Diffusion of the skyrmion and its application to the Brownian computing

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Current artificial intelligence (AI) has larger power consumption than that of a human brain. To suppress the power consumption of AI, it is significant to develop low power consumption technology taking account of not only von Neumann architecture but the non-von Neumann architecture. Currently, low power consumption technology such as the voltage controlled magnetic anisotropy (VCMA) effect has been investigated in spintronics research field [1-2]. However, the VCMA effect still has the energy limit which is the energy in capacitance CV^2. In this study, we focus on the Brownian computing [3], whose energy limit is k_BT log2 (Shannon's limit). To realize Brownian circuit, ratchet, hub and C-join are required as shown in Fig. 1 [4]. For this architecture, we have used the magnetic Skyrmion as Brownian particle [4].

The magnetic Skyrmion is topologically protected spin structure. The dynamical properties of Skyrmion can be controlled by VCMA effect. In addition, the Brownian motion of magnetic Skyrmion can be observed in experiment (Fig. 2) and simulation. Our aim is that total energy is suppressed by controlling the Skyrmion using Brownian motion and partially using VCMA effect. We have attempted to realize the ratchet and hub. However, the realization of C-join still has difficulty because of its complicated function. In addition, the power consumption of ratchet is large in the present architecture of the ratchet. We would like to discuss these problems in this workshop.

This research is supported by MIC.

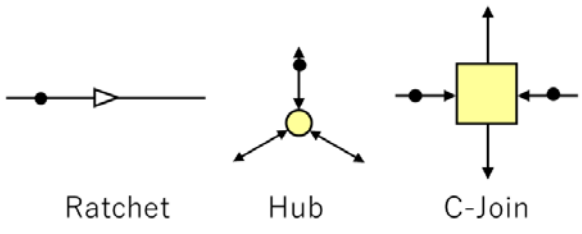

Fig. 1 Schematic of ratchet, hub, and C-join.

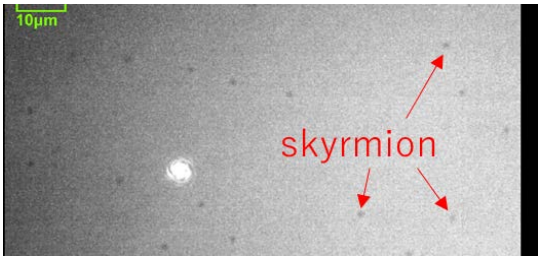

Fig. 2 Kerr microscope image of magnetic skyrmions.

[1] M. Weisheit *et al.*, Science, **315**, 349 (2007) [2] T. Maruyama *et al.*, Nat. Nanotechnol, **4**, 158 (2009) [3] C. H. Bennett *et al.*, **21** 905 (1982), [4] F. Peper *et al.*, ACM jour. Emer. Tech. Comp. Sys, **9**, 3 (2013)

Discussion

Question

Parameters are four, A, D, K, and Ms. However, the controllable parameter is only voltage. How to control them?

Answer

We cannot control these parameters independently only by voltage. However, these parameters depend on the interfacial state. So, by changing them using other materials, we can change the parameters.

Question

How much is the power consumption of silicon device and skyrmion Brownian motion?

Answer

The consumed energy depends on the system, but basically the energy is charged in capacitance, CV2 (C is capacitance and V is required voltage). The capacitance and required voltage depend on the system. In the Brownian computing, this energy CV2 can ideally decrease down to thermal limit.

Question

Why Skyrmion?

Answer

Domain wall can be easily pinned. Single electron easily leave from the circuit. In case of Skyrmion, the Skyrmion is not pinned by defect compared to the domain wall. And also, we can confine it in circuit by controlling anisotropy energy. Therefore, we use Skyrmion.

Question

How to make C-join?

Answer

We are also considering about the C-join. One of the idea, the Skyrmion can be brought by controlling anisotropy by gate voltage. It is same manner with CCD. However, the power consumption is still large. I think that making conventional logic circuit using Brownian circuit is not good idea because making logic circuit requires C-join. We need more efficient circuit function or system compared to the conventional logic circuit. But in the present stage, making half adder circuit has meaning. Because we can make half adder circuit to demonstrate that Skyrmion can calculate by Brownian motion.