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A New Branch of the Spectrum of Single Domain Wall Excitations in Magnetic Garnet Films

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Abstract. 180° and 90° domain walls in Bi-substituted [110] and [100] oriented garnet films with in-plane magnetization are studied by means of planar excitation-detection structures at microwave frequencies. New multiple resonance modes of single domain walls with very low linewidth (4.2 MHz) are observed at frequencies near 1 GHz. The resonances are excited by rf magnetic fields which are parallel or perpendicular to the wall plane. Resonance frequencies show a nonlinear dispersion dependence on the mode number. They decrease with an increasing static in-plane magnetic field normal to the wall plane. With decreasing film thickness the resonance frequencies increase. In addition the well known low-frequency resonances related to the wall translations or its flexural vibrations (Goldstone modes) are also observed in these samples.

1. Introduction

Epitaxial garnet films are currently investigated for a wide range of microwave and magneto-optical applications. Extremely low ferrimagnetic resonance linewidth and spin-wave damping of garnets allow to drive effectively different types of domain and domain wall excitations. Large Faraday rotation and low optical absorption of Bi-substituted garnet films are the basis to achieve high-frequency modulation and deflection of guided optical modes. In most cases these films have a large uniaxial anisotropy so that the magnetization is oriented normal to the film plane (so-called bubble films). In view of applications in integrated optics films with in-plane magnetization could also be very attractive. However, domain and domain wall dynamics in such films having low anisotropy constant K_u and high saturation magnetization M_s (i.e. $Q = K_u/\mu_0 M_s^2 \ll 1$) are not investigated as intensively as in bubble films. Here we present the results of an investigation of Bi-substituted yttrium and lutetium iron garnet films (Bi:YIG and Bi:LIG) grown by liquid-phase epitaxy on [110] and [100] oriented substrates of gadolinium gallium garnet.

Figure 1: Frequency response of a single 180° domain wall in [110] oriented Bi:YIG film (left) and [100] oriented Bi:LIG film (right). The curves 1, 2 and 3 at the left plot correspond to different input rf power levels -35 dBm, -25 dBm and -15 dBm, respectively. The lower plot at the right figure corresponds to the FMR signal without domain wall in the excitation region.

Figure 2: Plot of resonance frequency vs mode number n for 180° domain walls in $[110]$ -oriented films (left) and 180° and 90° domain walls in $[100]$ -oriented films (right).

2. Results and discussion

All the films studied have in-plane magnetization due to the proper choice of the parameters of cubic, uniaxial and orthorhombic anisotropy constants K_1 , K_u , K_i , respectively. A planar excitation-detection structure – slot line and coplanar waveguide – is used to study the domain wall response to high-frequency magnetic fields [1]. The size of the structure is smaller than the domain size so that the excitation of a single domain wall can be measured.

The frequency dependence of the 180° domain wall response displays a set of very sharp resonances both for $[110]$ and $[100]$ oriented samples (figure 1). They have a nonlinear dispersion dependence of the frequency on the mode number (figure 2). The resonance frequencies decrease with increasing in-plane magnetic field normal to the wall plane. The resonance frequencies are the same when the exciting rf magnetic field is parallel or perpendicular to the wall. A strong coupling between neighbouring walls is observed, if their distance becomes small. In this case each resonance is split into two coupled resonant modes.

In $[100]$ oriented samples 180° walls parallel to the $[011]$ and $[0\bar{1}1]$ directions and 90° walls parallel to the $[010]$ and $[001]$ directions are observed. The resonance frequencies of 90° domain walls are found to be lower than those of 180° walls (see right plot in figure 2). The character of the dispersion dependence for 90° and 180° walls is similar to that in $[110]$ oriented films.

The resonance frequencies increase with decreasing film thickness but do not depend on the geometric form of the sample. Therefore these resonances are due to the excitation of standing waves across the sample thickness. Furthermore, they are supposed to be related to the new branch of domain wall excitations predicted by Gilinskii [2]. It differs from the known mode of wall translations or its flexural vibrations (Goldstone mode). The latter kind of resonances is also observed in our samples at lower frequencies (in the range of 40-500 MHz) and has the linear dispersion. The small value of the frequency gap of this lower mode is due to the fact that in our samples restoring force which define the equilibrium wall position is very small.

In the Gilinskii mode both wall translations and oscillations of the magnetization transverse to the wall plane are involved. Thus, contrary to the Goldstone mode, the Gilinskii mode can be driven by rf fields both perpendicular and parallel to the wall plane as observed in our experiments. The frequency gap of the Gilinskii mode is proportional to the uniaxial anisotropy constant: $\omega_G = \gamma 2K_u/M_s$ [2] (γ is the gyromagnetic ratio). This is in qualitative agreement with our observations that films with lower K_u show lower resonance frequencies. Numerical simulations of the dispersion law $\omega(k)$ for the Gilinskii mode [3] show a nonlinear dispersion at large wave vectors k and that $d^2\omega/dk^2 < 0$. This also agrees with the measured dependence of resonance frequency on the mode number (figure 2). Unfortunately, the theory [2,3] was developed for the case of ferromagnets with a pure uniaxial anisotropy and can not be applied directly to the materials studied here, having in addition cubic and orthorhombic anisotropies.

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