Antiferroelectric Lead based Perovskite Material properties andapplications: A Review

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Abstract. In this review paper, the discussion is about some of the lead based antiferroelectric (AFE) perovskite materials. The antiferroelectric perovskite materials mainly lead zirconate (PZ) and lead zirconate titanate (PZT) prepared by solid state reaction route with their structure change at different concentrations, phase transition, their dielectric properties ormore. These materials caught the attention of the researchers because of their use in high energy storage devices, pyroelectric devices, sensors, cooling devices, pulse power generators and have many more applications. The reason could be their electric field phase transformation between the antiferroelectric (AFE) state and ferroelectric (FE) state and the phase switching property can be one of the strong factors responsible for the performance of the PZ based materials. Thecentral focus of this review is to briefly explain the continuous increase in research in the antiferroelectric materials by enhancing the PZ with many dopants. We mainly address PZ and PZT solid solution properties.

1 Introduction

1.1 Antiferroelectrics

In 1951, kittel proposed the concept of antiferroelectricity [1]. To understand about the antiferroelectrics, it is important to mention about ferroelectrics as they share very close relation. Ferroelectric wasdiscovered by Valasek in1920. And in earlier 1940s ferroelectric behavior is found in compounds such as oxideslike barium titanate [2] and since then the ferroelectricity was studied widely in many different compounds. Figure 1 shows the ferroelectricity state. Ferroelectricity is the state where the adjacent dipoles are aligned in parallel symmetry in the existence of electric field. Two types of characterization which can define FE state i.e. spontaneous polarization and the second one is reversibility of polarization by external electric field. In case of AFEs, the arrangement of adjacent dipoles is in antiparallel direction with respect to each other. When sufficient electric fieldis provided, the

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dipoles get aligned themselves in same direction to attain FE state. This is known as AFE-FE phaseswitching or phase transformation. The spontaneous polarization as a whole in AFEs is zero.

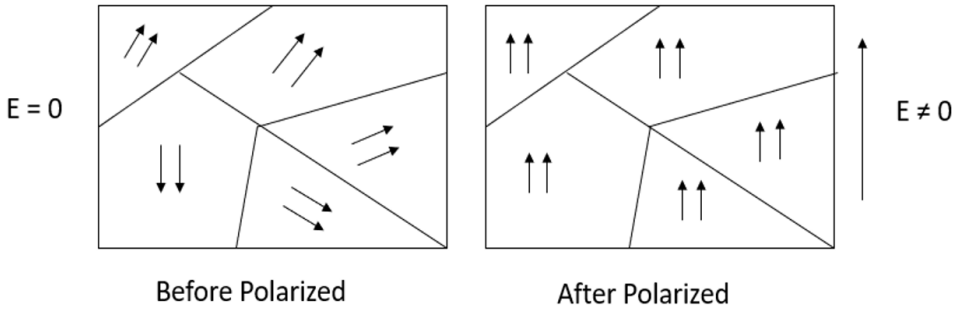


Fig. 1. Ferroelectrics polarization process [3]

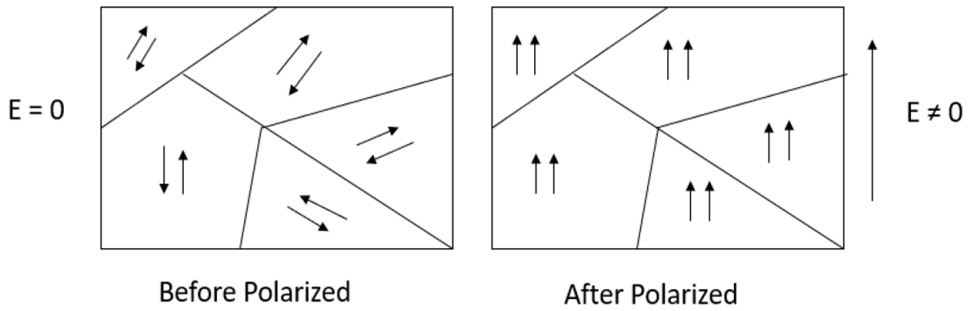


Fig. 2. Antiferroelectric polarization process

1.1.1 Antiferroelectricity in Perovskites

Antiferroelectrics have various number of sub-classes such as perovskite AFEs, pyrochlore AFEs, liquid crystals AFEs, and more of like these groups [3–5]. The perovskite group of AFEs is the most prominent one of these AFE categories, and it is the focus of this review work. Perovskite is generally articulated as ABO_3 type structure as shown in Figure 3. There is a network of oxygen octahedral linked at corners, enclosed in an octahedral (B-site) and interstices (A-site). To put it in more simply, A atoms are present at corners, B ions occupied the body center and oxygen atoms are present at face centers. ABO_3 perovskite-structure based oxides are widely used materials and able to show many exceptional properties such as high temperature superconductivity, magneto- resistance and piezoelectric properties and thus form a wide area of perovskite materials covering a broad range ofphysical properties and ideas. The study of ferroelectrics firstly was of very much interest and now with FE, AFEhas drawn the attention of the researchers towards this field. Some examples of AFEs with perovskite structure are$PbZrO_3$ which was the very first perovskite material recognized as an antiferroelectric crystal and then further many more compounds which show AFE state lead based as well as lead free such as $PbHfO_3$, $NaNbO_3$, $AgNbO_3$ and many more [6,7].

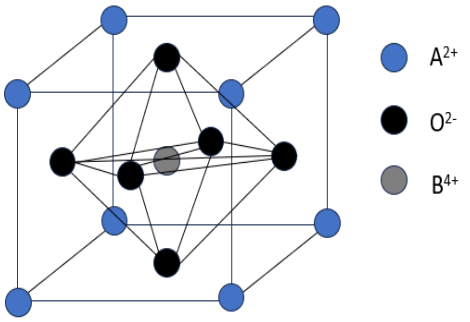


Fig. 3. Perovskite structure of AFEs

1.2 Basic Properties of AFEs

1.2.1 Dielectric Properties

AFEs studies have concluded that the value of dielectric constant is in the range 50–5000 which is less than the FEs. In antiferroelectrics, dielectric loss tangents typically vary from 0.5 percent to 10%. The value of dielectric constant of the AFEs (represented in C–V curves) exhibits a double buffer-fly type figure when the applied electricfield is external, as seen in figure 4. With the growing electric field from zero to maximum value, the dielectric constant of AFEs increases at first, peaks at A (A'), and then gradually drops. At A' (A) point, the phase shift fromantiferroelectric to ferroelectric is complete, and then this electric field possibly known as critical forward phase electric field. Likewise, the dielectric constant increases and subsequently declines as the electric field decreases from maximum values to zero. The change in phase transformation from FE to AFE state is shown by a second peak value at B (B') point. It's referred to as a critical backward phase field [8].

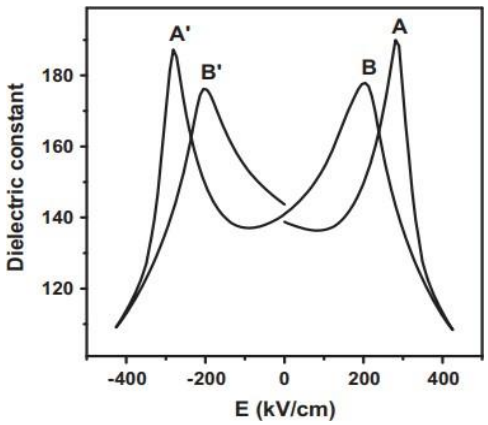


Fig. 4. Dependence of DC electric-field by dielectric constant of AFEs [8]

Park et al. describes the phase transformation in 6 steps as follows first stage the randomly arranged domains of AFE in absence of electric field. The AFE domains transition into the FE state is observed in the secondstage at the critical forward phase switching field by the exposure of electric field. Afterwards in third stage, withadditional increase in the electric field the polarization arrangement of the domains is arranged. At the 4th stage, the piezoelectric effect comes in consideration in the induced FE state even at the exposure of high value of electricfield. Then in the 5th stage, after the discharge of the electric field, the induced FE begins to return to its re-alignedFE condition and at the last stage, the re-aligned AFE reverts to its initial configuration. i.e. stage 1 above its Curie temperature [9]. This is how he explained phase transformation in easy manner in Figure 5. AFEs also shows comparable characteristics as FEs as a function of different temperature range in three aspects.

1. AFE does not appear in every temperature range; it shows for certain range of temperature as AFE properties does not show any influence when temperature is above the critical point that can be defined as Curie temperature (T_C).
2. As the temperature rises, the dielectric constant rises at first, then falls, reaching its maximum peak valueat Curie temperature (T_C).
3. Above the temperature (curie temperature (T_C), the temperature and dielectric constant follows the curie-Weiss law:

$$\epsilon_r\ (0) = \epsilon_r\ (\infty) + \frac{C}{T - T_0}$$

Where $\varepsilon_r(0)$ and $\varepsilon_r(\infty)$ are the low frequency and the optical dielectric constant respectively, Curie Weiss constant denoted by C and T_0 denotes the temperature.

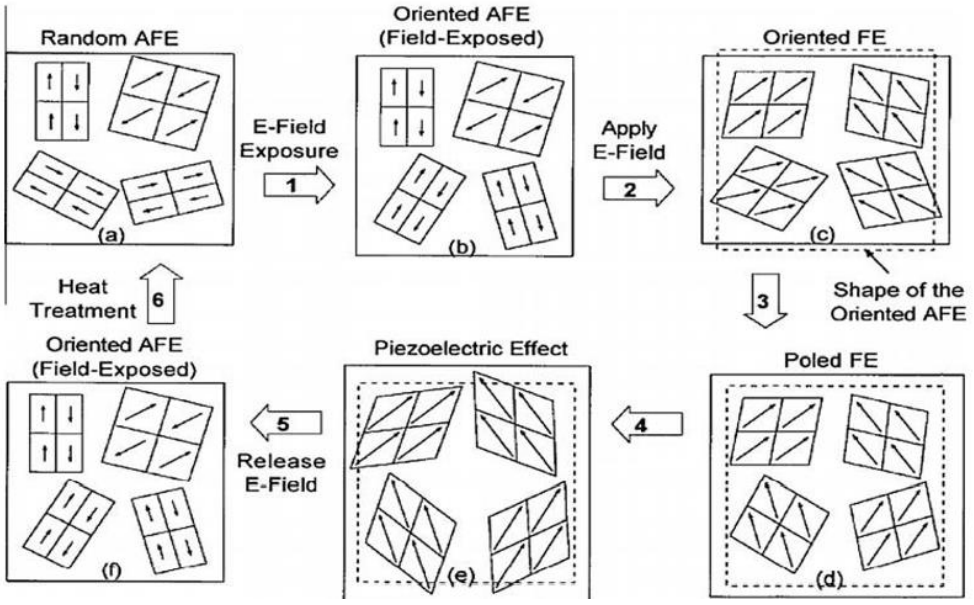


Fig. 5. Phase transformation from AFE-FE [9]

1.2.2 Phase Switching Properties

The crystal structure changes as the AFE-FE phase transformation takes place. This is reported and provenby many of the researcher who worked in the field of antiferroelectric. Also, the AFE lead based materials may be categorized in two subparts in accordance with their ability

to keep the induced FE condition stable. If FE state returns to its native state i.e., Antiferroelectric state after the removal of electric field, it is known as hard AFE andSoft AFE occurs when the induced FE condition persists after the field has been removed. However, at higher values of temperature (over curie temperature) and/or high pressure, the soft AFE state is not very stable, as it canrevert to its original AFE state.

1.2.3 P-E LOOP

Figure 6 displays the plot which shows change in polarization that can happen in ferroelectric materials and antiferroelectric materials when there is a function of electric field. On the basis of the characterization of theFEs it is clear that there is increase in polarization by applying the electric field reaches to saturation point. Hence,for FEs, the single hysteresis P-E loop is reported as shown in figure. Now, in case of AFEs there are 2 loops i.e., the induced field ferroelectric state is not very stable, it returns back to antiferroelectric state as the electric field changes or changes in temperature and/or pressure.

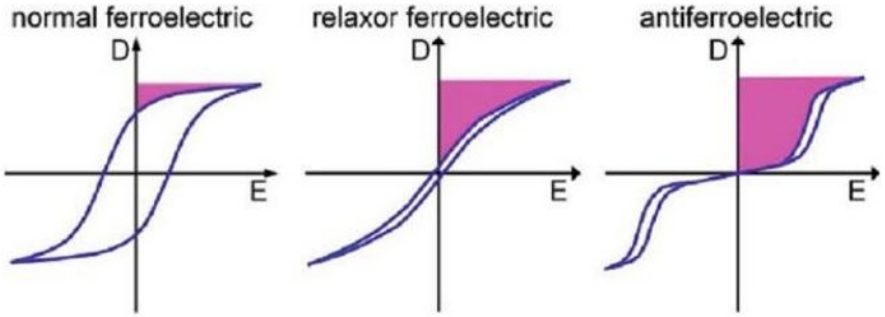


Fig. 6. P-E loops of FEs and AFEs [10]

2 Methods of fabrication technique

There are number of synthesis method such as Solid State Reaction (SSR) method is a method for makingpolycrystalline solids with a combination of solid initial materials; solids do not react with each other at room temperature over typical time scales, thus they must be heated to considerably higher temperatures (generally between 1000 and 1500°C) for the reaction to take place at all, Vapor Phase Transport (VPT) method where a condensed phase usually a solid is volatized when a gaseous reactant is present (transport agent includes halogensand halogen compounds) and deposited elsewhere in the form of crystals, Co-precipitation (CPT) method is a process in which chemicals that are ordinarily soluble at the conditions used are carried down by a precipitation and a wet chemical process for generating solid materials from tiny molecules is the Sol-Gel auto-combustion method.; that produces an integrated network (gel) using either a chemical solution that means the sol for solutionor colloidal particles i.e. the sol for the nanoscale particle and then removes the liquid phase after drying, PLD i.e.Pulsed Laser Deposition is a PVD (physical vapor decomposition) technique in which a high-power pulsed laser beam is concentrated within a vacuum chamber to hit a target of the material which to be deposited, Chemical Solution Deposition (CSD) is a general concept for any process that involves the use of a chemical precursor solution to form a film, Chemical vapor decomposition i.e. CVD is a technique in When a substrate is exposed to one or more volatile precursors, they react and degrade on the surface of the substrate, resulting in the desired thinfilm deposit and PVD (Physical Vapor Deposition) is another method for making thin films and coatings (vapor phase, then thin film condensed phase, before returning to the former phase) etc. Not necessarily all of these methods are used to prepare

antiferroelectric materials but some of them surely used by researchers to gain the specified objective of antiferroelectric property which is reported in many research papers.

2.1 Solid state reaction method

The method of Solid-state reaction technique can be defined as the straight and simple method for preparing bulk ceramics has been published as well as a number of articles on AFE ceramics. The sample synthesized by using solid state reaction method which includes following steps:

(a) Precursors
(b) Mixing and Milling
(c) Calcination
(d) Binder Addition
(e) Sintering
(f) Shaping

For the synthesis of solid-state reaction method, the material is fabricated by crushing and grinding the stoichiometric ratio of oxides and carbonates. Then, the solid-state reaction occurs among the crystal lattice and italso depends upon the lattice defects. In the synthesis method, chemical compounds are mixed carefully by using mortar pestle or if in bulk using ball milling and then the material is necessary to calcined at higher temperature range approximately more than 900 ^{o}C in order to achieve the required perovskite structure. Following that, with the use of organic reagents like PVA, the calcined powder is crushed again to obtain fine powder. The Pellets are made by using the calcined powder and then sintered at higher temperature. And hence the sample is ready for further characterizations to know about different properties. Many papers are published to show the desired resultsusing conventional solid state reaction method [11–14].

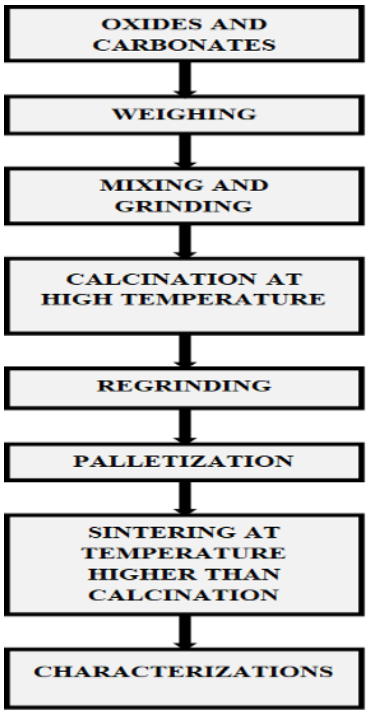


Fig. 7. Solid state reaction technique

3 Review of literature

Antiferroelectric materials have been broadly explored over the past few decades, and a large number of research papers on AFE materials have been published in the open literature. Although, it is a wide area for research, even now research on this topic is going on, and there are many more properties that researchers are stilllooking for. Therefore, we shall discuss some recent findings in this review paper and apart from this, some of thenew properties those researchers have found out.

Nevertheless, numerous unresolved questions persist regarding PZ and related solid solutions, such as PbZr1-xTixO3, commonly known as PZT, where x is less than or equal to 0.06. An essential aspect of this pursuit involves comprehending the presence and characteristics of an intermediate (IM) structure situated between the room-temperature AFE phase Pbam and the high-temperature paraelectric (PE) phase $Pm\bar{3}m$. This understanding holds paramount importance in advancing our knowledge in this field. PbZrO3, often regarded as a model antiferroelectric perovskite, presents a high level of complexity. Its transition to the antiferroelectric (AFE) phase involves intricate couplings and the emergence of multiple order parameters, including the tilting of oxygen octahedra. In the AFE phase, lead ions are displaced along the orthorhombic a-axis, specifically in the [110]-pseudo cubic direction. However, the transition to the polar phase is not a simple reversal of the sublattice displacement seen in the AFE phase. Instead, it likely involves a shift to an entirely different phase characterized by a distinct pattern of octahedral tilts. Generally, it is accepted that the polar phase of PbZrO3 assumes a rhombohedral structure with polarization along the [111] pc direction. This conclusion is drawn from the observation of a rhombohedral phase in the phase diagram of PZT, particularly at low concentrations of Ti [15].

The lead-based compound PbZrO3 was the first one in which the antiferroelectricity was noticed and further many of the researchers have proved this concept by doping different compound in PbZrO3. The research has not stopped here, after that there were many more of the lead-based materials come under notice that shows the AFE state. Also, the PbZrO3 was well-known as perovskite material having tetragonal distortion at room temperature before the concept of antiferroelectricity discovered. While reviewing about the structure it is noticedgradually that the crystal structure of this compound was found to be orthorhombic. According to Sawaguchi et al.,they determined that the crystal structure of single crystal PbZrO3 was orthorhombic with centrosymmetric space group Pbam using X-ray analysis and optical polar microscopy [16]. But later Jona et al in 1957, published that theorthorhombic distortions are confirmed by the characterizations i.e first is X-ray and the second one is neutron diffraction data, but with the non-centrosymmetric space group Pba2 [17]. Glazer et al. reclaimed the space groupPbam in 1993 with the lattice parameters of value as a = 5.889 Å, b = 11.784 Å, and c = 8.226 Å at the temperatureof 24 °C [18]. With the observation of PbZrO3 ceramic which shows weak piezoelectricity it is claimed that Pba2 could be used for diffraction data. Further, some of the researchers have found that there is no piezoelectric effectin single crystal. And these analysis and studies made the space group factor a big discussion for researcher. On the other side, the structural aspect also reveals that taking values of oxygen in refinement was not very easy and creating difficulties for proper refinement [19]. Also, in addition the hysteresis loop studies should be handled properly because some of the factors such as free charges creating errors in hysteresis loop. One of the points to consider is this, the movement of dipole moments responsible for antiferroelectricity as well as the movement of the lead ions; have no geometrical symmetry and the research move towards a two layered model of lead zirconate.It was observed that the presence FE state at room temperature was unsure and although there are many contradictoryfactors which were raised by researchers in their publications about the system's symmetrical nature but

still the Pbam space group is more often taken into consideration in case of $PbZrO_3$ [20]. According to Kittel's theory, normal ferroelectrics like $BaTiO_3$ are likewise unstable, making $PbZrO_3$ a non-strict antiferroelectric. The phase transition of $PbZrO_3$ was investigated by many researchers using different types of techniques such as X-ray, neutron diffraction [29-30], electron diffraction (SEM and TEM) [31-33] and raman spectroscopy [21–25]. Also, by doping different ions in PZ such as La, Ba, Ca, Sr [26–29]. The method can beused as an indicator of the stability of AFE in doped PZ by analyzing the tolerance factor t.

$$t = \frac{rA + ro}{\sqrt{2}(rB + ro)}$$

Where the terms r_a and r_b denotes the radius of A-site and B-site cations respectively and the term r_o denotes the radius of O anion. If the value of $t > 1$ then there must be existence of FE phase and when the value oft < 1, AFE phase exists. The tolerance factor of PZ comes out to be 0.97. In 1952, it was found that pure PZ goes under a phase change from AFE to PE at 233ºC which is considered to be standard curie point with increasing temperature and there is no AFE to FE transition from temperature dependent dielectric constant curve [12]. Tennery found through XRD analysis that with increasing temperature firstly, AFE phase changes into FE at 226ºCthen further change into PE phase at around 236ºC. Also, the transition from AFE phase to FE phase was not observed in pure PZ ceramics at ambient temperature. High-density lead zirconate single crystals and the films have stronger electric field resistance due to their homogeneous microstructure and higher density [14]. HuaxiangFu have reported PZ with electron doping and hole doping as in electron doping of value $n = -0.5$ per unit cell revealed that as the soft mode frequency at zone centre falls lower than the zone boundary R, the AFE turns into FE one; Whereas the soft mode at R or soft mode at M appears less in frequency than the hole doping at PZ. So, AFE instability seems strong following the hole doping. Doping of holes in $PbZrO_3$ results in metallic $PbZrO_3$, theconcurrence of metallicity and antiferroelectricity proves the viability of metallic antiferroelectricity. In addition, he said that the electron doping and the hole doping have extremely distinct special effects on the atom-atom interaction. Charge-doping occurrences have a known cause [30].

PZT are proposed by cross for the first time. XRD analysis states that there is intermediate state which exist is rhombohedral ferroelectric. In PZT, a Raman investigation demonstrates a shift from pure FE phase to orthorhombic AFE phase at the value of 0.3 GPa, and subsequently to PE phase at the value of 2.9 GPa. Also, raman spectroscopy studies indicates the rhombohedral phase at the value of 0.6 GPa from rhombohedral to orthorhombic AFE phase at the value of 0.9 GPa and into another orthorhombic phase at the value of 4GPa. Dopingof different ions gives good results but PZT and PLZT are considered to be more promising and wide range of studies have been done on these by researchers because of their properties such as structures, dielectric properties and phase switching [9,31,32]. When $PbZrO_3$ mixed with the FE $PbTiO_3$, there is formation of MPB region which comes into notice between the rhombohedral and tetragonal phase, which is critical, in response polarization rotation produces an ultrahigh electromechanical reaction. Noheda and others along with him have reported the occurrence of monoclinic FE phase in PZ [23]. Later, in 2001, it was demonstrated by Noheda that the piezoelectric crystal rotates its polarization through the monoclinic phase. $92\%PbZn_{1/3}Nb_{2/3}O_3$-$8\%PbTiO_3$. PZT becomes the centre of attraction because it shows morphotrophic phase boundary region around the value of x= 0.53, where mainly dominated by electrochemical responses and mostly utilized for some of practical applicationsas piezoelectric transducer devices. It is also noticed that ferroelectric phase appears between the paraelectric and antiferroelectric state in almost all PZ based solid

solutions and also, the AFE phase disappears completely for doping concentrations more than 10-20% [8].

PLZT solid solution was discovered by haertling as electrooptic materials [47]. PLZT at room temperaturephase diagram. Now according to the variation of compositions, various phases can be seen in PLZT including orthorhombic AFE can be seen in Zr rich side, rhombohedral, tetragonal, relaxor FEs; these FE phase can be seenwhen Ti content is more and the PE phase. Some of the practical applications in which PLZT are used are transducers, electro-optical devices, transducers, Pyroelectric detectors and many more. In PLZT, La^{3+} able to stabilize the AFE state when doped in PZ.

Kelley markowski et al states that their main purpose was to notice the compositional modifications withvariation of Ti-Sn and Zr-Sn ratios, which mainly shows the change in stability of phase. With these variations increase in transition between FE-AFE to lower the switching field always accompanied an increase in T_{max} whichleads the increase in hysteresis. And also they shows to increase the switching field and hysteresis, A-site modification is necessary i.e. decreasing T_{max} while controlling the stability of the AFE or FE state as it is the bestcase scenario. In this paper, on increasing the Sn^{4+} content perpendicular to the MPB some conclusions have made by them as the T_{FE-AFE} decreased, the switching field increased, the dielectric maximum peak grew more diffusiveand the decrease in room temperature dielectric constant was observed. Despite of the ratio of Ti-Sn, 0.2% strain came out at the switching field. There is continuous increase in strain as increase in field after phase switching; thetemperature of the dielectric maximum remained the same and the hysteresis remained at 25Kv/cm. with increasingcontent of Zr^{4+} along with the MPB resulted in the hysteresis increase, the decrease in switching field, but at the switching field the value of the strain remained almost constant at 0.16% and the dielectric maxima increased. Also, a sharper dielectric maximum peak emerged, and the AFE-PE transition temperature dropped .

In this paper, they have described that the polycrystalline $(Pb_{(1-3x/2)}Bi_x)(Zr_{1-3x/4}Al_x)O_3$ (PZO–BAO) ceramics, with the value of x = 0.0–0.3, formed from solid state reaction method. The X-ray diffraction (XRD), differential scanning calorimetry (DSC) and the dielectric spectroscopy characterizations have been considered which results that the existence of $BiAlO_3$: as a result of the BAO in case of it as solid solution, the stability of thestructure of the perovskite phase decreases. It was determined that no intermediate ferroelectric phase existed in the system of PZO–BAO based on dielectric studies, thermal studies, and P–E hysteresis results. BAO-induced antiferroelectric phase stabilization in perovskite lead zirconate is manifested by a "square" antiferroelectric behavior. The solid solution of the material $Pb_{(1-3x/2)}Bix(Zr_{1-3x/4}Al_xO_3)$, on the other hand, can be used to make capacitors and electromechanical transducers with high energy storage capabilities [33]. The material $0.99PbZrO_3$-$0.01Pb(M_{1/2}W_{1/2})O_3$ (M = Mg, Zn & Mn) made by the solid state reaction method. Further their structure and the study of dielectric properties and AFE properties have been recognized. X-rays show that the Pbam symmetry is orthorhombic, and the SEM resultant images show that the grain size increases in the solid solution series in the sequence of M = Mg, Zn, and Mn, which can be ascribed to the action of sintering by liquid phase produced by the availability of PbMW compound. As a result of the substitution of $Pb(M_{1/2}W_{1/2})O_3$ for $PbZrO_3$, the Curie temperature (T_C) is likewise reduced, while the maximum permittivity ('max) is much raised. By decreasing E_{Cr}, the critical field can be lowered, which also softens the AFE order of lead zirconate, making the AFE solid solutionmaterials viable for situations where dielectric breakdown at high field is not a concern. The increasing value of P_{Ind} points leads to a superior energy storage application for AFEs [48]. Some of the doped AFE materials are listed in the table 1 below:

Table 1. Doped Pb based AFE materials

Material	Specification	Composition	References
Lead based AFE material	Energy storage applications	Eu-Doped PbZrO3.	[34]
	Dielectric Tunability	PbZrO3 films	[35]
	Structure and improved electrical properties	Pr-doped $PbZrO_3$	[36]
	Energy storage performance	Sr-doped PbZrO3	[37]
	Phase transition of antiferroelectric	PbZrO3: Sn revisited. Phase Transitions	[38]
	High energy storage performance	Ca-doped PbZrO3	[39]
	ferrielectric nature of PbZrO3-based antiferroelectric	(Pb,La)(Zr,Sn,Ti)O3 (PLZST)	[39]
	Electrocaloric effect (ECE)	alkaline-earth element doped PbZrO3	[40]
	Phase transition from AFE to FE	W doped PbZrO3	[40]
	Energy storage performances	Sm-doped PbZrO3	[41]
	AFE to FE phase transition	charge doping in cubic PbZrO3	[42]
	Electrical and dielectric performances	Ba-doped PbZrO3	[12,43,44]

An overview of the Dielectric characteristics and associated variables of AFE or ceramics that resemble AFE

Materials	Dielectric constant	Curie Temperature	Polarization	References
(Pb0.97La0.02)(Zr0.95Ti0.05)O3	1534	246	40	[45]
Pb0.97La0.02(Zr0.58Sn0.35T0.07)O3	450	161	29	[46]
(Pb0.88La0.08)(Zr0.91Ti0.09)O3	580	170	32	[47]

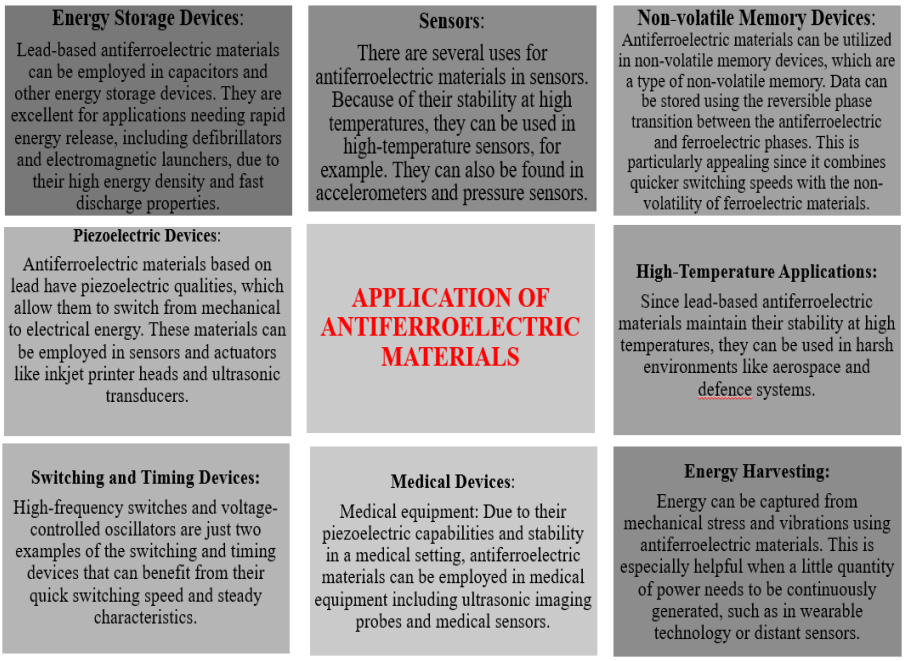
In lined up with essential work, there were significant advances in the improvement of the PbZrO3-PbTiO3 (PZT) strong arrangement stage outline. The research is shifting towards environment friendly materials. Some of the lead free antiferroelectric materials is listed in the table below:

	Materials	References
	AgNbO3 Ag(Nb0.85Ta0.15)O3 AgNbO3-0.1 wt % MnO2 AgNbO3-0.1 wt%WO3 (Ag0.97Bi0.01)NbO3 0.9Bi0.48La0.02Na0.48Li0.02Ti0.98Zr0.02 O3-0.1Na0.73Bi0.09NbO3 0.94(0.75Na0.5Bi0.5TiO3-0.25Bi0.5K0.5TiO3)-0.06BiAlO3 0.89Na0.5Bi0.5TiO3-0.06BaTiO3- 0.05(K0.5Na0.5)NbO3	

Lead free AFE materials	0.92(0.65BaTiO3-0.35Bi0.5Na0.5TiO3)-xNa0.73Bi0.09NbO3 Ag1-3xBixNbO3 Ag1-3xLaxNbO3 Ag1-3xSmxNbO3 NaNbO3 Na0.7Bi0.1NbO3 0.78(Bi0.5Na0.5)TiO3- 0.22NaNbO3 0.76NaNbO3- 0.24(Bi0.5Na0.5)TiO3 x(0.95Bi0.5Na0.5TiO3-0.05SrZrO3)-(1-x)NaNbO3 $0.90NaNbO_3$-$0.06SrSnO_3$-$0.04(Na_{0.5}Bi_{0.5})TiO_3$	[48–55]

4 Applications

AFEs are used commonly in many practical devices. Due to the fact that phase transitions are always preceded by variations in the volume and variation in polarization of the system and accordingly this process might be viewed as the function of temperature, electric field, hydrostatic pressure. AFEs, therefore, have the potential to succeed as the future application in the area of devices. For example, double hysteresis loop and highly saturated polarization in an influence of external electric field can significantly increase the energy storage capacity of AFEs. Resultantly, AFEs used in different devices such as high energy capacitors, high strain actuators, IR Pyroelectric detectors, cooling devices and pulse voltage or current suppliers [32]. These materials have been the center of attraction for researchers in energy-oriented research worldwide. In spite of this, AFEs have a long way to go, as there are still numerous properties/features to be uncovered; many other applications in different fields which are still to be discovered and can be considered as never-ending research. In addition, various additional applications, including memory devices, electronic energy storage devices, and coolers, as of right now, are beingconsidered, and interactions with other fields are being established. Also, the AFEs shows the properties of Pyroelectric effect which cites to its capacity, that when it is heated or cooled it can produce a temporary voltage or current and electrocaloric effect, the reverse course of pyroelectric effect, a material's temperature will fluctuate when an electric field is applied or removed, under adiabatic conditions [56].



5 Conclusion

Lead based antiferroelectric materials have been reviewed synthesized by solid state method. In this briefreview, we have highlighted the key features such as structure, phase transitions, dielectric properties, Raman studies and many other novel properties of the PZ-based AFEs such as multiferroics and what makes it different from PZ-based ferroelectric or piezoelectric materials and at the same time useful as much as FEs nowadays, in different areas/fields of science and technology or in everyday life used techniques.

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