Properties of $PrTiO_3$ at high temperature

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Abstract

Solid solution of the perovskite $PrTiO_3$ was synthesized by solid state reaction technique and characterized by XRD. Dielectric and electrical transport properties of the pressed pellet of $PrTiO_3$ is measured at high temperature (in the range of 350-1250K). The dielectric Constant (K') shows faster increase above a certain critical temperature. This is due to space charge effect of thermally generated charge carrier. The electrical transport study shows it is an electronic conductor and has no ionic conductivity over this temperature range. The majority charge carriers are holes throughout the studied temperature range and conduction mechanism is hopping type.

Key words: Dielectric constant (K'), Dielectric loss (K''), Electrical Conductivity(□) and seeback coefficient (s)

1. Introduction

Rare-earth materials are very important due to its interesting and useful properties. The abundance of these elements in our earth crust is comparable to many common and well-known materials. Therefore they as well as their compounds play a very significant role in our present and future life. The study of rare-earth compounds have been increasing interests because of their unique physical properties[1-3]. The compounds of rare-earth materials are typical perovskite compound with distorted cubic or orthorhombic unit cell at room temperature with four formula per unit cell[4]. These have been studies regarding the electrical conductivities and magnetic properties on few compounds[5-13], but no thorough investigation has been done on a paricular compound at high temperature. This lack of data prompted us to measure Dielectric constant (K'), Dielectric loss (K"), Electrical Conductivity (□) and Seeback coefficient (S) of $PrTiO_3$ in the temperature range of 350-1250 K.

2. Material preparation and Characterization

$PrTiO_3$ in powder form was prepared using their oxides Pr_6O_{11} (procured from Fluoka AG, Switzerland with stated purity of 99.9%) and TiO_2 (procured from Bonds, India with stated purity of 99.9%). The stoichiometric amounts of oxide and TiO_2 were taken to mix thoroughly. After mixing these materials were pressed and fired at 1400K for 50 hours with one intermediate grinding. The compound formation takes place with following solid state reaction.

$$Pr_6O_{11} + 6T_iO_2 \xrightarrow{1400K} 6\,PrTiO_3 + 5\,O\uparrow$$

The expected weight loss due to emission of oxygen was observed to be nearly same as expected for reaction. Now we record the XRD patterns of the PrTiO3 and all peaks have been assigned by proper hkl values. This confirmed that the prepared compound is PrTiO3 with specific structure.

3. Studies of Dielectric, Electrical Conductivity and Seeback Coefficient The compound was pressed at a pressure of 6.28x108Nm-2 to form pellet of circular cross section (area 90x10-4m2 and thickness = 0.50x10-2m). This pellet was then sintered in air for 24 hours at 1000K.

The pellet was covered with film of silver paint on the opposite surfaces to obtain a good contact was inserted between the two electrodes. The capacitance of the pellet was measured at different temperature employing LCRQ-meter (Aplab, India). Using these data and dimension of the pellet, dielectric constant (K') Dielectric loss (K"), electrical conductivity (□) and seeback coefficient(S) were calculated at different temperature.

The variation of log K' with absolute temperature (T) is shown in figure 1. It is seen from this figure that $PrTiO_3$ have high dielectric constant. The variation of log □ and seeback coefficient(S) with inverse of absolute temperature is shown in figure 2.

4. Results and Discussion

We have measured the dielectric constant of $PrTiO_3$ at frequency 1KHz as a function of temperature. The value of dielectric constant of $PrTiO_3$ at different temperatures has given in table 1.

Table -1

Temperature			
400K	**600K**	**800K**	**1000K**
190	**199**	**$1.10x10^4$**	**$6.31x10^4$**

The slow increase of K' below 600K indicates that the number of thermally generated charge carriers are small. The dielectric constant and dielectric loss shows a faster increase above certain critical temperature. It appears that the higher increase in K' at higher at higher temperature is due to space-charge polarization of thermally generated charge carriers.

The study of electrical conductivity (□) and seeback coefficient (S) gives an idea about conduction mechanism. It is seen from figure 2 that log □□vs T^{-1} plots are linear in specific regions with different slops. They can be divided in three linear regions. In each region they can be expressed by the relation.

$$\sigma=\sigma_0 \exp(-W/kT) \qquad (1)$$

Where □□□ is a constant and W is the energy corresponding to the slope of the straight lines. The value of □□ is a constant and W are different for different region. The evaluated values of W and T1, T2 (break temperatures) are given in table 2.

Table -2

$T<T_1$			$T_1<T<T_2$			$T<T_2$	
σ_0 ($\Omega^{-1} m^{-1}$)	W (ev)	T_1 (K)	σ_0 ($\Omega^{-1} m^{-1}$)	W (ev)	T_2 (K)	σ_0 ($\Omega^{-1} m^{-1}$)	W (ev)
3.97×10^{-5}	0.02	671	3.12×10^{2}	0.95	1000	1.15×10^{6}	1.65

The seeback coefficient (S) of the pressed pellets of $PrTiO_3$ has been measured in the temperature range 350-1250K. We adopt a sign convention for S, in which the sign of seeback coefficient is the sign of potential at hot end compared to cold end. In this convention, the sign of charge carriers is opposite to the sign of seeback coefficient. Similar convention has been used by many workers [14-15]. The result of the measurement presented in figure 2 as S vs T^{-1} plot. The S vs T^{-1} plot has three linear regions and the slope in each linear region is very small. The value of S in each linear region can be expressed by the following relation.

$$S=\square T^{-1} + H \qquad (2)$$

Where □is the slope of S Vs T^{-1} plot and H is constant whose value is equal to the intercept on S-axis. The evaluated values of □□and H for different temperature region of the material with the break temperature (T_B) given in table 3.

Table -3

$T<T_1$		$T_1<T<T_2$			$T<T_2$		
η(v)	H(mv K^{-1})	T_1(K)	η(v)	H(mv K^{-1})	T_2(K)	η(v)	H(mv K^{-1})
-0.03	-0.79	670	-0.02	-0.24	990	-0.13	-0.21

5. Conclusion

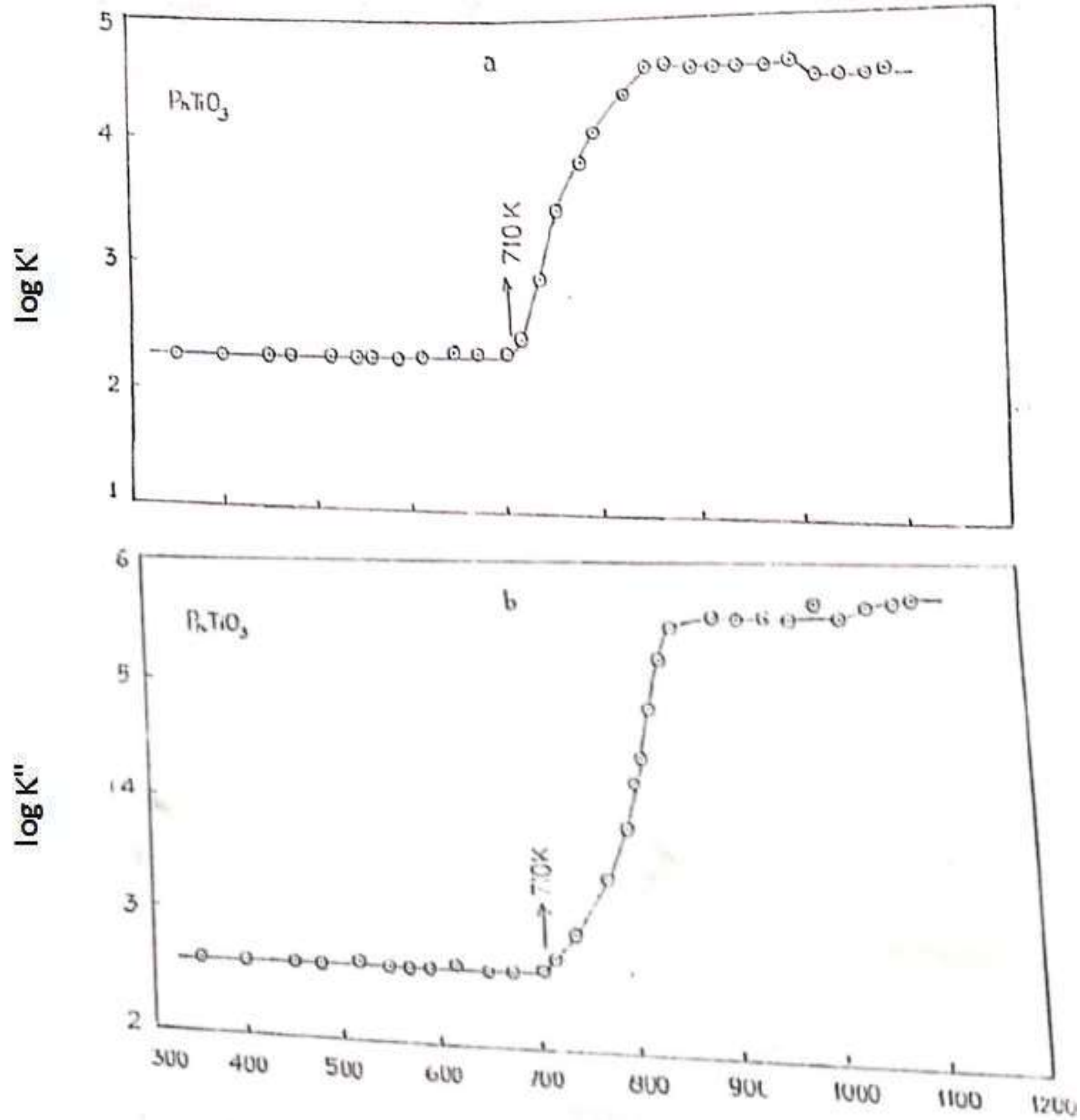
On the basis of the experimental studies we draw following conclusions -

(1) The faster increase of K' and K" at higher temperature is due to space charge effect of thermally generated charge carriers.

(2) It is typical semiconducting material with electrical conductivity value 3.97 $x10^{-5}$ □□□□□m□□□around 400K which becomes of the order of 1.15 $x10^{-6}$ □□□□□m□□□around 1200K.

(3) $PrTiO_3$ is essentially electronic conductor with almost no ionic conductivity over the temperature range (350-1200K)

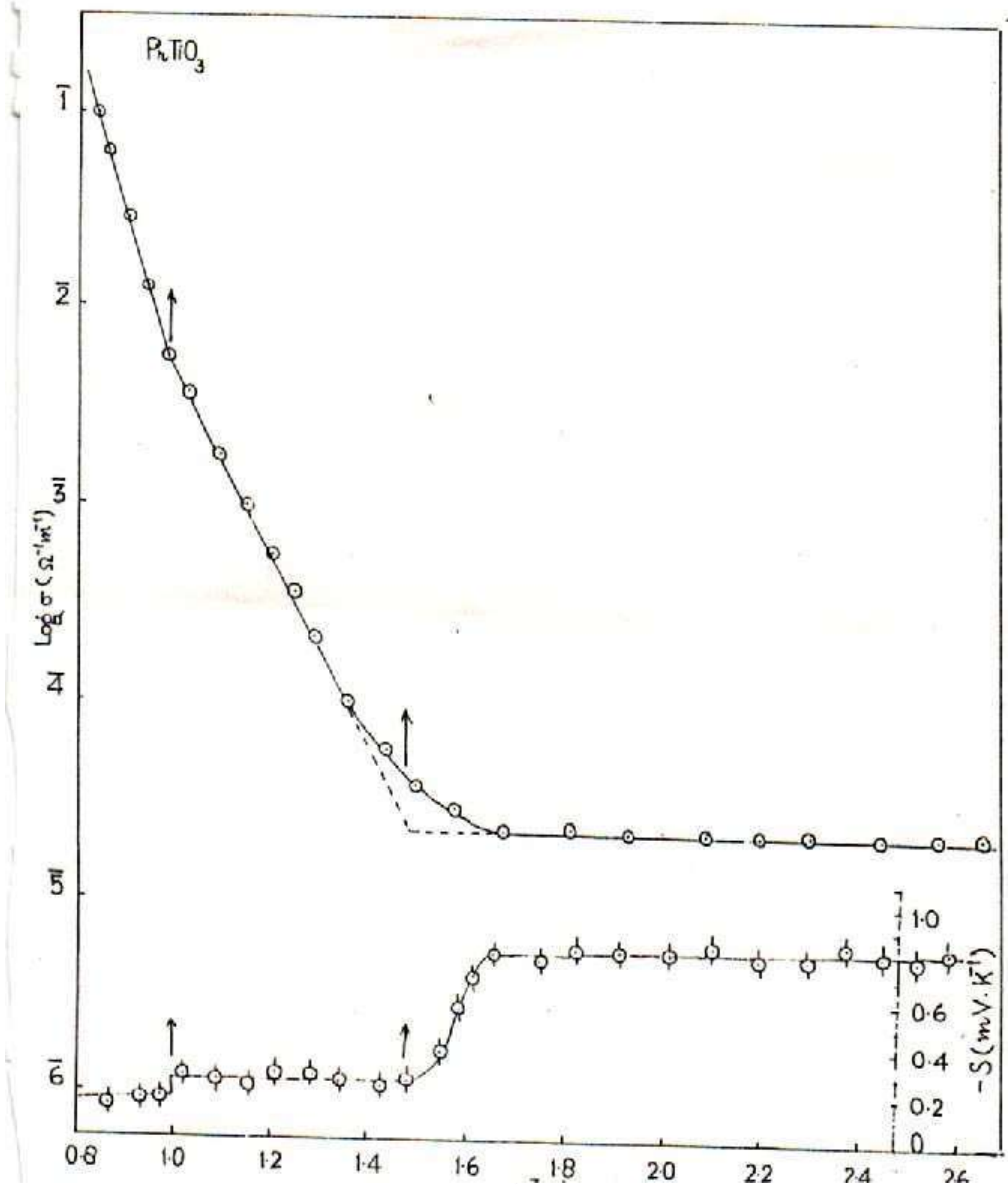
(4) The majority charge carriers are holes throughout the studied temperature range. Above 1000K, the intrinsic band conduction is dominates conduction mechanism. Below T=1000K, conduction mechanism is hoping type.



T (K)

Fig 1- (a) Plots of logarithm of dielectical constant (log K') Vs absolute temperature (T) for praseodymium titanate.

(b) Plots of logarithm of dielectical loss (Log K") vs absolute temperature (T) for praseodymium titanate.



10^3T^{-1}(K')

Figure 2- Plots of logarithm of electrical conductivity(logo) and seeback coefficient (S) vs inverse of absolute temperature (T) for praseodymium titanate.

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