# Lead-free antiferroelectric energy storage dielectric ceramics

Are lead-free antiferroelectric ceramics suitable for energy storage applications?
Lead-free dielectric ceramics with high recoverable energy density are highly desired to sustainably meet the future energy demand. AgNbO 3 -based lead-free antiferroelectric ceramics with double ferroelectric hysteresis loops have been proved to be potential candidates for energy storage applications.

Are lead-free AFE energy storage ceramics possible?
Therefore,the development of new lead-free AFE energy storage ceramics is extremely urgent. In 2016,Zhao et al. reported that pure AgNbO 3 lead-free ceramics showed typical double P - E loops (antiferroelectric behavior) and a high Wrec of 1.6 J/cm 3 at 14 kV/mm [13 ].

What is the optimal energy storage performance for lead-free ceramics?
Finally,optimal energy storage performance is attained in 0.85Ba (Zr 0·1 Ti 0.9)O 3 -0.15Bi (Zn 2/3 Ta 1/3)O 3 (BZT-0.15BiZnTa),with an ultrahigh i of 97.37% at 440 kV/cm(an advanced level in the lead-free ceramics) and an excellent recoverable energy storage density (Wrec) of 3.74 J/cm 3.

Can a relaxor/antiferroelectric composite improve the energy storage performance of lead-free ceramics?
Furthermore,the newly developed composites exhibit better energy storage characteristics at 120 °C,with a high Wrec of 3.5 J cm -3 as well as a high i of 91%. This study demonstrates that the design of a relaxor/antiferroelectric composite provides a highly effective methodto improve the energy storage performance of lead-free ceramics.

Which antiferroelectric materials have double hysteresis loops?
Lead-free antiferroelectric materials,which show double hysteresis loops,are becoming increasingly popular due to their superior energy storage capacity. Ta-modified AgNbO 3 ceramics achieving a recoverable energy density of 4.2 J/cm 3 with an efficiency (i) of 69% was reported by Zhao et al. .

Are lead-free relaxor ferroelectrics a good energy storage material?
Moreover,considering the significant environmental harm caused by the presence of lead,lead-free relaxor ferroelectrics are regarded as materials with tremendous potential to achieve high energy storage efficiency and energy storage density[,,].

Pulse power technology can compress various energy forms into electrical energy and store them in dielectric energy storage capacitors. This stored energy can be released rapidly in the form of a pulse with very short durations, ranging from milliseconds to microseconds or even nanoseconds [[1], [2], [3]].Thus, pulse power systems based on dielectric capacitors ...

NaNbO 3 (NN) is considered to be one of the most prospective lead-free antiferroelectric energy storage materials due to the merits of low cost, nontoxicity, and low density. Nevertheless, the electric field-induced

ferroelectric phase remains dominant after the removal of the electric field, resulting in large residual polarization, which prevents NN ...

The development of renewable, efficient, and clean energy storage devices has been highlighted with energy consumption soaring in recent decades [[1], [2], [3]].Dielectric capacitors with high density, fast charging speed and stable operating cycle are used in advanced power devices [[4], [5], [6]].For practical applications of pulsed capacitors, environmentally ...

As a matter of fact, based on the relationship between polarization and the applied electric field of E, dielectric energy storage ceramics can be classified into four types of dielectric material: linear dielectric, ferroelectric (FE), relaxor ferroelectrics (RFE) and antiferroelectrics (AFEs) -based dielectric ceramic capacitors.Linear dielectrics materials such as CaTiO 3 and ...

With the help of composition regulation, the ceramics not only exhibited a stable antiferroelectric phase but also underwent a structural transformation from an antiferroelectric P (Pbma) phase to R (Pnma) phase, ...

Compared to polymers or films, ceramic-based dielectric capacitors with perovskite structure are the promising candidates for energy storage application due to their superior thermal stability, large absolute energy storage and distinctive mechanical performance [[1], [2], [3], [4]].Among various dielectric ceramics, the antiferroelectric (AFE) ceramics exhibit excellent ...

These results not only suggest that the NaNbO 3 -based relaxor antiferroelectric ceramics are promising candidates for advanced energy storage capacitors, but also provide ...

Single-crystal growth has been explored as a means to improve the piezoelectric properties of lead-free materials, because, as shown for lead-based ferroelectrics, single crystals generally possess much higher dielectric and piezoelectric properties than their polycrystalline counterparts [].For example, the piezoelectric coefficients of Pb(Mg 1/3 Nb 2/3)O 3 -PbTiO 3 ...

Dielectric ceramic capacitors, as one of three passive electronic components, are widely used in numerous cutting-edge electronic devices and high-power pulsed systems including hybrid electric vehicles, surgical lasers, directed energy weapons, and distribution devices, owing to their merits in terms of larger power density (P D), faster charge/discharge ...

Dielectric materials have drawn increasing attention due to their high power density and fast charge-discharge speed. Although satisfactory energy storage performance has been achieved in lead-based ceramics, the exploration of suitable lead-free substitutions is highly desired since the rising environmental concerns caused by lead-based compounds.

NaNbO 3 (NN) is generally considered as one of the most promising lead-free antiferroelectric (AFE)

perovskite materials with the advantages of low cost, low density and nontoxicity. However, the metastable ...

Ceramic-based dielectrics have been widely used in pulsed power capacitors owing to their good mechanical and thermal properties. Bi 0.5 Na 0.5 TiO 3-based (NBT-based) solid solutions exhibit relatively high polarization, which is considered as a promising dielectric energy storage material.However, the high remnant polarization and low energy efficiency limit ...

Overall, the combined large U e of 215.8 J cm -3, high i of 80.7%, and ultrahigh E b of 7.4 MV cm -1 in the P 50 M 50 film with optimized thickness of around 100 nm (figs. S19 to S21) exceeds energy storage performance of ...

The comparable free energy between antiferroelectric (AFE) and ferroelectric (FE) phases in NaNbO 3 (NN) leads to unstable ferroelectricity, restricting future applications for energy storage devices. In this work, lead-free NN ceramics based on different sintering aids have been rigorously synthesized and the microstructural, dielectric, and ferroelectric properties of ...

It is crucial to discover lead-free materials with ultrahigh recoverable energy density (W rec) that can be employed in future pulse power capacitors  this work, a high W rec of 4.51 J/cm 3 was successfully obtained in lead-free Nd-doped AgNb 0. 8 Ta 0. 2 O 3 antiferroelectric ceramics at an applied electric field of 290 kV/cm. It is discovered that Nd ...

Dielectric ceramic capacitors, with the advantages of high power density, fast charge-discharge capability, excellent fatigue endurance, and good high temperature stability, have been acknowledged to be promising candidates for solid-state pulse power systems. This review investigates the energy storage performances of linear dielectric, relaxor ferroelectric, ...

Lead-free antiferroelectric AgNbO3: phase transitions and structure engineering for dielectric energy storage applications. J. Appl. Phys., 128 (7) ... Multiscale structural engineering of dielectric ceramics for energy storage applications: from bulk to thin films. Nanoscale, 12 (33) (2020), pp. 17165-17184, 10.1039/D0NR04479B.

With the rapid development of economic and information technology, the challenges related to energy consumption and environmental pollution have recen...

The primary AFE materials for energy storage applications have been the La-doped Pb-based ceramics [7, [9], [10], [11]], in which a W rec up to 12.8 J/cm 3 has been obtained [11].However, the high toxicity of Pb-containing compounds continuously raises severe problems [12].Thus, the intensive researches have been performed on lead-free counterparts [13, 14].

In this work, we systematically investigated the effects of single-step and two-step sintering methods on the

structural, dielectric and energy storage properties of pure AgNbO 3 ...

A typical antiferroelectric P-E loop is shown in Fig. 1.There are many researchers who increase the W re by increasing DBDS [18, 19], while relatively few studies have increased the W re by increasing the E FE-AFE pursuit of a simpler method to achieve PLZST-based ceramic with higher W re, energy storage efficiency and lower sintering temperatures, many ...

Antiferroelectrics (AFEs) are ideal candidates in dielectric, electromechanical, and electrothermal applications. NaNbO 3 (NN), as a lead-free antiferroelectric (AFE) material under extensive investigation, exhibits ferroelectric (FE)-like polarization-electric field (P-E) hysteresis loops, characterized by high remnant polarization and large hysteresis.

Dielectric capacitors are critical energy storage devices in modern electronics and electrical power systems 1,2,3,4,5,6 pared with ceramics, polymer dielectrics have intrinsic advantages of ...

Consequently, superior energy storage ceramics necessitate a higher W rec.Hence, the pursuit of a high W rec constitutes the primary research focus in the field of energy storage ceramics [10].NaNbO 3 (NN) is a lead-free antiferroelectric (AFE) dielectric material [11]  NN, spontaneous polarization dipoles are oriented in opposite directions within adjacent ...

Antiferroelectrics (AFEs) exhibit giant potentials in energy-storage capacitors owing to their high saturated polarization (P max) and near-zero remanent polarization (P r) during electric field induced reversible AFE-ferroelectric (FE) phase transition [1], [2].The recoverable energy storage density (W rec) of dielectric capacitors can be calculated from polarization ...

Lead-free antiferroelectric materials, which show double hysteresis loops, are becoming increasingly popular due to their superior energy storage capacity. Ta-modified ...

Lead-free dielectric ceramics with high recoverable energy density are highly desired to sustainably meet the future energy demand. AgNbO3-based lead-free antiferroelectric ceramics with double ferroelectric hysteresis loops ...

NaNbO 3 (NN)-based lead-free antiferroelectric (AFE) ceramics with ultrahigh energy-storage density (W rec) have attracted increasing attention for applications in high power electronic devices.However, large polarization hysteresis induced by the AFE-ferroelectric (FE) phase transition tends to cause high energy dissipation. In this work, a relaxor AFE ...

Here, we demonstrate a strategy of incorporating heterovalent elements into Ba (Zr 0·1 Ti 0.9)O 3, which contributes to achieving relaxor ferroelectric ceramics and reducing ...

# Lead-free antiferroelectric energy storage dielectric ceramics

The lead-free antiferroelectric material NaNbO 3 (NN) is highly regarded for its exceptional breakdown electric field strength (E b) and substantial recoverable energy storage density (W rec).However, the significant energy loss of NN reduces its W rec and i under a strong electric field, constraining its application in energy storage domains. This study explores a ...

Although NaNbO 3-based antiferroelectric ceramic is considered as a potential lead-free energy storage material, the field-driven antiferroelectric-ferroelectric phase transition greatly hinders its energy storage performance.Here the strategy of synergetic phase-structure construction and relaxation regulation is proposed to solve this issue. The strategy is conducted via A/B-site ...

Meanwhile, recent progress on lead-free antiferroelectric ceramics, represented by AgNbO 3 and NaNbO 3, is highlighted in terms of their crystal structures, phase transitions and potential dielectric energy storage applications. ...

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