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

New horizon in tunnel magnetoresistance: Orbital symmetry effect and new quantum devices

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Purpose and Background of the Research

●Outline of the Research

Tunnel magnetoresistance (TMR) is a phenomenon observed in junctions consisting of two ferromagnetic metal electrodes separated by a ultrathin insulating barrier. The resistance (quantum-mechanical tunneling probability) can be changed via the direction of the magnetic moment, which is used for HDD read heads, magnetic RAM and high-performance magnetic sensors. For future DX in the societies, it is necessary to improve TMR device performance.

In our recent studies, we showed that the observed TMR is much smaller than the theoretical value even for almost ideal samples. On the other hand, novel oscillatory behavior in TMR and junction resistance got remarkable in such high quality samples. Our basic question is "Do we understand the quantum mechanical tunnel effect of electrons truly?" Thus, we have started this study toward the new horizon in TMR researches.

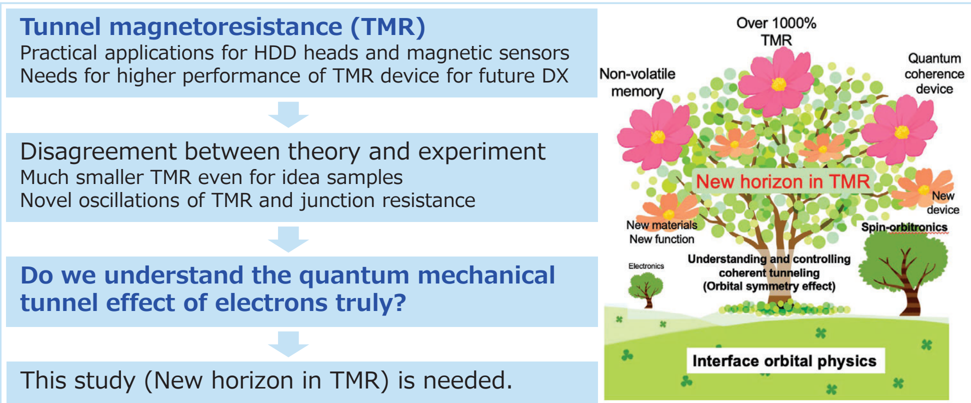

Figure 1. Outline of the Research.

●Purpose of the Research

A thorough investigation will be performed for fundamentals of TMR to clarify its true mechanisms. In particular, effect of orbital symmetry called "coherent tunneling", which plays a crucial role in crystalline barriers, will be studied intensively. Here, understanding of electron's orbitals at the junction interfaces can be a basis of the research of coherent TMR, so that we attempt to create a new research field of "Interface Orbital Physics".

The research targets include over-1000% TMR at room temperature for realizing new nonvolatile memory architectures and novel quantum devices as well as the true TMR mechanisms.

●Approach

By using our state-of-the-art atomic-scale thin film growth techniques, a variety of high-quality and well-controlled samples from a viewpoint of orbital symmetry will be prepared and characterized. Further, spectroscopic measurements for spin and orbital will be done to obtain microscopic understanding of the TMR mechanism. In addition, the so-called orbital magnetic materials will be developed, since "orbital" is the important key word in this study. Indeed, TMR and interface orbital physics are inseparable.

For microscopic understanding of TMR, precise transport measurements such as differential conductance and DFT-based theoretical calculations for electronic structure and transport in realistic heterostructures will also be done.

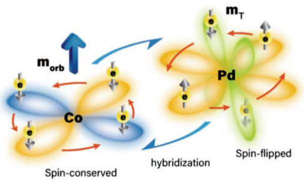

Figure 2. Illustration of the physical picture of spin and orbital spectroscopy based understanding. This is an example for the mechanism of the perpendicular magnetic anisotropy in a CoPd alloy.

Expected Research Achievements

●Elucidating the mechanisms of novel TMR oscillations

TMR oscillations such as the data in Fig. 3 should be the key to elucidate the true TMR mechanisms in crystalline barrier tunneling. A remarkable feature is the coexisting strong oscillation of junction resistance particularly for the case of MgAlO. To understand the basic physics of tunneling in the field of nanotechnology, the microscopic mechanism of the oscillations should be essential.

Based on the true understanding of TMR, we will attempt to achieve over 1000% TMR, which can be regarded as an important milestone of TMR research.

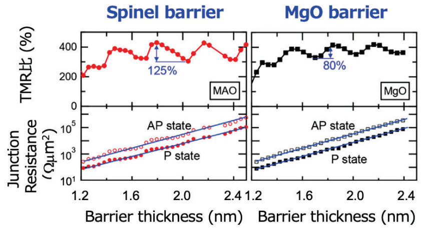

Figure 3. Examples of oscillatory behavior of TMR and junction resistance as a function of the barrier thicknesses. Novel and giant oscillation is observed for MgAlO barriers. (Appl. Phys. Lett. **120**, 032404 (2022).)

●Creation of the research field of "Interface Orbital Physics"

Interface orbital physics can be an important basis of better understanding of TMR, since TMR is a transport between the two barrier interfaces in the TMR junction. To do that, various spin and orbital spectroscopy studies will performed using synchrotron facilities.

●Development of orbital magnets

Novel approaches are very effective in implementing the study of interface orbital physics. Therefore, the so-called orbital magnets, which rich orbital physics is behind, will be developed. Characterization of the orbital magnets and their heterostructure will be done with transport measurements and spin and orbital spectroscopies.

●Over-1000% TMR and new quantum devices

As application of the above-mentioned fundamental studies, we will demonstrate over-1000% TMR at room temperature, which may contribute to the development of new magnetic RAM, resulting in higher-performance of smartphones. Also, we will attempt to develop new quantum coherence devices for possible future AI devices.

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