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Magnetostrictive strain monitoring of cement-based magnetoelectric composites in a variable magnetic field by fiber Bragg grating

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HIGHLIGHTS

- Cement-based magnetoelectric composite has been successfully developed.
- FBG sensors were employed to monitor the strain under variable magnetic field.
- Composite exhibits a brand new magnetoelectric coupling effect as expected.

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ABSTRACT

In this paper, a cement-based magnetoelectric (ME) laminated composite is fabricated by bonding the piezoelectric material lead zirconate titanate (PZT) between two C-M layers made of the mixture of cement and magnetostrictive material to form a sandwich structure. As well known, inherent measurement errors of traditional electric sensors are definitely induced by magnetic interference in magnetic field. Thus, it is impossible to measure the magnetostrictive strain due to a variable magnetic field. In this paper, the fiber Bragg grating (FBG) sensors were used instead of the traditional strain gauges to measure the strain of the cement-based magnetostrictive layers in a variable bias magnetic field. It can be concluded that the FBG sensors is a reliable choice as its tiny size, high sensitivity and immunity to magnetic interference.

1. Introduction

Functional materials with the mechanical, thermal, electrical, optical, magnetic, acoustic and other special properties play an important role in advanced materials research and high-tech development. With the increasing demand, it is difficult for single-performance materials to meet the requirements of new devices. Therefore, the research and fabrication of materials with multi-function have become a hotspot in the field of materials and sensing technology. The coupling effect between the various properties provides the possibility for the study and preparation of multi-functional materials.

Piezoelectric and magnetostrictive techniques have been used effectively for intelligent monitoring. Therefore, it is natural to have the ideal of mixing these two materials together to develop multi-functional composite, namely, magnetoelectric (ME) composite. The ME composite not only exhibits improved piezoelectric or magnetostrictive property of each phase, but also exhibits the ME properties which a single-phase does not have [1–5].

1.1. Magnetoelectric effect for multi-phase composites

For multi-phase composites, the generation of the magnetoelectric effect is generally believed to be the superposition effect between the piezoelectric phase and the magnetostrictive phase (denoted as P phase and M phase), which depends on the magnetic-mechanical-electrical interaction coupling effect.

When under the effect of applied magnetic field, the strain and stress due to the magnetostrictive effect of M phase is transferred to the P phase through the adhesive layer, and the polarization voltage or electric field is generated due to the inverse piezoelectric effect. On the other hand, when an electric field is applied to the ME composite, the P phase will generate stress due to the piezoelectric effect, then the stress is transmitted to M phase and causes a change in the magnetization due to the inverse magne-

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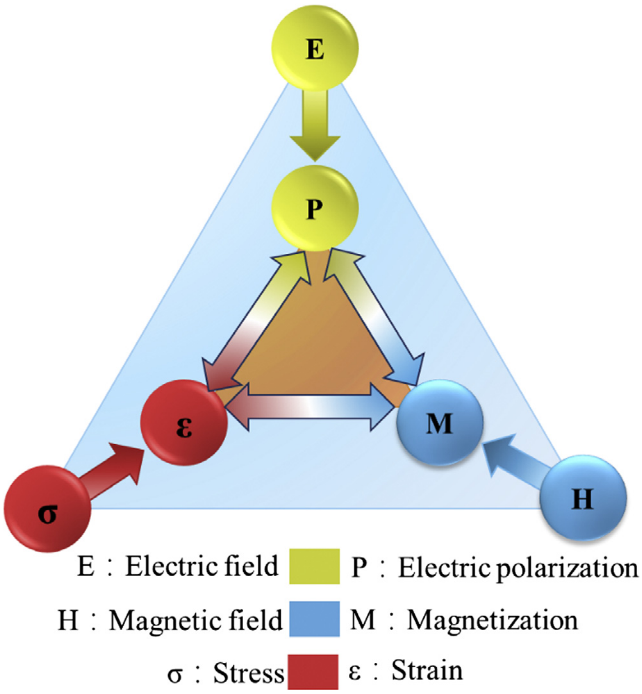

Fig. 1. Phase control in magnetoelectric composites.

tostrictive effect, thereby the ME conversion is realized. The mechanism of the ME effect is shown in Fig. 1.

The electric polarization *P*, magnetization *M*, and strain ε are spontaneously formed to produce ferromagnetism, ferroelectricity, or ferroelasticity, under the control of the electric field *E*, magnetic field *H*, and stress σ, respectively. In multi-phases composites, the coexistence of at least two characteristics leads to additional interactions. In ME composite, a magnetic field may control *P* or an electric field may control *M* [6].

In the past decade, piezoelectric ceramic composites incorporating lead zirconate titanate (PZT) in cement matrix have been fabricated and developed at the Hong Kong University of Science and Technology [7–11]. These composites have been successfully

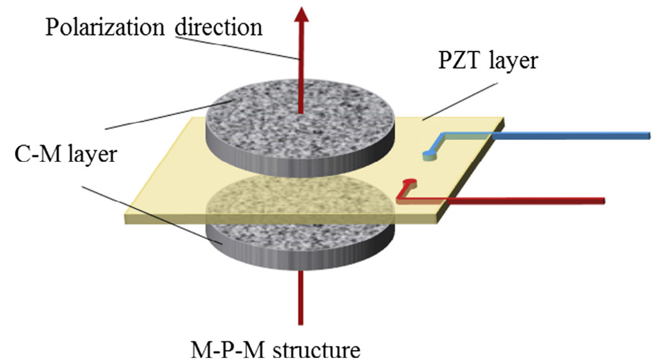

Fig. 3. Schematic illustration of the sandwich structure of cement-based ME composite.

applied in civil engineering. The cement-based piezoelectric composites can be used for actuators, sensors and transducers. The higher stiffness of the cement matrix makes it more conducive to the transmission of mechanical deformations and the durability performance is outstanding compared to polymer materials [12–15]. On the basis of the previous preparation of cement-based composites, this study focus on preparing a novel multi-functional ME composites by adding functional materials in cement matrix. Fiber Bragg grating (FBG) sensors were used to monitor the strain of cement-based magnetostrictive materials under variable bias magnetic field.

FBG sensors can be used to measure temperature and strain at multiple points at the same time and have many advantages compared to conventional electrical-based strain gauges, such as immunity to electromagnetic interference, corrosion resistance, excellent accuracy and so on. Therefore, FBG sensors have been widely used in civil engineering.

1.2. Working principle of fiber Bragg grating sensor

In 1978, Hill et al. fabricated a fiber Bragg grating for the first time by using a visible laser beam and a fiber [16]. Since then, FBG sensors have been further studied and widely applied. According to Bragg's law, the working principle of FBG sensor is shown in

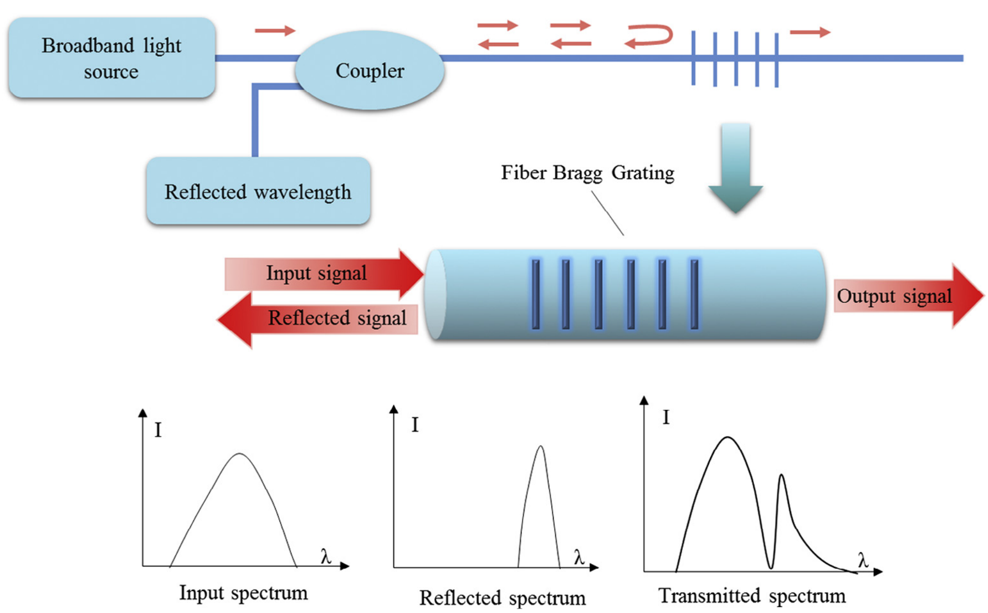

Fig. 2. Working principle of FBG sensor.