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Dielectric Materials: Innovations and Applications

V.P. Srivastava
Department Of Physics, St. Andrew's P.G. College, Gorakhpur
vijaiphys@gmail.com

Abstract: Dielectric materials have attracted great attention due to its capacity of storing charge and electrical energy. Due to its high thermal conductivity and outstanding dielectric properties it is highly desirable for advanced electronics. This article presents on overview of recent progress of the dielectric material targeted for high-temperature capacitive energy storage applications.

Keywords: Dielectric properties, energy storage, thermal conductivity, capacitor, high-temperature.

1. Introduction

Due to the global air pollution, climate change, energy deficiency and various new energy generation technologies, such as wind, solar and thermal energy, are developed to replace the fossil fuel energy resources with cleaner renewable sources. Sustainable development concerns the generation and storing of energy in environment friendly way, as well as improving the efficiency of conversion into electrical energy for further usage. It in turns lead to the high demand of the devices for effectively storing, absorbing and supplying the electricity. Researchers have investigated potential avenues for improving the large scale energy conversion process in terms of high energy density, high efficiency and long-term reliability and this lead to developed numerous devices including electrochemical batteries [1-3], super capacitors [4,5], hydrogen storage [6,7] and dielectric capacitors. Dielectric capacitors are widely used in high-voltage direct current transmission system [8], and electric vehicles [9], due to their fast charge-discharge speed, high reliability, good operating safety and low manufacturing costs [10]. The performance of a dielectric capacitor is determined by its dielectric material properties. Several materials, including mica, ceramics, paper, electrolyte and synthetic polymers have been used for making dielectric capacitors. It is found, polymer-based materials are most extensively used because of their good electrical properties, low cost and high flexibility. In order to improve energy storage performances of polymer dielectrics has attracted increasing attention and quite a few work had been published [11,12]. However, the overall summary on the research status of

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dielectric materials for high energy storage is still not carried out up to now. The aim of this review is to provide comprehensive information on research level of high energy-storage dielectric materials and its applications.

2. Basic principle of energy storage :

Generally a capacitor consists of two conductor plates filled with certain dielectric materials as shown in Fig 1.

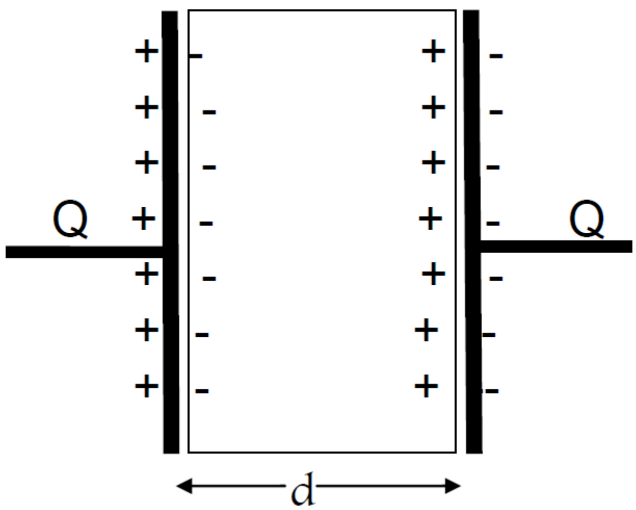

Fig 1

The energy-stored ability of a capacitor is called capacitance, which is only determined by the physical dimension of the conductors and the permitivity of the dielectrics. It is independent of the potential difference between the conductors and the total charge on them. For parallel-plate capacitor.

C=r0 A/d -- --(1)

Where C is the Capacitance, A is the area of each plates, r is the relative permitivity, 0 is the permitivity of free space, and d is the distance between the plates.

When an external voltage V is applied on the conductor plates, the electric polarization is happened. This will result in positive and negative charge with equal content appear on the two plates, which is the so called charge process of a capacitor. The Capacitance of the Capacitor C=Q/V

Capacitance can be defined in terms of incremental change.

$$C=dq/dv \quad --(2)$$

During the charge process, the charges are moved between the conductor plates by the function of external bias, indicating that work must be done and that the electrical energy is stored in the dielectrics at the same time. Hence, the amount of stored energy W

$$W=\int_0^Q V dq=\int_0^Q q/C\, dq= \frac{1}{2} Q^2/C=\frac{1}{2}CV^2 \quad ----(3)$$

We can also find out, the energy stored per unit volume of a dielectric J, known as energy storage density. Energy storage density is the core parameter for all standards for estimating the performance of energy storage materials. The energy can be improved by (1) increasing the dielectric constant and (2) enhancing the field strength of the materials.

3. Energy-Storage performance in the well-studied materials

For the energy-storage in antiferroelectrics, it is necessary to know ferroelectric because they have a close relationship in terms of polarization process. In ferroelectric materials, the adjacent dipoles in one domain share the same polarization orientation and orientation of dipoles can be changed by the applied external electric field. Differently, in case of antiferroelectric materials, the adjacent dipoles are aligned in opposite orientation, and under sufficient high electric field the orientation of dipoles could be re-arranged along direction of field and changed into ferroelectric state, because of the smaller free energy between antiferroelectric and ferroelectric phase. Therefore, antiferroelectric could be defined as : spontaneous polarization direction of adjacent dipoles are opposite and could be induced to same orientation under the function of electric field [13]. Thus, as compared with ferroelectrics, antiferroelectrics possess two district features. One is that the net macroscopic remnant polarization is zero. Another is that P-E Curves under sufficient high electric field display double hysteresis loops.

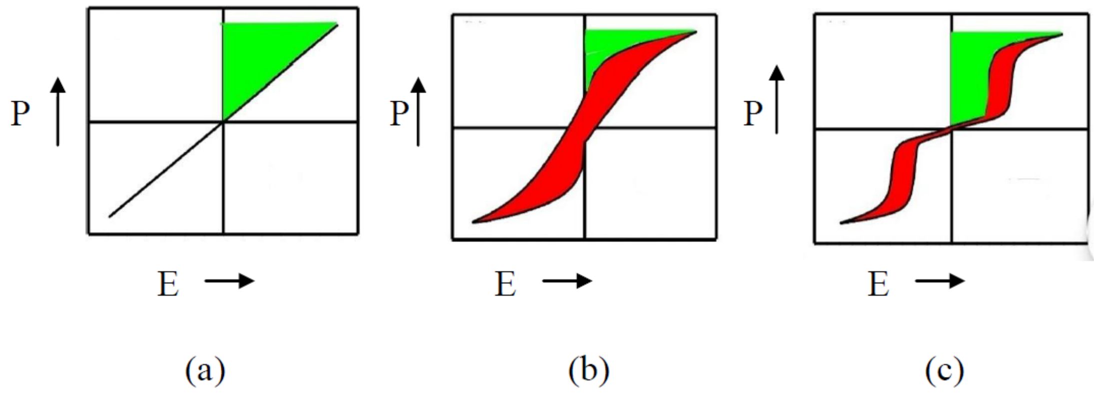

Fig 2. Diagram of hysteresis and energy storage density for (a) linear dielectrics (b) ferroelectrics (c) antiferroelectrics. The green area in the first quadrant is the recoverable energy density Jreco and the red area is the energy loss Jloss.

In the group of antiferroelectric materials, generally there are several subcategories, such as perovskite group [14], pyrochlore group, liquid crystal and so on. Among all of these antiferroelectrics, materials with pervoskite structure are the most important one, which is usually expressed as ABO3. It is found that PbZrO3, PbHfO3, NaNbO3 are their combinations are the typical antiferroelectrics with pervoskite structure at room temperature [15, 16]. The history of study on energy storage in antiferroelectrics could be traced back to 1961, in which Jaffe predicted high energy-storage performance in PbZrO3 [17,18]. Recently, with the rapid development of microelectronics devices towards miniaturization, lightweight and integration, thin film capacitors with improved performance are demanded. Moreover, dielectric materials in film form usually show an increased breakdown field, as compared with their bulk-ceramic counterpart. Thus, the studies on the energy storage behaviors in antiferroelectric thin films are attracted increased attention. In addition to higher energy-storage density, antiferroelectrics also possess a higher charge releasing speed, which is an important parameter for their practical application. The ferroelectric-antiferroelectric switching speed in antiferroelectric thin films were investigated by several groups [19, 20]. The typical work was reported by Bhardwaja and Krupanidhi in which electric field, temperature and thickness dependence of ferroelectric-antiferroelectric switching process were systemically studied in pure PbZrO3 thin films. The results indicated that 60% of the stored energy in the 550nm-thick films could be released in less than 7ns at room temperature and at an applied field of 200kV/cm, with further increase in the applied field, the switching time was slightly varied and the content of net released charge was increased. Whereas with increasing temperature, the switching time was reduced to 6ns and the released charge was found to decrease.

4. **Conclusions and further prospects**

We conclude that some interesting achievements have been obtained in high energy storage materials but there still exist many problems need to be solved in order to increase the application of energy storage capacitor in practice. The investigation is mainly focused on the improvement of energy-storage density in dielectric materials but their energy efficiency, charge and discharge speed, temperature stability and life time are often neglected. In fact, these parameters are also very important for their application in capacitors so, these aspects have to be addressed in the future study.

References :

1. Beltrop K, Beuker S, Heckmann A, Winter M and PlackeT 2017 *Energy & Environmental Science**10**(10)* 2090-2094

2. Wu J, Pan Z, Zhang Y, Wang B, Peng H. 2018 *Journal of Materials Chemistry A, Materials for Energy and sustainability **6**(27)* 12932-12944

3. Fic K, Platek A, Piwek J, Frackowiak E. 2018 *Materials Today **21**(4)* 437-454

4. Gonaleg A, Goikolea E, Barrena JA, Mysyk R. 2016 *Renewable & Sustainable Energy Reviews **58*** 1189-1206

5. Eftekhari A. 2018 *Journal of Material Chemistry A, Materials for Energy and Sustainability **6**(7)* 2866-2876

6. Niaz S, Manzoor T, Pandith AH. 2015 *Renewable & Sustainable Energy Reviews **50*** 457-469

7. BarthelemyH, Weberm, BarbierF 2017 *International Journal of Hydrogen Energy **42**(11)* 7254-7262

8. David M French, Brad W Hoff, Susan Heidger, Don Shiffler. 2011 *IEEE Pulse Power Conference* 341-345.

9. Yuan X, LiuX, Zuo J 2015 *Renewable & Sustainable Energy Reviews* **42** 298-305

10. WinterM, BroddRJ, 2005 *Chemistry Reviews* **105**(3) 1021

11. Zhu Y, Jiang P, Zhang Z, Huang X, 2017 *Chinese Chemical Letters* **28**(11) 2027-2035
12. Prateek, Thakur VK, Gupta RK 2016 *Chemical Reviews* **116**(7) 4260-4317
13. Zhai J, LiX and Chen. H. 2004 *Thin Solid Films* ***446*** 200
14. Subbarao EC 1973 *Ferroelectrics* ***5*** 267
15. Samara GA 1970 *Phys.Rev.B* ***1*** 3777
16. Zhelnova OA and Fesenko OE 1987 *Ferroelectrics* ***75*** 465
17. Jaffe B 1961 *Proc.IRE* ***49*** 1264
18. Singh K 1989 *Ferroelectrics.* ***94*** 433
19. Bharadwaja SSN and Krupanidhi SB 2001 *J Applied Phys* ***89*** 4541
20. XuB, MosesP, PaiNG and crossLE 1998 *Appl. Phys. Lett* ***72*** 593