Information and communication, IoT, AI hardware

Microwave spin devices utilizing heat-driven nano-magnet

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Abstract

We are studying the application of spins in nano-ferromagnetic materials to microwave devices by controlling them with heat. Since ferromagnetic materials have a resonance frequency at the microwave frequency used for communication (in this case, mainly in the vicinity of the gigahertz band), they are expected to enable highly sensitive detection and highly efficient output of electrical signals at that frequency. The detection sensitivity and output efficiency depend on the way in which the spin (direction of the magnetic pole) of the ferromagnetic material is made to resonate. In this study, we focused on the heat of a nanoscale ferromagnetic device called a magnetic tunnel junction. When an electric current is applied to this device, the temperature of the ferromagnetic layer rises due to Joule heat, and the spin direction changes. We have shown that the spin direction moves significantly and rapidly by heat. Using this control method, we succeeded in achieving the world's highest microwave detection sensitivity (diode sensitivity) in the sub-gigahertz frequency band [1]. In addition, we have experimentally demonstrated for the first time in the world that a magnetic material has a microwave amplification effect by controlling its spin with heat [2]. By implementing this microwave amplification effect in two devices, it was found that the devices amplify each other's microwaves and become microwave oscillators [3].

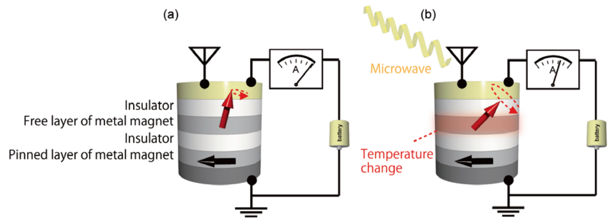
Background & Results

In recent years, with the development of IoT and AI, as well as the spread of COVID-19 infections, the importance of remotely connecting with various objects has increased. This has increased the importance of information and communication elements, and the need for higher performance of these elements. Microwaves, which are responsible for sending and receiving this information, are detected using diode elements. In recent years, in the research field of spintronics, which is electronics using magnets, our group discovered a diode device (spin torque diode) using magnets in 2005, and in 2013, we reported a diode sensitivity that exceeds that of semiconductor diodes.

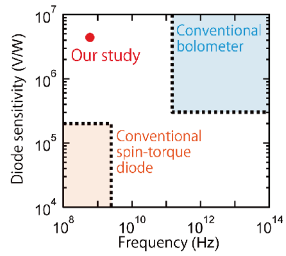
Spin torque diodes have been expected to be applied to communication devices, IC tags, and other fields due to their high sensitivity, small size, fast tuning, low resistance, and frequency selectivity. On the other hand, in the infrared frequency range, bolometers, which have much higher diode sensitivity than semiconductor diode devices and spin torque diodes, have been used. A bolometer is a device that converts incident electromagnetic waves into heat and outputs the temperature change as a DC voltage, similar in operation to a diode device. Bolometers are used to observe weak infrared in calorimeters, infrared imaging devices, and astronomical observations. There are several types of bolometers, such as superconducting, graphene, and semiconductor bolometers, and uncooled bolometers that can be used at room temperature are known to be around 1 million V/W. However, bolometers are not used in the sub-gigahertz frequency range used for long-distance communications. Spin torque diodes operate in the sub-gigahertz band, but no device has been reported to have as high a diode sensitivity as the bolometer. We have succeeded in achieving the world's highest microwave detection sensitivity (diode sensitivity) in the sub-gigahertz frequency band by controlling spins with high speed and high efficiency using Joule heating [1].

Significance of the research and Future perspective

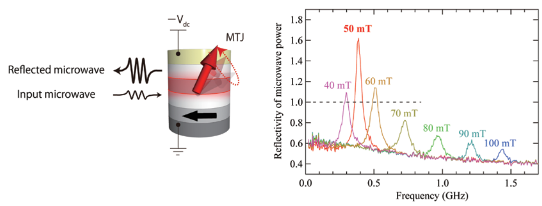
These results are still in the basic research stage, but we hope to realize them as novel microwave devices. It has also been found that the thermal spin control efficiency can be increased by improving the thermal design [4], and that the spin direction can be reversed by using fast Joule heat pulses. We expect that these methods can be used not only for microwave devices but also for spin-based memory devices and AI hardware control methods.



Schematic diagram showing the principle of a bolometer using a magnet. (a) without microwaves and (b) with microwaves applied to the element. The heat from the microwaves changes the direction of the magnetic poles, and the DC voltage change is detected.



The position of this study with respect to diode sensitivity and frequency. The regions of the conventional bolometer and spin torque diode are shown in blue and orange, respectively.



Schematic of the phenomenon of microwave amplification (left) and the magnetic field dependence of the reflectivity spectra of microwave power (right). In this experiment, we succeeded in obtaining a microwave power reflectivity of more than 1.6 at an external magnetic field of 50 mT and a frequency of about 0.4 GHz.

Patent

Treatise

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[3] Yamada, Y; Goto, M; Yamane, T. et al. Quasi-maser operation using magnetic tunnel junctions. Appl. Phys. Lett. 2021; 118: 192402. doi: 10.1063/5.0050151
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Keyword heat-spin control, microwave, diode devices, magnetic tunnel junction