

Which lead-free bulk ceramics are suitable for electrical energy storage applications?

Here, we present an overview on the current state-of-the-art lead-free bulk ceramics for electrical energy storage applications, including  $\text{SrTiO}_3$ ,  $\text{CaTiO}_3$ ,  $\text{BaTiO}_3$ ,  $(\text{Bi}_{0.5}\text{Na}_{0.5})\text{TiO}_3$ ,  $(\text{K}_{0.5}\text{Na}_{0.5})\text{NbO}_3$ ,  $\text{BiFeO}_3$ ,  $\text{AgNbO}_3$  and  $\text{NaNbO}_3$ -based ceramics.

Can lead-free ceramics be used for Advanced pulsed power systems?

This includes exploring the energy storage mechanisms of ceramic dielectrics, examining the typical energy storage systems of lead-free ceramics in recent years, and providing an outlook on the future trends and prospects of lead-free ceramics for advanced pulsed power systems applications. Graphical Abstract

What is the optimal energy storage performance for lead-free ceramics?

Finally, optimal energy storage performance is attained in  $0.85\text{Ba}(\text{Zr}_{0.183}\text{Ti}_{0.9})\text{O}_{3-0.15}\text{Bi}(\text{Zn}_{2/3}\text{Ta}_{1/3})\text{O}_3$  (BZT-0.15BiZnTa), with an ultrahigh  $\eta$  of 97.37% at 440 kV/cm (an advanced level in the lead-free ceramics) and an excellent recoverable energy storage density ( $W_{\text{rec}}$ ) of 3.74 J/cm<sup>3</sup>.

What are lead-free electronic ceramics?

In the field of dielectric energy storage, lead-free electronic ceramics have become an inevitable trend. Due to the similarity in the properties of  $\text{Bi}^{3+}$  and  $\text{Pb}^{2+}$ , the lone pair of electrons in the outermost 6s<sup>2</sup> layer can be hybridized with the 6p vacant orbital or the O<sup>2-</sup> orbital to produce high electron polarizability.

How are lead-free ceramic dielectrics used for energy storage?

As lead-free ceramic dielectrics employed for energy storage, their energy storage properties are commonly evaluated by constructing a parallel-plate capacitor, as shown in Fig. 4. This capacitor typically comprises internal dielectric materials and two external conductive electrodes.

Are lead-free dielectric energy-storage ceramics a hot spot?

At present, the application of dielectric energy-storage ceramics is hindered by their low energy density and the fact that most of them contain elemental lead. Therefore, lead-free dielectric energy-storage ceramics with high energy storage density have become a research hot spot.

In this paper, the basic principle of the capacitor for electric energy storage was introduced firstly and then the research advances of  $\text{BaTiO}_3$ -based,  $\text{BiFeO}_3$ -based,  $(\text{K}_{0.5}\text{Na}_{0.5})\text{NbO}_3$ -based lead-free ...

Over last few decades, extensive efforts have been put on the development of lead-free based high-performance dielectric capacitors. In this review, we comprehensively ...

The comparable free energy between antiferroelectric (AFE) and ferroelectric (FE) phases in  $\text{NaNbO}_3$  (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 ...

Here, an ultrahigh energy storage density of  $\sim 13.8 \text{ J cm}^{-3}$ ; and a large efficiency of  $\sim 82.4\%$  are achieved in high-entropy lead-free relaxor ferroelectrics by increasing configuration entropy ...

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  $\text{Pb}(\text{Mg}_{1/3}\text{Nb}_{2/3})\text{O}_3$  - $\text{PbTiO}_3$  ...

The dielectric ceramic capacitor serves as the core energy storage element in the pulsed power system. However, the inability to balance high energy storage density ( $W_{\text{rec}}$ ) and energy storage efficiency ( $\eta$ ) has become a technical challenge limiting the miniaturisation of pulsed power devices.This work proposes an entropy-driven strategy, through introducing  $\text{Sr}(\text{Sc}_{0.5}\text{Nb} \dots$

To improve the performance and design efficiency of lead-free ultrasonic transducers, in this work, an equivalent circuit model and intelligent optimization algorithm were combined for use in a transducer design. Firstly, ...

The ultrafast charge/discharge rate and high power density ( $P_D$ ) endow lead-free dielectric energy storage ceramics (LDESCs) with enormous application potential in electric ...

Summarized the typical energy storage materials and progress of lead-free ceramics for energy storage applications. Provided an outlook on the future trends and ...

Recently, with the need of constructing an environment-friendly society, the explore of lead-free ceramics for energy storage is urgently needed. Generally, relaxor ferroelectrics (RFEs) and antiferroelectrics (AFE) are the two kinds of potential materials for achieving high energy storage performance, which is attributed to their potentially ...

In the early 21st century, Saito et al. reported a  $(\text{K}_{0.5}\text{Na}_{0.5})\text{NbO}_3$ -based (KNN-based) ceramic with a piezoelectric coefficient up to  $416 \text{ pC/N}$  [9].Since then, researchers have focused on a thorough analysis of the structure and properties of KNN-based ceramics [10], [11], [12].Furthermore, increasing attention has been paid to the energy storage and optical ...

This review briefly discusses the energy storage mechanism and fundamental characteristics of a dielectric capacitor, summarizes and compares the state-of-the-art design strategies for high-energy ...

(a) The development of ferroelectric materials and the energy storage applications of BNT-based ceramics, the energy storage properties of several typical lead-free ferroelectric ceramic systems such as  $(\text{Bi}, \text{Na})\text{TiO}_3$ ,  $\text{BaTiO}_3$ ,  $\text{SrTiO}_3$ ,  $\text{Bi}_x \text{K}_{1-x} \text{TiO}_3$ ,  $\text{NaNbO}_3$  and  $\text{K}_x \text{Na}_{1-x} \text{NbO}_3$ ; (b) the relationship between energy storage density and ...

To better promote the development of lead-free dielectric capacitors with high energy-storage density and efficiency, we comprehensively review the latest research progress on the application to energy storage of several representative lead-free dielectric materials, including ceramics (ferroelectrics-relaxor ferroelectrics-antiferroelectrics), glass-ceramics, thin and thick ...

Here, we present an overview on the current state-of-the-art lead-free bulk ceramics for electrical energy storage applications, including  $\text{SrTiO}_3$ ,  $\text{CaTiO}_3$ ,  $\text{BaTiO}_3$ ,  $(\text{Bi} \dots$

However, limited research has been conducted into MLCC development using  $\text{NaNbO}_3$  (NN)-based materials. In this paper, the successful achievement of excellent overall energy storage performance in a novel ...

Dielectric ceramics with high energy storage performance are crucial for the development of advanced high-power capacitors. However, achieving ultrahigh recoverable energy storage density and ...

As a consequence of a reversible transition induced by an alternating electric field, competitive energy densities ( $0.39\text{--}0.51 \text{ J cm}^{-3}$  in the range  $25\text{--}175 \text{ }^\circ\text{C}$ ) with those of lead-based and ...

Here, we demonstrate a strategy of incorporating heterovalent elements into  $\text{Ba}(\text{Zr}_{0.83}\text{Ti}_{0.9})\text{O}_3$ , which contributes to achieving relaxor ferroelectric ceramics and reducing ...

Here, we present an overview on the current state-of-the-art lead-free bulk ceramics for electrical energy storage applications, including  $\text{SrTiO}_3$ ,  $\text{CaTiO}_3$ ,  $\text{BaTiO}_3$ ,  $(\text{Bi}_{0.5}\text{Na}_{0.5})\text{TiO}_3$ ,  $(\text{K}_{0.5}\text{Na}_{0.5})\text{NbO}_3$ ,  $\text{BiFeO}_3$ ,  $\text{AgNbO}_3$  and  $\text{NaNbO}_3$ -based ceramics.

$\text{NaNbO}_3$ -based lead-free energy storage ceramics are essential candidates for next-generation pulsed power capacitors, especially under the background of energy saving and environmental protection.

Request PDF | Superior energy storage performance in  $\text{NaNbO}_3$ -based lead-free ceramics under low electric field |  $\text{NaNbO}_3$  (NN)-based materials have attracted widespread attention due to their ...

Energy storage materials and their applications have attracted attention among both academic and industrial communities. Over the past few decades, extensive efforts have been put on the development of lead-free

high-performance ...

Lead-free bulk ceramics for advanced pulse power capacitors possess low recoverable energy storage density ( $W_{rec}$ ) under low electric field. Sodium bismuth titanate ( $\text{Bi}_{0.5}\text{Na}_{0.5}\text{TiO}_3$ , BNT)-based ferroelectrics have attracted great attention due to their large maximum polarization ( $P_m$ ) and high power density. The BNT-ST:  $x\text{AlN}$  ceramics are ...

In this review, we present perspectives and challenges for lead-free energy-storage MLCCs. Initially, the energy-storage mechanism and device characterization are introduced; then, dielectric ...

The solid solution  $\text{BaTiO}_3$ - $\text{BiFeO}_3$  ceramics have attracted great research interest due to its saturated hysteresis loop with a high maximum polarization ( $P_{max}$ ), especially in the field of ferroelectric, piezoelectric and energy-storage. This work, novel lead-free relaxor ferroelectric ceramics  $(0.67-x)\text{BiFeO}_3$ - $0.33\text{BaTiO}_3$ - $x\text{Sr}(\text{Al}_{0.5}\text{Ta}_{0.5})\text{O}_3$  (BF-BT- $x$ SAT) were ...

Therefore, lead-free dielectric energy-storage ceramics with high energy storage density have become a research hot spot. In this paper, we first present the requirements that ...

Over the past few decades, extensive efforts have been put on the development of lead-free high-performance dielectric capacitors. In this review, we ...

We then review our previous research work combined with research progress into bismuth (Bi)-based lead-free energy-storage ceramics including  $\text{Bi}_{0.5}\text{Na}_{0.5}\text{TiO}_3$  (BNT),  $\text{BiFeO}_3$ , and  $\text{Bi}_{0.2}\text{Sr}_{0.7}\text{TiO}_3$ , in ...

Here, we present an overview on the current state-of-the-art lead-free bulk ceramics for electrical energy storage applications, including  $\text{SrTiO}_3$ ,  $\text{CaTiO}_3$ ,  $\text{BaTiO}_3$ ,  $(\text{Bi}_{0.5}\text{Na}_{0.5})\text{TiO}_3$ ,  $(\text{K}_{0.5}\text{Na}_{0.5})\text{NbO}_3$ ,  $\text{BiFeO}_3$ ,  $\text{AgNbO}_3$  and  $\text{NaNbO}_3$ -based ceramics. This review starts with a brief introduction of the research background, the development ...

A greater number of compact and reliable electrostatic capacitors are in demand due to the Internet of Things boom and rapidly growing complex and integrated electronic systems, continuously promoting the development of high-energy-density ceramic-based capacitors. Although significant successes have been achieved in obtaining high energy ...

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