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Giant voltage generating microcantilevers based on $Ba_{0.85}Ca_{0.15}Zr_{0.1}Ti_{0.9}O_3$ and $Co_{76}Fe_{14}Ni_4Si_5B$ for next-generation energy harvesters

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ABSTRACT

Magnetoelectric thin-film heterostructures with piezoelectric $Ba_{0.85}Ca_{0.15}Zr_{0.1}Ti_{0.9}O_3$ and magnetostrictive $Co_{76}Fe_{14}Ni_4Si_5B$ are fabricated. Very high ME coupling coefficients of 8 V/(cm Oe) and ~5.8 V/(cm Oe) are observed for BCZT-MG-BCZT and MG-BCZT-MG trilayers at sub resonance. Micro cantilevers of multilayers with total thickness of 130 µm are also fabricated. The microcantilever of BCZT-MG-BCZT showed an enhanced resonance at a frequency of 840 Hz with MECC as high as ~1457 V/(cm Oe). These structures can be effectively employed as an active component in energy harvesters, sensors, and transducers due to their exceptional ME responses in the resonant and sub-resonant frequencies.

Multiferroic materials are the ones that possess both ferroelectric and ferromagnetic orders in single or multiphase materials [1]. These materials can offer unique physics as well as tremendous device application potentials, if there exists a cross-coupling between the ferroic orders (known as magnetoelectric (ME) coupling) [2]. There are a lot of single-phase materials, which exhibit multiferroicity due to several reasons, such as the presence of lone pairs [3], geometry [4], charge ordering [5], spiral spin ordering [6], etc.; but they often exhibit reduced ME coupling at room temperature. The weak ME coupling in these systems could not meet the demand of the hour, and hence, the interest of researchers extended to composite multiferroics, where the ferroic orders come from different phases and are coupled via mechanical strain [7]. Generally, these phases will be of well known magnetic and ferroelectric materials with large magnetostriction and piezoelectricity, respectively. It has been already reported that such piezoelectric/magnetostrictive composites can generate high ME coupling at room temperature [8]. In addition to the strong ferroic properties of the constituent phases, the connecting geometry between them also plays a vital role in achieving a strong ME coupling in these types of heterostructures. Thin-film heterostructures, in which both phases are connected in 2-dimensions, are more preferred, because it offers large area of contact and tightly packed geometry for close contact [9]. Hence, it could enhance strain transfer between the two phases (magnetic and electric) and subsequently could offer better ME coupling coefficients. Also, the 2D nature of thin-film heterostructures makes them easy to integrate into devices.

Here, authors fabricated trilayer sandwich heterostructures with 2–2 geometry consisting of piezoelectric $Ba_{0.85}Ca_{0.15}Zr_{0.1}Ti_{0.9}O_3$ (BCZT) and magnetostrictive $Co_{76}Fe_{14}Ni_4Si_5B$ (Metglas, MG) as the components. Two different geometries are fabricated: one with a middle Metglas layer sandwiched between the top and bottom BCZT layers (BCZT-MG-BCZT) and the other with the middle BCZT layer sandwiched in between two Metglas layers (MG-BCZT-MG). High piezoelectricity and magnetostriction are the essential qualities for getting very large ME coupling. BCZT is a promising lead-free candidate with a sizeable piezoelectric coefficient (d_{33} = 620 pC/N) [10] comparable to that of lead-based systems while Metglas is an amorphous magnetic alloy with large initial permeability and magnetostriction (upon annealing) [11–13] which is already employed as the magnetic phase in a few ME composite systems such as PZT/Metglas [14], PVDF/Metglas [15], KNN/Metglas [13], etc. One might expect large ME coupling in these thin-film heterostructures, as the area of contact between the individual layers is very high.

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