【Grant-in-Aid for Scientific Research (S)】

Broad Section B

Title of Project : Material design and electrical manipulation of antiferromagnets with broken time-reversal symmetry

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【Purpose and Background of the Research】

In recent years, symmetry and topology of materials have attracted a great deal of attention as the key to realizing innovative electronic functions. Magnetic materials are one of the major platform for such phenomena. For example, ferromagnets, in which the spins are aligned in parallel, allow one to hold, read, and write magnetic information due to the breaking of time-reversal symmetry. On the other hand, in the case of antiferromagnets, in which the spins are aligned antiparallel to each other, time reversal symmetry is usually maintained, making it impossible to process information using the same approach as in ferromagnets. However, recent theoretical studies have shown that it is actually possible to break the time-reversal symmetry even in a simple antiparallel spin structure by using a special crystal structure. In this case, even though the magnetization is zero, a huge fictitious magnetic field originating from the quantum mechanical phase is generated. Since this fictitious magnetic field plays the same role as the magnetization inside the material, it is strongly expected that such time-reversal symmetry-breaking antiferromagnets can be used to replace various material functions that ferromagnets have conventionally played. In this study, we will search for such antiferromagnets with broken time-reversal symmetry, which have not been experimentally explored so far, and demonstrate various material functions expected from the existence of their unique fictitious magnetic field (e.g., electrical reading and writing of antiferromagnetic domains, which have been thought to be impossible in ordinary antiferromagnets). Antiferromagnets with broken time-reversal symmetry have the potential to replace ferromagnets as the next generation of information functional materials, and we would like to establish a new basic science for their comprehensive understanding and application.

【Research Methods】

Ferromagnets and antiferromagnets are known as typical examples of magnetic materials, but the former has been used exclusively for retaining bit information in conventional magnetic storage devices. This is because in ferromagnets, the "up" and "down" states can be clearly distinguished (because time reversal symmetry is broken), while in an ordinary antiferromagnets, the two states of "up-down" and "down-up" perfectly coincide with each other by translational operations, making it impossible to distinguish between the two states (because time reversal symmetry is maintained).

However, it has been theoretically pointed out that in an antiferromagnet with non-symmorphic crystal structure, the two states "up-down" and "down-up" become inequivalent, and it is possible to distinguish between them. For example, when non-magnetic ions are present between magnetic ions in zig-zag manner, the "up-down" and "down-up" states do not coincide with each other even after translational manipulation, resulting in time-reversal symmetry breaking, and the two states can be clearly distinguished. In this situation, a huge fictitious magnetic field often appears inside the material due to the non-vanishing quantum Berry curvature, reflecting the time-reversal symmetry breaking. Since the fictitious magnetic field theoretically plays a role similar to that of magnetization in ferromagnets, antiferromagnets with broken time-reversal symmetry are expected to exhibit an external field response very similar to that of ferromagnets.

In this study, we will explore such time-reversal symmetry-breaking antiferromagnets and explore various read/write methods for the “up-down” and “down-up” states via fictitious magnetic fields.

【Expected Research Achievements and Scientific Significance】

Antiferromagnets with broken time-reversal symmetry can substitute for various known magnetism-related phenomena and spintronics functions that ferromagnets have conventionally played. They also have unique advantages such as (1) no leakage magnetic field due to magnetization, and (2) high magnetic resonance frequency and fast response time. The electrical reading and writing of the "up-down" and "down-up" states in antiferromagnetic metals, which are the subject of this research, have long been considered impossible. By developing a new material that can operate at room temperature and demonstrating the principle of a new control method for fictitious magnetic fields, we hope to establish a new academic foundation for the realization of information processing using antiferromagnets with broken time-reversal symmetry.

【Publications Relevant to the Project】

・ Smejkal *et al*, Science Advances **6**, 8809 (2020).

【Homepage Address and Other Contact Information】

http://sekilab.net/