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Electrophoretic deposition and characterization of a piezoelectric FGM monomorph actuator

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Abstract

In this paper, a piezoelectric ceramic FGM monomorph was fabricated using electrophoretic deposition (EPD) technique. The fabrication process was investigated. The phase and microstructure of the FGM actuator were examined using XRD and SEM, respectively. Single-tetragonal-phase perovskite structure and gradient microstructure were observed. The electric-field-induced displacement of the actuator was measured under the electric field ranging from 0.32 to 6.77 kV/mm. With the increase of the driving field, the hysteresis became large; and at around 3.22 kV/mm, the hysteresis loop began to turn to a butterfly shape. The maximum displacement obtained was about 40 μm under an electric field of 3.22 kV/mm.

Keywords: D. PZT; FGM; Monomorph; EPD

1. Introduction

Piezoelectric ceramics such as lead zirconate–titanate (PZT) are widely used in applications such as actuators, transducers, and micropositioners [1]. Piezoelectric bimorphs are a typical type of piezoelectric devices which can produce relatively large displacement [2]. However, the usual piezoelectric bimorphs have the shortcomings of low reliability and poor interfacial bonding conditions resulting from the possible cracking and peeling of the bonding agent at low temperature, and creeping at high temperature. These shortcomings would discourage the application of bimorph in severe environments. As a result, it is desirable to develop a monomorph with lower or no internal stress peaks when voltage is applied, and to minimize structural discontinuity which would result in devices failure under cyclic loading. Recently, the concept of "Functionally Gradient" has been proposed to form the monomorph [3,4]. However, it is noted that the proposed monomorphs in the literature are still to be further improved, especially in terms of sharp transitions due to limitations of the fabrication process.

In this paper, a new FGM monomorph is introduced as shown in Fig. 1. It has a compositional gradient over the cross-section. Electrophoretic deposition (EPD) technique, which is an effective method to form functionally gradient and multilayer ceramic composites [5], was applied to fabricate the monomorph.

2. Fabrication of FGM monomorph

The initial powders to fabricate FGM monomorph involve two kinds of ceramics: $0.95Pb(Zro._{52}Ti_{0.48})O_3{\cdot}0.03BiFeO_3{\cdot}0.02Ba(Cu_{0.5}W_{0.5})O_3 + 0.5\,wt.\%MnO_2$ (PZT1) and $Pb(Zr_{0.52}Ti_{0.48})O_3$ (PZT). Both powders were prepared using conventional oxide mixing method. The raw oxide powders were calcined at 750 and 800 °C for 2 h for PZT1 and PZT, respectively. Then they were ball-milled at 150 rpm for 8 h.

The suspensions of PZT and PZT1 were characterized before deposition. Zeta potential as a function of pH was measured as shown in Fig. 2. Zeta potential indicates the stability of the suspension [6]. It can be seen that zeta potential of PZT and PZT1 suspensions reach maximum around pH 4.6, implying that these two materials are both most stable around this value, which is the desired condition for the EPD process.

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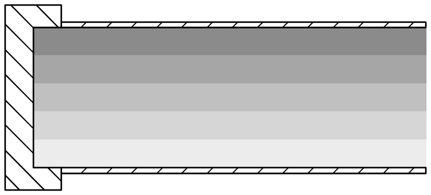

Fig. 1. Schematic structure of FGM monomorph actuator with composition profile.

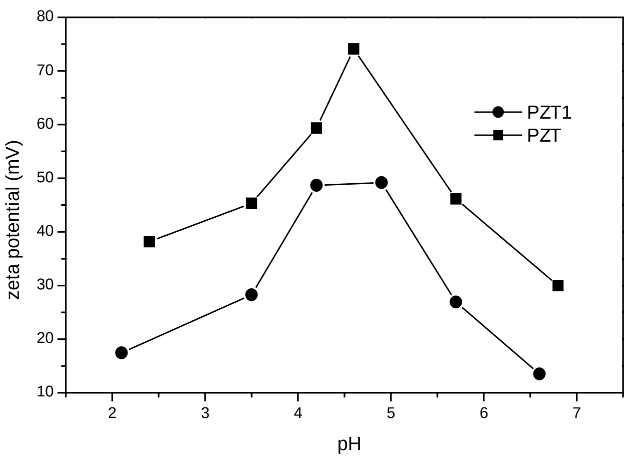

Fig. 2. Zeta potential vs. pH value of PZT and PZT1 suspensions.

Five suspensions for EPD were then prepared by adding the prepared powders with composition as shown in Fig. 1 in ethanol and then subjected to ultrasonic agitation for 10 min. The powder concentration in the suspension was 50 g/l and the suspension pH was controlled to be 4.6. The suspensions were stirred for 3–6 h to make sure the complete dispersion of the powders in the medium.

The five suspensions were deposited consecutively to the electrode. Each suspension was deposited for 5 min. The initial applied voltage was 25 V. The voltage was increased by 25 V each time when changing the suspension, as the resistance increases with the thickness of the deposits. After deposition, the deposits were dried in a dry keeper for 12 h.

The obtained FGM plates were sintered at 1100 °C for 1 h. Then they were cut into rectangular shape and coated with silver electrode and poled in silicone oil at 100 °C for 2 h under 2 kV/mm.

3. Characterization of monomorph

The phase composition of the material in sintered plate was first measured using XRD to ensure the formation of perovskite structure. Fig. 3 shows the XRD patterns of the sintered material. The expected single-phase perovskite structure was observed. From the insert in the figure, it can also be determined that the material is of tetragonal phase [7].

The microstructure of the FGM monomorph was also studied. Fig. 4(a) shows a photograph of FGM plate after sintering. Fig. 4(b) shows the cross-section of the monomorph. The thickness is approximately 0.27 mm. The gradient variation of the microstructure, resulted from compositional gradient, can be observed. Fig. 4(c,d) shows the surfaces of the monomorph. It can be seen that the grain size is reasonably uniform. The compositional and microstructure gradient-induced variation of the piezoelectric properties provides the driving source for the actuation.

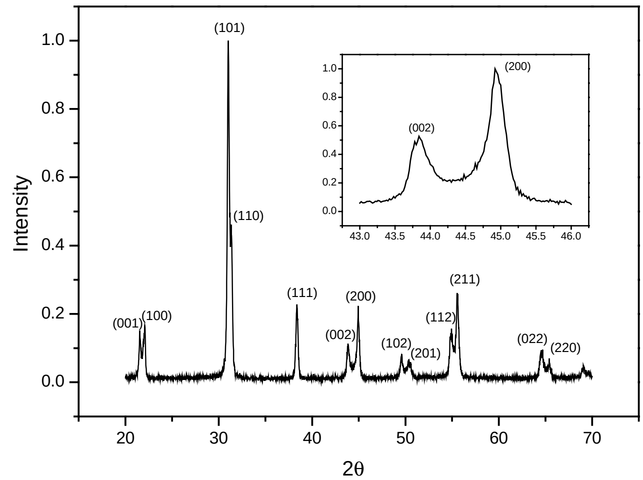

Fig. 3. XRD patterns of a FGM monomorph actuator sample.

The electric-field-induced displacement of a fabricated FGM monomorph actuator as a function of electric field was also measured using a system consisting of RT6000HVS (Radiant Technologies Inc.), a Vibraplane (RS Kinetic Systems Inc.) and a MTI-2000 fotonic sensor (probe: MTI2032RX. MTI Instruments). In the measurement, the monomorph was clamped to the vibraplane. A step voltage (0 to V to −V to 0) was applied to the monomorph via RT6000HVS. The tip displacement of the monomorph at the free end was then measured using the fotonic sensor and the data were stored by the RT6000HVS. The set voltage V was varied from 100 to 2100 V, and the measured frequency was 2.5 Hz.

The measured monomorph has a dimension of 10.0 mm in length, 2.65 mm in width and 0.31 mm in thickness. The measured electric-field-induced displacement hysteresis loops are shown in Fig. 5. The measurement was performed under electric field ranging from 0.32 to 6.77 kV/mm. Under lower electric field, the displacement linearly varies with the electric field. When the field increases, the slope and hysteresis of the loop become large. Around 3.22 kV/mm, the shape of the hysteresis loop starts to change and finally becomes a butterfly shape. The maximum displacement was about 40 μm under electric field of 3.22 kV/mm. This value 3.22 kV/mm, so called coercive field, for the current monomorph defines the maximum electric field that can be used to drive the monomorph under static or quasi-static driving conditions.

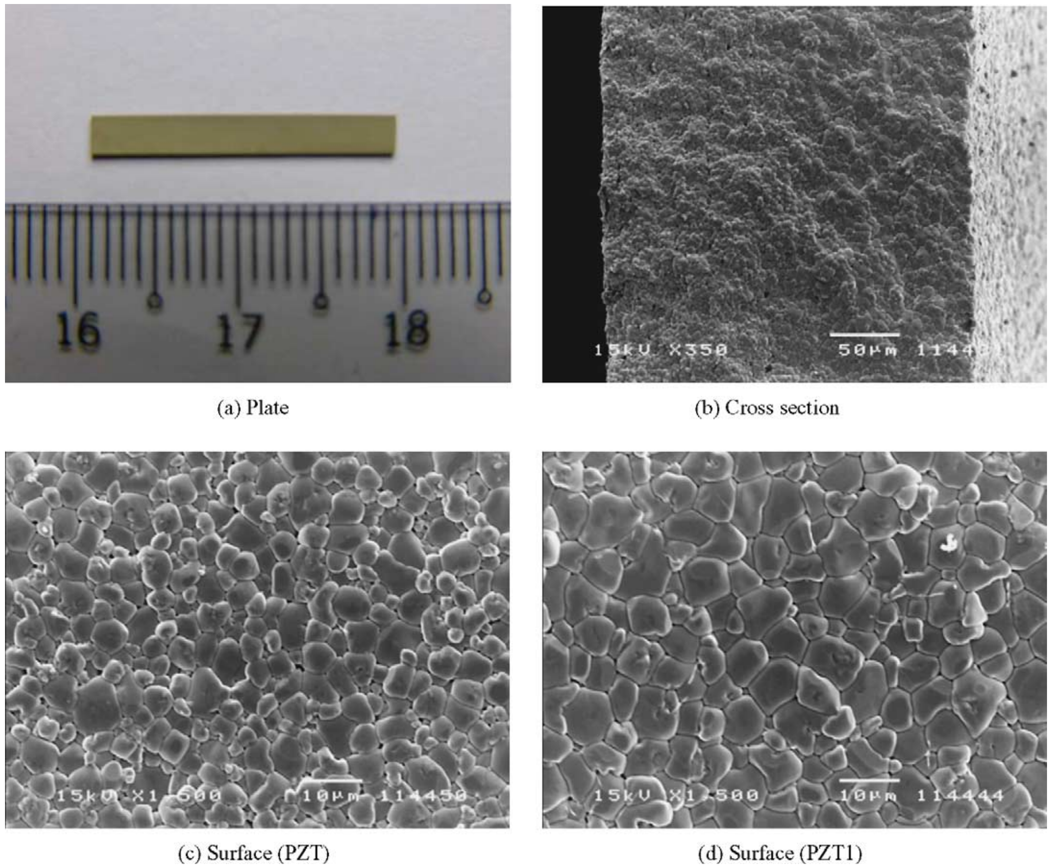

Fig. 4. Microstructure of the cross-section of FGM monomorph.

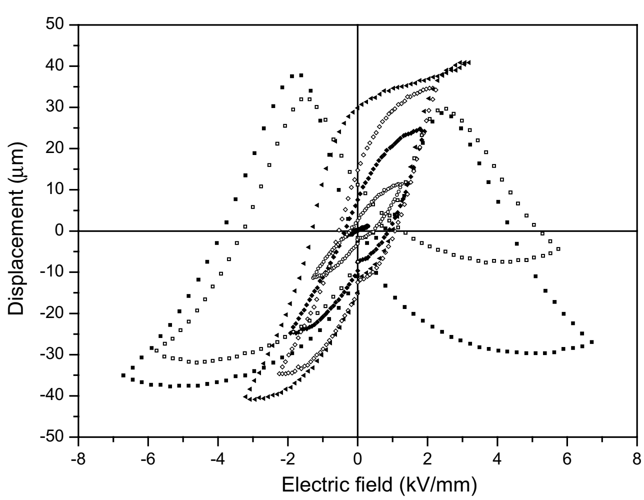

Fig. 5. The electric-field-induced displacement of the FGM monomorph under different electric fields.

4. Conclusions

EPD has been proven to be a good method to fabricate miniaturized FGM monomorph actuator. The obtained monomorph has a single-tetragonal-phase perovskite structure and fine gradient microstructure. The EPD prepared FGM monomorph provides a large coercive field 3.22 kV/mm. Below it, the slope and hysteresis of the field-induced displacement loop increases with the applied filed. Above it, the hysteresis turns to a typical butterfly shape.

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