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Effect of Magnetoelastic Interaction on Magnetostatic Mode Spectrum in Thick Ferrite Films with Nonpinned Surface Spins

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Effect of exchange magnetostatic wave and acoustic wave resonance interaction on dipole magnetostatic wave spectrum has been investigated theoretically and experimentally in ferrite film - dielectric substrate planar structures in microwave frequency range. Acoustic modes were excited by exchange spin modes across the whole thickness of the structure. Resonance interaction of spin wave and acoustic wave was achieved under their phase synchronism.

1.THEORY.

At first let's consider magnetostatic mode (MSM) spectrum in ferrite films without surface spin pinning and without magnetoacoustic interaction. The distributions of rf magnetization m(z) over the thickness of the film of magnetostatic modes in ferrite films with nonpinned spins are described by symmetry functions. The lowest thickness mode with quisyhomogeneos distribution of m(z) across the film thickness is well known to be named dipole mode. Only this mode is excited in the films with free spins because the coupling integral of m(z) with external rf magnetic field for higher thickness modes (exchange modes) is zero (Fig.1). In the crossover regions of dipole MSW and exchange MSW hybrid dipole-exchange MSW are well known to be excited. But the excitation of such hybrid MSW is also possible only in films with pinned surface spins films. In fact, the overlapping integral between $m_d(z)$ of dipole MSW and exchange MSW $m_e(z)$ is zero without pinning as it is well seen from Fig.1.

It should be mentioned that the distribution m(z) for hybrid MSW can be represented as a sum of three components: dipole, exchange and surface. But the amplitude of the last is negligible.

Thus in films with nonpinned surface spins pure dipole spectrum of MSW to be observed in ordinary conditions as it was known previously. It should be mentioned that pure dipole spectrum is necessary for the MSW device fabrication. In fact dipole-exchange interaction unpredictably disturbs the MSW spectrum and the control of MSW device control becomes impossible.

But we shell show that the resonance magnetoelastic interaction disturbs the pure dipole spectrum in some small range of the spectrum despite the surface spins pinning condition.

Now let's consider how magnetoelasic interaction will affect the MSW spectrum. We shell consider exchange waves and acoustic waves which wavenumber in the plane of the structure is zero (homogeneous in the plane of the structure modes). We can use this approximation because in practice the plane wavenumber component is much lower than thickness component.

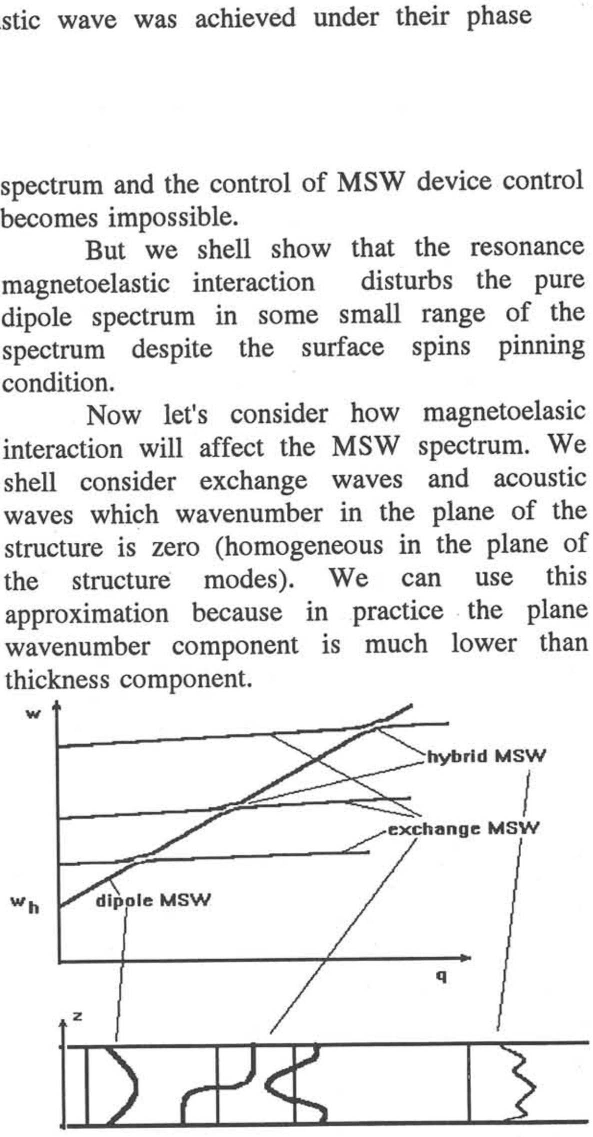

Fig.1. MSW spectrum in ferrite film and MSW rf magnetization thickness distribution of m(z) across the film thickness. q is wavenumber in structure plane.

The simultaneous consideration of magnetization vector motion and mechanical oscillations in the structure gives us the dispersion, frequency dependence of the resonance magnetic fields of the modes under the resonance magnetoelastic interaction, the m(z) distribution and the MSW intensity. It has been shown theoretically and experimentally that resonance magnetoelastic interaction greatly disturbs the dispersion of MSM in the narrow range of MSW spectrum where exchange MSM are in phase synchronism with acoustic modes.

Resonance magnetoacoustic interaction disturbs the distribution of rf magnetization m(z) across the thickness of the film also for the modes resonantly coupled with acoustic modes. The Fig.2 represents the calculated thickness distribution of rf magnetization component for the third exchange MSM m(z) at several frequencies. If microwave frequency is rather far from fi the distribution of m(z) is analogous to the distribution of m(z) of SWR mode (fi - are Lamb modes cut-off frequencies, which are the resonance frequencies of the acoustic resonator formed by opposite sides of the planar structure).

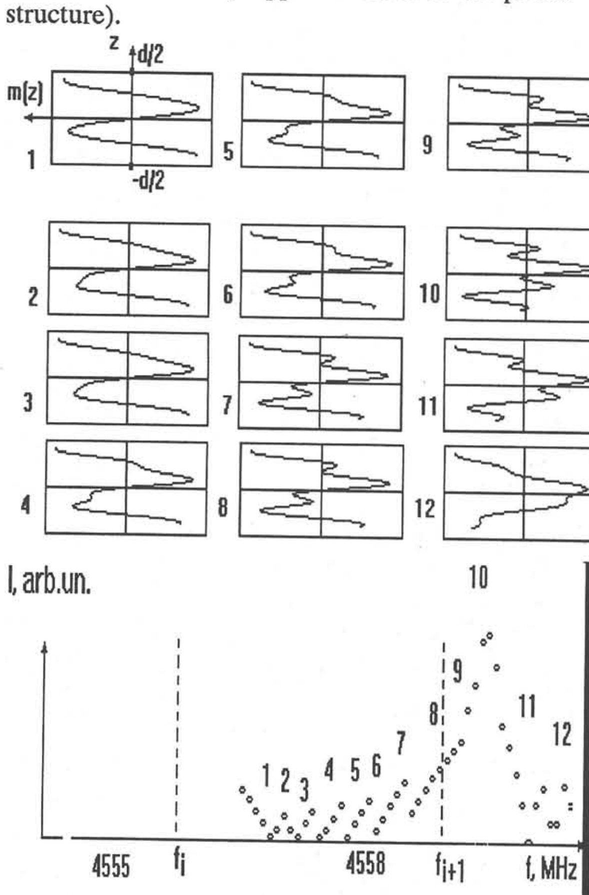

Fig2. The thickness distribution of rf magnetization (a) and intensity (b) of the third SWR mode. From 1 to 12 the third thickness MSM is smoothly transformed to the second thickness MSM.

The m(z) in pictures 1-3,12 are symmetrical to the ferrite film middle plane. But if microwave frequency f is close to one of fi hybrid exchange-acoustic modes are excited which $m_h(z)$ differs from corresponding symmetrical SWR mode $m_e(z)$ distribution. The resulting m(z) for exchange-acoustic modes doesn't symmetrical. In fact the distribution of u(z) (u(z) characterizes some acoustic mode component) is not symmetrical.

As a result linear excitation of exchange-acoustic modes becomes possible in ferrite films with nonpinned surface spins in a narrow magnetostatic wave spectrum range where phase synchronism of spin- wave resonance modes and acoustic waves is exist. The calculated MSM intensity frequency dependence is shown in Fig.2b for MSM shown in Fig.2a. Thus pure dipole spectrum observed in ferrite films without surface distortions (with nonpinned surface spins) to be disturbed by resonance exchange-acoustic interaction. In fact exchange-acoustic modes would be efficiently coupled with dipole MSW. This fact has been proved experimentally.

2.EXPERIMENT.

In experiments the structures composed of yttrium iron garnet (YIG) films with 2.54-10mcm thickness and 455mcm gadolinium gallium garnet (GGG) substrates were used. Experiments were made in ferromagnetic resonance condition and for propagating MSW.

The opposite sides of the planar structure forms the acoustic resonator, which Q-factor strongly depends upon the surfaces roughness. In the structures with damaged backside surface only dipole magnetostatic modes were excited. In fact because of mechanical roughing of the backside of the structure acoustic modes can't be excited in the structure and magnetoacoustic effect were impossible. In this structures pure dipole spectrum has been observed both in ferromagnetic resonance experiments and in propagating wave experiments. This fact proves the unpinning of surface spins.

But in planar structures at any excitation frequency some dc magnetic field range exist where exchange magnetostatic modes were excited. The position of this range depended upon the microwave frequency. According to the theory prediction the excitation of exchange modes were strictly observed in that range of magnetic fields where phase synchronism of SWR modes and acoustic waves to be exist. (Fig.3.)

If some dipole magnetostatic mode has resonance magnetic field in this range the triple dipole-exchange acoustic mode was excited and because of discretization of acoustic wave spectrum in planar structure the strong frequency dependence of the intensity and of the resonance magnetic field has been observed for this mode.(Fig.3, F=4241.1 and F=3855.2)

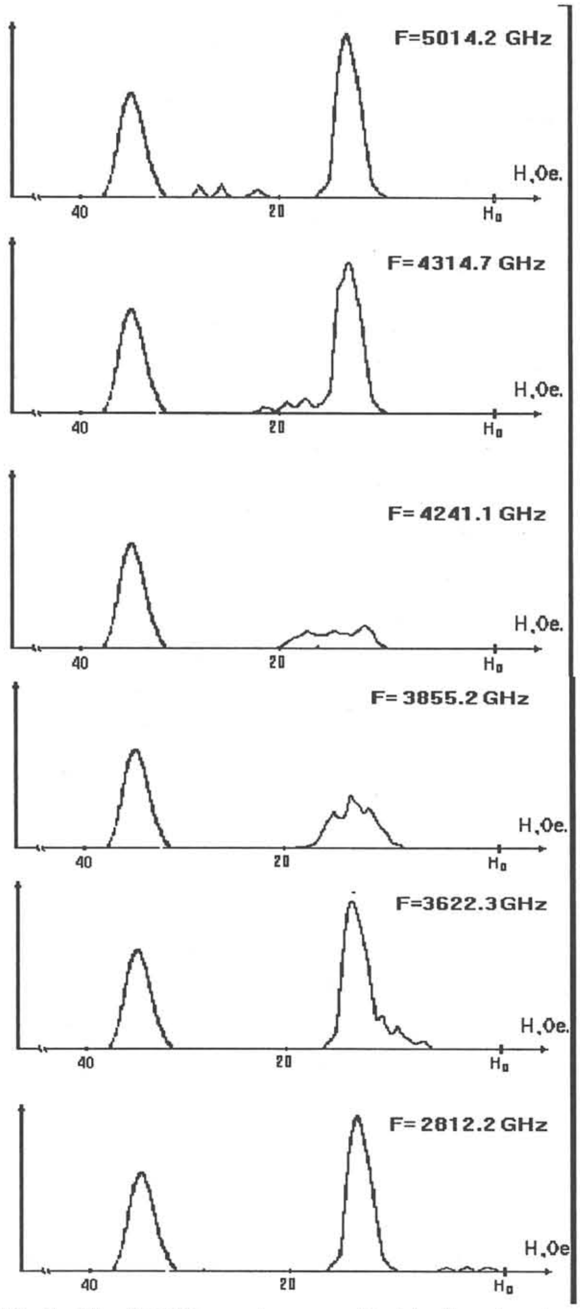

Fig.3. The MSM spectrum excited in the structures in ferromagnetic resonance experiments. The excitation of hybrid exchange acoustic and hybrid dipole-exchange-acoustic modes is evident in the range of resonance magnetoelastic interaction which position strongly depends on frequency. H_0 denotes the beginning of MSW spectrum, and of cause H_0 depends on frequency.

In experiments with propagation waves in the spectrum of magnetostatic waves excited in planar structure the slits have been observed in the narrow range of the spectrum corresponding to the region of resonance magneto-acoustic coupling (Fig.4). This slits are due to hybrid dipole-exchange-acoustic wave excitation and are analogous to the slits observed in thin films due to dipole-acoustic wave or due to dipole-exchange magnetostatic wave excitations. The insertion losses oscillations in this range is caused by the oscillations of group velocity. In fact because of distortion of the dispersion curve the group velocity decreases in the vicinity of dipole MSW and exchange MSW crossover region. The group velocity variation causes in turn the oscillations of time delay (and consequently the oscillations of propagation losses) and the oscillations of input and output MSW transducer impedance. The last fact was corroborated by the oscillations of reflectance in input circuit which was measured experimentally. As a result the oscillations of frequency response are observed in MSW delay lines, which are realized in propagating wave experiment conditions. If acoustic resonator formed by the opposite sides of planar structure is destroyed by corrugation of backside, unused surface of planar structure the pure dipole spectrum is observed. In fact only one YIG film is usually exploited in practice in YIG film -GGG substrate - YIG film planar structures. The oscillations are not observed if the backside is worked with emery cloth.

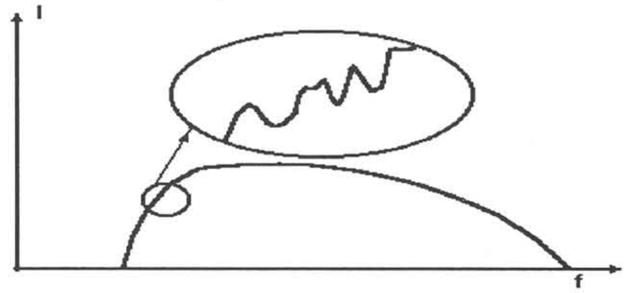

Fig.4. The MSW spectrum in the planar structure. It is shown the part of the spectrum where resonance magnetoelastic interaction is observed. The slits are well distinguished.

3. SUMMARY.

The resonance magnetoacoustic interaction observed under the phase synchronism of spin wave resonance modes and acoustic modes strongly affect the SWR mode rf magnetization distribution across the thickness of the film. As a result the liner excitation of SWR modes becomes possible in ferrite film with nonpinned surface spins. This excitation disturbs the dipole magnetostatic wave spectrum and slits appears in the spectrum because of the excitation of the hybrid dipole-exchange-acoustic waves. In ferromagnetic resonance experiments this effect reveals as an excitation of the exchange oscillation in the region of resonance magnetoacoustic coupling. This fact to be taken into account in MSW device elaboration. The backside, unused side of the planar structure to be worked with emery cloth to avoid the pure dipole MSW spectrum distortion.