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

Exploring new device frontiers using ultra-high quality oxide heterostructures

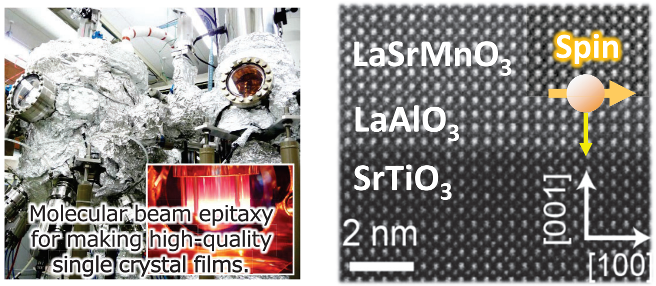
Principal Investigator	The University of Tokyo, Graduate School of Engineering, Associate Professor OHYA Shinobu	Researcher Number:20401143
Project Information	Project Number : 22H04948 Keywords : spintronics, functional oxides, semiconductors, epitaxy	Project Period (FY) : 2022-2026

Purpose and Background of the Research

●Outline of the Research

Due to the rapid progress of information processing technology in our society, especially in recent years, the energy required for information processing is increasing dramatically. This problem is expected to become even more severer with the further progress of artificial intelligence and IoT devices. To realize a carbon-free and low energy-consumption society, realizing more energy-efficient electronic devices is required. In this research project, we aim to realize new devices utilizing our technique to make ultra-high-quality oxide and semiconductor multilayer heterostructures [see Figure 1: molecular beam epitaxy (MBE) method], which we have explored over many years.

In today's electronics, the "charge" degree of freedom of electrons is used, especially in semiconductor devices. Although the speed of charge movement is fast and high-speed operation is possible, the major problem is that when the power is turned off, electrons escape, and the data is lost. On the other hand, if the "spin" degree of freedom of electrons can be used, data can be stored without consuming power. For many years, a lot of studies have been conducted to realize such a device using electron spin, mainly using semiconductors. However, in general, conventional ferromagnetic "metal" materials, which are used as a spin-injection source, and general semiconductors do not have good compatibility, and thus spin is scattered at interfaces between ferromagnetic materials and semiconductors. We have been exploring the fabrication of single-crystal multilayers composed of "oxides" and semiconductors. We have fabricated atomically flat interfaces (Fig. 1) consisting of various ferromagnetic materials and semiconductors or oxides. Using such a technology, we can handle electron spin precisely and realize new devices. In addition, by using the strong electron-electron interaction (strong correlation) that exists in various oxide materials, we will be able to create multiple new technologies that will lead to the realization of next-generation low-power-consumption devices. In this project, we will develop new devices, such as a spin transistor and flexible devices, which have been difficult to realize with conventional semiconductor materials.



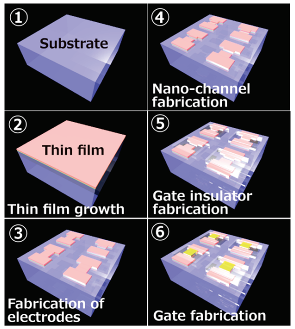


Figure 1. Single-crystalline multilayer structure and device fabrication.

●Toward the creation of spin transistors and other next-generation devices

One of the devices for which we aim to demonstrate basic operation in this project is the "spin transistor" (Fig. 2). This is a device in which a ferromagnetic material replaces the two electrodes of a metal-oxide-semiconductor field-effect transistor, which is commonly used today. Since the direction of the injected spins can be controlled by the magnetization direction of the injection ferromagnetic electrode, we can retain the data even without a power supply. Until now, conventional ferromagnetic and semiconductor materials have been mainly used for spin transistor studies. However, these material systems often have poor crystal matching, making it difficult to achieve highly efficient spin injection and spin transport. On the other hand, there are many ferromagnetic and semiconducting materials in oxides with good crystal compatibility. In this study, we aim to realize highly-efficient spin transport and transistor functions using high-quality single-crystal interfaces using oxide material systems.

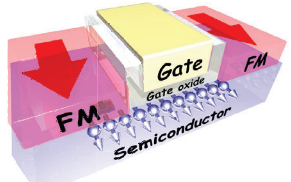


Figure 2.
Schematic structure of spin-MOSFET

This device has ferromagnetic (FM) source and drain electrodes as well as a semiconductor channel. Spin is injected from one of the electrodes. The spin direction needs to be maintained during the spin injection and transport in the channel until electrons reach the detection electrode.

Expected Research Achievements

●Establishment of the guidelines for the realization of various oxide devices

Oxide materials are expected to be applied to devices as wide-gap semiconductors. We aim to realize new oxide devices such as transistors utilizing high mobility two-dimensional carrier gas at oxide interfaces.

●Establishment of material design guidelines for realizing oxide/semiconductor-based spin transistors and the demonstration of basic device operation

Until now, many studies have been conducted to realize semiconductor-based spin devices mainly using conventional semiconductor materials. However, due to their crystalline incompatibility with ferromagnetic materials, there are various problems in their device application at present. In the oxide material systems, there are multiple materials with good lattice matching, with which we can precisely control the spin degree of freedom of electrons. In this project, we aim to demonstrate the basic operation of spin transistors using oxide materials.

●Clarification of the spin-current conversion mechanism in the oxide two-dimensional electron gas and search for the best electronic structure design

The two-dimensional electron gas formed in oxide interfaces is one of the ideal stages for highly efficient spin-current conversion due to its sizeable spin-orbit interaction. We aim to understand the intrinsic properties of electron spins in these systems to establish a method to artificially control the spin-current conversion with high efficiency by appropriately designing their electronic structure.

●Realization of highly efficient magnetization reversal

High-quality oxide interfaces are expected to be very promising systems for spin-current and current-spin conversion. Especially in spintronics devices, the reduction of the current required for magnetization reversal is a significant issue. If the conversion between spin and current can be carried out more efficiently, the energy of magnetization reversal can be reduced. In this project, we aim to realize highly efficient magnetization switching by using high-quality oxide multilayer structures.

Homepage Address, etc.	http://www.cryst.t.u-tokyo.ac.jp/ohya/entry_english.html http://www.csrn.t.u-tokyo.ac.jp/