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

Broad Section C

Title of Project： Development of artificial intelligence hardware using magnetic tunnel junctions

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Research Project Number: 20H05655 Researcher Number：30261605
Keyword：Magnetic tunnel junctions, artificial spin ice, natural computing

【Purpose and Background of the Research】

Internet-of-Things (IoT) and artificial intelligence (AI) are becoming popular nowadays. IoT connects various things through the internet. AI can surpass human ability in the recognition or prediction. They have been already adopted in several businesses and our daily lives. High computational performances in the IoT and AI are currently realized by von-Neuman architectures with various algorithms. Natural computing is a new computational system inspired from nature and has attracted much attention because of its potential achieving higher performance with lower power-consumption than von-Neumann architectures. Molecules and chemical-reaction system have been adopted to natural computing recently. In this study, we develop an artificial spin ice consisting of magnetic tunnel junctions (MTJs) and apply it to the natural computing. The MTJ is a core component in magneto-resistive random-access memory (MRAM), which is a typical commercial spintronic device. Nonvolatility, small size down to 40 nm, and low-power consumption of an MTJ are suitable for an implementation to high-density memory and/or logic circuit.

【Research Methods】

In this study, we develop artificial spin ices with MTJs for natural computing. The artificial spin ice consists of ferromagnets in submicron scale arranged as, for example, a square lattice. Figure 1 is a schematic illustration of the artificial spin ice with elliptical ferromagnet cells with in-plane magnetizations. Usually, the magnetization in a ferromagnet can point to either right or left directions of the ellipse. However, these states become unstable in the artificial spin ice due to complex interactions between magnetic cells. Then, a non-trivial alignment of the magnetizations, called frustration, appears. The frustrated physical system can show various kinds of reaction, such as an excitation, with respect to an injection of external stimulations. Such a dynamical behavior is similar to an activity of neurons in human brain. Therefore, the artificial spin ice is a promising candidate for the natural computing system. Our goal is to realize the highly energy-efficient natural computing based on the artificial spin ice by making full use of our technologies, ideas and experiences in magnetism and solid-state physics.

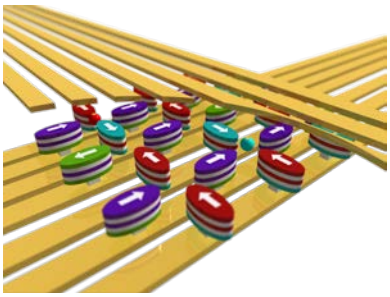

Figure 1 Artificial spin ice with magnetic tunnel junctions

【Expected Research Achievements and Scientific Significance】

We can clarify the relation between the computational performance and the statistical properties, such as a residual entropy and magnetic monopoles, in the artificial spin ice. Simulators for magnetism and natural computing with the artificial spin ice will be developed and opened for public, by which the realization of natural computing will be accelerated. Our research will open a new research field bridging solid-state physics, material sciences, and computer sciences.

【Publications Relevant to the Project】

・ Reservoir computing using an interaction between nanomagnets, Hikaru Nomura, Hitoshi Kubota, Yoshishige Suzuki, Magnetics Japan vol. 14, No. 6, 321-328 (2019)
・ Integrated reservoir computing modules with magnetic tunnel junctions, Hikaru Nomura, Hitoshi Kubota, Yoshishige Suzuki, The Institute of Electrical Engineering of Japan, Vol. 139, No. 10, 674-678 (2019).

【Term of Project】 FY2020-2024

【Budget Allocation】 154,500 Thousand Yen

【Homepage Address and Other Contact Information】

https://unit.aist.go.jp/d-tech/intra/RCECT/index.html