

Supplementary Information

Effect of strain-induced anisotropy on magnetization dynamics in $\text{Y}_3\text{Fe}_5\text{O}_{12}$ films recrystallized on a lattice-mismatched substrate

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Derivation of Kittel equations

Free energy density for (001) oriented films with lattice distortion is defined as:

$$F = F_{\text{Zee}} + F_d + F_u + F_c, \quad (\text{S1})$$

$$F_{\text{Zee}} = -\mu_0 H M_s (\sin\theta_M \sin\theta_H \cos(\phi_H - \phi_M) + \cos\theta_M \cos\theta_H), \quad (\text{S2})$$

$$F_d = \frac{1}{2} \mu_0 M_s^2 \sin^2\theta_M \sin^2\phi_M, \quad (\text{S3})$$

$$F_u = -\frac{1}{2} \mu_0 H_u M_s \sin^2\theta_M \sin^2\phi_M, \quad (\text{S4})$$

$$F_c = \frac{1}{2} \mu_0 H_c M_s (\alpha_x^2 \alpha_y^2 + \alpha_y^2 \alpha_z^2 + \alpha_z^2 \alpha_x^2), \quad (\text{S5})$$

where F_{Zee} is Zeeman energy term, F_d is the demagnetization energy term, F_u is the uniaxial out-of-plane anisotropy term, F_c is the magnetocrystalline cubic anisotropy term and $\alpha_x, \alpha_y, \alpha_z$ are the direction cosines. Expressions of F_d and F_u are defined for a film placed in the x-z plane. To derive Kittel equations, one can use the Smit-Beljers equation:

$$\left(\frac{\omega}{\gamma}\right)^2 = \frac{1}{M_s^2 \sin^2\theta_M} (F_{\theta\theta} F_{\phi\phi} - F_{\theta\phi}^2), \quad (\text{S6})$$

however, to avoid an angular-dependent mixing it is more convenient to use the expression with Basalgia correction ¹:

$$\left(\frac{\omega}{\gamma}\right)^2 = \frac{1}{M_s^2} \left[F_{\theta\theta} \left(\frac{F_{\phi\phi}}{\sin^2\theta_M} + \frac{\cos\theta_M}{\sin\theta_M} F_{\theta} \right) - \left(\frac{F_{\theta\phi}}{\sin\theta_M} - \frac{\cos\theta_M}{\sin\theta_M} \frac{F_{\phi}}{\sin\theta_M} \right)^2 \right], \quad (\text{S7})$$

where

$$\begin{aligned} F_{\theta} &= \frac{\partial F}{\partial \theta_M} & F_{\theta\theta} &= \frac{\partial^2 F}{\partial \theta_M^2} \\ F_{\phi} &= \frac{\partial F}{\partial \phi_M} & F_{\phi\phi} &= \frac{\partial^2 F}{\partial \phi_M^2} \\ & & F_{\theta\phi} &= \frac{\partial^2 F}{\partial \theta_M \partial \phi_M} \end{aligned} \quad (\text{S8})$$

and $\omega = 2\pi f$ is the angular frequency, γ is the gyromagnetic ratio.

For the in-plane applied magnetic field ($\phi_H = 0^\circ$), Eq. S7 takes the form:

$$f = \frac{\mu_0 \gamma}{2\pi} \sqrt{(H + H_c \cos 4\theta_H) \left(H + \frac{1}{4} H_c (3 + \cos 4\theta_H) + M_{\text{eff}} \right)}, \quad (\text{S9})$$

while for the out-of-plane applied magnetic field ($\theta_H = 90^\circ, \phi_H = 90^\circ$) it yields:

$$f = \frac{\mu_0 \gamma}{2\pi} (H + H_c - M_{\text{eff}}), \quad (\text{S10})$$

where $M_{\text{eff}} = M_s - H_u$ is the effective magnetization.

References

1. Baselgia, L. *et al.* Derivation of the resonance frequency from the free energy of ferromagnets. *Phys. Rev. B* **38**, 2237–2242 (1988).

X-ray diffraction pattern of 9.6 nm thick YIG film on YAG substrate

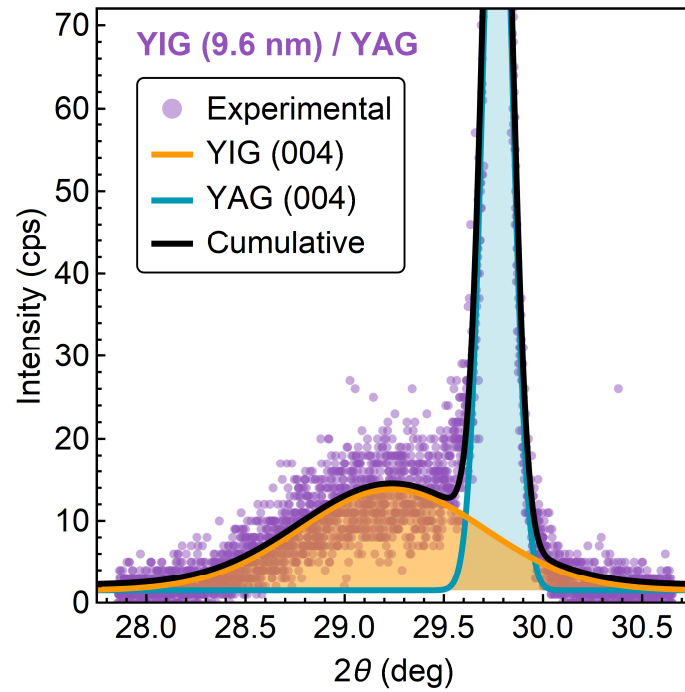


Fig. 1. X-ray diffraction pattern of 9.6 nm thick YIG film.

Typical FMR spectra of YIG/YAG and YIG/GGG films

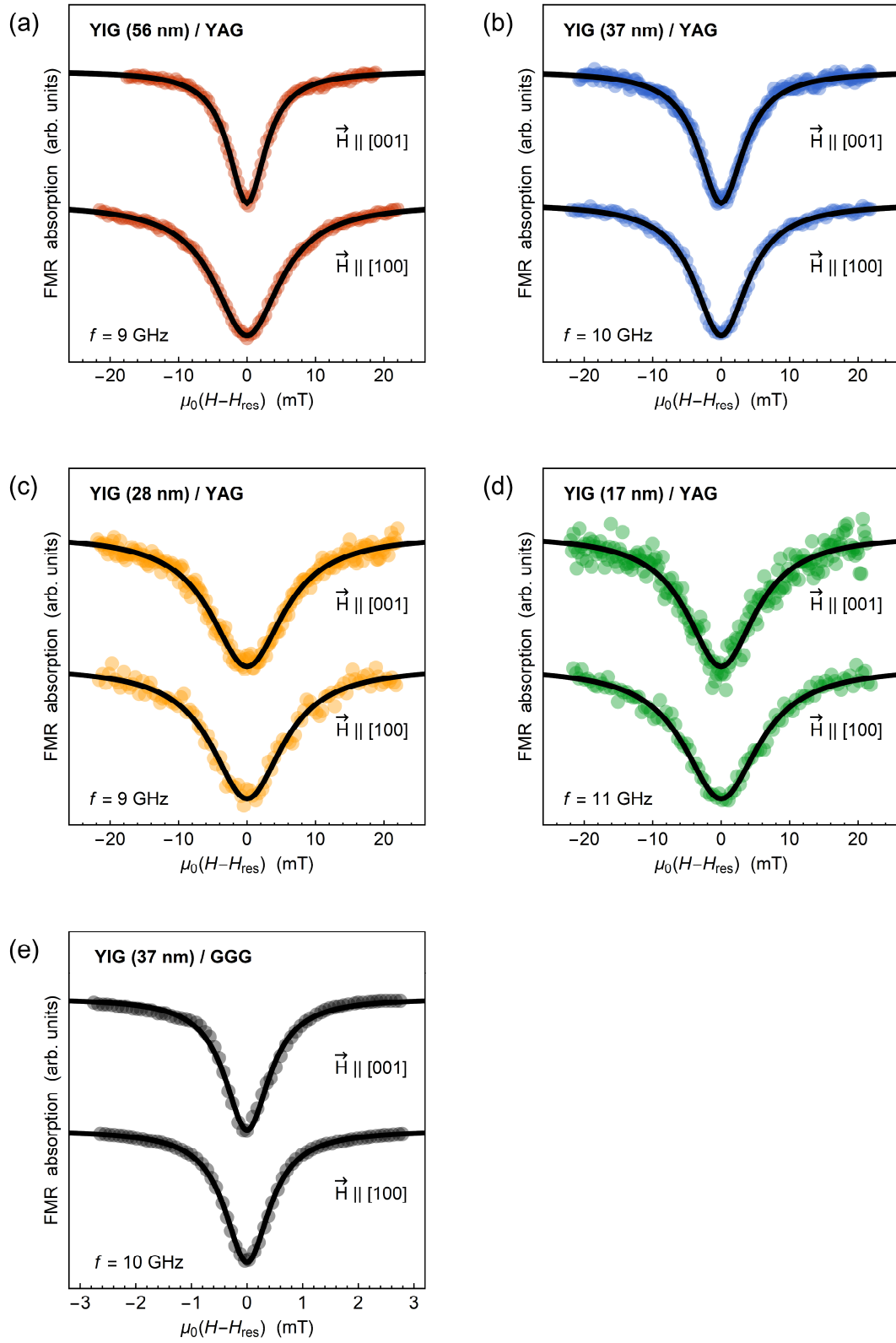


Fig. 2. (a)-(e) Typical FMR spectra taken at $f \approx 10$ GHz.