Study on the Flexoelectricity of BST Film Multilayer Structure

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Short Research Article

ABSTRACT

Single layer and bilayer Y^{3+}-doped $Ba_{0.65}Sr_{0.35}TiO_3$ (BST) thin-film cantilever beam, of which the single BST film thickness is 500 nm, was prepared on a composite silicon substrate. The flexoelectric coefficients of both types of BSTs were measured using a low frequency vibration method. The flexoelectric coefficient of the bilayer BST film multilayer structure is 1.66 μC/m, which doubles the effective flexoelectric coefficient comparing to the single layer BST. In addition, we discussed the effective piezoelectric coefficient of the BST film multilayer structure, which can reach as much as 2.08×10^{-10} C/N due to the scaling effect.

1. INTRODUCTION

Flexoelectricity is a phenomenon dielectric material which polarize under a strain gradient or deflect under an electric field gradient. It is another electromechanical coupling behavior resembling piezoelectricity. Unlike piezoelectric materials which work temperature is restricted below Curie's point and crystal types need to be non-centrosymmetric, flexoelectricity exists in all insulator and at all temperature. Kogan initiated a mathematical description of flexoelectricity [1-2]:

$$P_i = \mu_{ijkl} \frac{\partial \varepsilon_{kl}}{\partial x_j} \tag{1}$$

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where P_i is the polarization, μ_{ijkl} is the flexoelectric tensor, ε_{kl} is the strain tensor, and $\partial/\partial x_j$ is the gradient operator.

Cross and Ma [3-6] and Shu et al. [7-8] studied the flexoelectric coefficients of a series of dielectric buck materials. Of the known flexoelectric materials, BST series are famous flexoelectric buck materials of high flexoelectric coefficient. Recently, a multilayered BST-Si structure was presented and investigated [9-10]. Since silicon substrate is brittle and hard to bend, the few silicon substrates might result in the better electromechanical performance. For this purpose, the objective of this paper is to provide a modified multilayer BST film structure with one sole silicon substrate layer and its flexoelectric coefficient is measured experimentally.

2. METHODS

The silicon substrate (from Shanghai Research Institute of Materials) is a four-layer structure made of Si, SiO₂, Ti and Pt, in which Si is a common substrate material and the layer SiO_2 and Ti can maintain the continuity of the deformation of the multilayer structure. For the single layer BST film structure, firstly a 500nm Y^{3+}-doped BST film was prepared on the substrate using a modified Sol-Gel method [11]. The composition of Ba:Sr is 65%:35% and the doping concentration of $Y(C_2H_3O_2)_3$ is 1% mol. Secondly, an electrode Au is sputtered to the surface of the BST film as opposite to the electrode Pt by using Magnetron Sputtering Film Deposition System (ACS-4000-C4). Then the single layer BST film was completed (Fig. 1a).

The bilayer BST film structure is prepared based on the single layer BST film structure. A zirconium dioxide (ZrO_2) film, to insulate the BST film, was fabricated on the substrate also by the Sol-Gel method. Once the ZrO_2 film is accomplished, an electrode Pt is sputtered to the surface of ZrO_2 film. And then we arranged the BST film on the electrode Pt using the same method as the single layer BST film. Afterwards an electrode Au is sputtered to the surface of the new BST film and thus the bilayer BST film was completed (Fig. 1b).

In this work, a low-frequency dynamic micro-cantilever measurement method [3] is adopted to study the transverse flexoelectric coefficient of BST. The experiment setup is demonstrated in Fig. 2. A loudspeaker, driven by a signal generator (Agilent 33220A), was employed to deflect the BST cantilever through an insulating rod while the output current was obtained by a lock-in amplifier (SRS830). The amplitude of the cantilever was measured by a laser micrometer (Keyence LK-G5001). The experiment was carried at room temperature (25℃), higher than the Curie's temperature of BST (20℃). The dimension of the substrate is 20 mm×5 mm×0.5 mm and its Young's modulus is 153GPa. Thus no piezoelectric effect exits. In order to eliminate the polarization contribution induced by temperature gradient, a 10 minutes duration was held at each measurement. Current outputs and deflections were recorded under different frequencies (1~10Hz). During the experiment process, each driving frequency was repeated three times, and the mean value in the three times was employed as the effective value.
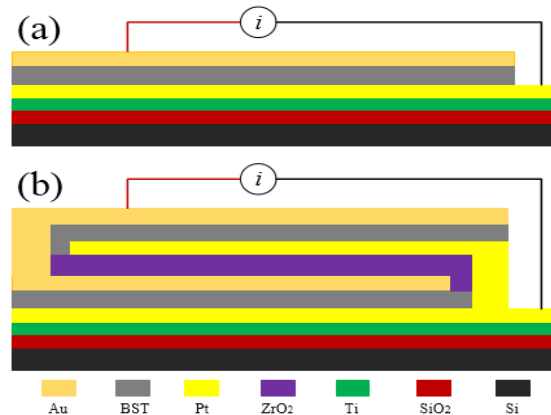

Fig. 1. The BST film diagrammatic sketch (a) single layer BST film structure (b) bilayer BST structure
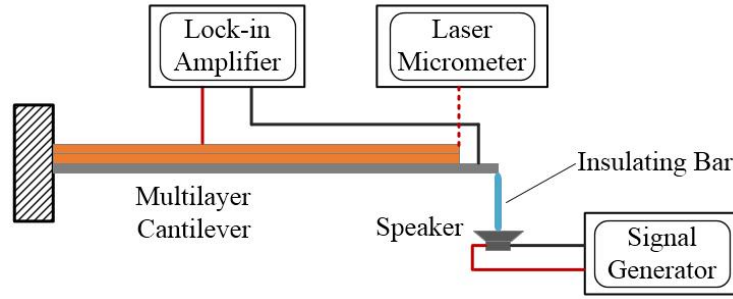
Fig. 2. The experiment setup

3. RESULTS, DISCUSSION AND CONCLUSION

The relationship of flexoelectric coefficient and the driving frequency is illustrated in Fig. 3. The mean flexoelectric coefficient of single-layer BST film structure is 0.86 *μC/m*. And the equivalent flexoelectric coefficient of bilayer BST film structure is 1.66 *μC/m*, about 2 times of single-layer BST structure. Thus one can make more BST function film layers in the multilayer structure to improve its equivalent flexoelectric coefficient.

Furthermore, as a sensor element we can also bridge flexoelectricity to piezoelectricity through its electromechanical effect by employing an effective piezoelectric constant d_{33}^{eff}, an important standard of sensor technology. When the beam material is composed of pure flexoelectricity material, the effective piezoelectric constant d_{33}^{eff}

of a flexoelectric cantilever structure can be denoted by [12].

$$d_{33}^{eff} = \frac{6\mu_{12}L^2}{Eh^3}$$

(2)

where E is Young's modulus, *L* and *h* are the beam length and thickness, μ_{12} is the transverse flexoelectric coefficient of the bilayer BST film structure. By calculation, the d_{33}^{eff} of the BST film multilayer structure is $2.08 \times 10^{-10} C/N$ .The flexoelectric coefficient is not structural related, but the effective piezoelectric constant is structural related. The double layer of BST films can get bigger piezoelectric parameter d_{33} because of the more area of BST. Apparently, for thinner BST sample, the scaling effect can be more significant. The characteristics enable the multilayer BST film structures promising in MEMS applications.
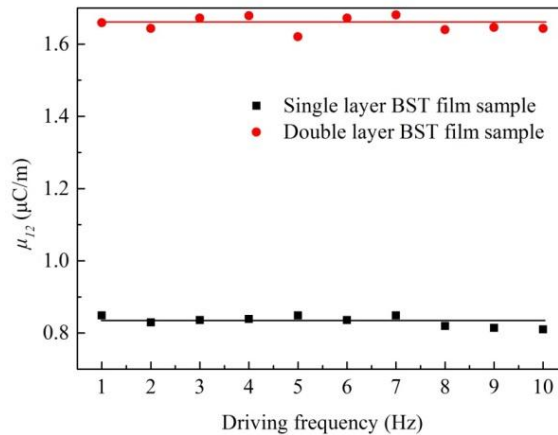

Fig. 3. Change curve of transverse flexoelectric coefficient with driving frequency

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COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Kogan SM. Soviet. Phys.-Solid State. 1964;5(10):2069-2070.
2. Yudin PV, Tagantsev AV. Fundamentals of flexoelect-Ricity in solids[J]. Naotechnology. 2013;24(43):1027-1031.
3. Ma W, Cross LE. Appl. Phys. Lett. 2010; 78(19):2920-2921.
4. Cross LE. J. Mater. Sci. 2006;44(1):53–63.
5. Ma W, Cross LE. Appl. Phys. Lett. 2002; (81):3440.
6. Deng Q, Kammoun M, Erturk A, et al. Nanoscale flexoelectric energy harvesting [J]. International Journal of Solids and Structures. 2014;51(18):3218-3225.
7. Wang KF, Wang BL. Energy gathering performance of micro/nanoscale circular energy harvesters based on flexoelectric effect[J]. Energy. 2018;149:597-606.
8. Huang W, Kim K, Zhang S, et al. Scaling effect of flexoelectric $(Ba,Sr)TiO_3$ microcantilevers[J]. Physica Stat-us Solidi-Rapid Research Letters. 2011;5(9):350-352.
9. Shu L, Wei X, Jin L, et al. Enhanced direct flexoelectricity in paraelectric phase of Ba (Ti0. 87Sn0. 13) O3 ceramics. Appl. Phys. Lett. 2013;102(15):152904.
10. Kwon SR, Huang WB, Zhang SJ, et al. Smart Mater. Struct. 2017;22(11):115017.
11. Abdelaal MY, Mohamed RM. Novel Pd/TiO2 nanocomposite prepared by modified sol–gel method for photocatalytic degradation of methylene blue dye under visible light irradiation. J. Alloy Compd. 2013;576:201-207.
12. Huang W, Kim K, Zhang S, et al. Phys. Status. Solidi-R. 2019;5(9):350-352.

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