Tackling for ultimate low-power consumption calculation by skyrmion Brownian motion

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Abstract

We aim to realize the ultimate low-power computation using the Brownian motion of skyrmions. Brownian motion is a random motion caused by thermal fluctuations. It has the potential to be the ultimate low-power technology as it works without consuming energy. We focus on a skyrmion which is a topological spin structure formed in two-dimensional ferromagnetic thin films. It has the advantage of exhibiting Brownian motion in a solid, being easy to implement in circuits and to detect and control at room temperature. In this research, we successfully implemented the skyrmion circuit and the cellular automaton shown in Fig 1 and Fig 2, respectively. The black circles are skyrmions, which move randomly in these elements and transfer information. In these systems, information is propagated and operated without supplying external energy except for control and detection at the input and output, therefore, calculation can be performed with extremely small energy.

Background & Results

Due to the recent development of AI and IoT devices and the explosion of digital data volume, there are concerns about a dramatic increase in energy consumption. For example, AI known as Alpha Go Zero requires about 100 times the power consumption of the human brain in order to achieve the same or better performance in Go. In order to realize a sustainable society, it is essential to reduce the power consumption of such devices. In the human body, unlike existing computers, thermal fluctuations are skillfully used to promote unidirectional motion of molecules with extremely small energy. In this research, we aim to realize a device that makes good use of thermal fluctuations, following such the method.

Skyrmions are suitable particles for the above experiments. Skyrmions are topological spin structures as shown in Fig. 3, and appear in two-dimensional ferromagnetic thin films. By appropriately controlling the magnetic properties, the skyrmion undergoes Brownian motion due to thermal fluctuations. Furthermore, skyrmions are easy to detect and control at room temperature, making them a good experimental system for ultra-low-power calculations. By forming an additional film of SiO2 along the shape of the circuit or element on the ferromagnetic multilayer film, we have made it possible to confine skyrmions in devices of arbitrary shape (Figs. 1 and 2). Figure 1 shows a Y-shaped three-way junction, and skyrmions move freely in the circuit by Brownian motion. Figure 2 shows a structure in which two skyrmions are confined in a square cell, and the skyrmions are energetically stable when the skyrmions are positioned one at the top right and one at the bottom left, or one at the top left and one at the bottom right. Skyrmions repel each other due to magnetostatic interaction, and skyrmions interact within and between cells. By adding Brownian motion to this, the information of the skyrmion propagates. Since the flow of information is reversible in these devices, we expect that bidirectional operations will allow us to compute factorizations.

Significance of the research and Future perspective

The significance of this research is to clarify the question, “What is the ultimate low-power computing?” Energy is required to control and detect skyrmions at input and output, but other information propagation and information calculations are performed by Brownian motion and do not consume energy. Through this research, if information processing can be performed with energy close to the thermodynamic limit, it is expected to become a basic technology to solve the increase in energy consumption of existing information devices.

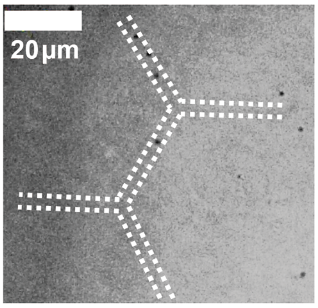

Figure 1 Circuit of skyrmions in Brownian motion. The black dots are skyrmions, which move randomly in the circuit without external energy supply.

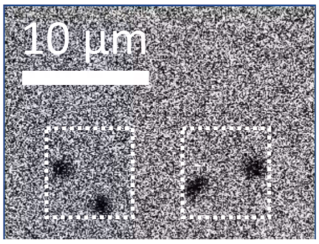

Figure 2 Skyrmion pair confined in square cells. Skyrmions interact with each other through magnetic dipole interaction, and information is propagated.

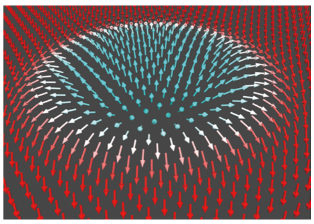

Figure 3 The spin structure of skyrmions appearing in a two-dimensional ferromagnetic thin film. The arrow indicates the direction of the magnetic pole, and the color indicates the component perpendicular to the film plane (upward blue, downward red).

Patent

Treatise

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Keyword skyrmion, brownian motion, information thermodynamics, low power consumption