Brownian computing using skyrmions and reservoir computing in magnetic dot-arrays

M. Goto[1,3], T. Nozaki[2], H Nomura[1,3], H. Kubota[2], and Y. Suzuki[1,2,3]
[1] Graduate School of Engineering Science, Osaka University, Osaka 560-8531, Japan
[2] National Institute of Advanced Industrial Science and Technology (AIST), Ibaraki 305-8568, Japan
[3] Center for Spintronics Research Network (CSRN), Graduate School of Engineering Science, Osaka University, Osaka 560-8531, Japan

Recent progress and attention regarding an artificial intelligence promotes the research on neuromorphic computing using various physical systems which is not von Neuman type computer. Spintronics is one of the candidates for such a computing technology with the low power consumption. In this study, we discuss two types of basic technology for spin computing, Brownian computing and reservoir computing.

Brownian computing utilizes the random motion of particles, such as Brownian motion, which can calculate information with low energy close to the thermodynamics limit[1)]. We use Skyrmion Brownian motion for Brownian computing. Skyrmion is the Brownian particle in solid state material and is topologically protected spin structure which can be detected and controlled at room temperature. We deposited the Skyrmion film, Ta | CoFeB | Ta | MgO | SiO_2, on Si | SiO_2 substrate. The magnetic anisotropy of CoFeB is partially modulated by changing thickness of SiO_2 capping, which forms Skyrmion circuit without strong pinning site. Figure 1 shows the magneto-optical Kerr effect (MOKE) microscope image of the Skyrmion film. The Skyrmion shown as a black dot is confined in the area surrounded by dashed lines which is the area of thin SiO_2 layer and is low potential energy for Skyrmion. Skyrmion can propagate in the Skyrmion circuit stochastically, which is the basic technology for Brownian computing.

The other is reservoir computing using magnetic dot array. Reservoir computing[2)] which extract important information from intricated signal by learning the weight of the output nodes. Figure 2 shows the time evolution of the magnetic anisotropy of the magnetic dots. Blue and yellow dots show finite and zero perpendicular magnetic anisotropy, whose states change from stage 0 to stage 6. The magnetization of dot array is numerically calculated, and the weight is optimized. We succeeded in calculating the AND, OR, and XOR operation by magnetic dots array at the temperature of 0 K. This research is the basis for experimental research of artificial spin glass.

Reference
1) C. H. Bennett *Int. Jour. Theo. Phys*, **21**, 905 (1982)
2) H. Jaeger and H. Haas Science, **304**, 78, (2004)

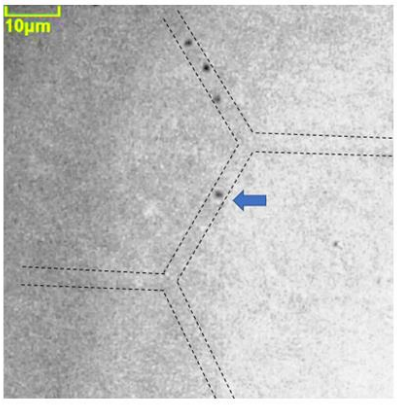

Fig. 1 MOKE microscope image of the Skyrmion film. Black dot is Skyrmion.

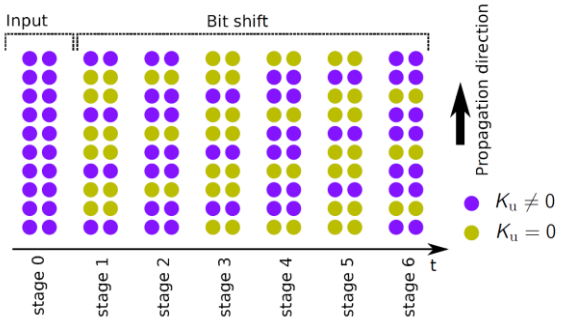

Fig. 2 Operation process of magnetic dot reservoir. Blue and yellow dots show finite and zero perpendicular magnetic anisotropy, whose states change from stage 0 to stage 6.