Control of Spin-Wave Instability Threshold in YIG Sphere

Michinobu Mino [a,1], Masayuki Tsukamoto [a], Misako Yamazaki [a], Hitoshi Yamazaki [a]

[a] *Department of Physics, Faculty of Science, Okayama University, Tsushima Okayama 700-8530, Japan*

Abstract

Spin-wave instability threshold under multiple drive excitations is studied in an yttrium iron garnet sphere at 4.2K. Both a static magnetic field and a parallel RF field are applied along the [111] direction. Another perpendicular RF field excites magnetostatic modes through the first order Suhl process. Interactions between spin-waves and magneostatic modes cause a change of instability thresholds.

Key words: Suhl Instability; Parallel pumping; apin-wave; YIG

1. Introduction

Nonlinear spin-wave dynamics in an yttrium iron garnet (YIG) beyond a parametric instability threshold is a very suitable subject for nonlinear science, for example chaotic oscillations and soliton transport [1,2]. What is more, YIG is an important material used in microwave devices. For example, a microwave limiter exploits the nonlinear relaxation on YIG. As the process of parametric generation of spin-waves, the first order Suhl instability, the second order Suhl instability and a parallel pumping instability are well known. In the first-order Suhl process, a spin-wave pair with $\omega_{\pm k} \sim \omega_{\mathrm{p}/2}$ can be deriven parametrically by $k \sim 0$ mode. This process is a three-magnon interaction. Where ω_k is a frequency of spin-waves with wave vector k, and ω_{p} is a pumping frequency. In the coincidence regime of the first-order Suhl instability, the threshold power is extremely small. Because both the resonance conditions for the excited ω_{p} mode and for parametrically $\omega_{\mathrm{p}/2}$ modes are satisfied simultaneously. A microwave limiter of YIG usually functions in this regime. If the static field H_0 exceeds the upper limit of the first order Suhl instability condition, the parametric excitation of spin-waves is achieved by the second-order instability. A threshold of second order instability is higher than the first-order one. In parallel pumping method, a microwave field h is applied parallel to the static field. Spin-wave pairs with the half pumping frequency and equal and opposite wave vector $\pm k$ are excited. As static field varies, a wavenumber of the excited magnon is selected. Above a spin-wave instability, multiple spin-wave modes are involved in the dynamics. Addition of the second microwave changes nonlinear dynamics and the instability threshold [3–5]. This dual-drive experiment can probe nonlinear interactions between spin-wave modes and magnetostatic modes beyond a thermal equilibrium. We employ 8.000GHz microwave for a parallel pumping and 4.000GHz microwave for a perpendicular pumping. New results in the coincidence regime of YIG spheres are reported.

2. Experimental

Experiments were carried out with a single crystal spherical sample of YIG at 4.2K. Microwave power was generated by two synthesized sweepers (HP83624). An open dielectric resonator, in which sample inside was installed, was put at a short-circuited X-band waveguide. The YIG sample with 1mm diameter was rotate freely within the hollow of the resonator. A static magnetic field H_0 was applied along the [111] easy magnetic axis. The parallel pumping microwave with 8.000GHz

[1] E-mail:mino@cc.okayama-u.ac.jp

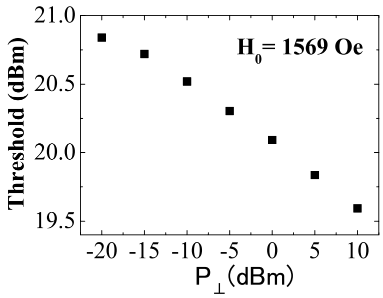

Fig. 1. Parallel pumping instability threshold as a function of $P_{\perp}$.

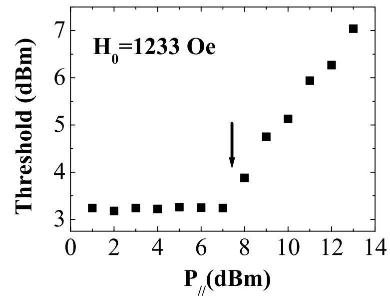

Fig. 2. First order instability threshold as a function of parallel pumping power $P_{\parallel}$ at H_0=1233 Oe.

was applied parallel to the static field direction. Another microwave field with 4.000GHz was perpendicular to both a static field and the first microwave field by a wire loop surround the sample. Two frequency microwaves are separated by a waveguide and a low-pass filter connected to the wire loop. The microwave signals reflected from the measurement section were detected by a tunnel diode. The threshold power was determined as the appearance of a chip on the reflected pulse signals.

The parallel pumping threshold has a minimum value $H_{\min}$, where an excited spin-wave has wavenumber $k \sim 0$ and propagation direction with $\theta_k = \pi/2$. At static field $H_0 < H_{\min}$, spin-waves with wavenumber $k \sim 10^5 \mathrm{cm}^{-1}$ are excited. On the other hand, excited spin-waves have $k \sim 0$ in $H_0 > H_{\min}$ region. In our experiments, the bottom field of parallel pumping threshold is $H_{\min} = 1289$ Oe. The magnetostatic modes, which are excited by the perpendicular field, are (220), (111) and (210) at H=1060, 1233 and 1569 Oe,respectively.

3. Result and Discussion

At first, we studied a parallel pumping instability threshold as a function of 4.000GHz microwave power $P_{\perp}$. Parallel pumping microwave power $P_{\parallel}$ with 8.000GHz had pulse modulation. Perpendicular pumping microwave $P_{\perp}$ was continuously generated. At H_0=1569Oe, the threshold is 21.3dBm without $P_{\perp}$. Increase of $P_{\perp}$ causes reduction of parallel pumping threshold as shown in Fig.1D This result is roughly consistent with Ref.[4,5], but a clear quadratic response at low perpendicular power region is not observed. At this field, the first order Suhl instability of magnetostatic mode (210) is not observed. The reduction of parallel pumping threshold is smooth. As parallel pumped spin-wave has wavenumber $k \sim 0$, the interaction between spin-waves and magnetostatic modes is strong.

In the region $H_0 < H_{\min}$, $P_{\perp}$ dependence of pumping threshold is small[4]. Because parallel pumped spin-waves have wave number $k \sim 10^5 \mathrm{cm}^{-1}$. At $H = 1233$ Oe, a slightly reduction of parallel pumping threshold is observed in $P_{\perp} < 0$dBm. In $P_{\perp} > 5$ dBm, parallel pumping threshold becomes higher with increase of $P_{\perp}$. At this field, perpendicular pumped magnetostatic mode (111) shows the first order Suhl instability at $P_{\perp} = 3.2$dBm as shown in Fig.2. This increase of parallel pumping threshold is caused by parametrically excited spin-waves through the first order Suhl instability.

In order to measure the first order instability threshold as a function of parallel pumping power, pulsed $P_{\perp}$ and contunuas $P_{\parallel}$ were employed. A perpendicular first order instability threshold was shown as a function of parallel pumping power in Fig.2 At $H_0 = 1233$ Oe, the threshold of magnetostatic mode (111) is 3.2 dBm without parallel field $P_{\parallel}$. When $P_{\parallel} < 7$ dBm, a striking change is not observed. When $P_{\parallel}$ exceeds parallel pumping threshold (7.5dBm), which is indicated by an arrow, the first order instability threshold varies linearly with the $P_{\parallel}$. At $P_{\parallel} > 15$ dBm, auto-oscillations of parallel pumped spin-waves occur, and this smooth change is destroyed. The threshold of i220jmode at H_0=1060 Oe shows same variation with (111) mode. At this field parallel pumping threshold is 8dBm. These results are contrary to paralle pumping threshold reduce at H_0=1569. It is conjectured that rapid increase of parametrically excited spin-wave amplitude cause a fast relaxation of magnetostatic modes.

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