Spin Wave based Frequency Division Multiplexing Device for Parallel Data Processing using Micro Structured Yttrium Iron Garnet Thin Films

The University of Tokyo, Sarker Md Shamim (D1)*, Shumpei Nakamura (M2), Hiroyasu Yamahara, Munetoshi Seki, Hitoshi Tabata
*E-mail: sarker@bioxide.t.u-tokyo.ac.jp

Spin waves (SWs) offer data transmission and data encoding capability in both amplitude and phase. Most of the works in this field focus on developing novel and energy-efficient control mechanisms of SW by different means such as voltage, current, light, heat etc., to use it in logic applications. However, this wave-based computation has the tremendous potential of parallel data processing. A multifrequency magnon network would allow parallel data processing within a single element. There are few reports about SW channeling in multiple paths in metallic ferromagnet [1][2]. In this work, we experimentally demonstrated a novel multi frequency SW device that can operate at multiple frequencies simultaneously using the shape anisotropy of the magnonic film.

A 145 nm-thick YIG film was grown on a (GGG) substrate by PLD. Two patterned YIG waveguide with width w_1 and w_2 were fabricated by hot orthophosphoric etching at 160 °C temperature after photolithography, as shown in Figure 1(a). w_1 was maintained at 100 μm, whereas w_2 was varied in the steps of 10, 20, 40, 60, 80, and 100 μm to implement a multichannel spin wave device. Subsequently, a system of two co-planner waveguide (CPW) made of 90 nm thick Au was integrated into the YIG film using *dc* magnetron-sputtering, maintaining a distance (D) of 200 μm between signal lines.

A *dc*-biased magnetic field ($\mu_0 H_{\text{ext}} = 25\text{mT}$) was applied in the in-plane and perpendicular to the SW propagation path, where magnetostatic surface SW was excited. We followed a similar approach to investigate SW propagation as in the reference [3] using vector network analyzer. The transmitted SW, S_{12} for multichannel device (Figure 1(a)) has been shown in Figure 2(b)-(g). Figure 2(b) to (e) show a single-mode SW transmission at $f_1 = 2.15$ GHz. However, Figure 2(f) and (g) shows the appearance of an additional SW mode at $f_2 = 2.06$ GHz and $f_2 = 1.92$ GHz, respectively. Thus, it indicates that additional mode appears only when the width of the second waveguide has been shrunk beyond 20 μm, and it happens at a lower frequency than the first mode. It can be explained by the demagnetizing field (H_d) in a micro structured waveguide. H_d is developed inside the micro structured waveguide [4] according to $H_{\text{d}} = t * 4\pi M_{\text{s}}/w$, where t, M_{s} and are the thickness, saturation magnetization and width of the waveguide, respectively. This demagnetizing field reduces the effective magnetic field based on the relation: H_{eff}=$H_{\text{ext}} - H_{\text{d}}$. According to the Kittle equation, the reduction of H_{eff} will result in the reduction of SW frequency, f_{FMR}:

$$f_{\text{FMR}} = \frac{\gamma}{2\pi}\sqrt{H_{\text{eff}}(H_{\text{eff}} + M_{\text{eff}})},$$

where γ is the gyromagnetic ratio. In this work, combining such two different magnonic channels with the distinguishable demagnetizing field has made it possible to make a SW based frequency division multiplexing device for parallel data processing.

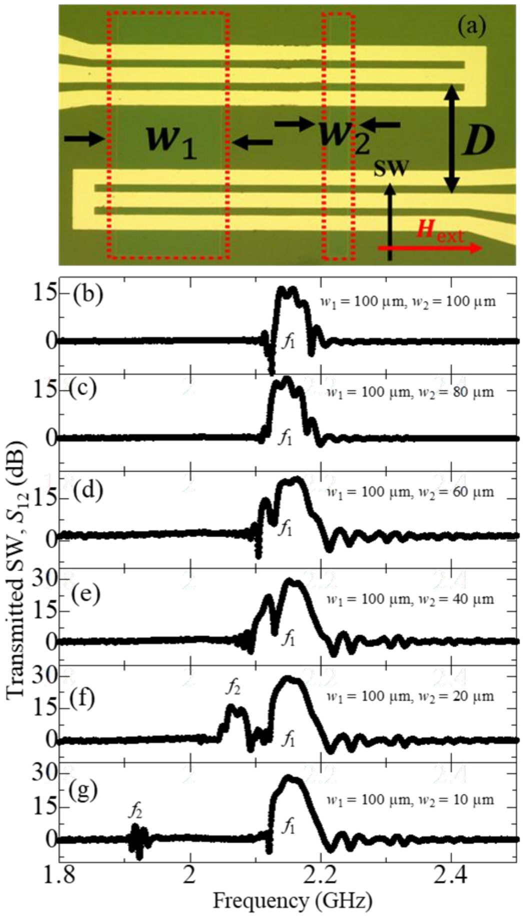

Figure 1. (a) Optical image of multichannel SW device. Transmitted SW signal for in multichannel device for w_1 = 100 μm and (b) w_2 = 100 μm (c) w_2 = 80 μm (d) w_2 = 60 μm (e) w_2 = 40 μm (f) w_2 = 20 μm (g) w_2 = 10 μm.

This research was partially supported by Institute for AI and Beyond for the University of Tokyo.

Reference

[1] F. Heussner *et al.*, PSS RRL 2020, 14, 1900695 [2] K. Vogt *et al.*, Nat. Comm, 5:3727 (2014) [3] S. Sarker *et al*, AIP Advances 10, 015015 (2020) [4] T. Manago et al, JJAP 52 (2013) 053001