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Understanding Techniques To Improve The Strain Response Of Piezoelectric Ceramics

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Mini Review

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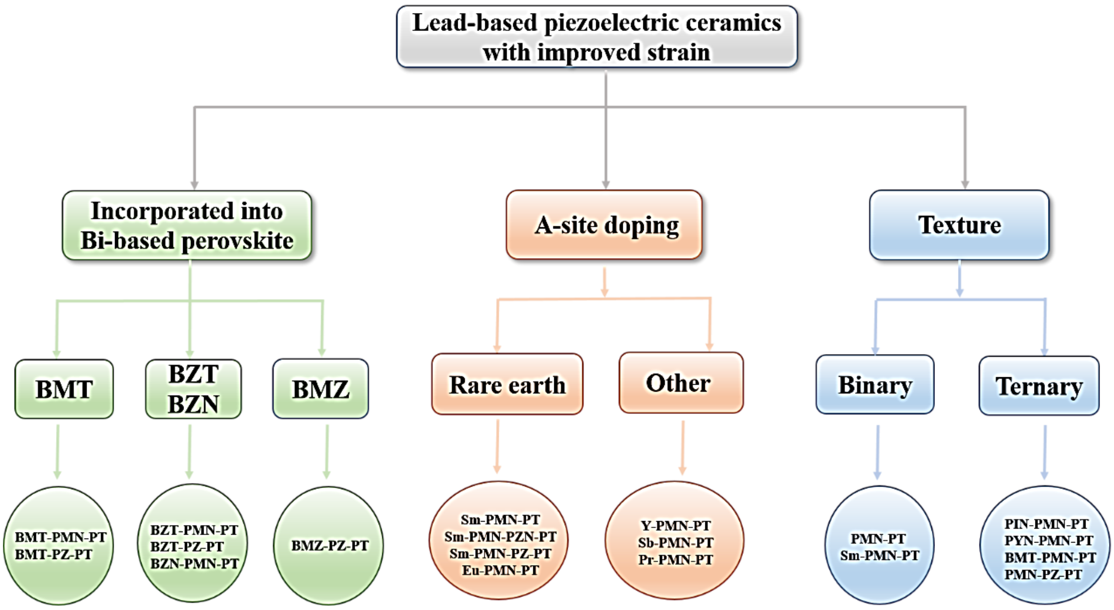
ABSTRACT

As the most promising material for high precision displacement actuators, piezoelectric materials have been extensively studied in the past few decades. The strain response characteristics of piezoelectric materials are very important for its applications in actuators. In this paper, three kinds of techniques for improving strain response of piezoelectric ceramics and their research status are briefly reviewed. In addition, we also summarize our ideas on improving the strain response of piezoelectric ceramics combined with the research work.

INTRODUCTION

Rare-Earth As one of the key technology in precision manufacturing, precision measurement and precision drive, precision positioning technology is widely used in optical engineering, aerospace, semiconductor industry and many other high-tech fields. Micro-displacement actuator is the key part of precision positioning system, which plays an important role in sensitivity and resolution of precision positioning system. At present, piezoelectric actuators are regarded as the most promising micro-displacement actuators because of their advantages of small size, large driving force, high-precision displacement, fast response, anti-electromagnetic interference [1]. As a piezoelectric actuator chip, piezoelectric ceramics with perovskite structure not only have excellent dielectric and piezoelectric properties, but also have the advantages of simple preparation process, short growth time, low production cost, which have been widely studied in the past decades [2]. The strain characteristics of piezoelectric ceramics are the key factors to determine the performance of piezoelectric actuators. The current research on strain characteristics of piezoelectric ceramics mainly focuses on the following three aspects: strain value, strain hysteresis and temperature stability. Based on our group's research on the strain characteristics of piezoelectric ceramics, we briefly summarize the techniques to improve the strain response of piezoelectric ceramics from three aspects (Figure 1).

Figure 1. Diagram summarizing techniques in improving lead-based piezoelectric ceramics strain response.



POSSIBLE TECHNIQUES FOR IMPROVING THE STRAIN RESPONSE OF PIEZOELECTRIC CERAMICS

Incorporated into Bi-based perovskite

In recent years, it has been found that lead-free bismuth-based ceramics have giant electric field-induced strain response, but the fatal shortcoming of these lead-free bismuth-based ceramics is that strain hysteresis is very severe, which greatly hinders their practical application in high-precision displacement actuators. However, many lead-based piezoelectric ceramics have low strain hysteresis, but their strain response is smaller than that of lead-free bismuth-based ceramics. Therefore, it is a very good idea to incorporate bismuth-based perovskite into lead-based piezoelectric ceramics to form ternary piezoelectric ceramics which may obtain excellent strain response, and this idea has been confirmed by us and other research groups. We recently reported that $Bi(Mg_{1/2}Zr_{1/2})O_3$ was incorporated into $PbZrO_3$-$PbTiO_3$ piezoelectric ceramics to form $Bi(Mg_{1/2}Zr_{1/2})O_3$-$PbZrO_3$-$PbTiO_3$ ternary piezoelectric ceramics, with an increase in strain response from 0.14% to 0.33% at 50 kV/cm and strain temperature stability was very good [3]. Xia et al. reported that the strain response increased from 0.16% to 0.27% at 50 kV/cm by introducing $Bi (Zn_{1/2}Ti_{1/2})O_3$ into $Pb (Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ piezoelectric ceramics [4].

A-site doping

In the past few decades, in order to improve the performance of piezoelectric ceramics to meet the application requirements, researchers mainly focused on the research of metal ion doping in piezoelectric ceramics, and a large number of excellent research results have been published. Qin, et al. reported that the strain response of PMN-PT binary ceramics increased from 0.07% to 0.12% at 25 kV/cm by doping Pr^{3+} [5]. Jiang, et al. reported that the piezoelectric coefficient (d33) and strain response of PMN-PT ceramics could be increased to 800 pC/N and

0.17% at 20 kV/cm by Ce ion doping, respectively [6]. What is more exciting for piezoelectric researchers is that Li et al. found that the piezoelectric properties of PMN-PT piezoelectric ceramics could be greatly improved by doping the rare earth ion Sm^{3+}, and its piezoelectric coefficient reaches 1510 pC/N [7]. Since then, it has been widely studied in recent years that doping the rare earth ion in lead-based piezoelectric ceramics can improve piezoelectric properties and strain response. Guo et al. reported that the piezoelectric coefficient and strain response of Eu^{3+}-PMN-PT binary ceramics can reach 1420 pC/N and 0.16% at 20 kV/cm, respectively [8]. Babu et al. reported that the piezoelectric strain coefficient (d33*) of Sm^{3+}-doped PIN-PMN-PT ternary ceramics is 2.5 times larger than that of undoped PIN-PMN-PT ceramics, and its strain value can reach 0.15% at 20 kV/cm [9]. We recently reported that the strain response of PMN-PZN-PT ternary ceramics increased from 0.21% to 0.24% at 50 kV/cm by doping Sm^{3+} [10].

Texture

It is well known that texturing technique can enhance the electromechanical properties of piezoelectric ceramics *via* controlling the orientation of piezoelectric ceramic grain to obtain an anisotropic characteristic similar to that of single crystal. It has been widely reported that lead-based piezoelectric ceramics were textured using $BaTiO_3$ template. Therefore, it is also a very novel idea to further improve the strain response of bismuth-containing lead-based ceramics by using texture technology. We recently used $BaTiO_3$ template to texture $Bi(Mg_{1/2}Ti_{1/2})O_3$-$Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ ternary piezoelectric ceramics, and the strain response of this ternary piezoelectric ceramics greatly increased from 0.23% to 0.42% at 40 kV/cm [11]. However, it is a pity that $BaTiO_3$ template is unstable at high bismuth content, so it is of great significance to discover or develop a new template for the texture of this type of piezoelectric ceramics. In addition, we also recently conducted texture on $Bi(Mg_{1/2}Ti_{1/2})O_3$-$Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ with low bismuth content, and found that large strain response (0.39%) and low strain hysteresis (1.94%) were obtained simultaneously, which is of great significance for its practical application in high-displacement precision piezoelectric actuators [12]. A summary of strain response of these piezoelectric ceramics is shown in Table 1.

Table 1. Field-induced strain in piezoelectric ceramics with perovskite structure (ABO3).

Type	Compositions	Strain (%)	E (kV/cm)	d_{33}*(pm/V)	Refs
Lead-free	BNBT-SMS	0.4	55	728	[13]
	BNBT-FN	0.42	50	844	[14]
	BNBT-Pr	0.43	50	770	[15]
	BNKT-NN	0.45	55	810	[16]
Lead-based	PSN-PMN-PT	0.12	20	580	[17]
	PIN-PMN-PT	0.17	40	597	[18]
	PZN-PZ-PT	0.16	30	658	[19]
	PMN-PT-PZ	0.22	40	550	[20]
Bismuth-lead-based	BMZ-PZ-PT	0.33	50	660	[3]
	BZT-PMN-PT	0.27	50	540	[4]
	BZT-PZ-PT	0.28	70	475	[21]
	BZN-PMN-PT	0.32	30	865	[22]
	BMT-PMN-PT	0.42	70	580	[23]
	BMT-PZ-PT	0.39	60	650	[24]

A-site doped lead based	Pr-PMN-PT	0.12	25	850	[5]
	Ce-PMN-PT	0.17	20	809	[6]
	Sm-PMN-PT	0.03	2	1530	[7]
	Eu-PMN-PT	0.17	20	1400	[8]
	Sm-PIN-PMN-PT	0.15	20	743	[9]
	Sm-PMN-PZN-PT	0.24	50	480	[10]
	Sm-PMN-PZ-PT	0.16	20	820	[25]
	Sm-PIN-PZ-PT	0.19	20	945	[26]
Textured	BMT-PMN-PT	0.42	40	1050	[11]
	PYN-PMN-PT	0.18	30	589	[27]
	PMN-PT	0.28	25	680	[28]
	PIN-PMN-PT	0.4	50	1620	[29]
	Sm-PMN-PT	12	20	600	[30]
Note: *The data were given or calculated according to reference.					

CONCLUSION

For high-precision displacement actuators, the strain response and strain hysteresis of piezoelectric ceramics are crucial parameters, so it is of great significance to reduce strain hysteresis while improving the strain response of piezoelectric ceramics. Furthermore, the temperature stability of piezoelectric ceramics strain is also an important parameter for the use of piezoelectric ceramics actuator in the environment with relatively large temperature changes. Therefore, it is also an important research direction to develop piezoelectric ceramics with high strain temperature stability while improving strain response. In addition, the above ideas to improve the strain response mainly focus on experiments, and there are few reports on mechanism research. Therefore, it is necessary to carry out mechanism research on the basis of more experiments in order to develop more excellent micro-displacement piezoelectric ceramics.

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