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THE FIELD DEPENDENCE OF BUBBLE MODE RESONANCE AT ARBITRARY MAGNETIZATION

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Abstract. — Recent experimental work on the bubble domain mode resonance were carried out on the garnet film grown by liquid phase epitaxy in the frequency range 2-4 GHz at arbitrary magnetization. Two branches of resonance frequency spectrum can be attributed to the magnetization precession in bubbles and in the matrix.

1. Introduction

Although there have been a few reports on the ferromagnetic resonance in unsaturated samples with bubble domain structure, their experimental results are not agreement with each other and the explanations of the data are different [1-5]. Besides the difference in the samples used in their experiments, any change of the domain patterns during measurement also causes the difference in the results. In this paper, therefore, the experiments were carried out in a apparatus which can allow us to observe the domain patterns and sweep frequencies at a constant field so as to clear out the confusion on the domain patterns. Besides, we have also measured the bubble domain resonance at arbitrary magnetization.

2. Experiment

The specimen used in the experiments, a thin substituted garnet film, was grown by liquid epitaxy (LPE) on (111) GGG substrate. The sample parameters are the following: the uniaxial anisotropy field \( H_a = 1100 \text{ Oe} \), the magnetization \( 4\pi M_s = 664 \text{ G} \), the magnetogyratic ratio = 2.42 \( \text{MHz} \) / Oe, the film thickness \( t = 2.85 \text{ um} \), the zero-field stripe width \( d_0 = 1.48 \text{ um} \), the zero-field bubble diameter \( D_0 = 3.15 \text{ um} \), the bubble collapse field \( H_{co} = 473 \text{ Oe} \). The cubic anisotropy field is very small relative to the uniaxial anisotropy field and can be ignored.

In the experiments the specimen was set on a microwave microstrip transmission line placed between the poles of a electromagnet. The domain patterns were observed from the above, using the Faraday Effect concurrently with FMR data acquisition. When the external field makes bubbles shrink the value was taken as positive. In this case the component of \( H \) normal to the film plane is opposite to the magnetization in bubble domains. In different directions of \( H \) with respect to the easy axis the field dependence of the resonance frequency was measured. During the measurement the field \( H \) remains constant, while the frequencies were swept from 2 to 4 GHz so as not lead to the change of the bubble size. In order to be able to show the weak multiple splitting, the external field was modulated with a small auxiliary h.f field and after being detected and amplified, signal was recorded by a \( x - y \) recorder. The precision of the microwave frequency measurement is 0.1 % and the magnetic field is determined to a precision of 0.1%.

3. Results and discussion

The field dependence of the resonance frequency measured at four orientations of \( H \) relative to the film plane was shown in figure 1. It can be seen that the spectra of the characteristic frequency in bubble domain mode resonance exhibit following several remarkable features:

(1) the spectra of the characteristic frequency of the bubble domain mode resonance consist of two branches with different resonance frequencies at zero magnetic field and the low-frequency branch can be split in an external magnetic field,

(2) when the external field is parallel to the easy axis, the field dependence of the resonance frequency is two straight lines which join together at the negative saturation field. The absorption intensity of the high-frequency branch decreases with increasing of the field and reduces to zero at the field \( H_{s0} \), while the variation of the intensity of the low-frequency branch is exactly opposite. Besides, in the range of \( H \) negative values some very weak resonance absorption can be observed;

(3) with the magnetic field normal to the easy axis the resonance frequencies of two branches both decrease in the quadratic way with increasing of \( H \) and the low frequency branch was split into two sub-branches of which the upper sub-branch ends with a limited value at the saturation field and connects with the curve of the saturated FMR, while the resonance frequency of the low sub-branch seems to go down to zero;
(4) when the external magnetic field rotates out from the film plane to the easy axis, the spectra of the characteristic frequency change continuously, as shown in the figures.

This experimental result can be explained by assuming that the high-frequency branch is attributed to the magnetization precession in bubbles, while the low-frequency branch corresponds to the magnetization precession in the matrix. With the field parallel to the easy axis, because the sizes of the bubbles decrease with increasing of $H$, its absorption intensity decreases because of reducing of the magnetization, while the change of the demagnetization energy parameters $N_{II}$ leads to the increase of the resonance frequency. For the low-frequency branch, it can be explained in a similar way. When the magnetic field is in the film plane, the different areas in the matrix have different responding to the field, for example, the (+) areas in figure 2, between the Bloch walls which are almost normal to the external field, should have different resonance frequency from the other areas, particularly, the areas between two walls which are almost parallel to the field according to the Smit and Beljers theory [6]. But for bubble domains they are all equivalent no matter how the field is applied, so it can not be split.

Fig. 1. – The field dependence of the bubble mode resonance frequency at the angle included between the external field $H$ and the film plan (a) $0^\circ$; (b) $20^\circ$; (c) $40^\circ$ and (d) $90^\circ$.

Fig. 2. – Simple bubble lattice domain structure (schematically) in the external field parallel to the film plane. Because of the dynamic demagnetizing fields the (+) areas in the matrix exhibit different frequency response from other areas in the matrix.