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Offering our little learning to the infinite ocean of knowledge…

Synthesis, Characterizations and Application of $BaTiO_3$ Ceramics

Introduction

A ceramic is a solid material comprising an inorganic compound of metal, non-metal or ionic and covalent bonds. Common examples are earthenware, porcelain, and brick.

Crystalline ceramics

Crystalline ceramic materials are not amenable to a great range of processing. Methods for dealing with them tend to fall into one of two categories – either make the ceramic in the desired shape, by reaction *in situ*, or by "forming" powders into the desired shape, and then sintering to form a solid body. Ceramic forming techniques include shaping byhand,slip casting, tapecasting,injection molding, dry pressing, and other variations.

Non-crystalline ceramics

Non-crystalline ceramics, being glass, tend to be formed from melts. The glass is shaped when either fully molten, by casting, or when in a state of toffee-like viscosity, by methods such as blowing into a mold. If later heat treatments cause this glass to become partly crystalline, the resulting material is known as a glass-ceramic, widely used as cook-tops and also as a glass composite material for nuclear waste disposal.

$BaTiO_3$ –An Introduction

Barium titanate is an inorganic compound with chemical formula $BaTiO_3$. Barium titanate appears white as a powder and is transparent when prepared as large crystals. It is a ferroelectric ceramic material that exhibits the photorefractive effect and piezoelectric properties.Barium titanate is one of the most important ferroelectric materials which have many applications. It belongs to a Perovskite structure as a ceramic. The wide range of applications of $BaTiO_3$ includes preparing multi-layer ceramic capacitors (MLCCs), electro optical devices, PTC and NTC resistors, piezo-electric actuators, transducers and chemical gas sensors.

Characteristics of $BaTiO_3$

MOLAR MASS	233.192g
DENSITY	6.02g/cc
MELTING POINT	1625°C
BAND GAP	3.2eV

Synthesis Of Ceramics

Different methods are employed for the preparation of ceramic powders with desiredproperties. These can be divided into three basic types:

i) Mechanical - *Mechanical methods* use coarse-grained materials that have generally been derived from naturally occurring minerals. They are subjected to a series of processes through which the particle size is gradually reduced

ii) Chemical - *Chemical methods,* such as sol-gel processing, offer several advantages over mechanical methods because they allow exceptional control over particle morphology and purity.

iii) Vapor phase- Vapor-*phase processes* can be used to produce ceramic powders.They tend to be expensive, but offer many advantages, such as the ability to produce particles of non-oxides.

We synthesized Barium titanate using solid state reaction route.

The most common method used for preparing ceramic powder is the solid-state reactionroute, because it is the simplest, easier, and cost effective to make bulk amount of ceramics.The conventional ceramic approach involves basically four steps:

(a) Intimate mixing of the stoichiometric amounts of various reactants,
(b) High temperature firing/calcination
(c) Intermediate grinding and followed by
(d) Sintering.

a) Weighing and Mixing of Raw Materials

The first step in the solid-state reaction method is to weigh the different oxides/carbonates, which act as reactants, according to the stoichiometry.The presence of impurities or any other phases may affect the formation of the required phase pure ceramic compound. Generally some of the oxides of reactants contain traces of their corresponding carbonates, which will affect the dielectric properties of the bulk material. Also, the presence of moisture may affect the stoichiometry. In order to avoid such problems, the oxides of the reactants are annealed above 100 °C for about one hour before weighing. The raw materials constituting the batch must be intimately mixed to maintain the homogeneity. The mixing and milling eliminates agglomerates, reduces particle size, and increases the points of contacts between reactants. In the milling process, the particles experience mechanical stresses at their contact points due to compression, impact, or shear with the milling medium or with other particles.The mechanical energy supplied to the particle is used not only to create new surfaces but also to produce other physical changes in the particles.

b) Calcination

Calcination is the intermediate heat treatment at a lower temperature prior to sintering. The purpose of calcination is to promote sufficient interaction between the constituents to form the

material. It is the process of subjecting a substance to the action of heat, but without fusion, for the purpose of causing some thermal decomposition, phase transition or the removal of volatile fraction. As a result, the calcined powder is found to be reduced in volume or shrinkage occurs. The calcination conditions such as temperature, duration, and heating atmosphere are important factors controlling densification during sintering.

c) Grinding and Shaping

The grinding of calcined powder helps to reduce the particle size and hence to increase thesurfacearea to promote densification during sintering. The homogeneity of the powders used for sintering has very much effect on the sintering process and grain growth of the final material, which strongly affects the dielectric losses especially due to space charge polarization. Thus, it is better to grind well the calcined specimen before the sintering process. The shape of the ceramic is formed using the method of dry pressing.It consists of three basic steps: filling the die, compacting the contents and ejecting the pressed solid. The pressure is applied either uniaxially or isostatically. Binder is a component that is added to hold the powder together while we shape the body.Polymers are often ideal binders. Poly vinyl alcohol (PVA) and Poly Ethylene Glycol (PEG) are the most popular binders for dry pressing ceramics

d) Sintering

Sintering is the process of transforming a powder into a solid body using heat. The idea of sintering is to join particles together without melting them. It is likely that the solid body thus formed will not be 100% dense, so it will contain pores.

Characterization Techniques

The techniques adopted to characterize the material synthesized are: X-ray diffraction (XRD), UV - visible spectroscopy, Fourier transforms infrared spectroscopy (FT-IR), scanning electron microscopy (SEM), Transmission Electron Microscopy (TEM) and surface area analysis (BET). In this synthesis X ray diffraction technique was used.

X-Ray Diffraction Studies

Bragg made the first direct determination of a crystal structure using X-ray diffraction(XRD), which is still generally the most accurate method for characterizing crystal symmetry. Powder XRD is one of the most widely used techniques to characterize ceramics. The material is in the form of a powder so that the grains will be present in all possible orientations so that all *d* spacing will appear in one pattern. Now the data are in the form of a plot (known as a diffractogram) of counts or intensity versus scattering angle.Powder XRD can be used to estimate the sizes of particles.In Powder Diffraction method,a powder may be composed of fine crystallites. These crystallites are (assumed to

be) randomly oriented to one another.If the powder is placed in the path of a monochromatic X-ray beam, diffraction will occur from the planes in those crystallites that are oriented at the correct angle to fulfill the Bragg condition,

$$2d\sin\theta=n\lambda$$

where d is the interplanar spacing ,
θ is the diffraction angle ,
n is the order of diffraction ,
λ is the wavelength of x-ray .
The diffracted beams make an angle of 2(theta) with the incident beam.
From the XRD data, the lattice parameters are calculated using the formula

$$(1/d_{hkl})^2 = (h^2 + k^2 + l^2) / a^2$$

(Interplanar spacing (d) and hkl planes can be found from XRD data)

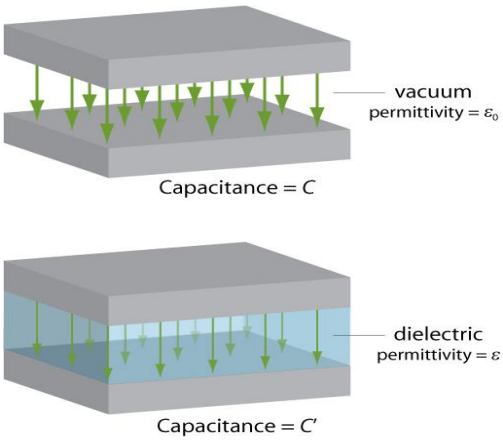
Dielectric and Curie temperature Measurement Of Ferroelectric Ceramics

Dielectrics

Dielectric or electrical insulating material are understood as the material in whichElectrostatic fields can persist for a long time. These materials offer a very high resistanceto the passage of electric current under the action of the applied direct-current voltage.Thus, they sharply differ in their basic electrical properties from conductive materials.Layers of such substances are commonly inserted into capacitors to improve theirPerformance and the term dielectric refer specifically to this application.The use of a dielectric in a capacitor presents several advantages. The simplest of these is that the conducting plates can be placed very close to one another without risk of contact. Also, if subjected to a very high electric field, any substance will ionize and become a conductor. Dielectrics are more resistant to ionization than air, so a capacitor containing a dielectric can be subjected to a higher voltage. Also, dielectric increases the capacitance of the capacitor. Capacitance can be calculated if the geometry of the conductors and the dielectric properties of the insulator between the conductors are known.
As a quantitative example consider the capacitance of a capacitor constructed of two parallel plates both of area '*A'* separated by a distance *d*. If *d* is sufficiently small with respect to the smallest chord of *A*, there holds, to a high level of accuracy:

$$C=\varepsilon_0\varepsilon_r A/d$$

where
'C' is the capacitance, in farad;
'A' is the area of overlap of the two plates, in square meter;
'ε_0'is the permittivity of free space($\varepsilon_0 \approx 8.854\times10^{-12}$ F·m^{-1}); and
'*d*' is the separation between the plates, in meters;



$\kappa = C'/C$ $\quad$ $\kappa = \varepsilon/\varepsilon_0$

Capacitor

An electric field polarizes the molecules of the dielectric, producing concentrations of charge on its surfaces that create an electric field opposed (antiparallel) to that of the capacitor. Thus, a given amount of charge produces a weaker field between the plates than it would without the dielectric, which reduces the electric potential. Considered in reverse, this argument means that, with a dielectric, a given electric potential causes the capacitor to accumulate a large charge.

Dielectric Constant (K)

The dielectric constant of a material provides a measure of its effect on a capacitor. It is the ratio of the capacitance of a capacitor containing the dielectric to that of an identical but empty capacitor. The dielectric constant of a dielectric material can be defined as the ratio of thecapacitance using that material as the dielectric in a capacitor to the capacitance using vacuum as the dielectric.

$$\mathbf{K=C/C_0 \text{ (or)}}$$
$$\mathbf{K=\varepsilon/\varepsilon_0}$$

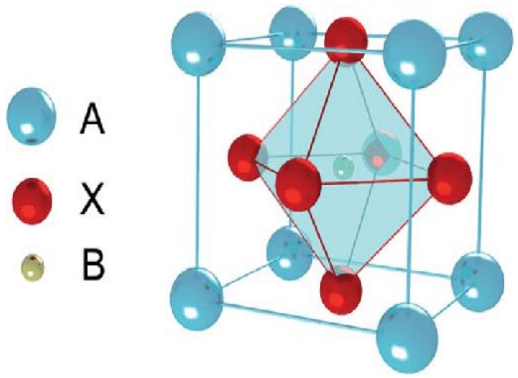
where,

'C' is the capacitance of the capacitor with dielectric (Farad)
'C_0' is the capacitance of the capacitor with vacuum (Farad)
'ε' is the permittivity of dielectric
'ε_0'is the permittivity of vacuum

Perovskite Structure

Perovskite is a family name of a group of materials and the mineral name of calcium titanate($CaTiO_3$) having a structure of the type ABO_3. 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 ($K_xNa_{1-x}NbO_3$), and Potassium Tantalate Niobate (KTa_xNbO_3) have a perovskite type structure (in the para-electric state) with chemical formulaABO_3.As conventionally drawn, A-site cation occupy the corners of a cube, while B site cation sit at the body center. Three oxygen atoms per unit cell rest on the faces. The lattice constant of the perovskite is always close to the 4 due to rigidity of the oxygen octahedral network and the well-defined of oxygen ionic radius of 1.35 Å. A practical advantage of the perovskite structure is that many different cation can be substituted on both the A and B sites without drastically changing the overallstructure. Complete solid solutions are easily formed between many cation, often acrossthe entire range of composition. Even though two cation are compatible in solution, theirbehavior can be radically different when apart from each other. Thus, it is possibleto manipulate a material's properties such as Curie Temperature or dielectric constantwith only a small substitution of a given cation.



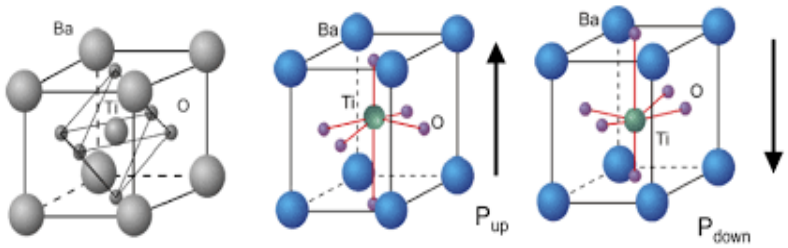
ABO_3 Perovskite Structure

Curie's temperature

All ferroelectric material, i.e. materials exhibiting permanent electric polarization which varies in strength with the applied electric field,has a transition temperature called the Curie point (T_c). At a temperature $T > T_c$ the crystal does not exhibit ferroelectricity, while for $T < T_c$ it is ferroelectric. On decreasing the temperature through the Curie point, a ferroelectric crystal undergoes a phase transition from a non-ferroelectric (paraelectric) phase to a ferroelectric phase.

Phase transition in barium titanate ($BaTiO_3$, BT)

Barium Titanate ($BaTiO_3$) has a ferroelectric tetragonal phase below its CuriePoint of about 130°C and paraelectric cubic phase above Curie point. The temperature at the Curie point appreciably depends on the impurities present in the sample and theSynthesis processes. In the paraelectic cubic phase, the center of positive charges (Ba^{2+}, Ti^{4+}) coincide with the center of negative charges (0-2ion) and on cooling below T_c, a tetragonal phase develops where the center of Ba2+ and Ti4+ ions are displaced relative to the 02-ions, leading to the formation of electric dipoles. The dielectric properties of $BaTiO_3$ are found to be dependent on the grain size.



$BaTiO_3$ Structure during Phase Transition

Effect of crystal structure on Dielectric Constant

More the available polarization mechanisms a material possesses, the larger its dielectric constant will be. For example, materials with permanent dipoles have larger dielectric constants than similar, non-polar materials. For polar structures, the magnitude of the dipole also affects the magnitude of polarization achievable, and hence the dielectric constant. Crystals with non-Centro symmetric structures such as barium titanate have especially large spontaneous polarizations and so correspondingly large dielectric constants.

Temperature Dependent Dielectric Constant

For materials that possess permanent dipoles, there is a significant variation of the dielectric constant with temperature. This is due to the effect of temperatureon orientational polarisation.However, this does not mean that the dielectric constant will increase continually as temperature is lowered. There are several discontinuities in the dielectric constant as temperature changes. First of all, the dielectric constant will change suddenly at phase boundaries. This is because the structure changes in a phase change and, as we have seen above, the dielectric constant is strongly dependent on the structure. Whether κ will increase or decrease at a given phase change depends on the exact two phases involved.

Loss in dielectrics

An efficient dielectric supports a varying charge with minimal dissipation of energy in the form of heat. There are two main forms of loss that may dissipate energy within a dielectric. In conduction loss, a flow of charge through the material causes energy dissipation. Dielectric loss is the dissipation of energy through the movement of charges in an alternating electromagnetic field as polarization switches direction.Dielectric loss is utilized to heat food in a microwave oven.

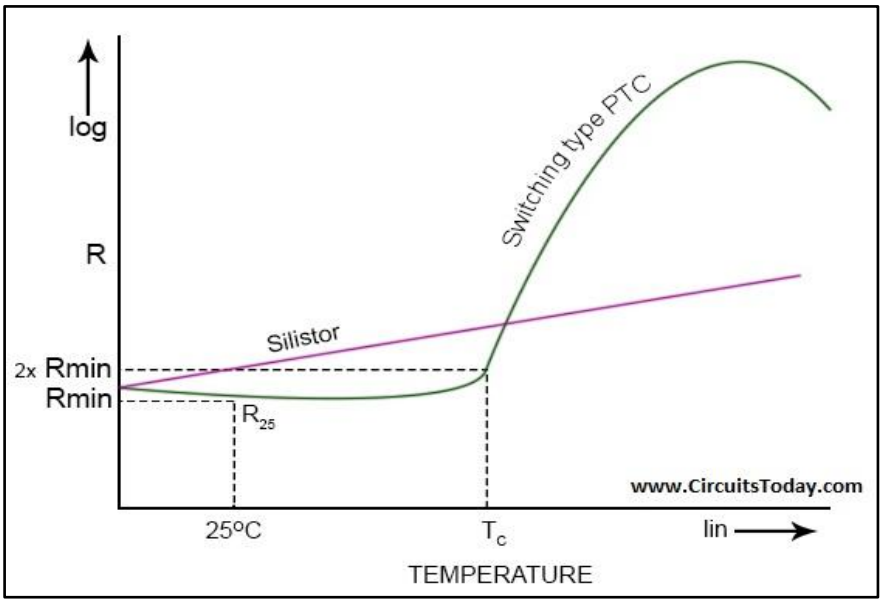
Dependence of resistance of ceramic on Temperature

Thermistor is a temperature controlled resistor. The resistance offered by this solid state temperature controlled device depends on the ambient temperature.As already discussed, temperature dependence of a resistor is defined by its temperature coefficient. According to this, the thermistor are classified into two categories based on the type of temperature coefficient- negative temperature coefficient and positive temperature coefficient.

NTC or negative temperature coefficient thermistor is a device whose resistance decreases with increase in temperature.

PTC or Positive temperature coefficient thermistors are those resistors whose resistance increases with increase in ambient temperature.

PTC Thermistors are grouped according to their structure, materials used and their manufacturing process. PTC Thermistorbelongs to the first group(according to material used and structure). They use silicon as the semiconductor and have linear characteristic. Switching type PTC Thermistor belongs to the second category (according to the manufacturing process). This Thermistor has a nonlinear characteristic curve. As the switching type PTC Thermistor gets heated, initially the resistance starts to decrease, up to a certain critical.This temperature is called the switch, transition or Curie temperature. The switch temperature is the temperature at which the resistance of switching type PTC thermistor starts to rise rapidly. The Curie temperature is most of the time defined as the temperature at which the resistance is twice the value of the minimum resistance.

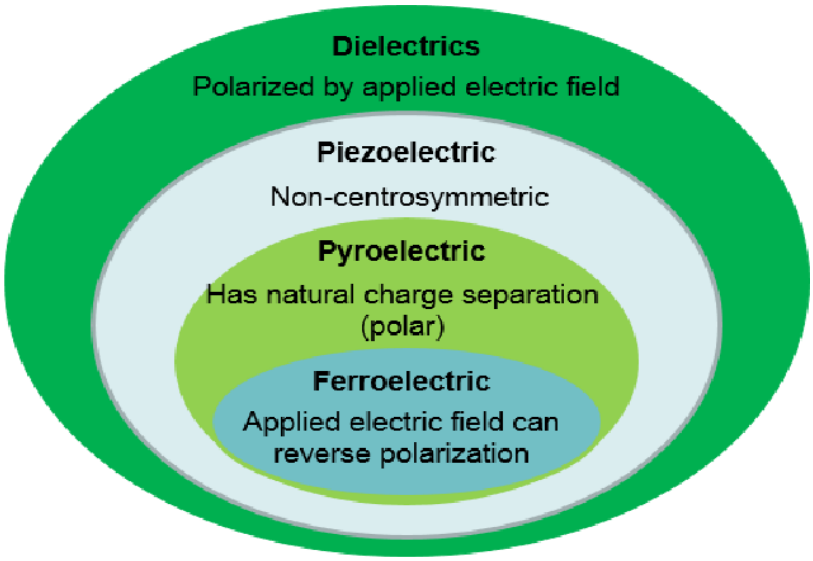


Resistance versus temperature characterstics

Piezoelectric Effect

Piezoelectric Effect is the ability of certain materials to generate an electric charge inresponse toapplied mechanical stress. All piezoelectric materials are non-conductiveinorder for the piezoelectric effect to occur and work. Some examples of piezoelectricmaterials are PZT (also known as lead zirconate titanate), barium titanate, and lithium niobate. These man-made materials have a more pronounced effect (better material to use) than quartz and other natural piezoelectric materials.Barium titanateis a ferroelectric ceramic material with piezoelectric properties.Piezoelectrics are the class of dielectric materials which can be polarized, in addition to an electric field, also by application of a

mechanical stress.Before subjecting the material to an external stress, the centers of the negative and positive charges of each molecule coincide—resulting into an electrically neutral molecule as indicated. However, in presence of an external mechanical stress the internal reticular can be deformed, thus causing the separation of the positive and negative centers of the molecule and generating little dipoles. As a result, the opposite facing poles inside the material cancel each other and fixed charges appear on the surface. That is to say, the material is polarized and the effect called direct piezoelectric



effect. This polarization generates an electric field that can be used totransform the mechanical energy, used in the material's deformation, into electrical energy. Also, all ferroelectric materials are piezoelectric. But, all piezoelectric materials need not be ferroelectric.

Experiment 1

Synthesis of $BaTiO_3$ Pellet by Solid State reaction

$$BaCO_3 + TiO_2 \longrightarrow BaTiO_3 + CO_2$$

Aim To synthesize a $BaTiO_3$ pellet using solid state reaction.

Materials Required

1.693g of $BaCO_3$, 0.686g TiO_2, Acetone, mortar & pestle, alumina crucible, weighing balance, spatula, furnace with temperature up to 1300^oC and Xpert Highscore software for XRD analysis.

Experimental Procedure

1) 1.693g of $BaCO_3$ and 0.686g TiO_2 were mixed using mortar pestle uniformly.

2) After the mixture was mixed homogeneously, Acetone was added to enhance homogeneity which was followed by further mixing.

3) IR lamp was used to provide heat to the mixture in order to avoid moisture and aid in evaporation of Acetone.

4)The mixture was carefully transferred to the alumina crucible.

5)The mixture was put in a furnace for calcination at 800 °C at the rate of 5 °C per min. The holding time was set for 2 hours and the cooling rate at 5 °C per min after it reaches 800 °C.

6) After the mixture was cooled, it was once again grinded using the mortar and pestle and was put inside the furnace for calcination at 1000 °C with same heating and cooling rate as mentioned above.

7)After this calcination, the samplewas grinded third time using mortar pestle which was given for XRD for determination of the phase of the sample $BaTiO_3$. THE XRD data was analyzed using Xpert High Score software to confirm the phase.

Pellet Pressing

1)1.0g of sample is taken in the mortar and pestle.

2) This Sample is grinded using binders PVA (polyvinyl alcohol) and PEG (polyethylene glycol).

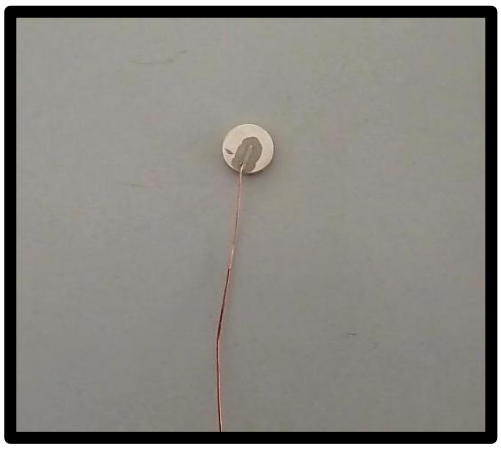
3) Two 0.5 g of pellets were fabricatedby using hydraulic presswith pressure not more than 35 kPa.

4) These two pellets were sintered at 1250 degree C at the heating rate of 2^o/min in the furnace.

5) After sintering, the sample was given for XRD for determination of the phase of the $BaTiO_3$pellet. The XRD data was analyzed.

6) Silver paste was applied to the pellet and leads were put on the pellets using silver paste.

7) The density of the pellet was determined by using Archimedes ‘principle and density was around 85%.

Hydraulic press machine and fabricated $BaTiO_3$ Pellet

Observations

- **Dimensions of the pellet**

  Using a Digital Screw Gauge following readings were taken-

  - **Diameter**

Trial no.	Diameter/mm
1	10.879
2	10.909
3	10.933
4	10.924
5	10.911

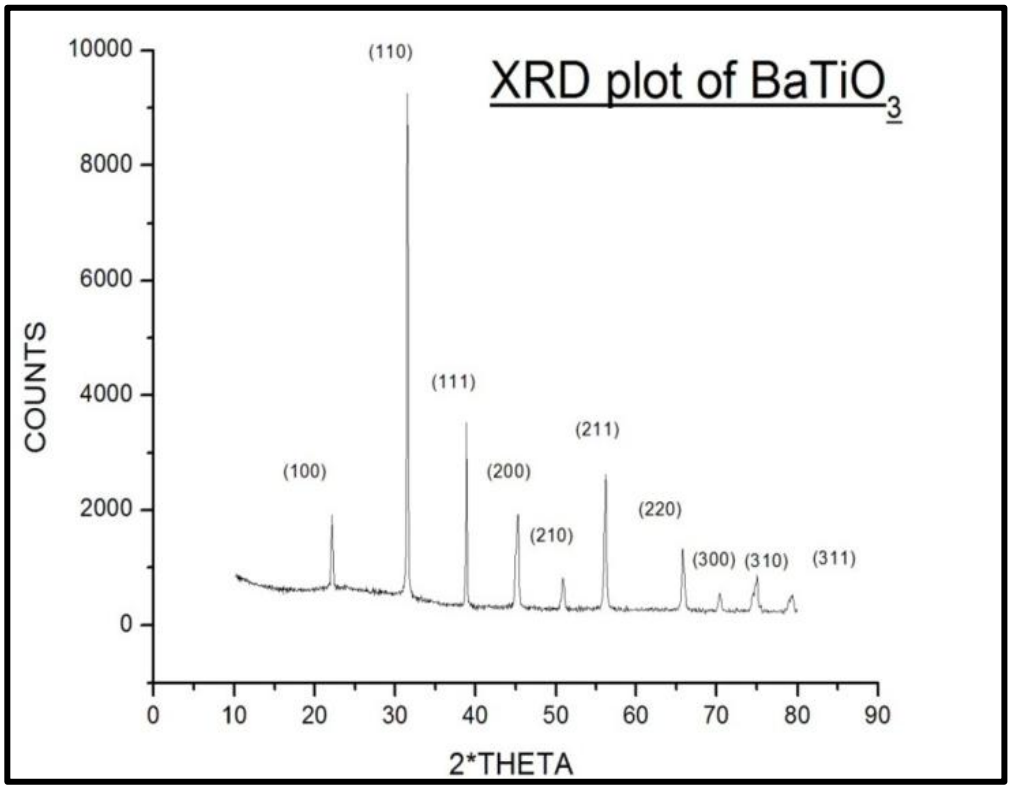
  Average diameter = 10.9112 mm
  Radius= 10.9112/2 =5.4556 mm=0.0054556 m

  - **Thickness**

Trial no.	Thickness/mm
1	1.170
2	1.180
3	1.280
4	1.147
5	1.140

  Average thickness = 1.1846 mm = 0.0011846 m

XRD Peak obtained after Calcination

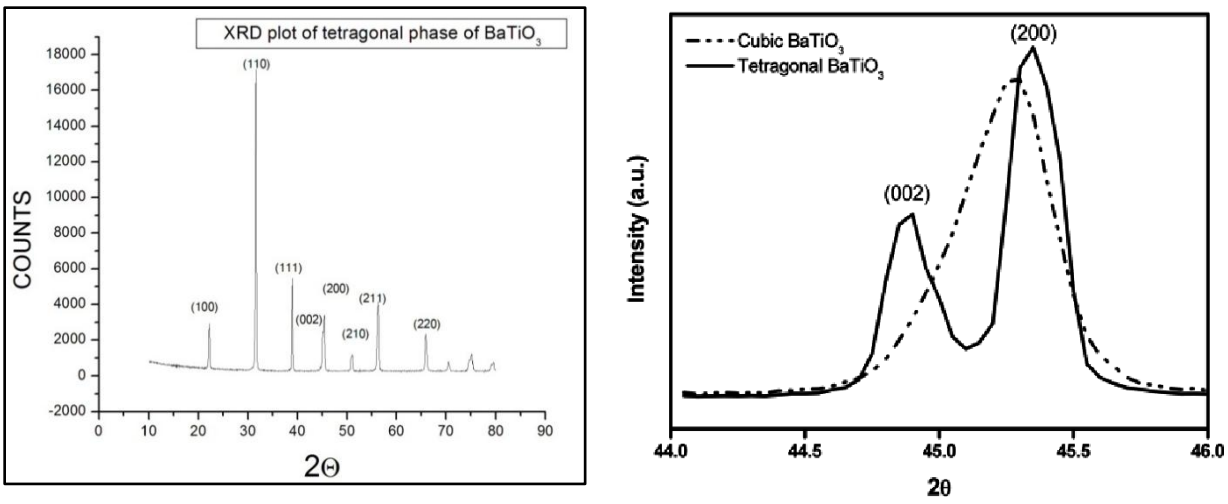


From the above XRD plot,lattice parameter was calculated using following formula

$(1/d_{hkl})^2 = (h^2 + k^2 + l^2) / a^2$

2θ	θ	$Sin^2\theta$	Ratio	d spacing (A)	(hkl)	Lattice parameter(A)
22.1192	11.0596	0.036798	1	4.01554	(100)	4.01554
31.5107	15.75535	0.073728	2	2.83688	(110)	4.019954
38.8642	19.4321	0.110675	3	2.31537	(111)	4.01033
45.2156	22.6078	0.147779	4	2.00379	(200)	4.00758
50.9010	25.4505	0.184668	5	1.79232	(210)	4.00774
56.1387	28.0693	0.221407	6	1.63705	(211)	4.009937
65.8358	32.9179	0.295325	8	1.41746	(220)	4.009182
70.3979	35.19895	0.332256	9	1.33636	(300)	4.00908

Lattice parameter of cubic $BaTiO_3$ ceramics:$a = b=c$ = 4.01986 Å



XRD Peak for sintered$BaTiO_3$ ceramics

In cubic phase, there was no split in the (200) peak in the XRD graph. But, when $BaTiO_3$ changed its phase from cubic to tetragonal, along with (200) peak, a (002) peak was also present which confirms the tetragonal phase of $BaTiO_3$.

Result and Discussion

(i) The $BaTiO_3$ pellet using the solid state reaction was synthesized with thickness=0.0011846 m and diameter=0.0109112 m.

(ii) The lattice paramater for the pellet was found to be4.01986Å.
From the XRD plot of $BaTiO_3$, the cubic phase of $BaTiO_3$ was confirmed before sintering and tetragonal phase of $BaTiO_3$ was confirmed after sintering.

EXPERIMENT 2

Phase Transition of $BaTiO_3$

Aim: To study the phase transition of $BaTiO_3$at curie's temperature from ferroelectric to paraelectric phase.

Materials Required:

Furnace with heating capacity up to 150 ^{o}C, LCR meter, Digital Temperature sensor, cottonand $BaTiO_3$pellet.

Experimental Procedure

1) A furnace setup was used to heat up the sample till 150^{o} C and measure capacitance at higher temperatures.
2) Cotton was used to prevent loss of heat due to radiation.
3) Pellet was inserted inside the furnace with its copper leads coming out of the furnace.
4) Copper leads were connected to the LCR meter to measure capacitance in Nano farad.
5) The furnace was heated up to 150^{o}C and while cooling, for each 1^{o}C difference, capacitance values were noted down.
6) A graph was plotted between Capacitance (nF) and temperature (^{o}C).
7) Dielectric constant for each reading was also calculated by using the formula:

$$\varepsilon_r = C\,(d/\,\varepsilon_o\,A)$$

where 'ε_r' is Dielectric constant, 'C' is Capacitance,'d' is thickness of the pellet, 'ε_o'is the permittivity of free space and A is the area of the pellet.

$$A=pi * r^2$$

where 'r' is the radius of the pellet.

8) The dimensions of the pellet were measured using a digital screw gauge.

Experimental Setup

Observations:

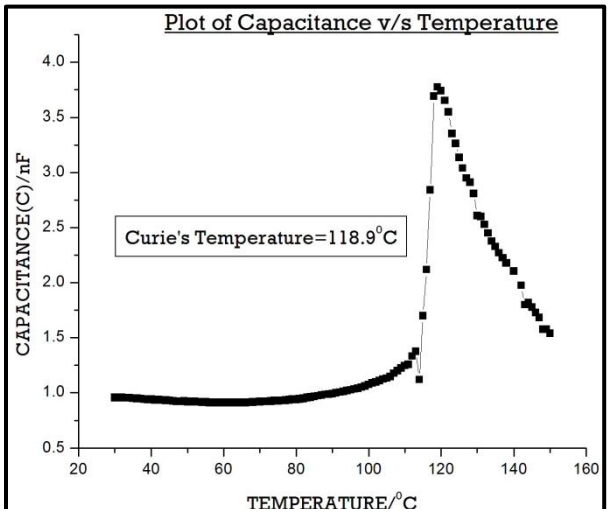
- **Capacitance v/s Temperature:**

  At room temperature=300K, C=0.9351 nF and Dielectric loss= 0.0216

T (Celsius)	C/nF	Dielectric Constant	T (Celsius)	C/nF	Dielectric Constant	T (Celsius)	C/nF	Dielectric Constant	T (Celsius)	C/nF	Dielectric Constant
150	1.539	2202.309	118	3.689	5278.959	86	0.973	1392.363	54	0.918	1313.65
149	1.577	2256.687	117	2.8417	4066.4727	85	0.969	1386.639	53	0.9195	1315.804
148	1.577	2256.687	116	2.1196	3033.1476	84	0.964	1379.484	52	0.9209	1317.807
147	1.684	2409.804	115	1.7	2432.7	83	0.957	1369.467	51	0.9219	1319.238
146	1.729	2474.199	114	1.12	1602.72	82	0.951	1360.881	50	0.9212	1318.237
145	1.777	2542.887	113	1.377	1970.487	81	0.947	1355.157	49	0.925	1323.67
144	1.82	2604.42	112	1.333	1907.523	80	0.943	1349.433	48	0.924	1322.24
143	1.8	2575.8	111	1.2565	1798.0515	79	0.941	1346.571	47	0.923	1320.81
142	1.9764	2828.2284	110	1.247	1784.457	78	0.938	1342.278	46	0.927	1326.53
141	–	–	109	1.225	1752.975	77	0.933	1335.123	45	0.932	1333.69
140	2.1049	3012.1119	108	1.2	1717.2	76	0.932	1333.692	44	0.9333	1335.552
139	–	–	107	1.178	1685.718	75	0.93	1330.83	43	0.936	1339.41
138	2.179	3118.149	106	1.147	1641.357	74	0.928	1327.968	42	0.9367	1340.417
137	2.225	3183.975	105	1.132	1619.892	73	0.926	1325.106	41	0.9395	1344.424
136	2.271	3249.801	104	1.125	1609.875	72	0.924	1322.244	40	0.9411	1346.714
135	2.3285	3332.0835	103	1.111	1589.841	71	0.923	1320.813	39	0.9417	1347.572
134	2.3762	3400.3422	102	1.098	1571.238	70	0.921	1317.951	38	0.9442	1351.150
133	2.45	3505.95	101	1.088	1556.928	69	0.919	1315.089	37	0.9477	1356.158
132	2.5295	3619.7145	100	1.075	1538.325	68	0.917	1312.227	36	0.9498	1359.163
131	2.5995	3719.8845	99	1.06	1516.86	67	0.916	1310.796	35	0.9533	1364.172
130	2.6075	3731.3325	98	1.05	1502.55	66	0.915	1309.365	34	0.9558	1367.749
129	2.8107	4022.1117	97	1.04	1488.24	65	0.914	1307.934	33	0.9564	1368.608
128	2.911	4165.641	96	1.034	1479.654	64	0.913	1306.503	32	0.9573	1369.896
127	2.9508	4222.5948	95	1.026	1468.206	63	0.9138	1307.6478	31	0.9562	1368.322
126	3.041	4351.671	94	1.02	1459.62	62	0.9136	1307.3616	30	0.959	1372.32
125	3.137	4489.047	93	1.012	1448.172	61	0.9135	1307.2185			
124	3.264	4670.784	92	1.005	1438.155	60	0.9134	1307.0754			
123	3.355	4801.005	91	1	1431	59	0.9146	1308.7926			
122	3.549	5078.619	90	0.992	1419.552	58	0.9131	1306.6461			
121	3.651	5224.581	89	0.987	1412.397	57	0.9139	1307.7909			
120	3.737	5347.647	88	0.985	1409.535	56	0.9147	1308.9357			
119	3.774	5400.594	87	0.979	1400.949	55	0.9169	1312.0839			

Observation Table: Capacitance of $BaTiO_3$ with Temperature

Graph of Capacitance vs Temperature

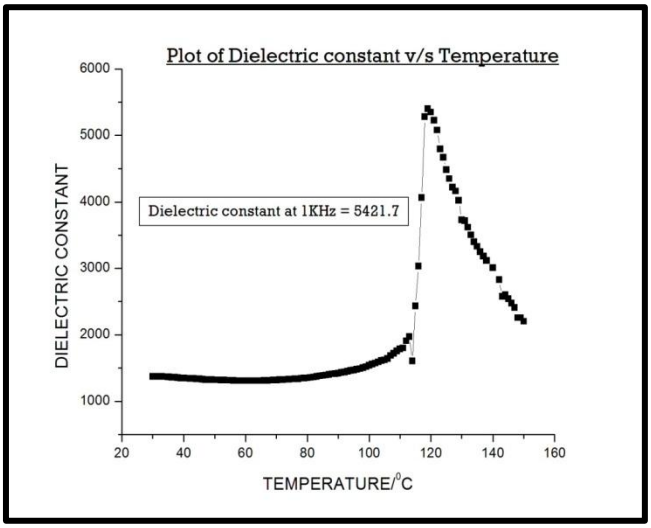


The peak point signifies the phase transition of $BaTiO_3$ which occurred at T_c=118.9^{o}C which is the Curie's temperature T_c of the sample $BaTiO_3$.

For standard $BaTiO_3$, T_c=120^{o}C.

From the graph,Capacitance at T_C=3.764 n F

Graph of Dielectric constant v/s Temperature



The peak point signifies the dielectric constant at T_C =118.9^{o}C.From the graph the dielectric constant at T_C IS 5421.7.
For standard $BaTiO_3$, the dielectric constant ranges between 7000-15000.

- **Calculations:**

Radius of the pellet (r)= 0.0054556 m
Area of the pellet (A)= pi * r^2
= 3.14 * (0.0054556m) ^{2} =$9.34*10^{-5}$ m^2

Capacitance (C)=$\varepsilon_0\varepsilon_r A/d$
Relative permittivity ($\mathcal{E}_r$)= Capacitance * ($d/\mathcal{E}_o$ A)

Thickness (d) = 0.0011846 m ; $\mathcal{E}_o=8.854*10^{-12}$ F/m

$\mathcal{E}_r$= Capacitance *(0.0011846 m) / ($8.854*10^{-12}$ F/m * $9.34*10^{-5}$ m^2)

$\mathcal{E}_r$= Capacitance *($1.4324* 10^{12}$)

Capacitance at T_C=3.764 n F

Using the formula ε_r=5391.55

Result:

The phase transition of $BaTiO_3$ from ferroelectric to paraelectric phase was studied. The Curie's Temperature T_C was found to be 118.9^{o}C and the dielectric constant at Curie's temperature was found as 5421.7.

EXPERIMENT 3:

Resistance versus Temperature Characteristics:

Aim:

To study the dependence of resistance on temperature for the ceramic $BaTiO_3$ i.e. as a thermistor.

Materials Required:

Furnace with heating capacity up to 150 ^{o}C, LCR meter, Digital Temperature sensor, cotton and $BaTiO_3$ pellet.

Experimental Procedure:

1) A furnace setup was used to heat up the sample till 150^o C and measure resistance at higher temperatures.
2) Pellet was inserted inside the furnace with its copper leads coming out of the furnace.
3) Copper leads were connected to the LCR meter to measure resistance in kΩ.

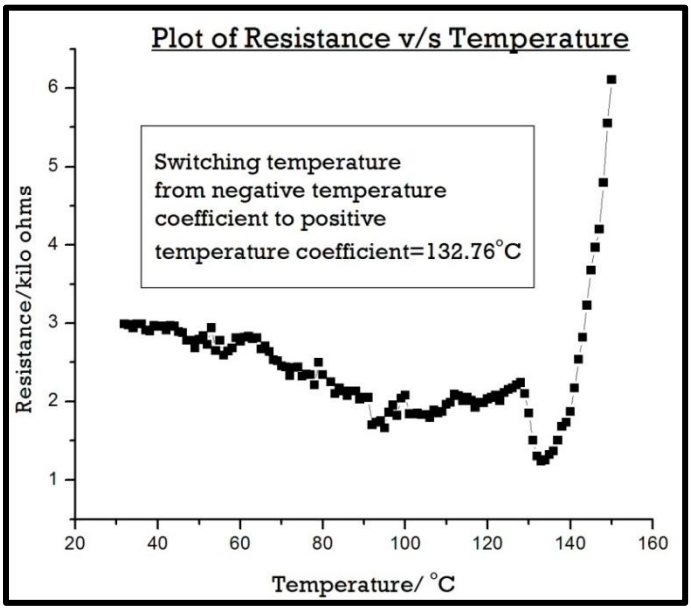
4) The furnace was heated up to 150^{o}C and while cooling for each 1^{o}C difference, resistance values were noted down.
5) A graph was plotted between resistance (kΩ) and temperature (^{o}C).

Observations:

- **Resistance v/s Temperature:** At room temperature=300K, R=2.8418 kΩ.

T/Celsius	R/k ohm	T/Celsius	R/k ohm	T/Celsius	R/k ohm	T/Celsius	R/k ohm
150	6.11	118	1.99	86	2.07	55	2.78
149	5.55	117	1.92	85	2.13	54	2.65
148	4.8	116	2.01	84	2.17	53	2.94
147	4.2	115	2.05	83	2.1	52	2.73
146	3.97	114	2.01	82	2.25	51	2.84
145	3.68	113	2.07	81	–	50	2.79
144	3.23	112	2.09	80	2.34	49	2.68
143	2.82	111	1.99	79	2.498	48	2.78
142	2.54	110	1.96	78	2.21	47	2.78
141	2.17	109	1.87	77	2.34	46	2.88
140	1.87	108	1.85	76	2.35	45	2.89
139	1.73	107	1.89	75	2.32	44	2.96
138	1.68	106	1.79	74	2.44	43	2.97
137	1.503	105	1.83	73	2.43	42	2.91
136	1.363	104	1.83	72	2.33	41	2.96
135	1.32	103	1.85	71	2.44	40	2.96
134	1.253	102	1.84	70	2.45	39	2.97
133	1.242	101	1.84	69	2.52	38	2.9
132	1.299	100	2.08	68	2.53	37	2.91
131	1.503	99	2.04	67	2.638	36	2.99
130	1.85	98	1.82	66	2.71	35	2.99
129	2.1	97	1.95	65	2.67	34	2.94
128	2.24	96	1.86	64	2.81	33	2.98
127	2.21	95	1.66	63	2.8	32	2.99
126	2.17	94	1.75	62	2.83	31	
125	2.15	93	1.73	61	2.82	30	
124	2.11	92	1.7	60	2.77		
123	2.01	91	2.05	59	2.81		
122	2.08	90	2.05	58	2.68		
121	2.05	89	2.03	57	2.64		
120	2.03	88	2.13	56	2.59		
119	1.98	87	2.13	55	2.78		

Observation table :Resistance versus Temperature for $BaTiO_3$



From the graph, The Switching temperature of $BaTiO_3$, from negative temperature coefficient to positive temperaturecoefficient was found to be 132.76^o C.

Results and Discussion:

(i) The dependence of resistance on temperature for the ceramic $BaTiO_3$ was studied.
(ii)The Switching temperature from negative temperature coeffiecient to positive temperature coeffiecient was found to be 132.76^o C.
The $BaTiO_3$ ceramic can be used as negative temperature coeffiecient thermistor from 30^oC-132.76^oC and as a positive temperature coefficient from 132.76^oC -149.86^oC.

EXPERIMENT 4:

Application of Piezoelectric material

Aim

To use a PZT transducer to make a glowing slipper by using the phenomenon of piezoelectricity.

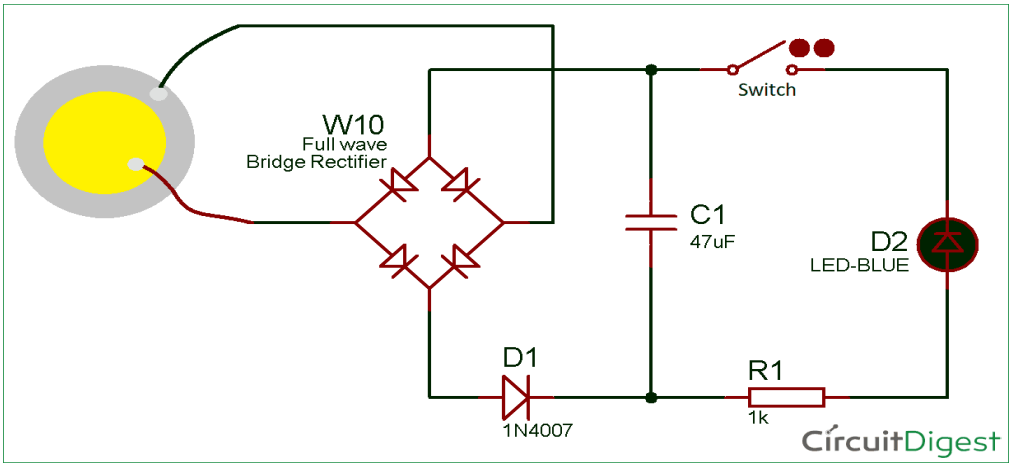
MaterialsRequired

3 PZT transducers, LEDs, connecting wires, 4*IN4007 diodes, digital multimeter, cardboard cut, socks, slippers, scissors, hot glue.

Experimental Procedure

1. Connect the transducers in series as shown in the circuit diagram.
2. Connect the two ends of the series connection to a bridge rectifier constructed using the 4 diodes.
3. Connect an LEDto the rectifier and also make sure that the LED project out of the cardboard .(filter was not used)
4. Cut out a cardboard piece in the shape of slipper's base. Using a hot glue gun, stick the entire circuit on a cardboard.
5. Stick the entire circuit under a slipper to make a glowing slipper.
6. The experiment can be repeated for many combinations of transducers and LEDs.

Circuit diagram:



Piezoelectric circuit on the stencil of the shoe

Result and Discussion

The voltage produced by one transducer was around 60mV. Also,an LED was made to glow using PZT transducers by applying pressure, thus confirming the property of piezoelectricity.

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