Title of Project : Development of Spin Coherent Microscopy with Time and Space Resolutions Dedicated for Quantum Information Processes

KOMEDA, Tadahiro
(Tohoku University, Institute of Multidisciplinary Research for Advanced Materials, Professor)

Research Project Number : 19H05621 Researcher Number : 30312234
Keyword : Nano microscope technique, Spintronics, Quantum Information Process

【Purpose and Background of the Research】

The development of the quantum computing (QC) attracts much attention, which is expected to play the crucial role in the quantum information process. Compared to the rapid progress of the software, the construction of the hardware faces technical difficulties.

In the QC system, the element of the information is called quantum bit (qubit) and the superposition of the assembly of the qubits is the core of QC. It is required to tune the interaction between qubits with a high precision, which is one of the technical barriers for the hardware construction. In terms of the precise placement of the qubit, the use of the molecule spin as the qubit has a large advantage due to the precision of the molecule structure. Combined with the use of the high-resolution spin detection system of ESR/NMR, the assembly of the molecules served as the platform of the Shor algorithm in the early stage of the QC development. However, ESR/NMR techniques require a large amount of molecules due to the sensitivity. This suggests that a new spin detection system for the nano-device composed of a small number of molecules has to be developed. In addition such a system can be used for the analysis of each qubit to judge whether it can be qualified for the qubit.

【Research Methods】

This project is dedicated to the development of the spin microscope, which can detect a spin of an atom/molecule with the atomic-scale space resolution. In addition, combined with the pulse RF application, the time evolution of the spin can be examined.

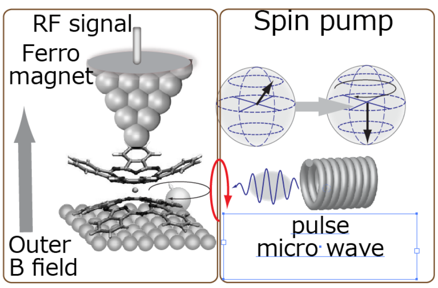

Figure 1. Skematics of the spin microscope. Spin probe part (left) detects the direction of the spin with ESR chemical analysis. Spin manipulation part (right) control the direction of the spin.

We pay special attentions for molecules, which is partially because the qubit with multiple states, which is called a qudit, is studied extensively to reduce the number of qubits. This can be realized with using bis(phthalocyaninato)terbium(III) complex ($TbPc_2$). The 4*f* spin of this molecule possesses a large magnetic anisotropy, the class of the molecules is called single molecule magnet (SMM).

We employ the tunneling magnetic resistance (TMR) to detect the spin direction of the molecule. (see Fig. 1) The 4f electron of the TbPc2 molecule has a large spin of $J=6$. Depending on whether the spins of the tunneling electrons and the 4f spins are parallel or anti-parallel, we see the increase/decrease of the tunneling conductance due to the TMR and the information of the nuclear spin state appears as the hyper structure in the conductance change of the TMR. In addition to the detection of the spin state of the electron/nucleus, we place coils to generate pulse magnet to manipulate the spin direction and observe it time-evolution to examine the dynamic.

【Expected Research Achievements and Scientific Significance】

The techniques that will be developed in this project enable the detection of a single spin together with the analysis of its dynamics and coherence. The new spin microscope can provide a similar chemical analysis currently produced by ESR/NMR techniques for a nano system which will play an important role in the characterization of the qubit and qudit of the quantum computer.

【Publications Relevant to the Project】

○Observation and electric current control of a local spin in a single-molecule magnet, T. Komeda, H. Isshiki, J. Liu, Y.-F. Zhang, N. S. Lorente, K. Katoh, B. K. Breedlove, M. Yamashita: Nat. Comm. 2, (2011) 217.
○Spatially Resolved Magnetic Anisotropy of Cobalt Nanostructures on the Au(111) Surface, P. Mishra, Z. K. Qi, H. Oka, K. Nakamura, T. Komeda: Nano Lett. 17, (2017) 5843-5847.

【Term of Project】 FY2019-2023

【Budget Allocation】 147,100 Thousand Yen

【Homepage Address and Other Contact Information】
http://db.tagen.tohoku.ac.jp/php/forweb/outline.php?lang=ja&no=1020