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Expression of Stop Bands in Forward Volume Spin Waves
–Contribution to the realization of super low-power spin wave integrated circuits–

A research group led by assistant Professor Taichi Goto at Toyohashi University of Technology have, for the first time in the world, demonstrated stop bands that prevent propagation of specific frequency components of "forward volume spin waves." Forward volume spin waves are transmitted through magnetic insulators without the flow of current, and are expected to be applied to the next generation of integrated circuits (ICs). Furthermore, among the spin waves that have been confirmed, forward volume spin waves are the most suitable for information transmission in IC chips, and there are high expectations for their application. However, until now, noise in forward volume spin waves was large, and the stop bands, which are one of the basic physical phenomena, could not be observed. In this demonstration, a magnetic insulator was combined with metal to suppress the noise in forward volume spin waves, and the expression of stop bands was confirmed experimentally.

This research was jointly conducted by Assistant Professor Taichi Goto, PhD student Kei Shimada, Associate Professor Yuichi Nakamura, Professor Hironaga Uchida, and Professor Mitsuteru Inoue of the Toyohashi University of Technology. Additionally, the samples used for the experiment were prepared under a joint research initiative with Shin-Etsu Chemical Co., Ltd.

In recent years, electronic devices using semiconductor materials have had difficulty in responding to the demands of the rapidly growing information society. For example, due to increases in energy density due to increased integration, chip temperatures have become high, causing defects. Therefore, the development of spin wave IC chips which can process information not by moving electrons themselves but by transmitting spin only, greatly reducing the generation of heat, is attracting attention. Specifically, spin waves traveling through magnetic insulators have the advantage of low energy loss and long-distance transmission. Furthermore, among the spin waves whose existence has been confirmed, forward volume spin waves that transmit in all directions are said to be most suited for ICs because they can be wired diagonally or in curved shapes as well as linearly. On the other hand, these forward volume spin waves are noisy, and several fundamental spin wave phenomena have not yet been demonstrated. Demonstration of these fundamental principles is indispensable for the development of IC chips and has become an important issue.

At this time, a research group led by Taichi Goto of the Toyohashi University of Technology combined a Yttrium iron garnet (YIG) – an oxide single crystal well known as a magnetic insulator – with two metals (gold and copper) to suppress noise. Through this approach the research team was able to confirm the expression of stop bands in forward volume spin waves experimentally for the first time in the world. In this research, firstly, a system that could simulate the propagation of spin waves was prepared using a three-dimensional model (Figure 1) with the same scale as real spin waves. Using this system, a sample structure was determined where noise was small and in which "stop bands," which are one of the fundamental spin wave phenomena, would be expressed. A stop band is a phenomenon that does not allow spin wave components of a specific frequency to pass through, and stop bands are also expressed in other waves such as electromagnetic waves including light. Next, samples were made to be as close as possible to the simulation. Figure 2 shows a sample prepared using materials from Shin-Etsu Chemical Co., Ltd. Both ends of the yttrium-iron garnet (which was processed into a wire shape) were covered with gold film to suppress noise generation, and by arranging a copper film in stripes like a pedestrian crossing, the research team tried to hinder the propagation of specific frequencies. Spin waves of various frequencies were passed through this sample and the transmission characteristics were measured. As a result, stop bands were expressed as shown in Figure 3. By comparing with the characteristics of samples without stripe-arranged copper, it can be seen that the expression of stop bands is due to the stripe-arranged copper. Also, the experimental results and the calculation results are in good agreement. From this, the results can be predicted by simulation before experiment, leading to the potential for efficient spin wave IC development.

The promising results of this research can be used for applications such as spin wave filters in spin wave IC chips in the future. In addition, they can also be used to slow down the transmission speed of spin waves and to control the direction of travel, contributing to the development of smaller chips capable of more dense information processing.

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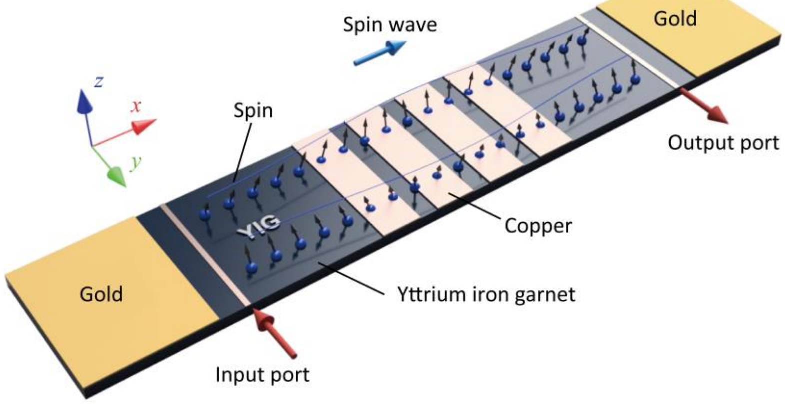
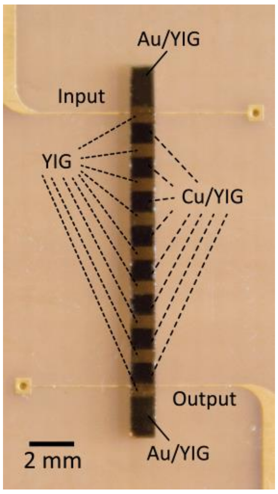
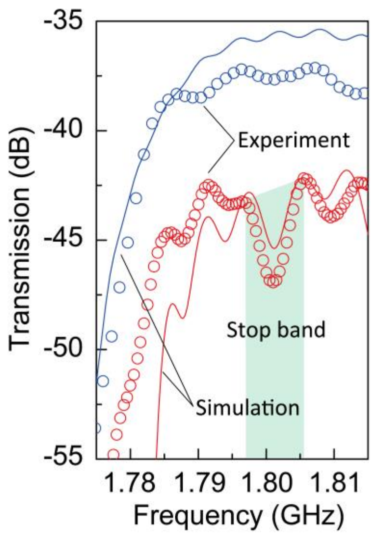


Title: Model of spin wave device (Figure 1)
Caption: A model of a spin wave device realized by combining yttrium iron garnet, gold and copper. "Stop band," which does not allow spin waves of specific frequencies to pass, were exhibited.



Title: Photograph of the fabricated spin wave device (Figure 2)
Caption: The spin waves flow through the yttrium iron garnet (YIG) from the input terminal to the output terminal. Both ends were covered with gold to suppress noise and copper was arranged in stripes to prevent propagation of spin waves of specific frequencies.



Title: Transmission characteristics of the fabricated spin wave device (Figure 3)
Caption: One cases when there is no copper stripe structure (blue circle point) are compared with the other cases (red circle point), and it can be seen that the stop band is expressed by introducing the stripe structure. In addition, the obtained experimental results (circles) are in good agreement with the calculation results (solid lines). From this, it is now possible to accurately predict the results by calculation before experiment.