WIDE-BAND MAGNETOELECTRIC EFFECTS IN FERROMAGNETIC METAL-PIEZOELECTRIC STRUCTURES

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The magnetoelectric (ME) effect is defined as the dielectric polarization of a material in an applied magnetic field or an induced magnetization in an external electric field [1]. In a composite consisting of magnetostrictive and piezoelectric phases, the ME effect is the result of a "product-property", i.e., the mechanical deformation due to magnetostriction results in a dielectric polarization due to the piezoelectric effect [2]. Most attempts in the past to realize strong ME effect in bulk composites were unsuccessful. Possible causes include microcracks, defects, undesired phases, leakage currents that result to poor mechanical coupling and bad polarization. Harshe and co-workers proposed a new direction in the development of ME composites: magnetostrictive-piezoelectric layered structures [3]. Their important virtues are a high degree of polarization in a piezoelectric phase and use of magnetostrictive materials with high conductivity [4].

Bilayer and trilayer structures of ferromagnetic permendur and piezoelectric PZT were synthesized. Permendur is a good material for studies on ME composites due to high magnetostriction. Piezoelectric component for the composite was made from PZT-850. The thicknesses of PZT and permendur layers were 0.4 mm and 0.25 mm, respectively. The PZT ceramics were poled at 420 K in an electric field of 5 kV/mm for 8 hours. Discs of permendur and PZT, 9 mm in diameter, were bonded with 0.01 mm thick layer of epoxy to fabricate the samples.

For ME characterization, we measured the electric field produced by an alternating magnetic field applied to the composite. The samples were placed into a measurement cell between the pole pieces of an electromagnet that was used to apply the bias magnetic field H. The required a.c. magnetic field of dH=0.01-1 Oe at 1 kHz – 500 kHz parallel to H was generated with a pair of Helmholtz coils. The induced electric field dE perpendicular to the sample plane was estimated from the voltage dV. The ME voltage coefficient is estimated from $dE/dH = dV/(t\cdot dH)$ where t is the thickness of PZT. The measurements were done for two different field orientations. In the first case, the electrical polarization was perpendicular to magnetic fields (transverse ME effect). In the second, the electrical polarization was parallel to magnetic fields (longitudinal ME effect). Magnetoelectric characterization was carried out at room temperature as a function of frequency of the a.c. magnetic field and bias magnetic field.

Figure 1 shows representative data on the H dependence of the longitudinal and transverse ME voltage coefficients. The measurements were done at 1 kHz on a trilayer sample. In the case of transverse ME effect (curve 1), ME voltage coefficient reaches a maximum value of 0,97 V/(cm·Oe) at 150 Oe. In the case of longitudinal ME effect (curve 2), ME voltage coefficient reaches a maximum value of 78 mV/(cm·Oe) at 600 Oe. These are attributed to the influence of the demagnetizing factor of the sample on the ME effect. In the case of transverse ME effect, the sample plane is parallel to magnetic fields and the demagnetizing factor is small. In the case of longitudinal ME effect, the sample plane is perpendicular magnetic fields and the demagnetizing factor is large. This decreases in the strength on internal a.c. and d.c. magnetic fields is accompanied by decrease of the ME voltage coefficient and the displacement of the maximum of ME signal to higher d.c. magnetic field. The ME voltage coefficient obtained for trilayer structures was about 2.5 times higher than ME voltage coefficient obtained for bilayer structures. Besides the ME voltage coefficient, there is another ME parameter $\alpha = 4\pi(dP/dH)$. This factor is dimensionless

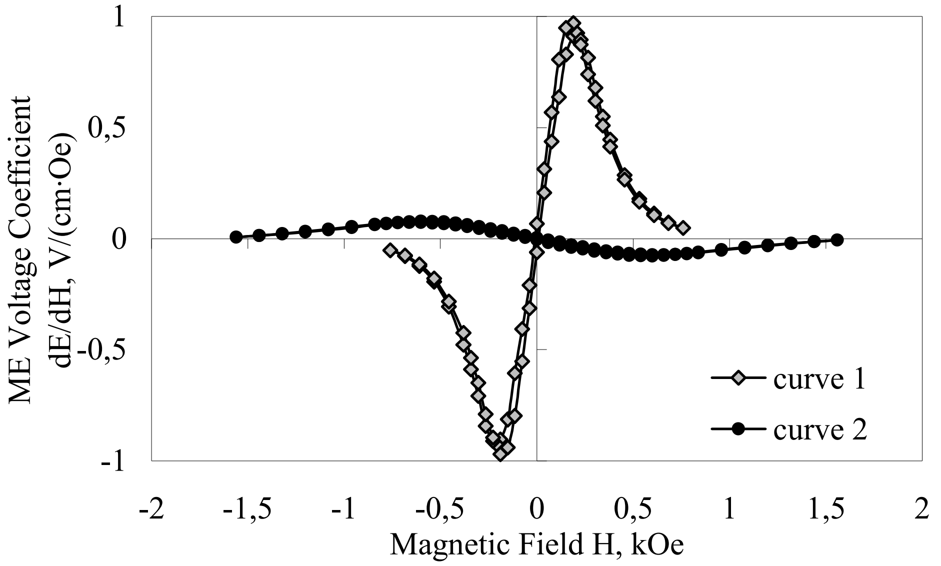

Figure 1. Field dependence of longitudinal and transverse ME voltage coefficients for trilayer structure of permendur-PZT-permendur.

and defines coefficient of change of polarization under the influence of magnetic field. For our composites the maximum is 3.4. This parameter is 10 times higher than that of the best ME bulk composites known.

We also performed studies on the frequency dependence of the transverse ME effect. The bias field was equal to 150 Oe and the voltage coefficients were measured as the frequency of the a.c. field. Consider first the data for the trilayer sample (Fig. 2). Upon increasing frequency, dE/dH remains small and constant for frequencies up to 250 kHz. At higher frequency, we observe a rapid increase in dE/dH to a maximum of 108 V/(cm·Oe) at 348 kHz. Finally, dE/dH levels off to 390 mV/(cm·Oe) at 500 kHz.

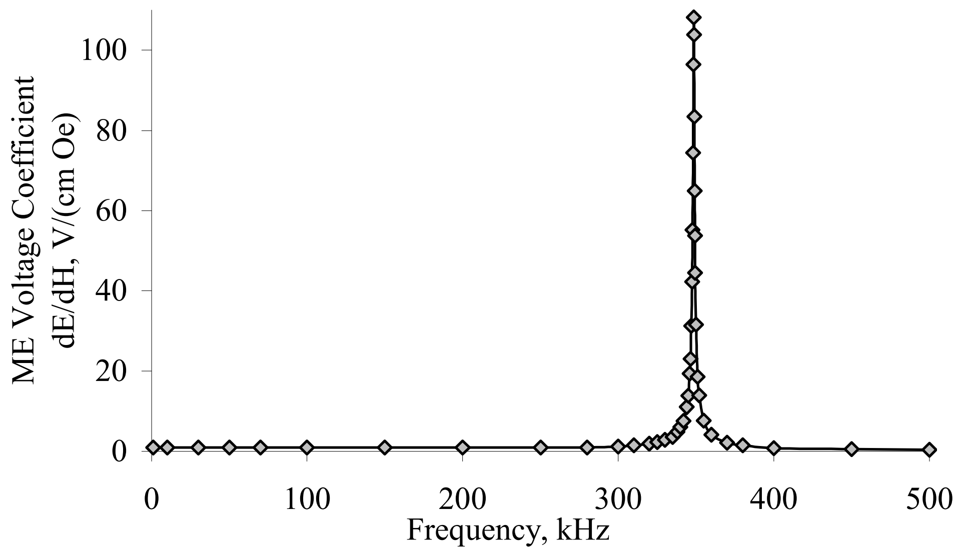

Figure 2. Frequency dependence of ME voltage coefficient for trilayer structure. The bias field H was set for maximum ME coupling.

Now consider the data for the bilayer sample (Fig. 3). We observe resonance at 64 kHz with maximum dE/dH equaled 6,0 V/(cm·Oe), which absent for trilayer sample. We also observe resonance at 330 kHz with maximum dE/dH equaled 30 V/(cm·Oe) (It is absent on Fig. 3). For frequencies up to 100 kHz, there is a qualitative difference in the frequency dependence of ME voltage coefficients for bilayer and trilayer samples. To understand observations, let us consider the mechanism of ME effect in layer structures. When a magneic field is applied to the composite, the magnetostrictive material is strained. This strain induces a stress on the piezoelectric, which generates the electric field. In trilayer structure metal plates are symmetrical with respect to plane of PZT. Therefore ME signal is generated due to compression – stretching. In bilayer structures such a symmetry is absent. Therefore ME signal is generated by compression – stretching and bending of piezoelectric. Due to bending vibrations we observe resonanse of dE/dH at 64 kHz.

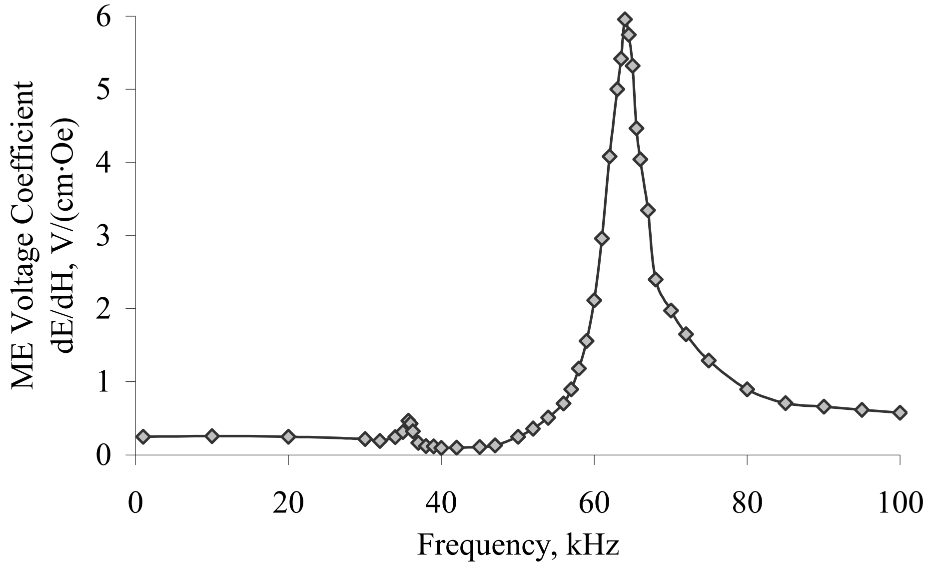

Figure 3. Frequency dependence of ME voltage coefficient for bilayer structure.
The bias field H was set for maximum ME coupling.

Layered ME materials were prepared by bonding permendure and PZT disks. Their “figure of merit” $\alpha = 4\pi(dP/dH)$ is 10 times higher than that of the best ME bulk composites. The maximum ME voltage coifficients obtained at low frequency and at resonance frequency are 0.97 V/(cm·Oe) and 108 V/(cm·Oe), respectively. There are different mechanisms of ME effect for trilayer and bilayer structures. In all cases, the transverse ME effect is about 10 times stronger than the longitudinal effect. Obtained results are of interest for further investigations of metal-piezoelectric structures.

References

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