New principle for significant electric-power saving in magnetic memories: topology-based manipulation of magnets in spintronics

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Magnetic memories store information by associating a binary number (0 or 1) with the magnetization direction (North or South pole) (Fig. 1 (a)). Developing magnetic memories with higher operation speed and denser integrability requires us to reduce the electric power consumption in manipulating magnetization within nanometer-size domains. For this purpose, the technique called "spin-transfer torque (STT)" has been commonly used for a decade or so, which manipulates the magnetization direction by applying an electric current (Fig. 1(b)). However, current injection in metals causes the Joule heating due to the electric resistivity. The waste of energy by the Joule heating is inevitable in the STT, which becomes a crucial problem in developing highly integrated magnetic memories. To solve this problem, we have carried out theoretical [1] and experimental [2] studies, and discovered a new mechanism for manipulating magnetization with significantly lower power consumption relying on the process free from electric resistivity.

The key to this power-saving mechanism is the "topology". Topology is the character of the quantum-mechanical structure of electrons in materials. When an electric voltage is applied, an electron having a nontrivial topological structure moves perpendicular to the voltage. This behavior, known as the "anomalous velocity", is unaffected by the electric resistivity and does not cause power consumption. In our theoretical work, we found a new mechanism for manipulating magnetization with low power consumption that is enabled by the anomalous velocity from the topology [1]. We coined a term the "topological Hall torque (THT)" for this mechanism, which can be induced by applying an electric voltage instead of a current (Fig. 1(c)). In comparison with the conventional STT, the electric current needed for manipulating magnetization by the THT mechanism is about 1/100 times smaller. This means that the THT can significantly reduce the electric power consumption by a factor of 1/10,000.

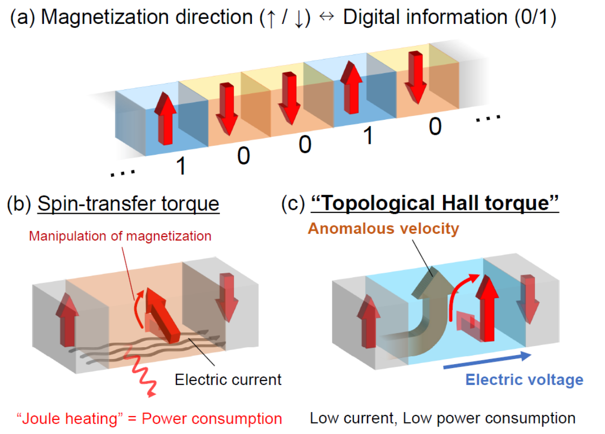

Fig. 1 (a) Magnetic memories store digital information (0 or 1) by manipulating the direction of magnetization (up or down, shown by red arrows). (b) The conventional technique called "spin-transfer torque" uses an electric current to manipulate magnetization, but it suffers from electric power consumption. (c) We discovered a new mechanism "topological Hall torque" based on the electron topology, to manipulate magnetization with low power consumption by applying an electric voltage.

We verified our theoretical proposal of the THT by the experimental measurement of a metallic ferromagnet, $SrRuO_3$ [2]. We injected an electric current in the system and measured the induced torque acting on the magnetization at various temperatures. The efficiency of the torque per current was so large that the theoretical estimation from the conventional STT cannot be applied, and moreover, it also showed a nonmonotonic two-peak structure depending on the temperature. Using a theoretical model calculation, we have clarified that both the magnitude and temperature dependence of the measured efficiency can be understood in terms of the THT (Fig. 2). The THT in this system is described by the anomalous velocity arising from the topological structure known as "Weyl points" in the electronic bands of $SrRuO_3$.

Our new findings of the topology-based principle for magnetization manipulation indicate a decisive role of topology in spintronics. By selecting and designing materials with a strong topological structure of electrons, our idea of the THT will be helpful in developing future magnetic memories operating with significantly less power consumption.

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References

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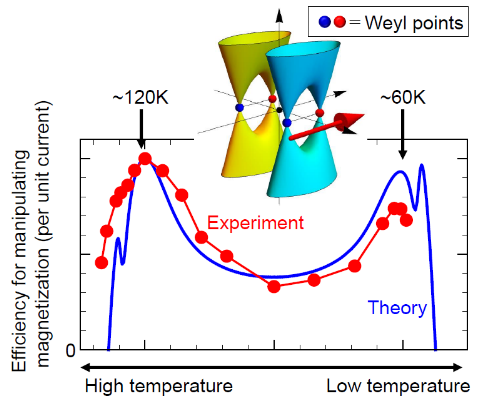

Fig. 2 Schematic pictures of the experimental verification of the newly found principle. The energy bands of electrons in $SrRuO_3$ show the topological structure called "Weyl points" (top panel). By measuring the efficiency for manipulating magnetization in this material, it showed the two-peak structure depending on the temperature (red line in the bottom panel). This behavior is consistent with the estimation by our theory of the topological Hall torque based on the Weyl point structure (blue line in the bottom panel).