EXPERIMENT NO. 10

Object: Study of dielectric (constant) behavior and determination of Curie's temperature of ferroelectric ceramics.

Apparatus:

Sample of barium titanate ($BaTiO_3$), apparatus that includes probe arrangement, sample, oven, oven controller and digital capacitance meter.

Formula used:

The value of the dielectric constant ε, of the barium titanate sample is given by

$$\varepsilon = \frac{C}{C_0} \qquad (1)$$

Where C is capacitance of the ferroelectric ceramic ($BaTiO_3$) in between the plates with area, A and thickness, t and C_0 (= ε_0 A/t) is capacitance of vacuum placed in between the plates. ε_0 is a universal constant, called permittivity of free space (vacuum) and its value is 8.85X 10^{-3} pF/mm.

Procedure:

1. Connect the probe leads to the capacitance meter
2. Connect the oven to main unit and put it in off position.
3. Switch on the main unit and note the value of capacitance. It should be a stable reading.
4. Switch on the temperature controller and approx adjust the set temperature. The green LED would light up indicating the oven is ON and temperature would start rising.
5. Controller of oven would switch off or on power corresponding to set-temperature. In case it is less then desired the set temperature may be increased or vice-versa.

Observations and Calculations:

Sample: Barium titanate

Area (A): _____ mm^2

Thickness (t):_____ mm

Permittivity of space (ε_0): 8.85X 10^{-3} pF/mm

[C] Readings for determination of ε :

S.No.	**Temperature(T) (°C)**	**Increasing tempertaure**		**Decreasing temperature**	
		Capacitance(C) (pF)	**Dielectric constant (ε)**	**Capacitance(C) (pF)**	**Dielectric constant (ε)**
1.	**20**				
2.	**25**				
3.	**30**				
4.	**35**				
.	**.**				
.	**.**				
.	**150**				

Plot the graphs between dielectric constant and temperature for increasing and decreasing temperature. **Temperature corresponding to maxima is Curie temperature.**

Result:

From both graphs, Curie temperature (T_c) ……....± ΔT.°C and corresponding value of dielectric constant (ε_m) is ……….± Δε

Precautions:

1. The spring loaded probe should be allowed to rest on the sample gently else it will damage the surface of sample.
2. Reading near curie's temperature should be taken at small intervals, say 1°C.
3. The reading of capacitance meter should be taken when oven is off i.e. when LED goes off.

Sources of error:

1. There may be some pickups if reading is not taken in oven off status.
2. Reading near Curie's temperature is taken at small intervals.
3. Due to wear and tear of the sample.

Maximum Probable error:

C_0 is constant, therefore maximum probable error (using (1)):

$$\Delta\varepsilon = \varepsilon\frac{\Delta C}{C}; \Delta C = 1pF$$

For Curie temperature, the maximum probable error, ΔT will be the temperature interval near the T_c.

Theory:

Ferroelectric Phase Transitions and Curie-Weiss Behavior

All ferroelectric materials possess a characteristic transition temperature, called Curie temperature T_o. At a temperature $T \geq T_o$, they do not exhibit ferroelectricity. On decreasing the temperature through the Curie point, a ferroelectric undergoes a phase transition from a non-ferroelectric (paraelectric) phase to a ferroelectric phase. If there are more than one ferroelectric phases, the temperature at which the crystal transforms from one ferroelectric phase to another is called the transition temperature.

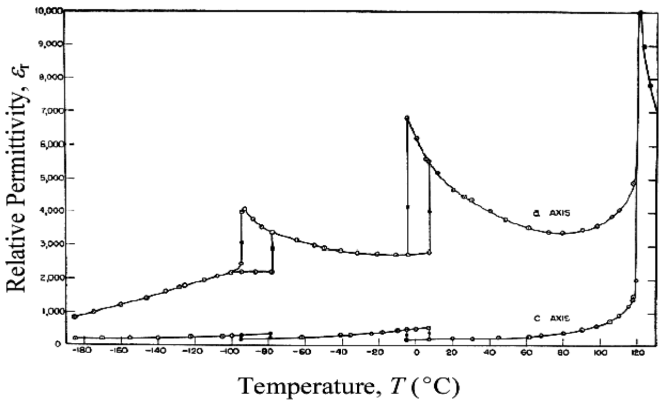

Fig.1 Relative permittivity measured along the a and c directions of a poled tetragonal $BaTiO_3$ crystal versus temperature in a ferroelectric [after, W. J. Merz, Phys. Rev. 95, 690 (1954).]

Fig. 1 shows the variation of the relative permittivity (ε_r) (or dielectric constant) with temperature for $BaTiO_3$ ferroelectric crystal as it is cooled from its non-ferroelectric (or paraelectric) cubic phase to the ferroelectric tetragonal, orthorhombic, and rhombohedral phases. Near the Curie point or phase transition temperatures, thermodynamic properties including dielectric, elastic, optical, and thermal constants show an anomalous behaviour. This is due to a distortion in the crystal as the phase changes. The temperature dependence of the dielectric constant above the Curie point ($T>T_o$) in most ferroelectric crystals is governed by the Curie-Weiss law :

$$\varepsilon = \varepsilon_o + \frac{C'}{T - T_o} \text{............}(1)$$

where ε is the permittivity of the material, ε_0 is the permittivity of the vacuum, C' the Curie constant and T_0 is the Curie-Weiss temperature.

Perovskite group

Perovskite is a family name of group of materials and the mineral name of $CaTiO_3$ having a structure of the type ABO_3 (Fig.2). Many piezoelectric (including ferroelectric) ceramics such as Barium Titanate ($BaTiO_3$), Lead Titanate ($PbTiO_3$), Lead zirconate titanate (PZT), Lead Lanthanum Zirconate Titanate (PLZT), Lead Magnesium Niobate (PMN), Potassium Niobate ($KNbO_3$), Potassium sodium Niobate and Potassium Tantalate Niobate have a perovskite type structure.

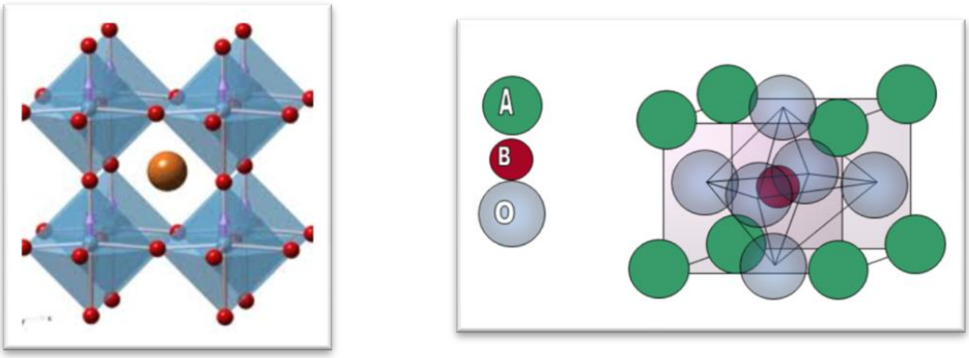

Fig. 2 Two representations of Perovskites structure.

Applications of ferroelectric materials

Ferroelectric ceramics have been found to be useful for various practical application such as high dielectric constant capacitors, piezoelectric sonar and ultrasonic transducers, radio and communication filters, pyroelectric devices, medical diagnostic transducers, positive temperature coefficient sensors, ultrasonic motors and electrooptic light valves.

Viva-voce:

1. **Define dielectrics and ferroelectrics.**
2. **Differentiate insulator and dielectric materials.**
3. **Corelate the above terms with diamagnetism and ferromagnetism.**
4. **Define ceramics and differentiate with electro-ceramic.**
5. **Explain pervoskite structure.**
6. **At temperature greater than Curie temperature, phase of ferroelectric ceramic is_________________ (paraelectric/ ferroelectric).**
7. **Define rattling space in perovskite structure.**
8. **How rattling of Ti-ion(+4) is related to ferroelectric phase?**
9. **State Curie-Weiss law.**
10. **From the data you have collected , can you find Curie constant. If Yes, then how?**
11. **What do you mean by Lead free materials?**
12. **What are the applications of ferroelectric materials?**
13. **What is the relation between piezoelectricity and ferroelectricity?**

References:

1. S. O. Pillai, Solid State Physics, New Age International (P) ltd., Publishers, Delhi (2005).

2. Charles Kittel, Introduction to Solid State Physics, Wiley, New York (2003).

Useful links for e-references:

en.wikipedia.org/wiki/Relative permittivity

en.wikipedia.org/wiki/**Dielectric**