CHAPTER - 3

ELECTRIC AND THERMAL ANALYSIS OF PURE AND DOPED L-PROLINIUM PICRATE SINGLE CRYSTALS

3.1 INTRODUCTION

Dielectric study is an important part of materials characterizations, because it does not only throw light on the materials behavior under the influence of applied electric field but also its applications. When an external electric field is applied to the dielectrics, the field exerts a force on each positive charge in its own direction while negative charges are pushed in the opposite direction. Consequently, an electrical doublet or dipole is created in all the atoms inside the dielectric. Thus, the process of producing electric dipoles and aligning them inside the dielectrics by an external electric field is called polarization in dielectrics.

3.2 POLARISATION VECTOR (\(\vec{P}\))

If the strength of the electric field \(\vec{E}\) is increased, the strength of the induced dipole also increases. The induced dipole moment is proportional to the intensity of the electric field.

\[
i.e., \quad \vec{\mu} = \alpha \vec{E} \quad (3.1)
\]

where \(\alpha\) is the constant of proportionality, called the polarizability.
If $\mu$ is the average dipole moment per molecule and $N$ is the number of molecules per unit volume, the polarization vector ($\vec{P}$) is defined as dipole moment per unit volume of the dielectric material.

$$\vec{P} = N\mu$$  \hspace{1cm} (3.2)

### 3.3 ELECTRIC DISPLACEMENT VECTOR ($\vec{D}$)

Electric displacement vector (or) electric induction ($\vec{D}$) is a quantity which is used for analyzing electrostatic fields in the presence of dielectrics, which is given by

$$\vec{D} = \frac{Q}{4\pi r^2}$$  \hspace{1cm} (3.3)

where $Q$ is the charge and $r$ is the distance of separation between the charges.

We know the electric field intensity,

$$\vec{E} = \frac{Q}{4\pi \varepsilon r^2}$$  \hspace{1cm} (3.4)

where $\varepsilon$ is the absolute permittivity.

From equations (3.3) and (3.4),

$$\vec{D} = \varepsilon \vec{E}$$  \hspace{1cm} (3.5)

$$\vec{D} = \varepsilon_r \varepsilon \vec{E}$$  \hspace{1cm} (3.6)

$$\vec{D} = \varepsilon_r (1 + \chi_e) \vec{E}$$  \hspace{1cm} (3.7)

where $\varepsilon_0$ is the permittivity of free space, $\varepsilon_r$ is the relative permittivity and $\chi_e$ is the electric susceptibility.
3.4 RELATION BETWEEN $\vec{P}$ AND $\vec{E}$

We know that,

\[ \vec{D} = \varepsilon_0 \vec{E} + \varepsilon_0 \chi_e \vec{E} \]  \hspace{1cm} (3.8)

\[ \vec{D} = \varepsilon_0 \vec{E} + \vec{P} \]  \hspace{1cm} (3.9)

(since $\vec{P} = \varepsilon_0 \chi_e \vec{E}$)

Equating (3.6) and (3.9) we have,

\[ \varepsilon_0 \varepsilon_r \vec{E} = \varepsilon_0 \vec{E} + \vec{P} \]  \hspace{1cm} (3.10)

\[ \frac{\vec{P}}{\vec{E}} = \varepsilon_0 (\varepsilon_r^{-1}) \]  \hspace{1cm} (3.11)

3.5 ELECTRIC SUSCEPTIBILITY ($\chi_e$)

The polarization vector $\vec{P}$ is proportional to the applied electric field $\vec{E}$, for the field strength that are not too large. So, we can write

\[ \vec{P} = \varepsilon_0 \chi_e \vec{E} \]  \hspace{1cm} (3.12)

where $\chi_e$ is a characteristic of every dielectric and which is called electrical susceptibility.

\[ \chi_e = \frac{\vec{P}}{\varepsilon_0 \vec{E}} \]  \hspace{1cm} (3.13)

since $\frac{\vec{P}}{\vec{E}} = \varepsilon_0 (\varepsilon_r^{-1})$ we can write,

\[ \chi_e = \frac{\varepsilon_0 (\varepsilon_r^{-1})}{\varepsilon_0} \]  \hspace{1cm} (3.14)

Therefore,

\[ \chi_e = \varepsilon_r - 1 \]  \hspace{1cm} (3.15)
3.6 DIELECTRIC CONSTANT ($\varepsilon_r$)

The dielectric constant determines the share of the electric stress which is absorbed by the material. The dielectric constant is the ratio between the absolute permittivity, $\varepsilon$ and the permittivity of free space, $\varepsilon_0$ and is given by,

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$

(3.16)

$\varepsilon_r$ is a dimensionless quantity and it is a measure of polarization in the dielectrics.

3.7 VARIOUS POLARIZATIONS IN DIELECTRICS

Dielectric polarization is the displacement of charged particles under the action of the external electric field. There are number of devices based on this concept. Those devices are rectifiers, resonators, amplifiers and transducers, which converts electrical energy to other forms of energy.

In modern computers, memory devices are also based on this concept. Several microscopic mechanisms are responsible for electric polarization. Specially, in the case of d.c electric field, the macroscopic polarization vector $\vec{P}$ arises due to following four types of microscopic polarization mechanisms

(i) Electronic polarization,

(ii) Ionic polarization,
(iii) Orientation polarization and
(iv) Space charge polarization.

3.7.1 Electronic Polarization

It occurs due to the displacement of positively charged nucleus and negatively charged electrons in opposite directions, when an external electric field is applied, and thereby creates a dipole moment in the dielectric.

Therefore the induced dipole moment,

$$\vec{\mu}_e = \alpha_e \vec{E}$$  (3.17)

Electronic Polarizability, \( \alpha_e = \frac{\mu}{E} = 4\pi \varepsilon_0 R^3 \)  (3.18)

where \( R \) is the radius of the atom. Monoatomic gases exhibit this kind of polarization. Electronic polarizability is proportional to the volume of atoms and is independent of temperature.

3.7.2 Ionic Polarization

It arises due to the displacement of cations (+ve ions) and anions (-ve ions) from their original positions in opposite directions, in the presence of electric field. The displacement is independent of temperature and it occurs in ionic solids.

Induced dipole moment is given by,

$$\vec{\mu}_i = \alpha_i \vec{E}$$  (3.19)
Ionic Polarizability, $\alpha_i = \frac{\mu}{E} = e^2 \left( \frac{1}{m} + \frac{1}{M} \right)$ \hspace{1cm} (3.20)

where $\omega_0$ is the angular frequency of the molecule, $m$ is the mass of the positive ion and $M$ is the mass of the negative ion. So the ionic polarizability ($\alpha_i$) is inversely proportional to the square of the natural frequency of the ionic molecule and directly proportional to its reduced mass which is given by $\left( \frac{1}{m} + \frac{1}{M} \right)$.

3.7.3 Orientation Polarization

Polar molecules are the molecules which have permanent dipole moments even in the absence of an electric field. The orientation polarization arises due to the presence of polar molecule in the dielectric medium. When the dielectric which consists of polar molecules is kept in an electric field, the molecules align themselves along the field direction. So there is a resultant dipole moment along the field direction.

Induced dipole moment,

$$\overline{\mu_o} = \alpha_o \overline{E}$$ \hspace{1cm} (3.21)

Orientation polarizability, $\alpha_o = \frac{\overline{\mu_o}}{\overline{E}} = \frac{\mu_o}{3k_B T}$ \hspace{1cm} (3.22)

where $\alpha_o$ is called as Orientational polarizability and is equal to $\frac{\mu_o^2}{3k_B T}$. Therefore orientational polarizability is inversely proportional to the temperature of the material.
3.7.4 Space – Charge Polarization

The space – charge polarization occurs due to diffusion of ions, along the field directions and giving rise to redistribution of charges in the dielectrics. Without the application of external field, the ions are orderly arranged and when the field is applied, the ions diffuse with respect to the direction of applied field. Thus the polarization occurs, known as space – charge polarization. Normally, this type of polarization occurs in ferrites and semiconductors and will be very small.

The total electric polarization is the sum of electronic, ionic, orientation and space charge polarizations. Since space charge polarization is very small when compared to other kinds of polarization it can be neglected. Therefore the total polarization is given by

\[ \vec{P} = \text{Electronic polarization} + \text{ Ionic polarization} + \text{Orientation polarization} \]

\[ \vec{P} = N \alpha_c \vec{E} + N \alpha_i \vec{E} + N \alpha_o \vec{E} \quad (3.23) \]

\[ \vec{P} = N \vec{E} (\alpha_c + \alpha_i + \alpha_o) \quad (3.24) \]

3.8 FREQUENCY AND TEMPERATURE DEPENDENCE OF ALL THE POLARIZATION MECHANISMS

When field is applied, the polarization occurs as a function of time. The polarization, \( \vec{P}(t) \) as a function of time \( t \) is given by

\[ \vec{P}(t) = \vec{P}(1 - e^{-t/\tau}) \quad (3.25) \]
where $\bar{P}$ is the maximum polarization which occurs at a static field applied for a long time and $t_r$ is the relaxation time (S.O. Pillai, 2006), i.e., the time taken for polarization. It is a measure of the time scale of a polarization process.

### 3.8.1 Frequency Dependence

(i) **Electronic polarization** is very rapid and will complete at the instant the voltage is applied. The reason is that the electrons are very light elementary particles than ions. Therefore for very high frequency applied voltage i.e., in the optical range ($\approx 10^{15}$ Hz) this polarization occurs during every cycle of the applied voltage.

(ii) **Ionic polarization** is slightly slower than the electronic polarization, because ions are heavier than the electron cloud. Also the frequency of the applied electric field with which the ions will be displaced is equal to the frequency of the lattice vibrations ($\approx 10^{13}$Hz).

(iii) **Orientation polarization** is even slower than ionic polarization. The relaxation time for this case varies with respect to the dielectric materials (i.e., solids or liquids) used. This type of polarization occurs at audio and radio frequency range ($\approx 10^6$Hz).

(iv) **Space charge polarization** is the slowest process, because in this case the ions have to diffuse (jump) over several interatomic distances. Also this process occurs at very low frequency in the order of $10^2$ Hz.

Therefore we can observe that, at lower frequencies all the four types of polarization occur and the total polarization is maximum. The
total polarization value decreases with the increase in frequency and becomes minimum at optical frequency range.

### 3.8.2 Temperature Dependence

The electronic and ionic polarizations are independent of temperature, whereas the orientation and space charge polarizations are temperature dependent.

The orientation polarization decreases with the increase in temperature because the randomizing action of thermal energy decreases the tendency of the permanent dipoles to align along the field direction. Hence in this case the \( \varepsilon_r \) decreases.

But in space charge polarization, when the temperature is increased, the ions can easily overcome the activation barrier and hence they diffuse through the inter atomic distances. Thus it gives rise to polarization. So, in this case the \( \varepsilon_r \) will increase with the increase in temperature.

### 3.9 DIELECTRIC LOSS

The dielectric loss is a measure of the energy absorbed by dielectric. So, if a dielectric is subjected to an electric field, the electrical energy is absorbed by the dielectric and certain quantity of electrical energy is dissipated in the form of heat energy. This is known as dielectric loss. It is known that in a capacitor, the dielectric material usually has a resistance \( R \) and reactance \( \frac{1}{\omega C} \) which are related to the phase angle.
\[
\tan \delta = \frac{1}{\omega CR} \quad (3.26)
\]

Here, the \( \tan \delta \) is called as power factor of the dielectric and the dielectric loss is obtained from the equation,

\[
\text{Dielectric loss} = 2\pi f CV^2 \tan \delta \quad (3.27)
\]

where \( f \) is the frequency, \( C \) is the capacitance and \( V \) is the Voltage. If \( f \), \( C \) and \( V \) are constants, then

\[
\text{Dielectric loss} \propto \tan \delta \quad (3.28)
\]

### 3.10 DIELECTRIC STUDIES FOR THE GROWN PURE LPP AND DOPED LPP CRYSTALS

HIOKI 3532 – 50 LCR HITESTER was used for the dielectric study. The samples of size 4 x 4 x 3 mm\(^3\) were prepared for all the crystals and mounted between copper electrodes. In order to ensure good electrical contact between the crystals and the electrodes, the crystal faces were coated with silver paint.

The dielectric measurements were carried out in a frequency range 100 Hz – 5 MHz and temperature range 35 – 95°C. The dielectric constant and dielectric loss were calculated for pure and doped crystals. The figures 3.1, 3.2, 3.3 and 3.4 show the variation of dielectric constant and dielectric loss as a function of frequency. It is found that the dielectric constants of pure and doped LPP are high at lower frequencies and they decrease with increase in frequency. The high value of dielectric constant at low frequencies may be due to the contributions from all the four polarizations, namely electronic, ionic, orientational
and space charge polarizations. The space charge depends on the purity and perfection of the material. Its influence is noticeable in the low frequency region (K. V. Rao and A. Smakula, 1965). The orientational effect can sometimes be seen in some materials even up to $10^{10}$ Hz. Ionic and electronic polarization always exists below $10^{13}$ Hz (Narsimha et al., 1988).

The trend of the dielectric constants of pure LPP, 5 mol % and 10 mol % doped LPP crystals are almost the same. But at fixed frequency, the dielectric constants of doped LPP crystals are less than that of pure one. In accordance with Miller rule, the lower value of dielectric constant is a suitable parameter for the enhancement of Second Harmonic Generation (SHG) coefficient (Von Hundelshausen, 1971).

Since the dielectric constant of doped crystals is lower than that of the pure crystals they are less polarized in comparison with pure crystal. The lower polarization may be due to ineffective transportation of polarization from one molecule to its neighbour in the presence of dopants (T. Kishore Kumar et al., 2008).
Figure 3.1 Plots of (a) Dielectric Constant vs. Log frequency for pure and Nb doped LPP crystals and (b) Dielectric loss vs. Log frequency for pure and Nb doped LPP crystals.
Figure 3.2 Plots of (a) Dielectric Constant vs. Log frequency for pure and Nd doped LPP crystals and (b) Dielectric loss vs. Log frequency for pure and Nd doped LPP crystals.
Figure 3.3 Plots of (a) Dielectric Constant vs. Log frequency for pure and La doped LPP crystals and (b) Dielectric loss vs. Log frequency for pure and La doped LPP crystals
Figure 3.4 Plots of (a) Dielectric Constant vs. Log frequency for pure and Ce doped LPP crystals and (b) Dielectric loss vs. Log frequency for pure and Ce doped LPP crystals
The characteristic of low dielectric loss at high frequencies for these samples suggest that the pure and doped crystals possess enhanced optical quality with lesser defects (Christo Balarew and Rumen Duhlev, 1984). For a particular frequency, the dielectric loss of doped LPP is slightly lesser than that of pure, which indicates that the dopant further enhances the optical quality of LPP and reduces the defects.

3.11 THERMAL STUDIES

According to widely accepted definition of thermal analysis (Thermo analytical), it is a group of technique in which physical properties of a substance and/or its reaction products are determined as a function of temperature whilst the substance is subjected to a controlled temperature program (Skoog et al., 1998). According to International Confederation for Thermal Analysis and Calorimetry (ICTAC), thermal analysis is defined as a group of technique in which a property of the sample is monitored against time or temperature while the temperature of the sample, in a specified atmosphere, is programmed (J. O. Hill, 1991). Nearly over a dozen thermal methods can be identified, which differ in the properties measured and temperature programs (W. W. Wendlandt, 1985; M. E. Brown, 1988; P. J. Haines, 1995). These methods find widespread use for both quality control and research applications of various substances, such as crystals, polymers, pharmaceuticals, clays, minerals, metals and alloys.
3.12 CLASSIFICATION OF THERMAL ANALYSIS TECHNIQUE

Thermal analysis technique involve the measurement of various properties of materials subjected to dynamically changing environments under predetermined condition of heating rate, temperature range and gaseous atmosphere or vacuum. Among the various thermal methods, the most widely used techniques are, Thermo Gravimetric Analysis (TGA), Differential Thermal Analysis (DTA) and Differential Scanning Calorimetry (DSC), which are employed in inorganic and organic chemistry, metallurgy, mineralogy and other areas.

3.12.1 Thermo Gravimetric Analysis (TGA)

Thermo gravimetric analysis is a technique in which the mass of a substance is measured as a function of temperature or time while the substance is subjected to a controlled temperature program. The curve obtained in a thermo gravimetric analysis is called thermogram (TG) and its first derivative is called a derivative thermogram (DTG). Modern commercial TG instrument consists of the following main parts,

(i) a sensitive analytical balance,
(ii) a temperature programmable furnace,
(iii) a purge gas system for providing suitable gas atmosphere and
(iv) a microprocessor for instrument control, data acquisition and display.
The null-point weighing mechanism is employed since the sample remains in the same zone of furnace irrespective of the change in mass. The furnace is normally an electrical resistive heater and the temperature range for most of the furnace is from ambient to 1000-2000 °C. The rate of heat exchange between the furnace and the sample depends on the heating rate which influences the TG curve in a number of ways. A slower rate gives a better resolution of the closely lying steps, while the faster heating rate merges such steps. The shape of the thermogravimetric curve of a particular compound is influenced by the heating rate of the sample and the atmosphere surrounding it (S. M. Khopkar, 1984; L. Erdey, 1963).

One of the objectives of TG and DTG is to delineate as accurately as possible the various temperatures associated with the thermal behavior of a given substance, i.e., temperature of decomposition, stability range of an intermediate compound and the temperature at which the reaction get completed. As noted earlier that the TGA involves change in weight with respect to temperature. The acquired data obtained as a plot of mass or loss of mass in percentage as a function of temperature is considered as a thermal spectrum, or a thermogram, or a thermal decomposition curve. These thermograms characterize a system in terms of temperature dependence of its thermodynamic properties and physical-chemical kinetics. The TGA involves measurement of a change in weight of a system with the temperature. Changes in weight are a result of the rupture and/or formation of various physical and chemical bonds at elevated temperatures that lead to the evaluation of volatile products or the formation of heavier reaction products.
From such curves, parameters concerning the thermodynamics and kinetics of the various chemical reactions, reaction mechanism, the intermediate and final reaction products can be identified. Usually, the temperature range is from ambient to 1200 °C with inert or reactive atmospheres. The derivative in TG is often used to pinpoint completion of weight-loss steps or to increase resolution of overlapping weight-loss occurrences. A few significant applications of TGA are,

(i) to study thermal degradation / decomposition / dehydration,
(ii) to evaluate chemical reaction resulting in changes of mass, such as absorption, adsorption, desorption and
(iii) to check the sample purity.

3.12.2 Differential Thermal Analysis (DTA)

Differential Thermal Analysis (DTA) is a technique in which the temperature difference between a substance and a reference material is measured as a function of temperature whilst the substance and reference material are subjected to a controlled temperature program (J. O. Hill, 1991). DTA provides information on the chemical reactions, phase transformations and structural changes that occur in a sample during heating or cooling cycle. The DTA measures the differences in energies released or absorbed and the changes in heat capacity of materials as a function of temperature. The graph of DTA signal, i.e., differential thermocouple output in micro volts on the Y-axis plotted versus the sample temperature in °C on the X-axis gives the results of DTA.
Modern thermo-balances are often equipped so as to record the DTA signal and the actual thermo-gravimetric measurement, simultaneously. In addition to showing the energetic nature of weight loss events, the DTA signal can also show thermal effects that are not accompanied by a change in mass, e.g. melting, crystallization or a glass transition. Transition temperatures are measured precisely using the DTA. The DTA identifies the temperature regions and the magnitude of critical events during a drying or firing process, such as binder burnout, carbon oxidation, sulfur oxidation, structural clay collapse, Alpha to Beta quartz transition, carbonate decompositions, recrystalizations, melting and cristobalite transitions, melting, solidification or solidus temperature, glass transition temperature ($T_g$), curie point, energy of reaction, heat capacity and others. The transition enthalpy is estimated from the DTA curve using the heat capacity of the heat sensitive plate as a function of temperature. A few applications of DTA are,

(i) primarily used for detection of transition temperature and 
(ii) to check the sample purity.

3.13 THERMAL STUDIES FOR THE GROWN PURE LPP AND DOPED LPP CRYSTALS

The thermo gravimetric and differential thermal analyses (TG – DTA) response curves were drawn for pure LPP, Nb doped LPP, Rare earth elements Nd, Ce and La doped LPP samples in the temperature range from 20 to 800 °C using the instrument NETZSCH STA 409C at the heating rate of 10 K/min., in nitrogen atmosphere. The TG - DTA curves of pure and doped LPP crystals appear nearly similar kind of
decomposition between 20 and 800 °C as shown in figures 3.5, 3.6, 3.7 and 3.8. In order to study the influence of the dopant on the thermal stability of LPP, the temperature corresponding to a peak maximum of first stage of phase transition in DTA trace is taken into account for comparison.

3.13.1 Thermal Studies for Pure LPP

For pure LPP, initial mass of the material subjected to analysis was 2.99 mg and the final mass left out was only 0.363 % of the initial mass at the temperature of 800°C indicating the bulk decomposition of pure LPP. From TGA curve, shown in figure 3.5, it is observed that the decomposition of the compound starts at 230°C. Since this temperature is beyond 100°C, it is concluded that there is no water of crystallization present in the sample.

From DTA curve, the endothermic peak found at 156°C is assigned as phase transition temperature without any mass loss. Since this phase transition involves no mass loss it is a first order phase transition i.e., melting point of LPP. The sharpness of the endothermic peak shows good degree of crystallinity and purity of the grown crystal.
3.13.2 Thermal Studies for Nb10 : LPP

The TG-DTA spectra for Nb10 : LPP is shown in figure 3.6. From the TGA curve, it is revealed that the Nb10 : LPP exhibits weight loss starting at 282 °C due to the liberation of volatile substances from the compounds. This illustrates the absence of physically adsorbed or lattice water in the crystal. In DTA curve, the endothermic peak found at 211 °C without any mass loss is attributed to the melting point of Nb10 : LPP. The sharpness of the endothermic peak in DTA spectra is attributed to the good degree of crystallinity and purity of the material. Since there is no weight loss and any physical transition in the temperature range from room temperature up to 211 °C these materials are stable thermally up to 211 °C.
3.13.3 Thermal Studies for Nd10 : LPP

Thermal properties of 10 mol % Neodymium doped L-Prolinium Picrate single crystal was studied by thermogravimetric analysis (TGA) and differential thermal analysis (DTA). The corresponding thermograms are presented in figure 3.7. From the TGA curve, there is no weight loss up to 252°C. Hence it can be recognized that the crystal is devoid of any physically adsorbed water on it. The sharp endothermic peak is found at 179°C in the DTA curve. Since there is no weight loss observed in TGA curve at 179°C this endothermic peak is corresponds to first order phase transition, i.e., melting point of the sample and the material starts to melt at this temperature and dissociate immediately thereafter.
3.13.4 Thermal Studies for La5 : LPP

From the TG thermogram of La5 : LPP, presented in the figure 3.8, it is observed that the sample is characterized by a step wise mass-loss reaction, starts at 290 °C, which involves thermal dissociation and vaporization process. The sharp endothermic peak observed at 191 °C in the differential thermal analysis indicates the melting point of the grown crystal. Hence from the thermal analysis, it is concluded that the grown La5 : LPP crystal is thermally stable upto 191°C.
3.13.5 Thermal Studies for Ce5 : LPP

The Ce5 : LPP single crystal sample weighing 42.74 mg was taken for the thermal analysis. The TG - DTA thermogram is shown in figure 3.9. In the differential thermogram, a sharp endothermic peak is found at 163 °C. This endothermic peak is assigned to the melting point of the sample since no weight loss in TG is noticed at this temperature. As indicated by TG curve, the initial decomposition of the compound starts at 240 °C. Since this temperature is beyond 100 °C, it is concluded that there is no water of adsorption and water of crystallization present in Ce5 : LPP single crystal.

The melting point and decomposition point for pure and doped LPP crystals are shown in the table 3.1.
Figure 3.9  TG-DTA graph for Ce5 : LPP crystal

Table 3.1 Melting point and Decomposition point for pure and doped L-Prolinium Picrate single crystals

<table>
<thead>
<tr>
<th>S. No</th>
<th>Crystals</th>
<th>Melting point (°C)</th>
<th>Decomposition point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pure LPP</td>
<td>156</td>
<td>230</td>
</tr>
<tr>
<td>2</td>
<td>Nb10 : LPP</td>
<td>211</td>
<td>282</td>
</tr>
<tr>
<td>3</td>
<td>Nd10 : LPP</td>
<td>179</td>
<td>252</td>
</tr>
<tr>
<td>4</td>
<td>La5 : LPP</td>
<td>191</td>
<td>290</td>
</tr>
<tr>
<td>5</td>
<td>Ce5 : LPP</td>
<td>163</td>
<td>240</td>
</tr>
</tbody>
</table>

3.14 CONCLUSION

The dielectric properties of the grown crystals were studied and the different types of polarizations present in the grown crystals were confirmed by the dielectric studies. High purity of the grown crystals
was confirmed by the low dielectric loss values. The thermal stability of the grown crystals was studied TG-DTA analysis. The pure and doped L-Prolinium Picrate crystals studied in the present work, such as LPP, Nb10 : LPP, Nd10 : LPP, La5 : LPP and Ce5 : LPP are found to melt at 156 °C, 211 °C, 179 °C, 191 °C and 163 °C. The melting point and decomposition point of the doped L-Prolinium Picrate single crystals are found to be higher than that of the pure L-Prolinium Picrate single crystal. The results indicate that the doping improves the thermal stability of the LPP. The sharp weight loss and the corresponding narrow endothermic thermograms of these samples are indicative of phase pure and high quality crystalline nature.