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Propagation of elastic waves in bilayer ferrite-piezoelectric structure

T.A. Galichyan[1, 2] and T.O. Firsova[1]

[1] 173003 Velikiy Novgorod, Russia, Novgorod State University

E-mail: tigrangalichyan@yahoo.com

Abstract. Propagation theory of elastic wave for ferrite-piezoelectric bilayer structures is presented. The expression for the dispersion relation of the longitudinal mode planar oscillations is derived. It is shown that in limited cases this expression come to dispersion relation for ferrite and piezoelectric accordingly.

Keywords: bilayer structure, elastic wave, dispersion relation.

1. Introduction

The mechanism of occurrence of magnetoelectric (ME) effect in ferrite-piezoelectric structure is caused by the elastic interaction of magnetostrictive and piezoelectric subsystems. Alternating magnetic field causes elastic oscillations in the magnetostrictive component which pass into the piezoelectric phase, where an electric field is occurred through polarization. As a consequence of that, the frequency dependence of magneto electric effect in such structures is directly related with the spectrum of elastic waves. The distribution of elastic waves in bilayer medium significantly differs from the distribution in homogeneous medium. Attempts were made earlier [1] to consider ME effect in such structures, but in the same time, a supposition was made, that the amplitude of oscillations was not changing its direction perpendicular to the line of the partition. This suggestion can be used in the description of the effect for rather thin layers, with some accuracy. At more detailed examination this method [1] reduces to the method of effective parameters, which was first used in describing the frequency dependence of ME effect [2,3]. Recently [4], the dispersion relation was obtained for a structure, representing a thin film grown on a semi-infinite substrate. In this paper, the distribution of the elastic waves in bilayer ferrite-piezoelectric structure was investigated given the fact that the amplitude of the wave is changed on the thickness of the sample. The dispersion relation for the elastic waves of acoustic range was obtained. Under the limiting transition it is shown that the dispersion relation, when one of the layers is thinner than the other, passes to a dispersion relation of one, or the other media.

2. Model

As a model, we consider a structure, composed of piezoelectric and magnetostictive phases mechanically interacting on the boundary (figure 1). The alternating magnetic field exits elastic oscillations in the ferrite component transferring through the boundary of the partition to the piezoelectric component, which brings to interconnected oscillations of ferrite and piezoelectric subsystems. The amplitude of the vibrations will be inhomogeneous, perpendicular to the line of the partition, as there is a sharp boundary between the ferrite and piezoelectric layers.

[2] **Corresponding author:** Tigran Galichyan, postgraduate, research fields: condensed matter physics, magnetoelectric effect.

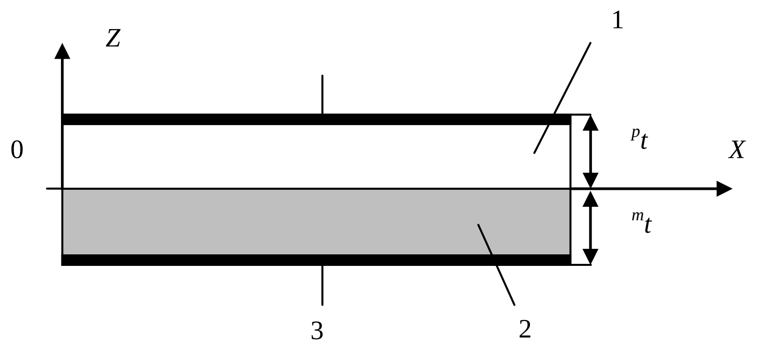

Figure 1. Schematic view of the sample
1- piezoelectric phase with ^pt thickness, 2- magnetostictive phase with ^mt, 3- Electrodes.

3. Dispersion relation

Taking into account the inhomogeneity along the Z axis, the solution of the equation for the displacement vector of the media will be presented as planar waves, which amplitude is changed on the thickness of the sample which is shown in Eq. (1).

$$^\alpha u(x,z) = {}^\alpha g(z)\,{}^\alpha A\cos(\omega t - kx) + {}^\alpha B\sin(\omega t - kx)\,, \tag{1}$$

where the index α is accordingly m for the ferrite and n for the piezoelectric. $^\alpha A$, $^\alpha B$ are the constants of integration.

The substitution of this expression into the expression for the motion of the media carries to the equation for function $^\alpha g(z)$. Solution of this equation depends on the ration of elastic wave velocities in ferrite and piezoelectric phases. The boundary conditions, namely, the normal components of stress tensor on top and bottom surface are zero, the displacement of ferrite and piezoelectric media on interface are the same, so as the shear stresses. These boundary conditions produce a system of equations, consistency of equations give the dispersion relation in the form shown in Eq. (2).

$$^m\chi\,{}^m Y \mathrm{tg}({}^m\kappa) = {}^p\chi\,{}^p Y \mathrm{th}({}^p\kappa)\,, \tag{2}$$

where $^\alpha\kappa = {}^\alpha\chi\,{}^\alpha t$ is a non-dimensional parameter, $^\alpha t$ is the thickness of ferrite and piezoelectric phases accordingly $^m\chi^2 = 2(1+\nu)\left(k^2 - \frac{\omega^2}{^mV_L^2}\right)$, $^p\chi^2 = -2(1+\nu)\left(k^2 - \frac{\omega^2}{^pV_L^2}\right)$, $\frac{1}{^mV_L^2} = \frac{^m\rho}{^mY}$, $\frac{1}{^pV_L^2} = \frac{^p\rho}{^pY}$, ^mV_L, ^pV_L are the velocities of longitudinal waves, respectively in the ferrite and piezoelectric media, ^mY, ^pY are the Young's modulus of ferrite and piezoelectric phases accordingly.

Equation (2) defines the dependence of angular frequency ω from the wave vector k, in an implicit form, at the distribution of elastic waves in bilayer ferrite-piezoelectric structure.

In limited case, when the thickness of the piezoelectric phase is much less than the thickness of the ferrite phase, we have relation in Eq. (3), which presents the dispersion relation for the ferrite phase.

$$\omega = {}^mV_L k\,. \tag{3}$$

In case, when the thickness of ferrite phase is much less than the piezoelectric phase, we have the Eq. (4), which presents the dispersion relation for piezoelectric phase.

$$\omega = {}^{p}V_{L} k \, . \tag{4}$$

For thin ferrite and piezoelectric phases, when ${}^{m}\kappa = {}^{m}\chi\, {}^{m}t << 1$ and ${}^{p}\kappa = {}^{p}\chi\, {}^{p}t << 1$, the approximate expression is obtained, for the dispersion relation, which is shown in Eq. (5).

$${}^{m}Y({}^{m}\chi)^{2}\, {}^{m}t = {}^{p}Y({}^{p}\chi)^{2}\, {}^{p}t \, . \tag{5}$$

Taking into account the expressions for ${}^{m}\chi$, ${}^{p}\chi$ and Eq. (5), after simple transformations, the dispersion relation is obtained in the following form, shown in Eq. (6).

$$\omega = \sqrt{\frac{{}^{m}Y\, {}^{m}t + {}^{p}Y\, {}^{p}t}{{}^{m}\rho\, {}^{m}t + {}^{p}\rho\, {}^{p}t}} \, . \tag{6}$$

Thereby, for small thicknesses of ferrite ${}^{m}t$ and piezoelectric ${}^{p}t$, the linear dependence of angular frequency from the wave vector is retained.

4. Conclusion

The amplitude of the wave is changed on the thickness of the sample, on direction perpendicular to the line of the partition, in the distribution of the elastic waves in bilayer structure. The boundary conditions produce a system of equations which give the dispersion relation for the planar oscillations. Nonlinear relation between the angular frequency ω and the wave vector k is defined from that expression. In limited cases, when one of the layers is thinner than the other, this relation passes to a dispersion relation of one, or the other media, thus the speed of the distribution of elastic waves is less than the speed of the distribution of elastic waves in ferrite, but more than in piezoelectric phase. In limited cases, this dispersion relation passes into dispersion relation for ferrite and piezoelectric accordingly.

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