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厦门大学

硕 士 学 位 论 文

磁电复合材料的磁电相位移动机理及多层制备工艺研究

Study on Mechanism of Phase Drift in Magnetoelectric Composite & Preparation Technology of Multi-layer Materials

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摘　要

磁电材料是指具有磁电效应或者逆磁电效应的材料。磁电效应为施加磁场产生极化的效应，逆磁电效应为其逆过程，即施加电场产生磁化的效应。在磁电材料的大家族中，磁电复合材料在室温下表现出良好的磁电性能，是目前最具有实用潜力的磁电材料。但是，目前多数的研究主要集中在如何提高材料的磁电幅值，对于磁电材料的相位信息关注较少，相位移动现象及其机理缺少系统的研究。另外，为了满足当代社会对电子器件微型化、多功能化及高性能化的要求，对于磁电复合材料的研究也趋向于小型化、高性能化。多层磁电复合材料磁电性能较高，但是其制备工艺多是机械重复两层结构的工艺，制备工艺复杂，工作量大，有待改进。本文针对磁电相位研究现状，展开了关于磁电相位移动机理的研究。另外，本文尝试改进传统多层磁电复合材料的制备工艺，以期望便捷、高效、批量化地制备多层磁电复合材料。

本文以 Ni 块体/PZT（Pb（Zr，Ti）O_3，以下统称 PZT）为研究对象，观察到了一系列相位移动现象，与 Ni 粉末/Epoxy/PZT 进行对比，二者的磁电相位移动现象存在显著的不同。为了系统地研究磁电相位移动的机理，采用磁弹耦合性能强的 Terfenol-D（$Tb_{0.28}Dy_{0.72}Fe_2$ 以下统称 Terfenol-D）合金为铁磁相，采用粘合法制备出叠层 Terfenol-D 块体/PZT、Terfenol-D 粉末/Epoxy/PZT 磁电复合材料，分别对其在非谐振频率、谐振频率下的磁电回线、磁电频谱进行测试，观察到了与 Ni 体系磁电材料相似的相位移动现象。经过对比分析得出结论：在非谐振频率下，磁电相位移动幅度来源于金属铁磁相中的涡流，移动幅度较小；在谐振频率下，磁电相位来源于外磁场导致的铁磁相弹性模量的变化，并发生了大幅度的移动，最大移动幅度接近 180°，体现出了巨磁电相位移动的现象。

多层磁电复合材料制备工艺的改进开始于多层材料的一体化工艺设计。通过编写线切割程序代码，将铁磁相一次性切割成形，同时，通过将环氧树脂与压电性粉末混合，得到具有良好流动性的压电相，随后将压电相灌注到铁磁相中，实现多层磁电复合材料的一次性制备工艺。本文更换了多个铁磁相原料进行制备，研究了压电相粉末含量的改变及极化工艺的变化对性能的影响。实验结果表明，所设计的工艺路线是可行的，所制备的多层磁电复合材料都显示出明显的磁电效

应。

关键词：磁电效应；磁电复合材料；磁电相位；多层结构制备工艺

Abstract

Magnetoelectric material is one kind material which has magnetoelectric effect or converse magnetoelectric effect. Magnetoelectric (ME) effect is an effect of a polarization can be induced upon applying of a magnetic field , conversely, converse ME effect is an effect of a magnetization can be induced upon applying of an electric field . Magnetoelectric composite, as one kind of magnetoelectric materials, has been the practical magnetoelectric material potentially for its excellent magnetoelectric property at room temperature. However, most of researches focused on how to improve the amplitude of magnetoelectric effect，while the phase of magnetoelectric effect received little attention. Systematical study about the phenomena and the mechanism of phase drift of magnetoelectric effect is still leaking. Moreover, to meet the requirement of miniaturization, multi-functionalization and high performance in electronic devices, the researchers tend to realize the miniaturization and high performance in magnetoelectric composites. Multi-layer magnetoelectric composite has high magnetoelectric performance relatively. However, the traditional process of multi-layer magnetoelectric composite only simply repeat the process of bilayer composite, so it`s highly reduplicative, and need to be improved. According to the recent research backgrounds, this thesis researches the mechanism of magnetoelectric phase`s drift. In addition, in order to prepare the multi-layer magnetoelectric composite conveniently, efficiently and mass-produced, we try to make some improvements in the preparation technology of multi-layer magnetoelectric composite.

Series of phenomena about phase drift were observed in Ni bulk/PZT, which was quite different with the phase drift result of Ni power/Epoxy/PZT. In order to find out the mechanism of magnetoelectric phase drift systematically, bilayer magnetoelectric composite Terfenol-D bulk/PZT, Terfenol-D power/Epoxy/PZT were prepared by stacking process, where Terfenol-D has strong magnetic-mechanical coupling. The magnetoelectric loops under resonant frequency and un-resonant frequency and

magnetoelectric spectrum were measured, respectively. The same phase drift phenomenon as Ni based magnetoelectric materials. After comparison, it was concluded that a tiny magnetoelectric phase drift occurred under un-resonant frequency, which resulted from eddy current; and a larger magnetoelectric phase drift, which was close to 180°, was found under resonant frequency, and this giant phase drift was proved to result from the variation of elastic constant induced by external magnetic field, which showed a giant magnetoelectric phase drift effect.

The improvement for preparation technology of multi-layer magnetoelectric composite began with the structure design. A multi-layer structure of ferromagnetic phase was cut by wire electronic discharging machine with self-developed cutting code. The piezoelectric phase with good liquidity was prepared by mixing epoxy resin and piezoelectric powder. Then the piezoelectric phase was injected into the gap of the ferromagnetic multi-layer structure to prepare the multi-layer magnetoelectric composite by only one time. Several kinds of ferromagnetic raw material were used for the preparation of multilayer magnetoelectric composite, the influence of piezoelectric powder`s content and the procedure of polarizing was studied as well. The experimental results showed that the designed preparation technology for multi-layer magnetoelectric composite is quite effective, and all the prepared multi-layer magnetoelectric composites had obvious magnetoelectric effect.

Key words: Magnetoelectric effect; Magnetoelectric composite; Magnetoelectric phase; Preparation technology of multilayer

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