Information dynamics in the skyrmion system

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Spintronics called for a revolution in conventional electronics by introducing spin currents. And now, spintronics is about to contribute to realizing intelligent hardware. Among many proposals, utilizing the natural computational power of materials seems to be an attractive scheme for developing ultra-energy-saving computing machines. In order to realize such a system, advanced science and technology that can freely control the information flow in materials will be required in addition to the control of charge and spin-currents.

As a first step, we report the result of evaluating the information flowing between skyrmions during thermal motion by measuring the transfer entropy [1] between skyrmions. Experimental results reveal that a simple skyrmion system performs some degree of natural computing.

The experiments were performed by observing the thermal motion of two skyrmions confined in a potential box (Fig. 1) [2]. The skyrmions were made in the $Co_{16}Fe_{64}B_{20}$ layer in the SiO_2(3.0)/MgO(1.5)/Ta(0.23)/ $Co_{16}Fe_{64}B_{20}$(1.26)/Ta(5.0)/SiO_2/Si-substrate multilayer structure. The numbers are the thickness (nm) of each layer. Finally, the potential box was formed by fabricating an additional square-shaped SiO_2 layer with a thickness of 0.5 nm [3]. The number of skyrmions in the box was tuned to 2 by controlling the film temperature and the application of a small external perpendicular magnetic field. We then used magneto-optical Kerr microscopy to observe the Brownian motion of skyrmions in the box. The transfer entropy flowing from past skyrmion A to present skyrmion B is defined by the reduction of the Shannon entropy of the present B by knowing the A's past position. Our analysis shows that the information flow from A to B requires a finite time, consistent with the diffusion time of skyrmions in the box [4]. An analysis of the transfer entropy considering 5 nodes (past and present positions of A and B. And the future position of B) reveals the non-Markovian nature of the system. Therefore, the system can be viewed as a hidden Markov system, which may have computational power. To verify this, we create an artificial XOR calculation node that calculates the XOR of the past and current binarized positions of the skyrmion A. Next, we evaluated the mutural information between the skyrmion B in the future and the XOR node. The results show the presence of a non-negligible size of mutual information, demonstrating the computation power of such a simple two-skyrmion system.

Further experiments with multiple skyrmion boxes are also being conducted and will be presented in the talk.

References

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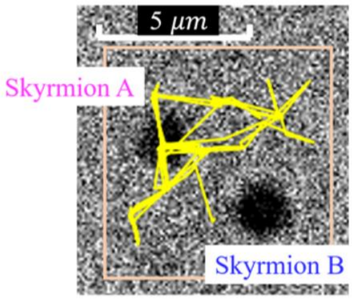

Fig. 1, The trajectory of Skyrmion A

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