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Ferrimagnetic resonance linewidth in single-crystal Mn-doped $\text{Ba}_2\text{Zn}_2\text{Fe}_{12}\text{O}_{22}$

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The ferrimagnetic resonance linewidths in single crystals of Mn-doped $\text{Ba}_2\text{Zn}_2\text{Fe}_{12}\text{O}_{22}$ were measured as a function of frequency (0.01–40 GHz) and temperature (4–300 K). In addition, the saturation magnetization, g factor, and planar anisotropy fields were measured. The field linewidth ΔH appears to scale with frequency; however, the field linewidth as a function of temperature for the hexaferrite exhibits maxima. The temperature-dependent resonant field values were used to calculate the anisotropy field as a function of temperature. These measurements were performed in a frequency-swept slot-coplanar device at a fixed value of applied magnetic field and in a traditional ferrimagnetic resonance system.

I. INTRODUCTION

Ferrimagnetic materials with low loss and unique magnetic properties are still irreplaceable for many microwave device applications. Due to a large planar anisotropy, Mn-doped $\text{Ba}_2\text{Zn}_2\text{Fe}_{12}\text{O}_{22}$ [$\text{Zn}_2\text{Y}(\text{Mn})$] possesses an easy plane (basal plane) of magnetization perpendicular to the c axis (hard axis). This results in a reduction of the applied magnetic field required for ferrimagnetic resonance and thus provides an ideal material for use at high frequencies. Although extensive work has been done on studying the ferrimagnetic properties of this material without doping,^{1–3} there are still many aspects of considerable interest which have not been thoroughly investigated. In particular, the relaxation processes and resonant field as related to frequency and temperature are of interest from both a practical and fundamental point of view. Therefore, this paper presents the results of an investigation of the magnetic properties and constants of $\text{Zn}_2\text{Y}(\text{Mn})$ to augment and compare with reported data on Zn_2Y with and without doping, and to provide a foundation for analysis of the relaxation processes characteristic of this material.

II. EXPERIMENTAL DETAILS

The $\text{Zn}_2\text{Y}(\text{Mn})$ single crystals used in these experiments were produced by a flux-growth technique. Shape effects and overlap of magnetostatic mode excitations were reduced by cutting 3.175-mm-diam samples from single crystals using a diamond corer. In order to decrease linewidth,⁴ the circular platelets were thinned to 0.127 mm employing traditional metallurgical polishing techniques. The ferrimagnetic resonance (FMR) experiments were performed in a conventional Varian E -line spectrometer operating at 9.32 GHz with a cavity resonating in the TE_{102} mode. A 100-kHz modulation field was applied to the sample, and field values were measured using a Bell gaussmeter with an accuracy of $\pm 1.5\%$. Low-temperature experiments were

performed on the $\text{Zn}_2\text{Y}(\text{Mn})$ samples using this system in combination with a liquid-helium Oxford ESR900 continuous gas flow cryostat. The temperature of the samples was varied from 3.2 to 300 K with a stability of ± 0.5 K. The linewidth dependence on frequency for the hexaferrite was determined using a frequency-swept slot-coplanar device⁵ connected to a scalar network analyzer. Linewidths were measured from resonances in the device's transmission signal when a fixed dc magnetic field (H_{dc}) is applied perpendicular to the c axis of the sample, which was situated over the device's junction. Saturation magnetization ($4\pi M_s$) was determined using a Digital Measurement Systems vibrating sample magnetometer (VSM) with an accuracy typically of $\pm 5\%$, depending on the particular sample and orientation.

III. RESULTS AND DISCUSSION

A. Cavity measurements (9.32 GHz)

An angular variation FMR experiment was performed with the applied magnetostatic field being rotated in the plane of the hexaferrite ($H_{\text{dc}} \perp c$ axis). Due to the hexagonal symmetry of the crystal, a corresponding sixfold symmetry in the resonant magnetic field would be expected. However, we have observed an 180° or twofold symmetry. This may be attributed to a slight tilt of the sample plane relative to the applied magnetic field, resulting in a component of the larger first-order uniaxial anisotropy term K_1 being measured, thus masking the smaller in-plane anisotropy, K_3 . The data, however, do give an indication of the magnitude of the sixfold anisotropy field component, since it would have to be smaller than the measured 25-G maximum-to-minimum variation in resonant field. This would be consistent with the reported value for the third-order anisotropy of less than 5 G.⁶

The uniaxial anisotropy field, $H_u = 2K_1/M$, and g value were determined using the uniform mode resonant equations for planar ferrites as derived by Kittel.⁷ Reducing these equations for the case where the c axis is along the z axis and the base of the platelet is in the x - y plane so that the demagnetizing factors $N_x = N_y = 0$; $N_z = 4\pi$ gives

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$$\omega_0/\gamma = H_{0\parallel} - H_a - 4\pi M_s, \quad (1)$$

$$(\omega_0/\gamma)^2 = H_{0\perp} (H_{0\perp} + H_a + 4\pi M_s). \quad (2)$$

A g factor of 1.97 and $H_a = 9075$ G were calculated by substituting the parallel ($H_{0\parallel}$) and perpendicular ($H_{0\perp}$) resonant magnetic field values (relative to c axis) at room temperature into Eqs. (1) and (2). The room-temperature saturation magnetization $4\pi M_s$ used in these calculations was 2170 G, and the perpendicular and parallel linewidths measured 14 ± 2 and 21 ± 2 Oe, respectively. Earlier measurements by Bady⁸ at 14.9 GHz revealed a similar value for H_a , but significantly larger linewidths. Buffers⁶ measurements of the magnetic parameters are more consistent with our values for H_a and ΔH at the X band, although they are also slightly higher. More direct comparisons can be made to Stinson and Green's values of 9560 G for H_a , a g factor of 1.92, and a minimum perpendicular linewidth of 16 Oe for spheres of $Zn_{1.5}Mn_{0.5}Y$ at the X band.⁹

Figure 1 shows the linewidth and resonant magnetic field as a function of the angle between H_{dc} and the c axis. The linewidth varies from the parallel value to a peak of 179 Oe at 5° and then decreases to the perpendicular ΔH of 14 Oe. The behavior of the linewidth is attributed to the magnetization lagging the magnetic field by some angle except when H_{dc} is parallel or perpendicular to the easy plane. These results correspond to those produced and analyzed for $Zn_{1.5}Mn_{0.5}Y$ by Stinson and Green.⁹ However, in our case large enough fields were attainable so as to exceed the uniaxial anisotropy field. This allowed for measurement of linewidth and resonant values along the c axis and at small angles.

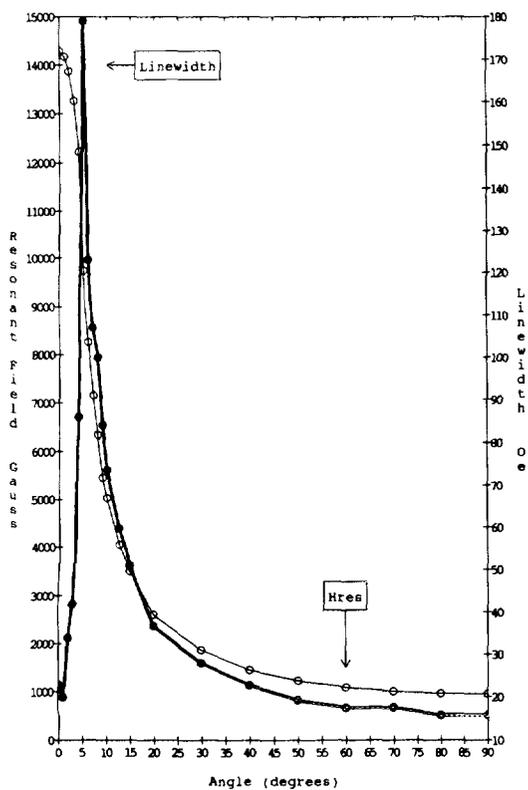


FIG. 1. Linewidth and resonant magnetic field (H_{res}) vs angle relative to the c axis at 9.32 GHz.

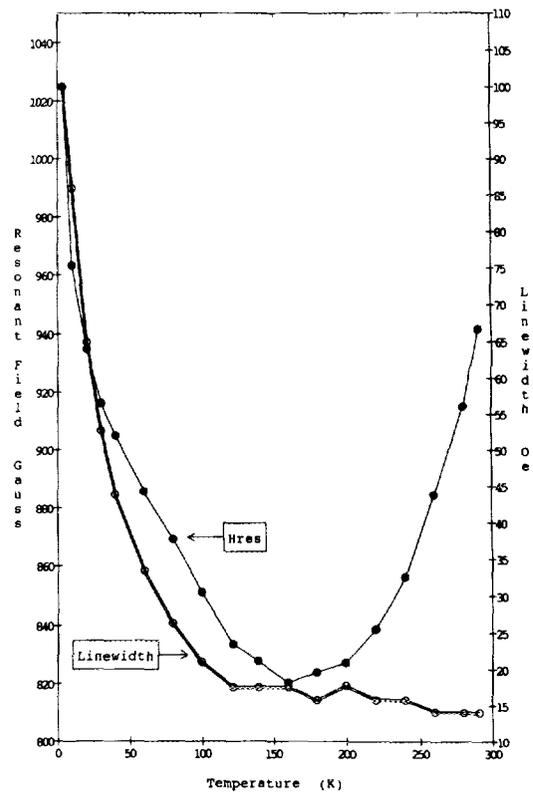


FIG. 2. Linewidth and resonant magnetic field (H_{res}) vs temperature when the applied magnetic field is perpendicular to the c axis at 9.32 GHz.

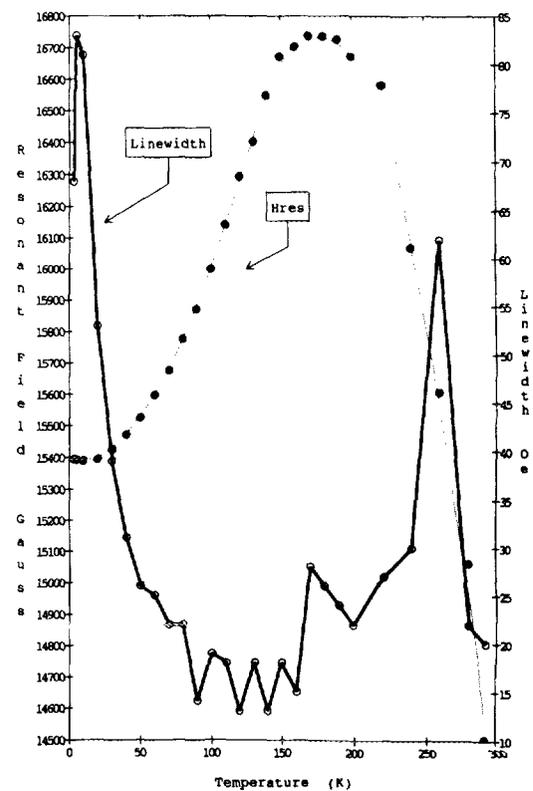


FIG. 3. Linewidth and resonant magnetic field (H_{res}) vs temperature when the applied magnetic field is parallel to the c axis at 9.32 GHz.

Two related FMR temperature experiments involved H_{dc} applied perpendicular and parallel to the c axis. The results of these measurements are plotted in Figs. 2 and 3, respectively. In Fig. 2 the linewidth at 3.2 K with a value of 100 Oe is still rising with lower temperature, but as temperature increases, the linewidth drops off rapidly. This behavior is similar to published measurements at 8.26 GHz (H_{dc} perpendicular to the c axis) where the linewidth decreased from 300 Oe as temperature was raised from 77 K.⁶ However, in the parallel case there are two maxima in the linewidth at 5 K, $\Delta H = 83$ Oe, and at 260 K, $\Delta H = 62$ Oe. The smaller variations in the linewidth between the two main peaks are attributed to the uncertainty in measuring the linewidth due to a slight instability in H_{dc} at high fields (≥ 12 kOe).

The results from the temperature-dependent linewidth are indicative of impurity peaks which have been comprehensively investigated for YIG.¹⁰ This process involves the direct transfer of energy from the uniform precessional mode to lattice vibrations via ions which couple the magnetic spin system to the crystal lattice. Additional experimentation on the frequency dependence of these peaks is necessary to determine which peaks are fast or slow relaxing impurity peaks.

The resonant magnetic field versus temperature data and saturation magnetization were then used to calculate H_u versus temperature from Eqs. (1) and (2). As shown in Fig. 4, H_u is highly sensitive to changes in temperature. The reason H_u is not calculated below 100 K, even though resonant field values were available to 4 K, is because $4\pi M_s$ had not been measured below 100 K.

B. Slot-coplanar measurements (0.01–40 GHz)

Previous measurements of linewidth as a function of frequency were performed from the X band to 70 GHz on Zn_2Y

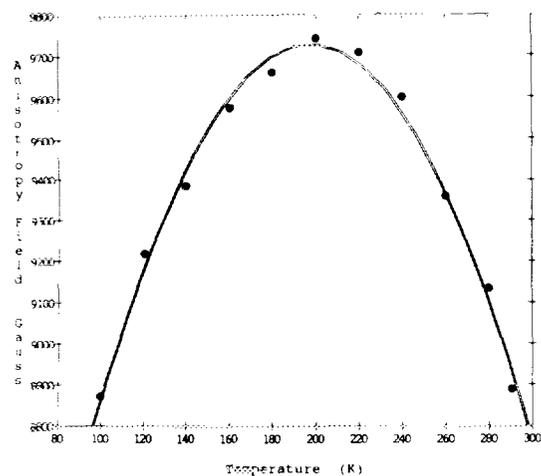


FIG. 4. Anisotropy field H_u vs temperature at 9.32 GHz.

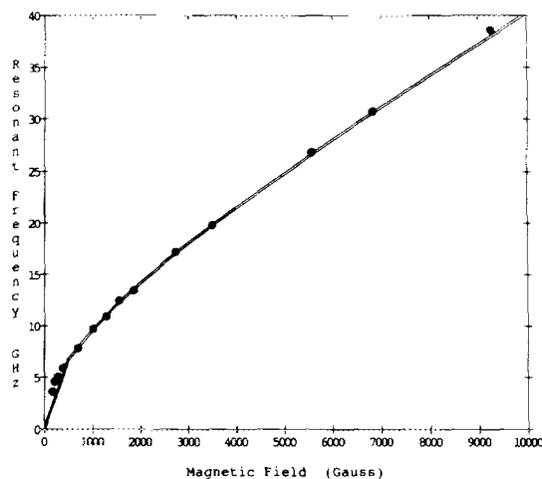


FIG. 5. Theoretical curve [Eq. (2)] and experimental data for resonant frequency vs applied resonant magnetic field (H_{01}).

with the linewidth increasing from 20 to 200 Oe.⁶ Measurements over a narrower frequency band (8–12 GHz) were performed on $Zn_{1.5}Mn_{0.5}Y$, which also yielded increasing linewidth with increasing frequency.⁹ Our measurements of the linewidth for $Zn_2Y(Mn)$, scale linearly at the higher frequency range from 15 to 40 GHz.

In order to verify that the slot-coplanar device is suitable for determining the resonant frequency over a wide frequency range, the theoretical curve and experimental data of the resonant frequency versus magnetic field are plotted in Fig. 5. The magnetic parameters, $\gamma = 2.758 \times 10^6$ Hz Oe⁻¹, $4\pi M_s = 2170$ G, and $H_u = 9075$ G, for the theoretical curve are from the cavity measurements at 9.32 GHz and VSM measurements. The experimental data for $Zn_2Y(Mn)$ agrees with the theoretical results predicted by Eq. (2).

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