Research area in Strategic Objective *“Fundamental technologies for utilizing low-dimensional materials in new semiconductor device structures"*

Nano materials for new principle devices

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Overview

The objective of this research area is to establish basic science and develop fundamental technologies for electronic devices based on various nano materials, including two-dimensional (2D) materials. Recently, van der Waals materials such as nanotubes and 2D materials are expected to be core materials for advanced semiconductor devices. Also, their applications to various functions such as sensors, optical devices, and spintronics devices are rapidly growing. On the other hand, the devices of 2D materials have led to the discovery of numerous quantum phenomena that cannot be realized with bulk materials, causing a significant impact in materials science. Using nano materials and their devices, we develop the fundamentals for the cutting-edge electronics, explore new physical sciences, and create new device principles. Through these efforts, we aim to realize new functions and high-performance devices that can be achieved only with nano materials.

The target materials include all kinds of nano materials with electronic functions, such as thin films and interfaces, and not limited to Van der Waals materials. Using interdisciplinary approaches that combine physics, chemistry, material science, and electronic engineering, the research aims to establish highly original basic science and fundamental technologies for utilizing nanomaterials.

Research Supervisor’s Policy on Call for Application, Selection, and Management of the Research Area

1. Background and Basic Policy

Today, materials research for electronic devices encompasses an extremely diverse group of materials. This is a characteristic of modern materials science that differs greatly from the electronic device material research in the previous century, which was specialized in limited specific materials. Carbon materials, including nanotubes and graphene has taken a leading role in this field, and now materials are expanded to inorganic materials such as transition metal dichalcogenides (TMDCs) and so on. These materials are expected to become core materials for semiconductor integrated circuits that form the foundation of the rapidly developing digital society. In addition, research is underway for various functions and their practical applications, such as optical and terahertz devices, spintronics devices, sensors, and others, that utilize the unique electronic properties of this class of materials.

On the other hand, devices made from such nano materials have recently received significant attention as a unique platform for investigating novel physical properties and functions. The most famous examples are the diverse quantum properties such as strongly correlated superconductivity and ferromagnetism that are realized in the moiré superlattice of twisted bilayer graphene. These are typical examples of realizing novel quantum phenomena that appear for the first time in nano materials using device structures.

As described above, nano materials and their devices have great potential as advanced semiconductor devices or as a stage for realizing unknown electronic properties and innovative functions. In this research area, we will discover the new possibilities of nano materials and promote research to maximize these possibilities and break through the status quo by taking advantage of the characteristics of nano materials. We will also take academic leadership in the basic science of new materials that will support the digital society of the future.

2. Research Field and Selection Policy

The research area envisioned in this program encompasses the physical properties and functions of nano materials and their devices in a broad sense. Nano materials refer to substances with 2D, 1D, and 0D structures. This includes van der Waals materials such as carbon-based, layered, and organic materials, as well as nanorods, nanotubes, nanoparticles and their assemblies. Also ultra-thin films and interfaces of semiconductors, oxides, and other materials are included. The focus is not limited to semiconductor devices, but encompasses a wide range of electronic properties such as strongly correlation phenomena like superconductivity and topological properties. Examples of devices include transistors, spintronic devices, THz/optical devices, and various sensors, as well as energy devices for thermoelectric conversion and energy storage. The fields involved in this research program include condensed matter physics, applied physics, chemistry, materials science, and electronic engineering, but there are no particular restriction.

Under this policy, we will broadly recruit research proposals in three approaches:

(1) Research on novel properties and functions of nano materials and their devices

This approach is the seamlessly study of the growth of nano materials, device fabrication, and exploration of physical properties and functions.

(2) Research on the elemental technologies

This approach involves synthesizing special or high-purity nano materials, advancing device fabrication processes, and clarifying interface properties.

(3) Research to promote the advancement of nano material devices

A) theoretical and computational approaches

B) development of measurement and evaluation techniques

C) bulk property research

For these approaches, consideration and perspective on how to apply these approaches to device research is required.

3. Principle of research-area management

PRESTO is an individual research project that may encounter difficulties in covering all research aspects that extend from material synthesis to device fabrication and physical properties/functions research. To promote research efficiently, collaboration with related research laboratories including overseas partners, is encouraged. We aim to promote active exchange and collaboration among researchers in this research area through biannual meetings, and to launch new interdisciplinary research. We hope that this forum will provide opportunity for young researchers to make networks and to aim high through friendly competition. We will also promote collaboration with CREST "Fundamental technology for semiconductor-device structures using nanomaterials", which is implementing the same strategic objective.

The budget for one research project at the beginning is 40 million yen at the maximum (direct expenses). The research period begins in fiscal year 2023 and ends in fiscal year 2026 (three and a half years or lesser).