【Grant-in-Aid for Scientific Research (S)】

Coherent spin-dynamics for energy-saving and energy-creating devices

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Project Information	Project Number : 24H00039　Project Period (FY) : 2024-2028 Keywords : Spintronics, Auto-oscillation, Resonance, Non-collinear antiferromagnet

Purpose and Background of the Research

●Outline of the Research

Interconversion between the dynamics of collective spin system (e.g., magnetization in ferromagnets) and the electrical signals are an important research topic in both science and technology. Figure 1 shows dynamics and electrical signal interconversion exhibited in various spin systems and the status of their applications. The magnetization reversal induced by spin polarized current [left] is used in commercialized non-volatile memory. Probabilistic computers utilizing random telegraph noise generated by thermal fluctuation of magnetization [second from the left] are expected to provide efficient platform to address hard problems for classical computers. On the other hand, in addition to magnetization reversal and thermal fluctuations, coherent dynamics such as oscillation [middle], which outputs an RF signal with respect to a DC input, and its reciprocal effect, resonance [second from the right], which outputs DC with respect to an RF input, have been studied extensively over the past 20 years. In addition, we have recently found a new phenomenon, coherent planar rotation of chiral spin structure [right] in non-collinear antiferromagnetic heterostructures.

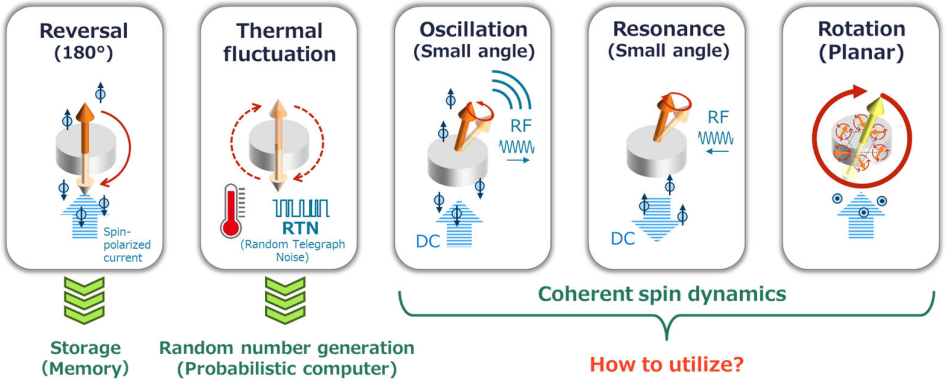

Figure 1. Interconversion between the collective spin dynamics and electrical signal and their applications

The purpose of this project is to clarify how to utilize these coherent dynamics of collective spin systems and to demonstrate their functionalities as energy-saving and energy-creating devices, showing new possibilities in the spintronics, a fusion area of electronics and magnetics. Prior to this project, the principal investigators and co-investigators of this project have obtained the following outcomes, which form the basis to conduct this project.

●Energy harvesting using ferromagnetic resonance in magnetic tunnel junctions

With the increasing demand for battery-free IoT devices, we developed a magnetic tunnel junction that generates DC voltage by a ferromagnetic resonance with Wi-Fi band wireless signal and showed a proof-of-concept of energy harvesting (Fig. 2). [Nat. Commun. 12, 2924 (2021)]

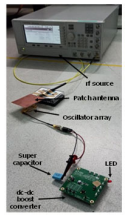

Fig. 2. Demo system for energy harvesting from wireless signals

●Probabilistic computing using random telegraph noise of superparamagnetic tunnel junctions

Probabilistic computing, consisting of stochastic elements, is expected to be an efficient method for computationally hard problems. We have shown a proof-of-concept of probabilistic computer with superparamagnetic tunnel junctions addressing combinatorial optimization. [Nature 573, 390 (2019)]

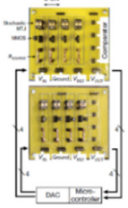

Fig. 3. Demo system of probabilistic computing

Expected Research Achievements

In this study, we will systematically investigate the coherent spin dynamics induced in magnetic tunnel junctions, ferromagnetic heterostructures, and non-collinear antiferromagnetic heterostructures and clarify the path toward their applications. We will demonstrate energy-creating devices that generate sizable electric power from weak radio-frequency wireless signals as well as energy-saving devices such as reservoir/Ising computer that utilizes the nonlinear response of oscillators to input signals and “mutual synchronization" in an array structure. In addition, by deepening the physics of coherent dynamics, we will be able to intentionally design the "incoherence“, allowing us to create high-performance random number generator that could enhance the computational speed of the probabilistic computers [Figure 4].

By exploring various functionalities of the coherent spin dynamics in various structures, new guiding principles for spintronics and promising technologies for future sustainable society will be systematically established.

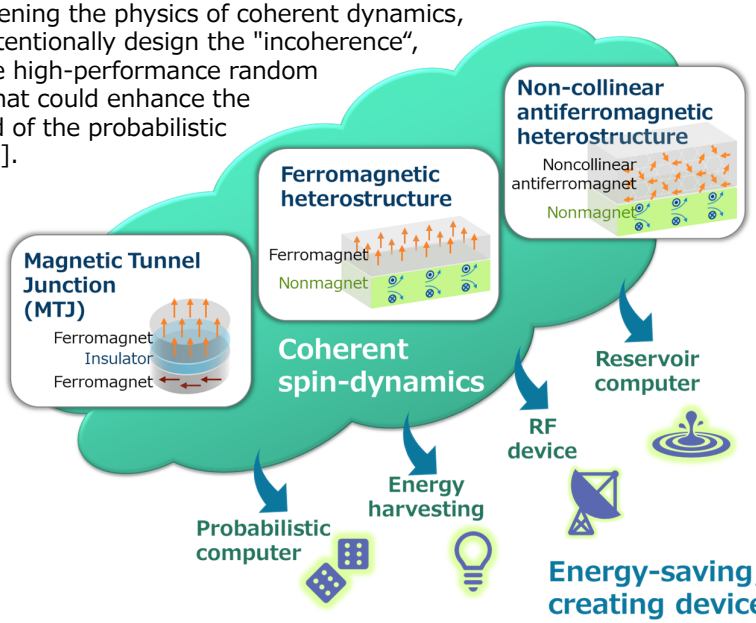

Figure 4. Structure to be used in the project and the explored functionalities utilizing the coherent spin dynamics therein

Homepage Address, etc.	http://www.spin.riec.tohoku.ac.jp/en http://www.akermanlab.com/