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Advances in the Synthesis, Characterizations and Applications of Barium Titanate. A review

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Abstract
Barium titanate ($BaTiO_3$) is a compound that has a structure called perovskite. Synthesis of $BaTiO_3$ can be done by employing separate methods. $BaTiO_3$ has four polymorphs which are cubic, tetragonal, orthorhombic and rhombohedral, depending on the temperature, it has a tetragonal structure at ambient temperature. This paper aims to review different synthesis methods of $BaTiO_3$, these techniques can be used in the process of making ceramics as a molding material and also as an intermediate between thin films of metal oxides in various applications. The characterization techniques mostly used in determining the lattice constant, crystal structure functional group, morphology, elemental compositions and electrical properties, of the nanomaterial, including the various applications of $BaTiO_3$ which includes modern electronic appliances and electrical power systems, the Multilayer Ceramic Capacitors (MLCs), biological, and microwave absorption, due to their piezoelectric and dielectric properties are reviewed.

Keywords: Applications, Barium titanate, Characterization, Perovskite, Synthesis.

INTRODUCTION
Barium titanate ($BaTiO_3$) is white to grey colour with a perovskite structure.it is soluble in many acids e.g., sulfuric, hydrochloric and hydrofluoric acids. $BaTiO_3$ is insoluble in alkalis and water; $BaTiO_3$ is a very attractive material in the field of microelectronics due to its good characteristics. Its high dielectric constant and low loss characteristics make $BaTiO_3$ an excellent choice for many applications, such as capacitors, multilayer capacitors (MLCs), PTC thermistors and piezoelectric devices, energy storage devices. (Ismail et al., 2016).

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Presently, $BaTiO_3$ has been widely utilize in ordering electronics relevance, for example, the multilayer ceramic capacitors, gate dielectrics, and waveguide modulators because of its outstanding ferroelectric possessions, (Hai et al., 2014). $BaTiO_3$ is a perovskite with excellent ferroelectric, and dielectric characteristics, with numerous effects and uses. (Tewatia et al., 2020). (Tomar et al., 2020).

$BaTiO_3$ has four polymorphs which are cubic, tetragonal, orthorhombic and rhombohedral, in this order depending on the temperature. However, it has a tetragonal structure at ambient temperature. (Elius et al., 2019).

The convectional solid state reaction method has been measured by numerous researchers measured for discrepancy in order to lessen condition of the mixture and get fine particles in the absence of hard agglomeration, (Andrade et al., 2014). Fine particles of $BaTiO_3$ are firmly influenced by the mixture path with the agglomeration reign, (Vijatovi et al., 2008b).

In the past, $BaTiO_3$ ceramics are the earliest poly- crystalline piezoelectric items and are broadly applied for electronic devices, (Huan et al., 2014). With a high dielectric constant and a suitable loss tangent, it makes a good dielectric material. (Fasasi et al., 2009).

Perovskite brood composite accompanied by common blueprint ABO_3 are referred to as $BaTiO_3$. It is the earliest come across ferroelectric perovskite with widespread primitive cube crystal structure, with the arrangements as; the Ba-bigger cation by the section, Ti-little cation by mid in the cuboid and O, present at core of the features boundary. This perovskite structures are embraced with several oxides having a synthetic recipe ABO_3. $CaTiO_3$, being the alloy, is the reason for its perovskite formation. A negatively charged ion, mostly present at midpoint at faces border, the positively charged ion represented as A-bigger at a district, a little positively charged ion B, is at cube's middle, A-bigger should have one covalent bond, having a chemical valence of two or having a valence of three and B in the middle of cube should also be either having five valence, four covalent bond or having a valence of three, separately.

A very important element in regulating the structure type is a symmetrical position of atoms at a grid. A combination of perovskite could be regarded as solid substructure , *(Vijatovi et al., 2008a)*. As the temperature decreases, the ferroelectric perovskite ceramic barium transitions through three phases: from cubic to tetragonal, from tetragonal to orthorhombic and finally from orthorhombic to rhombohedral.

$BaTiO_3$ has excellent mechanical and chemical stability as well as ferroelectric characteristics at and above room temperature. A porous ceramic called barium titanate is created by ionic or covalent bonding, (Singh et al., 2017).

Tomar et al examine the electrical effects of barium titanate in the appearance of Tin (Sn) applying the sol-gel path. It was noticed that on doping barium titanate with Tin, there is an enlargement of dielectric permittivity by the substance triple compared to Undoped $BaTiO_3$ along with an extremely small loss of dielectric of less than one was detected. It is thus deduce that doping $BaTiO_3$ with Tin can function as a favourable material for piezoelectric relevance, (Tomar et al., 2020). The surface modification of TiO_3 particles by the sono-assisted exfoliation method can optimize the photo catalytic activity by yielding synergetic effects of the high surface reactive sites of the Nano sheets and the high degree of crystallinity of the bulk structure, according to research conducted by E. Thasirisap et al, (Thasirisap et al., 2017).

To comprehend the impact of phase composition on the functional qualities of $BaSn_xTi_{1-x}O_3$(x = 0.00, and 0.05) ceramics with orthorhombic/tetragonal phases at room temperature, comparative studies were conducted. Doping Ti^{4+} sites with 5% Sn improves the switching polarization, permittivity peak, tunability, and piezoelectric coefficients relative to $BaTiO_3$ values, (Horchidan et al., 2019). C. Mao et al. (2014) explored the doping of barium strontium titanate $Ba_{1-x}Sr_xTiO_3$(BST), one of the best electronic materials due to its composition-dependent Curie temperature and effective electrical devices. Under a DC bias field, the impact of grain size on the dielectric, pyroelectric, and phase transition properties was investigated. Smaller grains in ceramics had higher surface effects, mechanical stress effects, and extrinsic grain boundary effects. This led to a lower Curie temperature, more diffused phase transitions, and altered the characteristics of the dielectric and pyroelectric materials, (C. Mao et al., 2014). *Tomar et al., 2020* used the sol-gel method to examine the electrical characteristics of barium titanate in the presence of Sn2+ dopant. It was found that adding Sn to barium titanate enhanced the material's dielectric permittivity by three times compared to pure BaTiO3, and an extremely low dielectric loss of just one was found. This leads to the conclusion that tin doping BaTiO3 can make for a promising piezoelectric material, (Tomar et al., 2020).

Deficient A-site Ganguly et al. studied barium titanate that had been doped with lanthanum; structural studies indicated that the lanthanum caused the barium titanate to change from tetragonal to cubic symmetry, and scanning electron micrographs showed that the addition of the lanthanum caused the barium titanate Undoped grain size to drastically shrink, (Ganguly et al., 2013). By using the sol-gel method to investigate the influence of La doping on thermal, mechanical, and high dielectric properties, Kumari and Ghosh found that Nano composites had excellent mechanical and high thermal stability, (Kumari & Ghosh, 2018). By using a modified Pechini technique to create Nano powders co-doped with various concentrations of Niobium and Manganese, the donor-acceptor joint effect in BT systems was studied. It was found that the change of the dielectric characteristics was strongly influenced by the presence of dopant, (Vijatovi et al., 2015). By using a solid-state sintering procedure, Sasikumar looked at the electrical structure, optical, and chemical bonding characteristics of BT that has been doped with strontium. EDS spectral analysis confirmed the sample's phase purity, and SEM revealed that the BT's chemical bonds are both ionic and covalent in nature, with the particles having regular forms and distinct grain boundaries, (Sasikumar et al., 2019). Lanthanum doped barium titanate was created using the sol-gel method by Xinle et al. The results show that when the annealing temperature and doped concentrations rise, the size of the powder particles will change in opposite directions, (Xinle et al., 2006). Wang et al. study pure phase BTO and fibers that have been electro spun with lanthanum doping. All of the fibers were found to be in the tetragonal phase following heat treatment, with high crystallinity. Tetragonal phase BTO ceramics also exhibit greater dielectric characteristics than cubic ones, (Wang et al., 2021). When Cernea et al. explored the hydrothermal preparation of terbium-doped barium titanate; they looked at its structural, electrical, and photoluminescence properties. They found that the powders had a cube-shaped grain microstructure with an average particle size of between 75nm and 150nm, (Cernea et al., 2021). Kadira et al. used the sol-gel method to test the dielectric properties of calcium-doped BT, and they found that the powders are in a pure perovskite phase without any secondary phases, (Kadira et al., 2016). In their investigation of the structural and dielectric characteristics of zirconium-doped BT ceramics using solid state reactions, Urmi et al. found that the tetragonal phase with space group P4mm predominates. Zirconium doped BT may therefore be an appealing material for ceramic capacitor and electronic device applications if it has an appropriate current density and resistance, (Urmi et al., 2022).

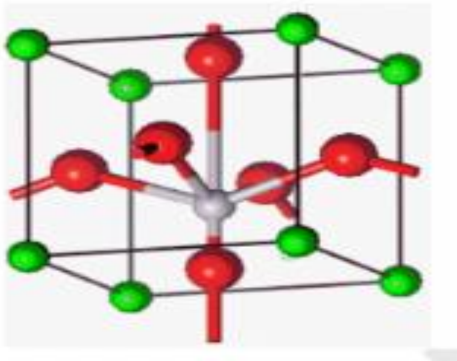

Fig. 1. Structure of perovskite barium titanate. (Gao et al., 2019).

This perovskite structures are embraced with several oxides having a synthetic recipe ABO_3. $CaTiO_3$, being the alloy, is the reason for its perovskite formation.
A negatively charged ion, mostly present at midpoint at faces border, the positively charged ion represented as A-bigger at a district, a little positively charged ion B, is at cube's middle, A-bigger should have one covalent bond, having a chemical valence of two or having a valence of three and B in the middle of cube should also be either having five valence, four covalent bond or having a valence of three, separately. A very important element in regulating the structure type is a symmetrical position of atoms at a grid. A combination of perovskite could be regarded as solid substructure. (Vijatovi et al., 2008a). As the temperature decreases, the ferroelectric perovskite ceramic barium transitions through three phases: from cubic to tetragonal, from tetragonal to orthorhombic, and finally from orthorhombic to rhombohedral.(Singh et al., 2017). Thus, this material known to have four polymorphs, which are cubic, tetragonal, orthorhombic, and rhombohedral, in that order, depending on the temperature. (Elius et al., 2019).

Physical and chemical properties of $BaTiO_3$ are collated in Table 1.

Table 1. Physical and chemical properties of $BaTiO_3$

Physical properties	*Chemical properties*
It is an insulator in its pure form	Its chemical formula is $BaTiO_3$
As a powder, it has a white to grey has a colour	It is soluble in many acids such as hydrochloric, sulfuric and hydrofluoric acids.
It has a perovskite structure	It is insoluble in water and alkalis
It became a semiconductor when doped with little amount other metals.	It has a melting point of 1650^{o}C

Due to its high dielectric constant, barium titanate, one of the modern ferroelectric oxides with perovskite structure and formula ABO_3, is widely employed in the electrical industry. (Ghayour & Abdellahi, 2016). To meet the stringent requirements for developing diverse electro-ceramic components, its features, such as dielectric and polarization response, conductivity mechanism, and Curie temperature, can be modified by chemically substituting suitable dopants at the lattice locations. (Batio et al., 2022). Many contemporary technologies, like piezoelectric actuators and electro-optic modulators, utilize ferroelectric materials. (Tudorache, n.d.). A strong dielectric material, $BaTiO_3$ with a perovskite structure has numerous uses in the electronics sector.(Du et al., 2009). Due to its inherent ferroelectric properties, $BaTiO_3$ is the ferroelectric perovskite oxide that has been the subject of the most research in recent years. (Journal & Science, 2022). It is well known that adding dopant ions to a Ba or Ti location in the $BaTiO_3$ lattice changes its structural and microstructural characteristics as well as its electrical properties. (Ramos et al., 2011). It is well known that doping and grain size affect the ferroelectric ceramics' electric and optical characteristics. (Cernea et al., 2021). Dielectrics are materials with increased electrical resistivity, such materials have uses in pulsed capacitor technology due to their high energy storage density, strong temperature stability, and para-electric, piezoelectric, and ferroelectric characteristics. $BaTiO_3$ will be used in numerous sectors for things like energy storage devices and multilayer actuators (MLAs) (Biglar et al., 2017). Electronics applications for barium titanate include microwave devices, high-density optical data storage, thermistors, and multilayer ceramic capacitors It also finds wide possibility of applications in the form of ceramic capacitors, PTCR thermistors, piezoelectric sensors, optoelectronic components, transducers, actuators, etc. (Ramos et al., 2011). Additionally, $BaTiO_3$ has been generally used as the primary component in numerous importance, including temperature or humidity-gas sensors, piezoelectric transducers, electro-optic devices, and ferroelectric memory. (Ashiri et al., 2011). $BaTiO_3$ being a ferroelectric perovskite at room temperature shows a large permittivity, achieving an advantageous material for application in capacitors. (Morrison et al., 2016). Rare earth elements not long ago gained exceptional attention for ultra-high-temperature sensor importance due to its specific high resistivity, stable piezoelectric properties. (Gessow, 2001). Barium titanate is mostly used in electronics devices, like multilayer ceramic capacitors due to its outstanding ferroelectric, thermoelectric and piezoelectric features. (Li et al., 2017). In the presence of an electric field, barium titanate also exhibits remarkable visual qualities and ferroelectric polarization. (Singh et al., 2017). Dopants would make it possible to customize the structure and electrical characteristics of barium titanate, increasing its potential for use in electronics. (Vijatovi et al., 2015).

SYNTHESIS METHODS OF BARIUM TITANATE

Several methods of synthesis have evolved and being used for the production of Barium titanate powders, including sol–gel auto combustion technique, and the hydrothermal technique, (Hai et al., 2014). There are many different ways to make $BaTiO_3$, including hydrothermal, co-precipitation, sol-gel, solid state processes, and polymer precursor methods, (Mukherjee et al., 2013). The production of ferroelectric $BaTiO_3$ bulk powder and ceramics has been carried out using a number of techniques, including coprecipitation, hydrothermal process, sol-gel, and traditional solid state reaction, (Galassi et al., n.d.). $BaTiO_3$ synthesis methods generally depends on the end application most importantly or the cost.

The Sol-Gel Technique

The Sol-gel auto combustion technique that acts in making solid substances from little molecules, (Rane et al., 2018). Though, the technique was initially manufactured because of developing glass and pottery substances by short measured degree of heat at the beginning. Wet chemical method finds application with composition in oxides, together with hybrids of organic and inorganic, and composites. It is a straightforward method, and the main bedrock of the sol–gel technique is inorganic polymerization reactions, (Kolahalam et al., 2019). The synthesis technique was used to produce Ce-doped $BaTiO_3$ and characterize by XRD, FTIR, and SEM. It was observed that frequency has influence beside dielectric effects of the doped $Ba_{0.945}Ce_{0.055}TiO_3$ in the 100HZ to 1MHZ empire, (Galassi et al., n.d.). Ghamsari develop a modified sol-gel synthesis technique route to obtain several nanostructures of barium titanate such as, transparent amorphous Nano layers, Nano crystalline $BaTiO_3$ powders, ultrathin $BaTiO_3$ and very stable embedded colloids nanoparticles, all from the precursor solution a lower temperature. The outcome of the research indicates that there is an improvement within visual clarity by a fine photographs compare to other investigations, (Ghamsari, n.d.). Sol-gel technique has been customary combine with barium strontium titanate $(Ba_{0.6}Sr_{0.4})\ TiO_3$ and characterize by the use of X-ray diffraction (XRD), scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS), toward looking into a crystalline formation, microstructure, and also the chemical constitution. The results indicates that, the maximum electric permittivity temperature is relevant with the barium strontium ion ratio, (Science-poland, 2007). A sol-gel technique that is cost effective and modified was adopted for the synthesis of barium titanate powder, and then using the scanning electron microscopy (SEM), transmission electron microscopy (TEM), and X-ray diffraction (XRD) to categorize a sample. From the results obtained, it was observed that the condition of hydrolysis, their ratio and the precursors types both have a significant consequence on the cost of the synthesis process, time and temperature, (Ashiri et al., 2011). A schematic diagram of sol-gel synthesis method as seen in, (Pierre & Pajonk, 2019).

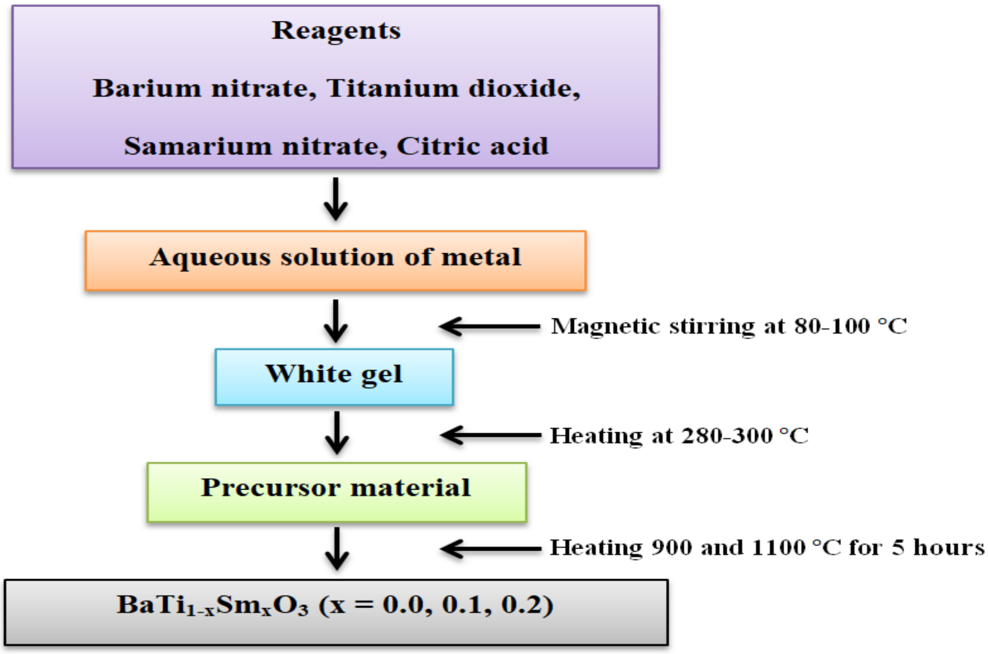

Fig. 2. Flow chart of the sol-gel synthesis of Samarium doped barium titanate. (My dissertation).

Advantages of Sol-gel Technique

At the beginning, the stuffs are in molecular size, and the end results produced are similar.
The clarity of the results is reasonably very high.
Porosity can be controlled.
Different dimensions can easily be produced and perform. .
Synthesis can be done with little degree of heat.
Permit excellent influence about materials synthetic structure is permitted, mostly acceptable for producing various component substances.
Little amount of dopants can be instituted in the solution and evenly distributed in the end result.

Disadvantages

Takes a lengthy reaction period.
Human body can be injurious due to organic solution.

Hydrothermal Technique

This synthesis technique by chemical reactions of materials in a secured warmed up mixture greater than the pressure and ambient temperature, (Rane et al., 2018). The mixtures are exposing to excessive pressure and temperature. The major upper hand of the technique is the composition of fine class crystals with managing the composition, (Kolahalam et al., 2019). $BaTiO_3$ powders have been prepared using hydrothermal method, evidence emerges in the experimental process that the dissolution-precipitation as the hydrothermal apparatus of preparing the barium titanate in the powerful fundamental mixture, (Xu & Gao, 2002). Hydrothermal method was used to synthesize nano-grained $BaTiO_3$ by two-step sintering process; it was observed that, there is a variation in relative mass density with small variation in grain size, (Moon et al., 2009). Nyutu et al analyze the outcome of microwave frequency of tetragonal $BaTiO_3$ nanocrystal using hydrothermal technique, and then using Raman spectroscopy, infrared spectroscopy, field emission scanning electron microscopy, X-ray diffraction, thermal analysis, transmission electron microscopy with EDS analyzer to characterize the sample. It was noticed that, morphologies particle sizes, and surface area of the powder have an effect on microwave frequency and bandwidth sweep time, (Nyutu et al., 2008). A hydrothermal method was use to synthesize barium titanate to determine the consequence of Titania precursor and heating temperature on stage change, a pure $BaTiO_3$ on an actual cubic stage with spherical morphology at a smaller heating temperature was observed, (Sasirekha et al., 2008). It was observe by Xu and Gao, that a brand new proof of a dissolution-precipitation mechanism in hydrothermal method of synthesis of barium titanate powders, (Xu & Gao, 2002). The flow chart of hydrothermal synthesis method can be seen in ,(Li et al., 2017).

Advantages of hydrothermal technique

Almost all substances are ordered to build solvable at reality by warming together with pushing near a structure critical end.

Chemical activity of the reactant has a notable development, and the possible to substitute a solid-state technique, with substances and that cannot have been procured across solid-state response could be adapted along hydrothermal/ solvothermal techniques.

Results by halfway, more stable state condition along with particular stage feasibly simply fabricated; new composites at more stable state condition along with specified precipitate condition feasibly combined.

Dimensions, structure dispensation, with crystallinity by end result between adaptations in variables, like degree of heat of the response, measure of reaction, category of solvent, chemical agent, with predecessor are accurately and easily managed.

Materials with small melting end, big vapor pressures, are acquired when they reach pyrolysis.

Disadvantages

Castrates required are costly.

Protection matter during the procedure of response.

Difficulty in noticing the procedure response ("black box").

Coprecipitation

This process require a contemporary phenomenon with seeding, growing, hardening, with collection procedures, (Rane et al., 2018). This straightforward technique is extensively used to create variety of nanoparticles, (Kolahalam et al., 2019). Ulfa et al studied how temperature and time holding affected the dielectric characteristics of barium titanate using the co-precipitation process, which was then characterised using x-ray diffraction, and scanning electron microscopy was, barium titanate was found to have a perovskite structure in its ideal single phase, (Ulfa et al., 2020). A novel formation of barium titanate Nano dendrites was investigated by C. Huang et al., (2014) using co-precipitation, the addition of $BaCl_2$ solvent is a factor to the shape and size of $BaTiO_3$, also $BaCl_2$ has an effect on crystalline size, morphology and emergence of dendrite-like structures. (C. Huang et al., 2014). Solid-state reaction and co-precipitation methods was used to detect the consequence of powder preparation on the PTCR characteristics of barium titanate, it was concluded that co-precipitation process produce a greater PTCR features and superior repeatability of prepared samples and low temperature resistance, (Chatterjee, n.d.). Er^{3+}/Yb^{3+} co-doped barium titanate was synthesized via the co-precipitation method also characterize by X-ray diffraction in order to find its emission properties. It was observe that the $BaTiO_3$ was in cubic phase and possess fine crystallinity, (Rai, n.d.).

Advantages of Coprecipitation

Quick and easy preparation.
The ability to easily alter particle size and makeup.
There are numerous ways to change the particle surface state and overall homogeneity.
Minimal temperature.
Efficient with regard to energy.
Excludes the use of organic solvent.

Disadvantages

Uncharged species are not covered by this.
Additionally, traces of contaminants could precipitate with the results. It takes time.
Issues with reproducibility from batch-to-batch.
When the reactants have significantly varied rates of precipitation, this approach does not perform well.

Solid-state method

The simplest option is the solid-state approach. Despite being modest in number, the parameters are challenging to control. This technique is frequently used to create transition metal and monovalent cation arsenates phosphate single crystals and polycrystalline powders. The phenomenon of crystallization often takes place after a phase shift and is accompanied by a heat action. It is completed in two steps: emergence and development, (Smida & Marzouki, 2020). A chemical reaction system without a solvent is known as a dry media reaction, solid-state reaction, or solvent-less reaction, (Viruthagiri et al., 2013). Pure and doped $BaTiO_3$ powder were synthesize using solid-state reaction that is identified by XRD, FTIR, and SEM. XRD detected a perovskite structure that is tetragonal at a temperature above 700^0C and 500^0C for the pure and doped $BaTiO_3$ powder, (Andrade et al., 2014). Barium titanate powders doped with Er^{3+} were prepared via the solid-state reaction technique with different concentrations and site substitution, and then characterize using XRD and Raman Spectra. The photoluminescence (PL) quenching was investigated by increasing the doping concentrations Er. It was observed that the emission of replaced ions can be assumed as evidence from structure for ferroelectric titanate,(Zhang et al., 2011). To study the influence of grain-size on piezoelectric characteristics , barium titanate was created using a solid state reaction process; it was observe that there is an increase in piezoelectric constant and dielectric permittivity at room temperature with depletion on the average grain-size, (Zheng et al., 2012).

CHARACTERIZATIONS.

3.1X-Ray Diffraction (XRD)

X-ray diffraction is one of the most widely used and efficient techniques for identifying the types of phases, lattice parameters, and conducting a thorough structural analysis of nanoparticles. (Zubeda & Haider, 2013).

Islam et al. 2022 examined the sol-gel synthesized Yttrium-doped $BaTiO_3$ (Y-BT) $Ba_{1-x}Y_xTiO_3$ (with x = 0.00, 0.01, 0.03, 0.05, 0.07 mmol) perovskite ceramics, the as-made powder samples were formed into pellets and sintered for five hours at 1300 °C in the air. XRD confirms the development of single-phase tetragonal $BaTiO_3$ with a mean crystallite size of between 23 and 33 nm was discovered. (Islam et al., 2022).

A hydrothermal approach is employed in a mixture of chloride metal sources and KOH with the polyvinylpyrrolidone method of generating tetragonal high-dispersion $BaTiO_3$ nanoparticles (PVP), investigating the effects of reaction temperature and duration on various parameters, XRD results show that high temperatures encourage the synthesis of tetragonal $BaTiO_3$, which changes the phase of $BaTiO_3$-PVT nanoparticles from cubic to tetragonal. (Li et al., 2017).

To create $BaTiO_3$ nanoparticles at low temperatures, a wet chemical process is used to prepare $BaCO_3$ particles covered with an amorphous TiO_2 precursor. The behavior of $BaTiO_3$ particle production and growth after the precursor undergoes heat treatment is then investigated by Mochizuki et al. (2014). According to the findings of the XRD studies, small $BaCO_3$ particles coated with the TiO_2 precursor $BaTiO_3$ at changed into 550-650^{o}C, while bigger at particles created $BaTiO_3$ at 900^{o}C.(Mochizuki et al., 2014).

Alkoxide-hydroxide was used in the process of creating $BaTiO_3$ (BT) nanopowders. At 60 °C, the formation of BT nanopowders began, and as the temperature rose, so did their production. At different temperatures and a Ba/Ti ratio of 2.0, BT nanopowders formed. XRD patterns peaks for the BT phase were already present in the material that was synthesized at 60 °C, and their strength rose as the temperature rose. In addition, as temperature rose, the peak intensity of the $BaCO_3$ phase dropped. It was discovered that the (0 0 2) and (2 0 0) peaks did not split, indicating that the specimens' structures were very similar to those of the cubic BT phase. (Joung et al., 2011).

Fourier Transform Infrared Spectroscopy (FTIR).

The electromagnetic radiation's absorption at wavelengths between 4000 and 400 cm-1 is measured using a technique called Fourier-transformed infrared spectroscopy. (Manuscript, 2018b).

By using barium acetate, titanium (IV) isopropoxide, and cerium (III) acetylacetonate as starting materials, $BaTiO_3$ was doped with 5.5 mol% cerium. It was observed that the Fourier transform infrared spectroscopy FT-IR spectra of the (Ba, Ce) TiO_3 gel were recorded after the gel had been dried at temperature of 100^{o}C and then fired up to 350^{o}C. (Cernea et al., 2006).

High-dispersion and tetragonal $BaTiO_3$ (BT) nanoparticles are produced using a hydrothermal process in which chloride metal sources, potassium hydroxide (KOH), and BT-PVPs are combined. The FT-IR spectra of the BT-PVP nanoparticles generated at various reaction temperatures are examined in order to determine the effects of varying reaction temperature and time on the characteristics. The peak found at 1280cm^{-1} corresponds to PVP rings being stretched by (CH_2) wag + (CN) stretching, and the feature at 1640 cm^{-1} can be attributable to symmetric C-O stretching. 1640, and 1570 cm^{-1} were found as the reaction temperature rose, however the intensity peaks of 1280 cm^{-1} gradually dropped and vanished at temperatures above 190°C .(Li et al., 2017).

$BaTiO_3$ nanoparticles in the cubic and tetragonal phases have been made using a polymeric complex technique. By using FTIR, the produced samples were characterised. The peak at approximately 1440 cm^{-1} is the typical band of the crystalline $BaTiO_3$, and the characteristic band at around 499 cm^{-1} denotes the Ti-O vibration mode. The FTIR results are in agreement with published values in the literature as well. (Kappadan et al., 2016).

Spin coating was used to create a thin film of perovskite $BaTiO_3$ nanocomposite. By using a variety of techniques, the surface morphology, structure, chemical composition, and optical characteristics of the film were examined. The FTIR results show that the vibrational peaks of $BaTiO_3$ assigned to 438 cm^{-1}, 540 cm^{-1}, 860 cm^{-1}, 1421 cm^{-1}, 1634 cm^{-1}, and 3412 cm^{-1} show stretching in Ti-O (normal and bending mode), Ti OH, COO, OH, and Ba OH bonds. The infrared absorption area is defined as 400 to 600 cm^{-1}. Strong peaks at 438 cm^{-1} and 540 cm^{-1} are caused by Ti-O bending vibrations along the polar axis and stretching vibrations, respectively. The vibrational peaks at 860 cm^{-1} and 1421 cm^{-1} are caused by bending vibrations in the COO- group that were induced by acetic acid.(Singh et al., 2017).

Scanning Electron Microscopy (SEM).

Using electron microscopes, it is possible to characterize both organic and inorganic materials. Using barium acetate, titanium (IV) isopropoxide, and cerium (III) acetylacetonate as starting materials, the sol-gel method was used to add 5.5 mol% cerium to $BaTiO_3$. Ceramic pellets sintered at 1250 °C for 2 h in air showed uniform grains size morphology of 0.5^{-1}m as can be seen in the image. (Cernea et al., 2006).

Ba1xYxTiO3 (with $x = 0.00$, 0.01, 0.03, 0.05, and 0.07 mmol) perovskite ceramics were examined by Islam et al. in 2022. These ceramics were made using the sol-gel process. The powder samples were sintered at 1300^{o} C for 5 hours in air after being compressed into pellets. Comparing Y-BT to undoped $BaTiO_3$, the microstructural analysis from SEM shows that the development of the grains is uniformly distributed, compact, and well-faceted. With increasing doping concentration, the average grain size of the Y-BT (0.29–0.78 m) falls. .(Islam et al., 2022).

High-dispersion, tetragonal $BaTiO_3$ (BT) nanoparticles are created by hydrothermally combining KOH, chloride metal sources, and BT-PVPs, which are then made using the polyvinylpyrrolidone method. Investigations into the properties of reactions at various temperatures and reaction times result in particles with torus-like morphologies, which are what is shown. The widths of the torus tubes grew as the reaction speeded up and temperature advanced, shrinking the torus-like tubes' holes while maintaining their size. (Li et al., 2017).

The alkoxide-hydroxide method was used to create nanopowders of $BaTiO_3$ (BT). BT nanopowders started to form at 60 °C, and as the temperature rose, so did their production. Images captured by a scanning electron microscope (SEM) of BT nanopowders produced at 260°C for various periods and generated at 100°C with a 2.0 Ba/Ti ratio. From roughly 65.4 nm for a 20-hour synthesis to 128.6 nm for an 80-hour synthesis, the particle size of the BT nanopowders rose with increasing heating time. (Joung et al., 2011).

Using a solvothermal technique, $BaTiO_3$ nanoparticles of varied sizes were created. All of the $BaTiO_3$ particles, which come in a variety of sizes, are uniformly disseminated by scanning electron microscopy (SEM). (Y. Mao et al., 2010)

Energy dispersive x-ray spectroscopy (EDS or EDX)

Powders are routinely subjected to elemental analysis using the EDS technique, which is semi-quantitative for a variety of materials and samples.

By using a chemical coating technique, fine-grain $BaTiO_3$-based ceramics were co-doped with varying concentrations of Ho and Dy, providing good dielectric characteristics and mild temperature stability. Based on a sequence of locations along a straight line from one grain boundary (A) to the other grain boundary (B), the EDS line-scan analysis results were performed. Since the electron scattering of the EDS in this instance was only 1 nm, the evaluation of the shell thickness was largely unaffected by the electron scattering. Consequently, it can be said that each sample's grains have core-shell structures.(Gong et al., 2016).

As a very effective piezo catalyst, $BaTiO_3$ has been treated with silver. Methyl orange (MO) degradation under ultrasonic vibration in the dark was observed to determine the piezo catalytic effectiveness of the samples as they were manufactured. The findings suggest that the Ag-loaded $BaTiO_3$ particles exhibit the atomic ratio of Ba:Ti:O in each sample, as determined by the EDS data, is consistent with the stoichiometry of the compound $BaTiO_3$. (Manuscript, 2018a).

A solid-state reaction method was used to create $BaH_xTi_{1-x}O_3$ powders and ceramics with x ranging from 0 to 0.15. SEM images and EDX spectra were used to measure and confirm the microstructures and composition of the powders and ceramics. The results of the EDX analyses of the powders and ceramics were almost identical and showed no sign of other ions, which was consistent with the stoichiometry of as-prepared BHT. (Tian et al., 2007).

At room temperature, Ti metal plates were used to create $BaTiO_3$ nanoparticles using an electrochemical process. The EDX tests demonstrate that the samples were composed of the elements Ba, Ti, and O.(Bhuiyan et al., 2012).

Spin coating has been used to create a perovskite BaTiO3 nanocomposite thin film. Elemental Dispersive X-ray (EDX) spectroscopy verifies the development of $BaTiO_3$ with compositions as Ba 59%, Ti 20%, and O 21% in our sample after various techniques were used to examine the surface morphological, structural, compositional, and optical aspects of the film. There is a tiny quantity of Co impurity present.(Singh et al., 2017).

Impedance Spectroscopy

Impedance spectroscopy (IS), a powerful and relatively new method, can be used to characterize a number of electrical properties of materials and their interactions with electronically conducting electrodes. Any type of solid or liquid material, including ionic, semiconducting, mixed electronic-ionic, and even insulators (dielectrics), can use it to study the dynamics of bound or mobile charge in the bulk or interfaces. (Macdonald & Johnson, 2018).

By adopting a sol-gel process with barium acetate, titanium (IV) isopropoxide, and cerium (III) acetylacetonate as starting materials, barium titanate $BaTiO_3$ has been doped with 5.5 mol% cerium. In the frequency range of 100 Hz to 1 MHz, there was a negligible effect of frequency on the dielectric characteristics of ceramics made of $Ba_{0.945}Ce_{0.055}TiO_3$. The dielectric constant was 10130 at 100 Hz at the Curie temperature point (220^{o}C), while the dielectric loss (tan δ) was 0.018. (Cernea et al., 2006).

Yttrium-doped $BaTiO_3$ (Y-BT) $Ba_{1-x}Y_xTiO_3$ (with $x = 0.00$, 0.01, 0.03, 0.05, and 0.07 mmol) perovskite ceramics were examined by Islam et al., 2022. The as-made powder samples were formed into pellets and sintered at 1300^{o} C for 5 h in air. Frequency dependent impedance tests reveal improved dielectric properties including dielectric constant, quality factor, and conductivity with reduced dielectric loss in the presence of Yttrium. (Islam et al., 2022).

Chemical coating was used to create fine-grain $BaTiO_3$-based ceramics that were co-doped with varying concentrations of Ho and Dy, producing materials with good dielectric characteristics and moderate temperature stability. The impact of co-doping on the dielectric characteristics and microstructure evolution of ceramics based on $BaTiO_3$ was studied. According to impedance studies, differing co-doping levels of Ho and Dy have essentially no impact on the resistance and activation energy of grain boundaries in ceramics made using $BaTiO_3$. (Gong et al., 2016).

W. Chen et al. (2017) investigated a core-shell structure, where $BaTiO_3$ (BT) particles were synthesize by sol-gel method. It was fabricated and confirmed by impedance analysis, and it was observed that showing a single semicircular, indicating a more uniform microstructure than BT. The only circuit that could adequately accommodate it was an RC equivalent. This shows that the resistances at grain borders and within grains were essentially identical, negating the need to consider the impact of the ceramic/electrode interface. (W. Chen et al., 2017).

Table 2. characterization techniques and their functions use for $BaTiO_3$ ceramics

Characterization technique	Functions
x-ray diffraction	crystal size, d-spacing, lattice parameter, etc.) as well as qualitatively (e.g., compound, structure, etc.). and the comprehensive structural investigation of nanoparticles
Fourier Transform Infrared Spectroscopy (FTIR).	used to determine the type of bond between two or more atoms, the functional groups, and the attachment of organic ligands.
Scanning Electron Microscopy (SEM).	morphological analyses and used to determine a material's composition.
Energy dispersive x-ray spectroscopy (EDS or EDX)	an estimation tool; elemental analysis
Impedance Spectroscopy	evaluating the fundamental electronic properties of thick, thin films and single nanowires.

APPLICATIONS OF BARIUM TITANATE.

Multilayer Ceramic Capacitors (MLCs)

The Multilayer Ceramic Capacitors (MLCs), which is among those biggest categories in capacitor ceramics manufactured with figures by advantage. A capacitor's most basic design consists of two parallel metal plates separated by empty space. When a voltage is applied across the plates, a charge develops on them that is proportional to the supplied voltage. . (Z. Chen et al., 2017).

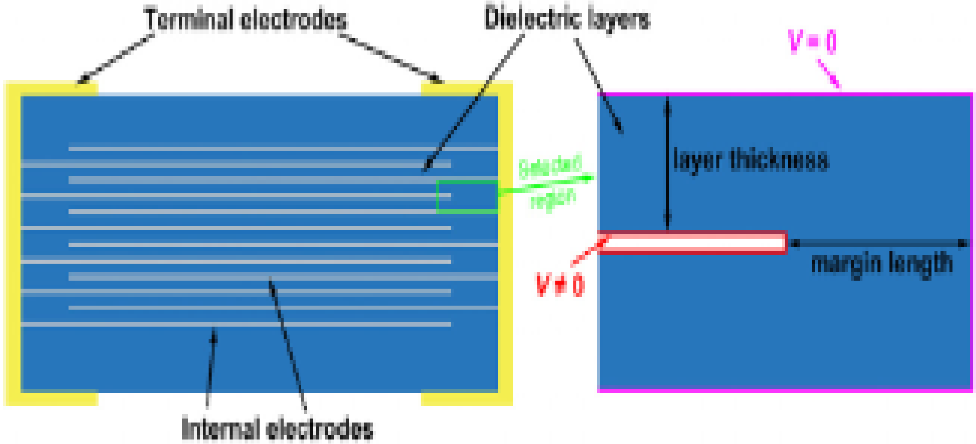

Fig. 3. Cross-sectional schematic diagram of multilayer ceramic capacitor. (Z. Chen et al., 2017).

In ultrasound transducers, which typically have arrays of piezoelectric ceramic components, barium titanate, a piezoelectric ceramic material, is employed, (Z. Chen et al., 2017). A schematic diagram of ultrasound transducer and transducer assembled with barium titanate are seen in, (Z. Chen et al., 2017).

In barium titanate-based ceramics, a sharp increase in resistivity by many orders of magnitude occurs over a physical change in crystal structure from tetragonal to cubic at the Curie temperature, producing positive temperature coefficient of resistivity (PTCR). Barium titanate can be doped with acceptors to multiply the effect of PTCR by many orders of magnitude or with donors to change the conductivity at ambient temperature, (Rowlands & Vaidhyanathan, 2019). Among the most interesting uses of barium titanate is as semi-conductor with positive temperature coefficient of resistivity (PTCR), dopants must be added to host titanate composition when the temperature coefficient of resistivity is positive to improve the PTCR, (Chatterjee, n.d.).

Microwave Absorption

Consequential electromagnetic interference (EMI) contamination become apparent from extreme evolution of telecommunication has prompt significant interest in electromagnetic-absorption machinery to find solution to the problem, thus, in conjunction with carbon nanotubes, barium titanate has been applicable for microwave absorption, (Ni et al., 2015). A fundamental factor in the effectiveness of EMI shielding is barium titanate with high dielectric constant, positive temperature coefficient, and nonlinear characteristics, (Sebastian, n.d.). In the wideband frequency region, the composites of barium titanate flakes and polyurethane can be employed as effective EM wave absorption materials.(Jain et al., 2013). The addition of a modest amount of silver particles to Polyvinylidene fluoride (PVDF) – $BaTiO_3$ composites clearly increased their dielectric and shielding properties.(Joseph et al., 2013). High microwave absorption efficiencies are primarily attributed to the tetragonal $BaTiO_3$ (TBT) nanoparticles' implanted good dielectric characteristics and the Polyaniline matrix's limited electrical conductivity.(Online et al., 2013). Composite 40M.20B.40B@C, which is made up of 40% barium titanate and 40% paraffin coated on multi-walled carbon nanotubes, demonstrated an absorption of 80–90%. (Sardarian et al., 2017).

Biological Applications

Nanomaterials influence substantial assurance by control with care of mesenchymal stem cells because it permits characteristics of modulation together with differentiation. Barium titanate is a category of ceramics materials that have fascinating characteristics for biological request due to their piezoelectric and dielectric properties, they are applicable in intracellular nano vectors and bio conjugated nanocrystals, (Ricotti et al., n.d.). $BaTiO_3$ Nanoparticles have the potential to operate as alternative antibacterial agents since they can inhibit the biofilm-formation processes of pathogenic bacteria at very low concentrations.(Shah et al., 2018). Hard tissue replacement has been reported to use the well-known ferroelectric substance $BaTiO_3$.(Wu et al., 2020).

Energy Storage

Dielectric capacitors that have excessive energy density are of considerable possible use in modern electronic appliances and electrical power systems, (Shen et al., 2016). Barium titanate with a much good medium for relative permittivity for use in higher-bit density with dynamic random access memory (DRAMs), (He et al., 2013). Due to low loss, high dielectric constant and fine electromechanical barium titanate features, they are use for applications in capacitors at room temperature, (Sharma et al., 2015). Capacitors are among the essential energy storage appliances used in electronic industry, (Niu et al., 2015). The very answerable character of barium titanate related with pyroelectric, thermoelectric and piezoelectric can be the explanation to give multifunctional Nano devices in the area of heat control, sensing and control of energy, (Karvounis et al., 2020).

CONCLUSION

In this review, different synthesis methods of $BaTiO_3$ nanoparticle are discussed with their advantages and disadvantages. There are many different ways to make $BaTiO_3$, including hydrothermal, co-precipitation, sol-gel, solid state processes, and polymer precursor methods, the techniques can be used in the process of making ceramics as a molding material and also as an intermediate between thin films of metal oxides in various applications. The characterization techniques mostly used in determining the lattice constant, functional group, morphology, elemental compositions and electrical properties, including the various applications of $BaTiO_3$ which includes modern electronic appliances and electrical power systems, the Multilayer Ceramic Capacitors (MLCs), biological request due to their piezoelectric and dielectric properties, and microwave absorption are reviewed.

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