CHAPTER 10

# DIELECTRIC PROPERTIES

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## 10.1 Introduction

A good insight into the electric field distribution within crystalline materials is gained by an investigation of their dielectric properties. The permittivity of materials is greatly vary in magnitude with variation in their structural properties. Through a study of the dielectric constant as a function of frequency, dc-bias, and temperature, etc., the different polarization mechanisms in materials such as atomic polarizations of lattice, orientation polarization of dipoles, space charge polarization, electronic, ionic polarizations,etc. are understood very easily. The study of dielectric property also helps in understanding defect concentration of crystalline materials. Considerable amount of work along these lines are carried out on a variety of alkaline earth compounds[1-4], on tin iodates[5], on europium fluoride[6], on Rb, K, Cs perchlorates[7], on transition metal oxides[8], and on lead hydrogen and lead nitrogen phosphate[9,10] yielding valuable information. Van Beck[11] reviewed the different procedures that are used for correlation

of the dielectric properties of powders with those of bulk materials. Such investigations also help in detecting structural transition in crystalline solids because of abrupt changes in dielectric properties take place at these transitions[12]. The permittivity of ferroelectric crystals is usually high due to polarization catastropy and is markebly dependent on the field strength and the temperature[13]. The large increase in dielectric constant by as much as a factor $10^4$, is found by Glazer[14] on heating ferroelectric $BaTiO_3$. In this chapter, efforts are made to understand the dielectric properties and an attempt is made to draw some qualitative conclusions, taking in view, the existing theories of various kinds of polarizations.

## 10.2 Experimental Procedure

The dielectric measurements are carrired out on RHT single crystals and the poly-crystalline samples in the form of pellets. To obtain pellet samples of RHT, the crystals grown in the laboratory are finely ground and the resulting powder are compressed into a die of diameter 1 cm.

and thickness 0.2 to 0.3 cm. under a pressure ranging from $9 \times 10^2$ to $17 \times 10^2$ kg $cm^{-2}$ using a hand operated hydrulic press. The geometrical dimensions of the crystalline sample is measured using a travelling microscope, of least count $10^{-3}$ cm.

The crystal or pellet, as the case may be, is mounted between the flat silver electrodes in an ordinary conducting cell. The silver paste is applied on both the experimental surfaces for firm contact. Prior to the dielectric measurements, the samples are heated and cooled for two to three cycles to get reproducible results and to avoid moisture. For studying temperature effect on dielectric measurements, the samples are then enclosed in a resistance heated furnace and the temperature of the sample is monitored using a platinum rhodium thermocouple ($\pm$ 1°C). The temperature of the sample is increased by regulating the input power. The rate of heating is maintained linear for a reasonably large range of temperature.

The dielectric measurements, i.e. measurements of capacitance is made in the temperature range 300 to 430 K, using a "GR 1820 Capacitance Bridge"

operating at frequencies, ranging from $10^2$ to $10^4$ Hz. The measured values of capacitance at different frequencies and temperatures are changed into permittivity ( $\epsilon$ ) using the relation :

$$\text{Permittivity } (\epsilon) = \frac{Cd}{A} \qquad (10.1)$$

where C, d and A represent the capacitance, thickness of the sample and the area of the opposite faces in contact with electrodes respectively. The dielectric constant ( $\epsilon'$ ) and losses ( $\epsilon''$ ) are determined as a function of different frequencies and temperatures. The accuracy in measurements of dielectric constant ( $\epsilon'$ ) is $\pm$ 3 % and in dielectric losses ( $\epsilon''$ ) is about $\pm$ 6 %.

## 10.3 Results

The variation of dielectric constant ( $\epsilon'$ ) and the dielectric losses ( $\epsilon''$ ) with different frequency at room temperature are shown in Figures 10.1 and 10.2 respectively. and the values are given in Table 10.1. From the Figure 10.1 it is clearly seen that at low frequency the

Table 10.1

Dielectric parameters of RHT samples for different frequency at room temperature

| Ob. No. | Frequency in kHz | Crystal | | | Pellet | | |
|---|---|---|---|---|---|---|---|
| | | Permittivity ($\times 10^{-9}$ F cm$^{-1}$) $\epsilon$ | Dielectric constant $\epsilon' = \epsilon/\epsilon_o$ | Dielectric loss $\epsilon''$ | Permittivity ($\times 10^{-9}$ F cm$^{-1}$) $\epsilon$ | Dielectric constant $\epsilon' = \epsilon/\epsilon_o$ | Dielectric loss $\epsilon''$ |
| 1. | 10 | 2.388 | 269.75 | 0.006 | 2.433 | 274.75 | 0.062 |
| 2. | 5 | 2.392 | 270.23 | 0.022 | 2.445 | 276.18 | 0.078 |
| 3. | 2 | 2.419 | 273.27 | 0.051 | 2.481 | 280.19 | 0.103 |
| 4. | 1 | 2.455 | 277.30 | 0.086 | 2.508 | 283.29 | 0.130 |
| 5. | 0.5 | 2.486 | 280.78 | 0.118 | 2.524 | 285.12 | 0.148 |
| 6. | 0.4 | 2.492 | 281.53 | 0.129 | 2.534 | 286.17 | 0.159 |
| 7. | 0.2 | 2.504 | 282.83 | 0.143 | 2.547 | 287.72 | 0.172 |
| 8. | 0.12 | 2.509 | 283.46 | 0.156 | 2.555 | 288.61 | 0.183 |

$\epsilon_o = 8.854 \times 10^{-12}$ F cm$^{-1}$

value of dielectric constant ( $\epsilon'$ ) is high and it decreases with increase in frequency and becomes frequency independent beyond $10^4$ Hz. Figure 10.2 shows the variation of dielectric losses ( $\epsilon''$ ) with frequency and it is similar to the variation of dielectric constant ( $\epsilon'$ ) with frequency. The dielectric loss ( $\epsilon''$ ) decreases with increase in frequency and its value is of the order of tens in the region where dielectric loss becomes frequency independent.

The variation of the dielectric constant ( $\epsilon'$ ) and the dielectric loss ( $\epsilon''$ ) with different temperatures (ranges from 300 to 430 K) and at a fixed frequency, 5 KHz, are shown in Figures 10.3 and 10.4 respectively. The nature of variation of $\epsilon'$ and $\epsilon''$ are same for single crystal and pellet RHT samples, in the studied range of temperature. The values of $\epsilon'$ and $\epsilon''$ are given in Table 10.2. It is observed that the values of $\epsilon'$ and $\epsilon''$ for pelletized samples are slightly greater than that of single crystals samples. The variation of $\epsilon'$ with pelletizing

Table 10.2

Dielectric parameters of RHT samples for different temperature at a fixed frequency of 5 KHz

| Particulars of the sample | Temperature T in K | Permittivity ($\times 10^{-9}$ F cm$^{-1}$) $\epsilon$ | Dielectric constant $\epsilon' = \epsilon/\epsilon_0$ | Dielectric loss $\epsilon''$ |
|---|---|---|---|---|
| Crystal | 305 | 2.426 | 274.02 | 0.058 |
| | 310 | 2.430 | 274.48 | 0.060 |
| | 315 | 2.430 | 274.48 | 0.062 |
| | 325 | 2.432 | 272.72 | 0.065 |
| | 340 | 2.435 | 275.03 | 0.068 |
| | 355 | 2.453 | 277.12 | 0.074 |
| | 380 | 2.507 | 283.21 | 0.104 |
| | 405 | 2.596 | 293.25 | 0.174 |
| | 420 | 2.727 | 308.05 | - |
| Pellet | 305 | 2.426 | 274.06 | 0.064 |
| | 310 | 2.435 | 275.01 | 0.066 |
| | 325 | 2.435 | 277.28 | 0.074 |
| | 335 | 2.472 | 279.18 | 0.082 |
| | 350 | 2.505 | 282.92 | 0.098 |
| | 370 | 2.557 | 288.84 | 0.132 |
| | 385 | 2.621 | 296.00 | 0.176 |
| | 400 | 2.714 | 306.58 | 0.218 |
| | 415 | 2.861 | 323.08 | - |

pressure is illustrated in Figure 10.5 and observed that it is independent of pelletizing pressure.

## 10.4 Discussion

The dielectric constant at low frequencies is dependent, on electronic, ionic, dipolar orientation and space charge polarizations. Contributions due to electronic and ionic polarizations are frequency independent whereas dipolar orientation and space-charge contributions are frequency dependent. Figures 10.1 and 10.2 clearly show that dielectric constants and losses are frequency dependent in the low frequency region. This behaviour may be attributed to space-charge polarization contribution which will usually depend on the purity and perfectionof the crystal[15,16].

Figures 10.3 and 10.4 show that the increase of dielectric constant takes place in two ways, namely,increases slowly upto 360 K and then more rapidly at higher temperatures. The slow increase in dielectric constant may be attributed to the increases of ionic polarization[17] with temperature.

The subsequent rapid increase beyond 360 K may be ascribed to space charge polarizations of thermally generated charge carriers[18]. In the pelleted form of the sample, the number of trapping centres increase and, therefore, the orientation polarization increase considerably which accounts for the large value of the dielectric constant compared to the single crystal sample. The relaxation time (t) for the sapce charge polarization of thermally generated charge carriers in the studied temperature range is given by equation[19] :

$$t = t_o \exp\left[\frac{H}{kT}\right] \qquad (10.2)$$

where H is the activation energy of the dielectric oscillator, and

k is the Boltzmann constant.

From the plot of ln $\epsilon'$ versus 1/T, (Figure 10.6) the activation energy of these oscillators are calculated.

## 10.5 Conclusions

1. The dielectric constant and the dielectric

losses of RHT samples are determined in the frequency range $10^2$ to $10^4$ Hz and in the temperature range from 300 to 430 K for a fixed frequency of 5 KHz.

2. The different polarizations that contributed to the dielectric constants of RHT samples are identified from the nature of variation of the dielectric constants with frequency and temperature.

3. Dielectric constants of pelletized samples are larger than that of crystalline sample.

4. For pelletized samples, the dielectric behaviour is independent of the pelletizing pressure.

5. The activation energy of the oscillator is calculated and found to be 1.03 eV.

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Captions of the figures

| | |
|---|---|
| Figure 10.1 | Variation of dielectric constant ( $\epsilon'$ ) with frequency at room temperature. |
| Figure 10.2 | Variation of dielectric losses ( $\epsilon''$ ) with frequency at room temperature. |
| Figure 10.3 | Variation of dielectric constant ( $\epsilon'$ ) with temperature at a fixed frequency 5 KHz. |
| Figure 10.4 | Variation of dielectric losses ( $\epsilon''$ ) with temperature at a fixed frequency 5 KHz. |
| Figure 10.5 | Variation of dielectric constant ( $\epsilon'$ ) with pelletizing pressure. |
| Figure 10.6 | A plot of ln $\epsilon'$ versus 1/T at 5 KHz frequency. |

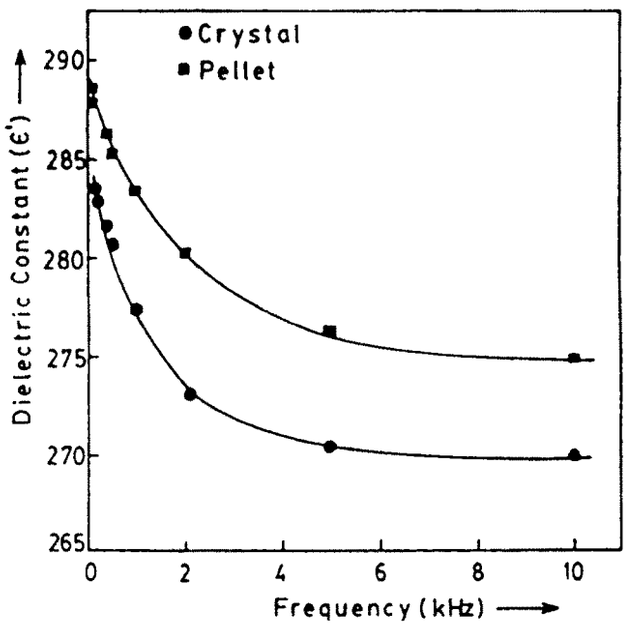


Fig. 10.1

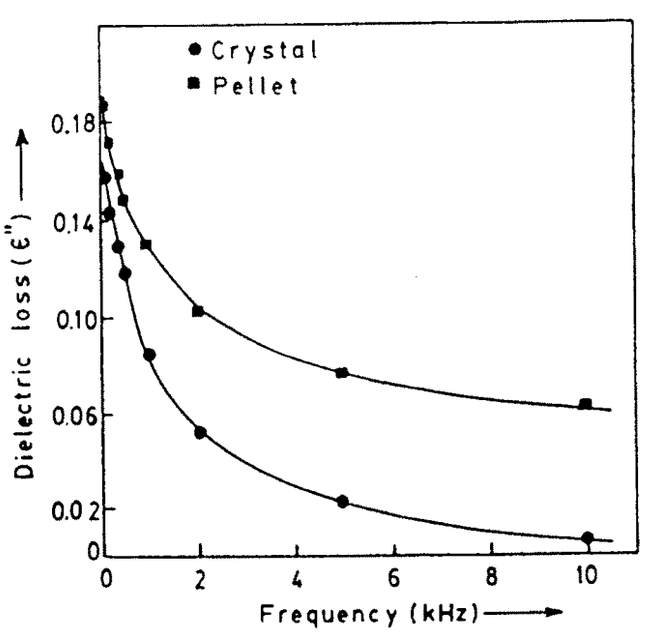


Fig. 10.2

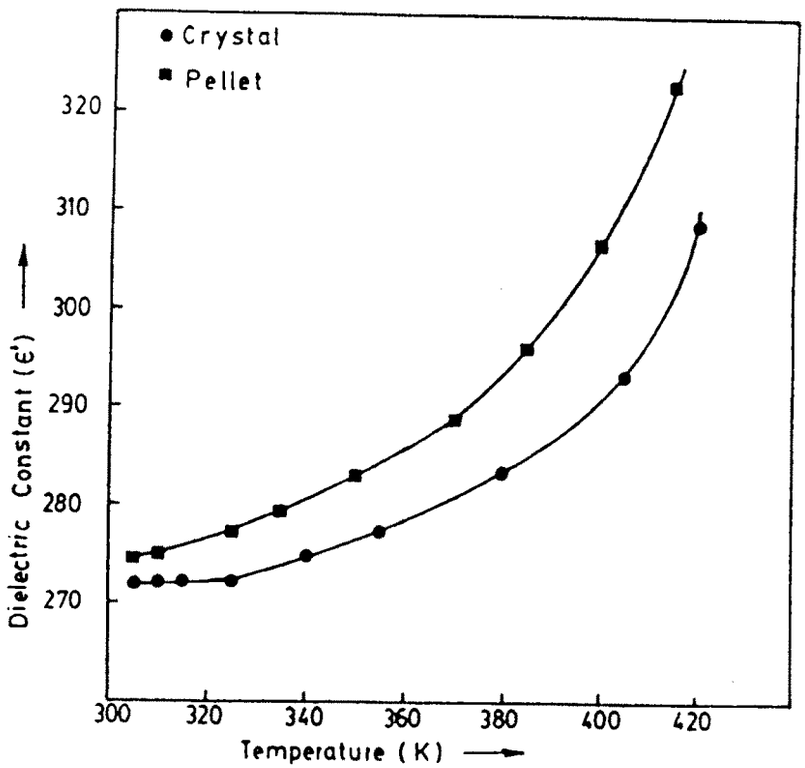


Fig. 10.3

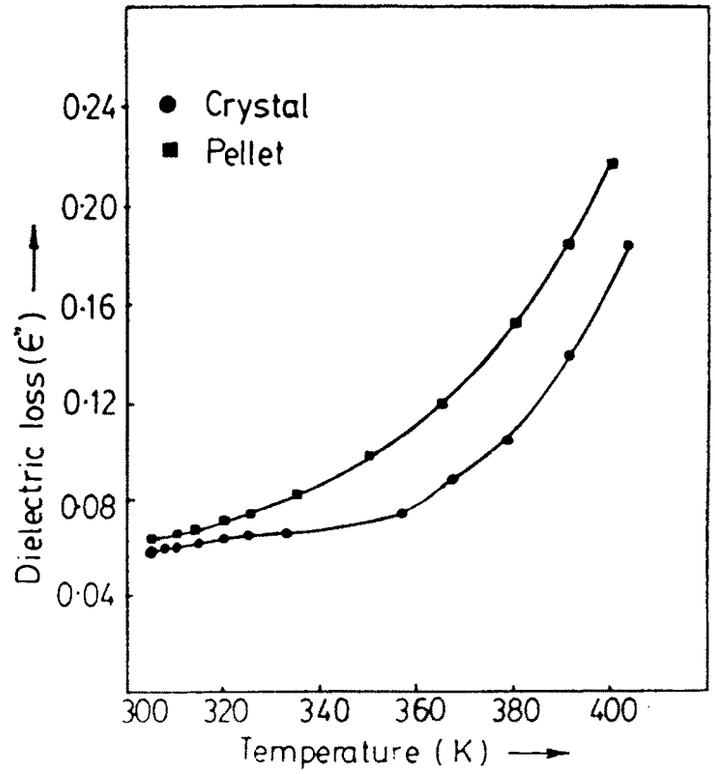


Fig. 10.4

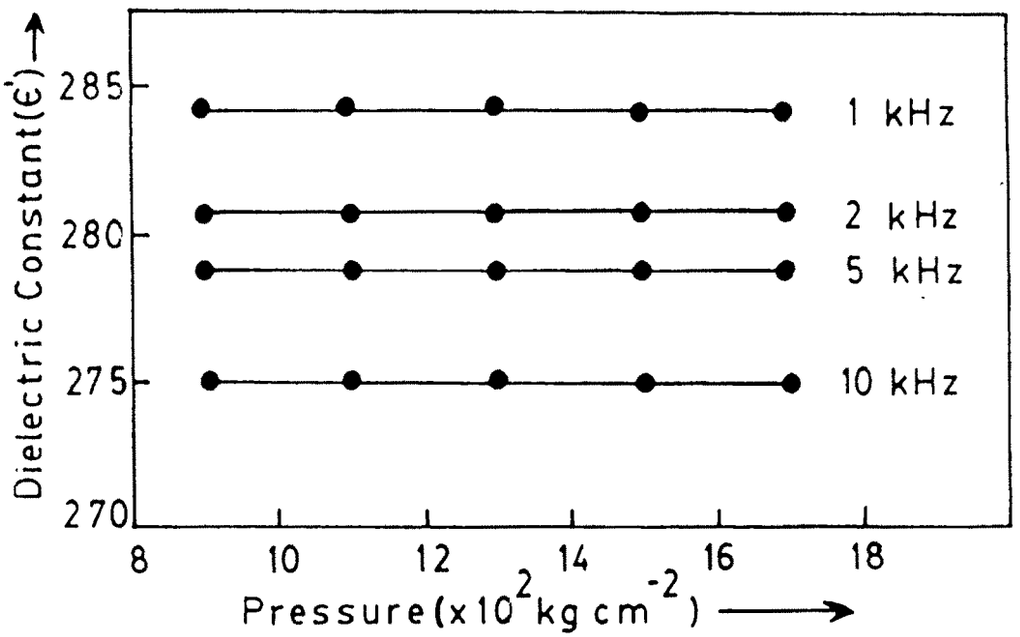


Fig. 10.5

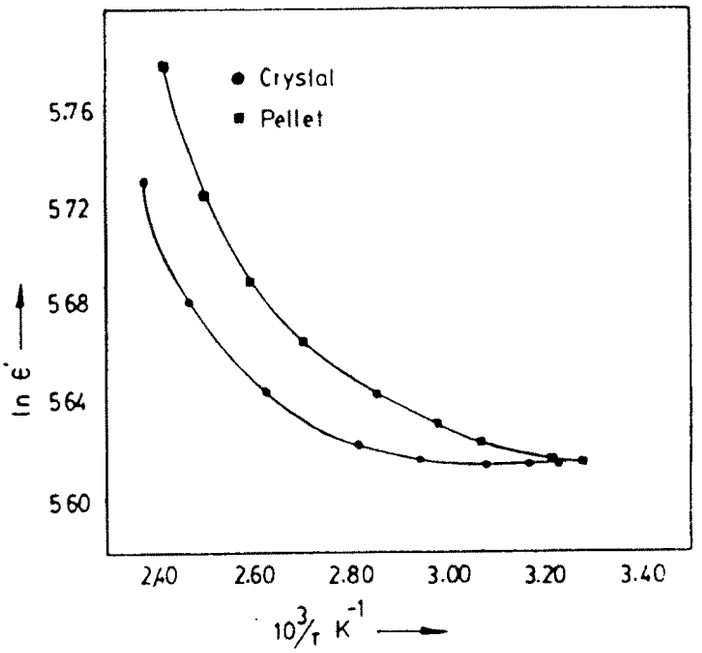


Fig. 10.6