Research area in Strategic Objective “

Fundamental technologies for utilizing low-dimensional materials in new semiconductor device structures"

Fundamental technology for semiconductor-device structures using nanomaterials.

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Abstact

Based on the 2023 strategic objective "*Fundamental technology for utilizing low-dimensional materials towards new semiconductor device structures*", this research area will establish fundamental technologies for semiconductor devices by using two-dimensional materials such as graphene and transition metal dichalcogenide or one-dimensional materials such as nanotubes and nanowires (hereafter nanomaterials).

Fundamental technologies here refer to technologies and principles that have a significant ripple effect in improving the productivity. More specifically, it refers to the creation of semiconductor wafers and devices using nanomaterials and the construction of operating circuits, as well as the operating principles of nanomaterial-specific devices. The subject areas should include nanomaterial-based semiconductors. The scope includes field-effect transistor (FET) logic circuits, flexible devices, pn/heterojunction devices, thermoelectric devices, solar cells, light-emitting diode (LED) and light-receiving devices, THz far-infrared devices, chemical/biological sensors, artificial muscles, MEMS/NEMS and various other devices. The aim is to comprehensively construct not only individual elements but also circuits and systems, and to build a bridge over “the valley of death” (a term that symbolizes the difficulties between basic research and industrialization) towards practical use.

In order to build a system, a cross-disciplinary fusion team is formed between researchers with proven research experience to provide nanomaterial samples, device production and circuit configuration in the first half of the research period, as well as process technology and basic science to create innovative semiconductor platform technology directly linked to practical applications over the period.

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

Proposals are invited that realize the three attainment targets set out in the strategic objectives given by MEXT. The keyword is semiconductor devices made of low-dimensional materials (nanomaterials). After sharing the background, let us explain our policies.

1. Background

Here we overview (1) the semiconducting roadmap and (2) Progress of nanoscience.

(1) Nanomaterial on the semiconductor roadmap

With Si semiconductors being industrially processed in units of 2 nm, an inherently unavoidable problem has been pointed out, such as the appearance of reduced mobility below 10nm for Si semiconductors. On the other hand, two-dimensional (one-dimensional) nanomaterials with a thickness (width) of nm can avoid this problem by selecting atomically smooth surfaces and wire, and nanomaterials are emerging as a near-future semiconductor material on the semiconductor roadmap. Although the ideal properties for nanomaterial devices have already been achieved at the laboratory level, a long way is expected before the nanomaterials can be implemented in future integrated circuits. It is desirable as a semiconductor strategy for our country to establish basic technologies for various semiconductor applications using nanomaterials and to train young researchers. Here we would like to point out following three points;

A. Difficulties in fundamental research for practical use

The basic technology has already been established in conventional Si semiconductor integrated circuits; Si semiconductor technology has a roadmap and updates the achievement level on an annual basis. However, it is not realistic to introduce nanomaterial semiconductors into Si integrated circuits. On the other hand, single FETs with nanomaterial semiconductors have been made and evaluation methods have been established. However, in nanomaterial exploration and basic research, it is difficult to get at the problems that arise when they are implemented in circuits. The creation of a research field based on the fusion of knowledge of semiconductor circuits and nanomaterial science is expected to produce tangible results that will appeal to society.

B. Tackle what Si devices cannot

It is also not realistic to use nanomaterial semiconductors to achieve a level of integration comparable to today's Si integrated circuits. On the other hand, thin nanomaterials have the advantage of doing what Si devices cannot do, such as building semiconductor devices on flexible substrates or on curved surfaces that move, such as on the skin. The aim should be to challenge the properties that cannot be achieved with silicon devices.

C. Creating a base technology for semiconductors

In the past, Japan did not choose to build large-scale semiconductor integrated circuits, opting instead for technologies such as memory and custom ICs. As a result, there is no domestic investment in the technology to large-scale logic circuits (CPUs). For Japan, which has leaded the field in nanomaterials in the world, to secure a certain position in nanomaterial semiconductor devices in the future, it is necessary to create fundamental technologies for semiconductors, including the training of young people.

(2) Advances in nanomaterials science

The discovery of nanomaterials such as fullerenes, nanotubes, graphene, atomic layer materials and 2.5D materials and the establishment of the basic science of nanoscience has been a major achievement to date. There are many laboratories and companies in Japan and abroad that synthesize and provide nanomaterials, and active research is being conducted all over the world. Many universities and research institutes also have clean rooms for shared use, and we believe that there is a research base for the creation of small-scale semiconductor circuits.

With carbon nanotubes, we have a track record, both domestically and internationally, of creating circuits on flexible substrates using printing and deposition techniques. With atomic layer materials, semiconductor elements have been created on atomically smooth h-BN substrates and top data as semiconductor elements have been obtained. Furthermore, hetero-stacking and in-plane heterostructures of atomic layer materials have enabled light-emitting devices such as LEDs. In nanotubes, technology-integrated 16-bit CPUs, for example, are being made in the USA.

Thus, we think that the basic science of nanomaterials through exploration, stacking techniques, single device creation, sample evaluation and theory has been sufficiently matured by existing or ongoing projects. This research area aims to realize 'semiconductor circuits with visible practical applications' as the next step after the creation of single devices, and fundamental analyses the issues involved, aiming to establish fundamental technologies for nanomaterial semiconductors and to develop basic science on nanomaterials.

2. Possible research areas

(1) Fundamental technology for nanomaterial semiconductor devices.

Starting from semiconductor device structures made of one- and two-dimensional materials (nanomaterials), which have been achieved to date, the project overcomes technical difficulties and builds fundamental technology with a view to industrialization. Here, the device structure includes the circuits in which semiconductor elements operate, but the degree of integration is not pursued

A. The scope of the project covers basic technology, including the device structures that drive FET-based logic circuits, LEDs and other optical elements, thermoelectric elements, MEMS elements, artificial muscles, etc.
B. It is assumed that the device structure as a starting point for the basic technology

has already been created or can be realized in the first year. It is envisaged that problems at the starting point can be identified and innovative basic technologies proposed afterwards.

(2) Basic principles of nanomaterial semiconductor devices.

Up to now, many achievements have been made in nanomaterial semiconductor devices, but problems have also been identified. To overcome these problems, various proposals have been made in industry and academia. If you have a completely new operating principle or any idea other than that the proposals, it can become a theme as one of the fundamental technologies if you can objectively demonstrate its effectiveness and feasibility. However, even in this case, the team should be as comprehensive as in (1), and the goal should be achievable.

(3) Unforeseen proposals consistent with strategic objectives

Although the research is limited to nanomaterial semiconductors, we would like to leave open the possibility that proposals with innovative content not envisaged by the research area may also be accepted. Even in this case, the team composition must be such that the proposed nanomaterial semiconductor works and can be validly characterized and presented.

3. Selection Policies

(1) Basic Policy

In this research area, research teams are selected that can realize semiconductor devices based on nanomaterials, which are challenging and milestone (an important step for the field) that will lead to fundamental technologies for near-future semiconductors. A team consists of several groups, with several researchers in a group.

A. In order to promote a comprehensive project, we would like to actively recruit a large team consisting of many groups compared to conventional CREST. The team will consist of groups with proven experience in sample preparation, sample evaluation, circuit production, etc., and will be evaluated if they have experience in device structure fabrication. It is important to stress that the fabrication of device structure is not the goal but the starting point.

B. We will evaluate an objective of application that everyone can accept as to what kind of fundamental technology will be obtained from the starting point of the section A. We will evaluate the Principal Investigators who lead the research field concerned and can communicate agilely with different fields, for example by seeking collaboration even outside the team, in order to develop the field of nanomaterials science in Japan and the world.

C. It is important to note that we appreciate your fair approach to society, such as your consideration of the development of the next generation of researchers by actively including researchers from different fields with no previous achievements, as well as female researchers and young researchers from local universities and companies in your team.

(2) Outcome Images

The initial image of the outcome for each team is a starting point from which they can present the characteristics of semiconductor circuits that operate at room temperature and ambient pressure in the interim presentation. Based on the results of the interim presentation, we hope to realize the sharing of ideas through joint research between the teams and even between different research fields, and to achieve a goal by bringing together all the forces that can be brought together to achieve a major outcome towards the strategic objective. The image of the goal is to appeal to society in an easy-to-understand manner that "it is likely that circuits using nanomaterial semiconductors can be put to practical use". The outcome image includes the development of research with companies that will be realized ahead of time, so that society can recognize the importance of the research.

4. Area Management Policy

This research area will also collaborate with ongoing CREST and PRESTO projects related to the strategic objectives. In principle, the necessary arrangements for collaboration will be made between the teams, but the arrangements between the areas will be made in cooperation with JST to ensure that the results between the research areas and between the teams are joint results. Through these efforts, we will manage the areas together with our research area advisors to ensure more efficient and effective area management and to respond flexibly to the emergence of urgent and powerful technological infrastructures.

Although this research area is basically aimed at the domestic research group, international collaboration is strongly encouraged to promote research. To this end, the project promotes personnel exchanges, such as mutual dispatch of researchers, and cooperation in organizing symposia at relevant academic societies and international conferences on nanomaterials.

5. Matters that require attention

The research period should not exceed five and a half years. Total research funding is limited to 200-300 million yen per team.

The achievement of the proposal at the time of the interim evaluation is assessed to determine whether the proposal is ultimately feasible. Proposals are invited over a three-year period. Researchers with large budgets currently underway are requested to be mindful of the timing of their applications, as well as the budget allocation, in order to avoid duplication of research content and excessive concentration of research funding.