen in a-Si films is not sufficient to clean the states in the gap. The observed reduction in the conductivity and the increase in $E_0$ show that the hydrogenated silicon films are characterised by a larger band gap, but the absence or doping effect and the small value of photoconductivity indicate that a large number of states are still present in the gap. This could possibly be due to the way in which hydrogen bonds on to silicon in the evaporated films which may be different from that in the silane films. It has been recently shown that in a glow discharge or rf sputtered films, depending on the deposition conditions one can have Si-H, SiH$_2$, SiH$_3$ bonds. The films having predominant Si-H bonds have very few states within the gap, whereas films containing SiH$_2$ or SiH$_3$ bonds still contain a large number of states and are insensitive to doping. We have carried out infrared absorption measurements on our films to find out the way in which
Si bonds on to hydrogen. The results are reported in the next section.

4.7 Infrared Absorption Measurements

In this section we present the infrared transmission measurements of hydrogenated a-Si films, prepared under partial pressure of hydrogen of the order of $1 \times 10^{-4}$ Torr, on to a Silicon substrate. The measurements are taken in the infrared range from 3000 cm$^{-1}$ to 400 cm$^{-1}$. In Fig.13, the transmission spectrum for a film deposited on to a substrate, kept at 250$^\circ$C, is shown. There are two absorption peaks at 2090 cm$^{-1}$ and at 635 cm$^{-1}$. Comparing this with the earlier published data by Brodsky et al.$^{24}$ on hydrogenated sputtered and glow discharge a-Si films, we find that the band at 635 cm$^{-1}$ corresponds to the wagging mode frequency of SiH, SiH$_2$, and SiH$_3$ bonds, and the one at 2090 cm$^{-1}$ corresponds to the stretching mode frequency of SiH$_2$ bonds. It is interesting to note that in these films the Si-H bonds are much less (below the detection limit) as compared to SiH$_2$ or SiH$_3$ bondings. The spectrum of hydrogenated a-Si films, deposited at room temperature, is similar to that of the high temperature deposited films, except that the band is split up into a doublet, with the centre at 2110 cm$^{-1}$, having a shoulder at 2250 cm$^{-1}$, which corresponds to the stretching mode of SiH$_2$. To some extent these spectra are similar to the ones for glow discharge films deposited at room temperature and higher silane pressures, and field effect measurements have shown that these films contain a large number of localised states in the gap. Along this line one
Fig. 13  Infrared transmission spectrum of a H-a-Si film, deposited at 250°C and at a partial pressure of the order of $1 \times 10^{-4}$ torr. The absorption peaks at 2030 cm$^{-1}$ corresponds to a stretching mode frequency of SiH$_2$ bonds and the one at 635 cm$^{-1}$ corresponds to a wagging mode frequency of Si-H, SiH$_2$, SiH$_3$ bondings.
may suggest that the hydrogenated a-Si films prepared by evaporating under partial pressure hydrogen also contain a large number of localized states in the gap. These localized states are caused by Si H$_2$ or Si H$_3$ bonds, which may have their antibonding states within the gap.

The reason why it is not possible to eliminate the Si H$_2$ or Si H$_3$ bonds in the evaporated hydrogenated films unlike the case for the sputtered or glow discharge deposited ones is not very clear. It is, however, known that the plasma in the reaction chamber during deposition using the latter methods has a profound influence on the properties of these films. More work on the reaction kinetics of hydrogen incorporation will be necessary to have a proper understanding of this problem.