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

New quantum frontier on All-in-One semiconductor platform

Principal Investigator	The University of Tokyo, Graduate School of Engineering, Associate Professor LE Duc Anh	Researcher Number : 50783594
Project Information	Project Number : 24H00018 Keywords : All-in-One semiconductor, ferromagnetic semiconductor, proximity effect, epitaxial growth, quantum technology	Project Period (FY) : 2024-2028

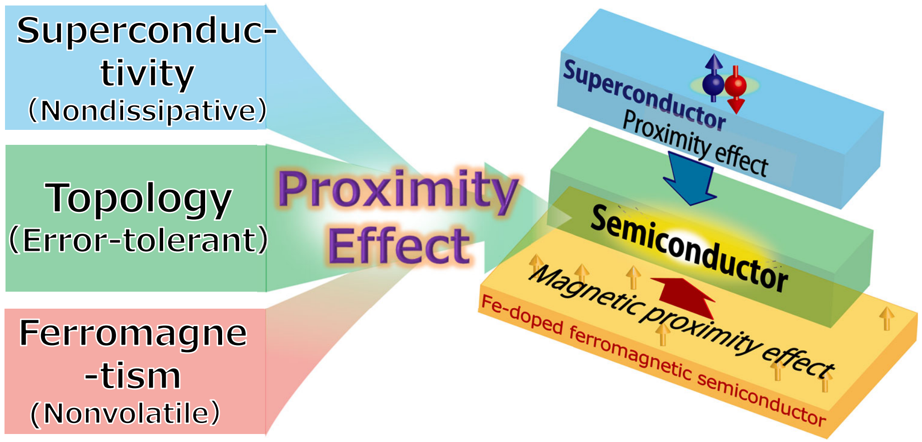
Purpose and Background of the Research

●Outline of the Research

We aim to transform semiconductors by integrating new physical properties those were once impossible, such as “zero-resistance” of superconductivity, “nonvolatility” of ferromagnetism, and “robustness” of topological materials, and by which implement fundamental technologies for highly sensitive quantum sensing, energy-saving and robust quantum computation for next-generation electronics.

All-in-One Semiconductor Platform

Integrating of quantum states at high-quality heterointerfaces between semiconductor materials and other quantum materials



Unexplored quantum states and functionalities created by synergistic effects of multiple quantum states, by which we develop fundamental technologies for next-generation quantum sensing and computing

Figure 1. Image of the All-in-One semiconductor platform proposed by this research

●All-in-One Semiconductor Platform

Semiconductors, which have been used for half a century, still have great untapped potential. Various new physical properties such as ferromagnetism, superconductivity, and topology, which were once unimaginable in semiconductor materials, are now becoming possible through state-of-the-art crystal growth and device fabrication technology controlled at the atomic level. In this research, we develop a crystal growth technology to fabricate high-quality heterojunctions of superconductors, topological materials, and ferromagnetic semiconductors, and integrate multiple quantum states in the semiconductor material using the quantum mechanical "proximity effect." Through these innovations in semiconductor materials, we aim to pioneer the future of electronics.

●Fe-doped ferromagnetic semiconductor (FMS):

*FMS: Made by doping magnetic elements (Mn, Fe...) to a non-magnetic semiconductor (II-V, III-V, IV group). FMSs are important to combine ferromagnetic order and magnetism-related functions in semiconductors.

The Fe-doped narrow-gap FMSs that we developed are the only that exhibit ferromagnetism at room temperature for both N-type and P-type.

Advantages

- ●Spontaneous spin splitting
- ●High controllability by electrical gating
- ●Strong spin-orbit coupling
- ●Rich of spin-related physics
- ●High compatibility to semiconductor technology

Using Fe-doped FMSs, we aim to integrate multiple quantum states into a single semiconductor

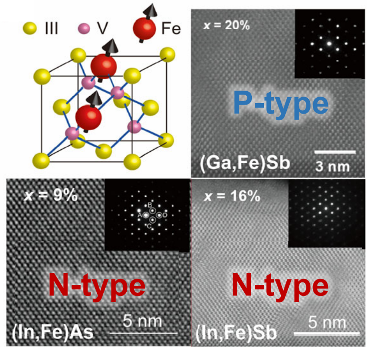


Figure 2. Fe-doped ferromagnetic semiconductors are our unique materials that enable both N-type and P-type and exhibit ferromagnetism at room temperature.

Expected Research Achievements

● Creating All-in-One semiconductor platform: We grow high-quality superconductor/topological material/Fe-doped FMS heterojunction in an ultra-high vacuum, using molecular beam epitaxy.

- ☐ Control of atomically flat interfaces of different materials
- ☐ Achieving and controlling long-range proximity effects
- ☐ Control quantum state with gate voltage
- ☐ Predicting and elucidating new physics using photoelectron spectroscopy and theoretical calculations

All are unexplored and important issues in quantum materials science.

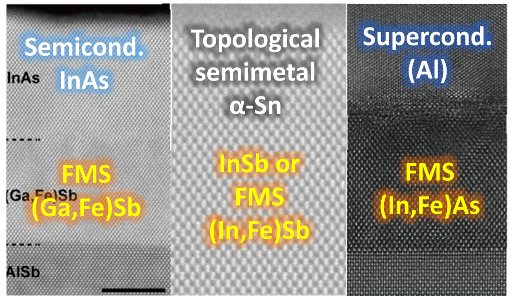


Figure 3. Examples of high-quality heterostructures grown by our group.

●Exploring new quantum states and functionalities in All-in-One semiconductor platforms:

<Giant electromagnetic response effects and development of quantum sensing>

Giant responses to electric/magnetic field in various All-in-One semiconductor are promising for sensing and high-performance computing.

<Coexistence of superconductivity and ferromagnetism: Spin-triplet superconductivity>

Unconventional superconductivity formed by Cooper pairs with parallel electron spins. We explore the possibility to utilize it in low-power information processing.

<Generation and control of Majorana bound states (MBS) in semiconductor materials>

MBS is predicted to exist in All-in-One semiconductor structures. Because of its noncommutative statistics, it is thought that error-tolerant quantum computing can be performed using MBS states. Our research might lead to the realization of practical-level quantum computers.

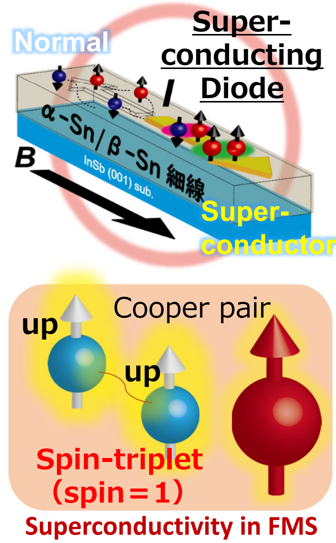


Figure 4. Examples of new functionalities

Homepage Address, etc.	Anh-lab homepage : https://www.anh-lab.com Anh-lab’s X account : https://twitter.com/AnhLD_UTokyo

QR code ☞