Magnetopiezofiber

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Abstract. The results of the magnetoelectric effect study in the magnetopiezofiber are presented. Magnetopiezofiber consists of mechanically coupled piezoelectric (one layer of lead zirconate titanate) and magnetostrictive (two metglass layers) fibers. The layers were joined together by epoxy under pressure and heating. The sample active area dimensions were 28x7x0,34 mm. The study of the magnetoelectric effect was carried out in the frequency range from 0 to 150 kHz and external magnetic field range from 0 to 100 Oe. Maximum value of the ME voltage coefficient α_E = 62,75 V/cm·Oe was measured on the electromechanical resonance frequency f = 61 kHz with an external magnetic field of 4,5 Oe. Obtained results indicate the prospects of the proposed design in magnetoelectric devices application.

1 Introduction

Magnetosensitive devices and systems are widely used in various fields of science and technology, such as automotive electronics, automation, security systems, biomedical equipment, navigation, Earth sensing and etc.

A multiferroics possessing both magnetic and electrical ordering can significantly improve the parameters of magnetosensitive devices such as sensitivity, speed, power consumption, noise parameters and resistance to external conditions.

The operation of most electronic devices with multiferroics is based on the magnetoelectric (ME) effect. The ME effect consists in the occurrence of electric polarization induction in a material in an external electric field or the occurrence of magnetization in an external electric field [1].

The ME effect in single-crystal materials is very small and observed at temperatures significantly below room temperature, therefore, the most used materials are two-phase composites based on magnetic and piezoelectric materials which are free from these disadvantages. Due to the possibility of varying physical properties of composite materials, there are exist wide opportunities to optimize the characteristics of devices based on them. The best properties have layered composite structures with mechanically coupled magnetostrictive and piezoelectric materials.

A number of devices operating in a wide frequency range and based on the ME effect are developed, for example, magnetic field sensors, current sensors, energy harvesters, resonators, filters, attenuators, phase shifters, antennas, et al. [2]. The operating frequency of ME devices is divided into low frequency, electromechanical resonance (EMR) and

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ferromagnetic resonance (FMR) regions. The area of coincidence of frequencies of the EMR, FMR and magnetoacoustics (MAR) resonance looks promising [3].

Depending of the frequency range ME composites are made on the basis of material, such as nickel, yttrium iron garnet, metglass, PZT, PMN-PT, GaAs, $LiNbO_3$, et al [4-6].

Recently, in the literature provides data on high values of the ME effect in composites in which one of the components is a fiber material, for example in [7,8].

In this paper magnetopiezofiber consisting of mechanically coupled piezoelectric and magnetostrictive fibers are proposed.

3 Magnetopiezofiber manufacturing technology

Magnetopizofiber is a two-phase layered composite material, consists of mechanically coupled piezoelectric (one layer of lead zirconate titanate) and magnetostrictive (two metglass layers) fibers [9].

Piezoelectric lead zirconate titanate (PZT) rods rectangular section with dimension 28x0,3x0,2 mm are enclosed in polymer matrix of epoxy was used as piezoelectric fiber. To protect against external influences piezoelectric fiber in polymer matrix coated on both side with a polyimide film. To create a push-pull mode polarization in the PZT rods and measure the fiber induced voltage metallization was applied to polyimide films by metallization inside. The metallization was interdigital electrodes made of copper. M2807-P1 (Smart Material) with active area dimension about 28x7x0,3 mm was used as piezoelectric fiber.

Metglass AMAG 225 (PJSC Mstator) rods size 28x0,9x0,018 mm in the number of 7 pieces was used as each of the layers of magnetostrictive fiber. Rods was made from metglass foil by laser cutting.

The two magnetostrictive fibers and piezoelectric fiber between them were joined together using epoxy (BF-2 glue) under pressure (390 kPa) and heating to 60 degrees Celsius. The direction of the long side of the magnetic and piezoelectric fibers are coincided. The sample active area dimensions was 28x7x0,34 mm.

The structure of the magnetopiezofiber in the section is conditionally presented in Fig.1.

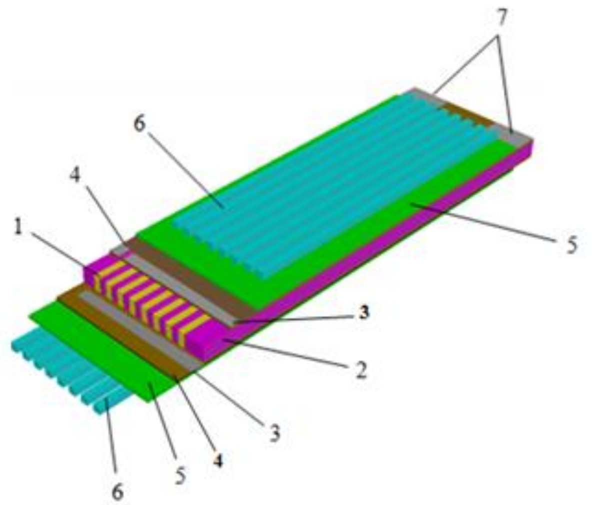

Fig. 1. The structure of the magnetopiezofiber in the section: 1 - piezoelectric fibers; 2 - epoxy; 3 - interdigital electrode; 4 - polyimide films; 5 - epoxy; 6 - magnetostrictive fibers.

3 Description of the experiment

The ME effect in the magnetopeizofiber was studied using a measuring apparatus consisting of modulating solenoid, system of permanent magnets, DX-180 magnetometer, HMO722 oscilloscope and HAMEG HMF2550 signal generator. Diagram of the measuring unit and the direction of the magnetic fields H_0 and h(t) is shown in Fig.2.

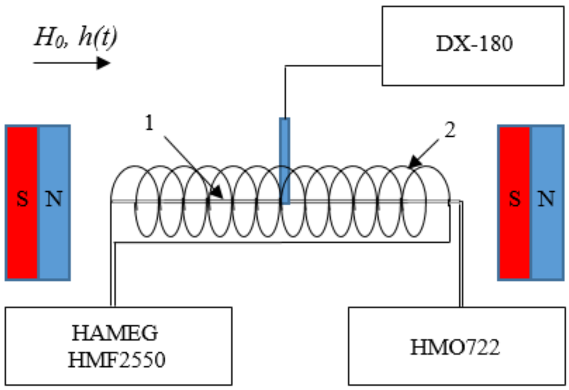

Fig. 2. The scheme of the measuring unit and the direction of the magnetic fields: 1-magnetopiezofiber; 2-modulating coil.

The magnetopiezofiber were placed inside a solenoid that creates a modulating magnetic field h(t) = 1 Oe at a frequency of 0 to 150 kHz. The coil with the sample was in a uniform constant magnetic field of 0 to 100 Oe, created by a system of the permanent magnets.

The presence of magnetostriction in magnetic fibers leads to elastic stresses, which due to the mechanical coupling realized through the adhesive connection are transmitted to the piezoelectric fibers, and due to the piezoelectric effect leads to a change in polarization. Induced due to ME effect the output voltage that occurs at the interdigital piezofiber electrodes, was measured on the oscilloscope.

The dependence of the magnetopiezofiber ME coefficient α_E on the frequency of the modulating magnetic field f and the value of the constant magnetic field H_0 was investigated.

4 Measurement results

Figure 3 shows the experimental dependence of the ME voltage coefficient of the proposed sample. The dependence has a resonant character with a pronounced maximum. The maximum value of the magnetopiezofiber ME voltage coefficient α_E was 62.75 V/cm·Oe at the EMR frequency f = 61 kHz and outside the resonance region about 4.8 V/cm·Oe. This frequency corresponds to the longitudinal vibrations mode of the sample and depends on its length and elastic properties. The resonance frequency of the sample is determined by the following ratio [10, 11]:

$$f_p = \frac{n}{2l}\sqrt{\frac{\bar{Y}}{\bar{\rho}}}, \tag{1}$$

where $\bar{Y}$ - effective young's modulus; $\bar{\rho}$ - effective density; n - harmonic number; l - the length of the sample.

$$Y = \frac{Y_m a_m + Y_p a_p}{a_m + a_p}, \tag{2}$$

$$\rho = \frac{\rho_m a_m + \rho_p a_p}{a_m + a_p}, \tag{3}$$

where Y_m, Y_p, ρ_m, ρ_p, a_m, a_p- young's modules, density and thickness of magnetostrictive and piezoelectirc fibers. The experimentally obtained value of the resonance frequency corresponds to the calculated one.

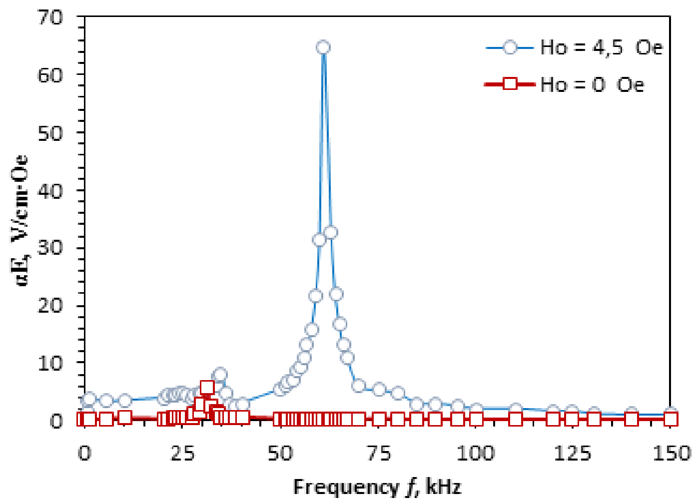

Fig. 3. Frequency dependence of the α_E.

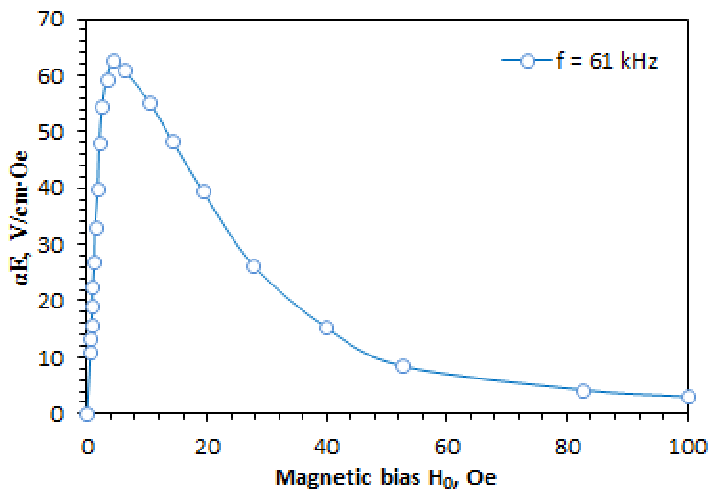

Fig. 4. Dependence of the αE on the external magnetic field H_0.

Figure 4 shows the experimentally obtained dependence of the ME voltage coefficient on the magnitude of the constant magnetic field. The maximum value of the α_E was measured at an small value of external magnetic field H_0=4.5 Oe. With this field, the piezomagnetic coefficient q=dλ/dH in metglass fiber reachs their maximum value.

5 Conclusion

Experimental studies of the magnetopiezofiber in the low frequency region and at the frequency of the EMR in this paper were carried out. The maximum value of the ME voltage coefficient α_E was 62,75 V/cm·Oe at a frequency of 61 kHz and 4.8 V/cm·Oe out of resonance. The obtained results indicate the prospects of the proposed design in magnetoelectric devices application.

In addition, the obtained results allow us to optimize the design, materials, manufacturing technology and miniaturization in order to shift the operating frequency of the device to the MAR region.

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