【Grant-in-Aid for Transformative Research Areas（B）】

Science on group-14 nanosheets (Group-14 nanosheets)

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Project Information	Project Number : 24B208　Project Period (FY) : 2024-2026 Keywords : group-14 nanosheets, heavier group-14 element (Si, Ge, Sn), low-dimensional materials, semiconductor, developing new functionality

Purpose and Background of the Research

●Outline of the Research

The purpose of this project is (1) to understand the novel properties of group-14 nanosheets (14NSs), that is, 2D materials in which the carbon in graphene is replaced by heavier group-14 elements (Si, Ge, Sn), and (2) to create a new research area "Group-14 Nanosheet Science," to maximize the latent potential of these materials. The 14NSs are theoretically predicted to exhibit novel properties, such as topological properties, even though they have the same characteristics as conventional bulk group-14 semiconductors and low-dimensional materials. In this project, we aim to advance the elucidation of physical properties by integrating the four fields (synthesis, physical properties, applications, and theory) and to dramatically improve the academic level in this community, which has been limited to the pursuit of profound physical models. We also aim to develop device process technologies for application development and provide new guidelines for the surface and interface designs to precisely control the physical properties of 14NSs for domestic and international industries.

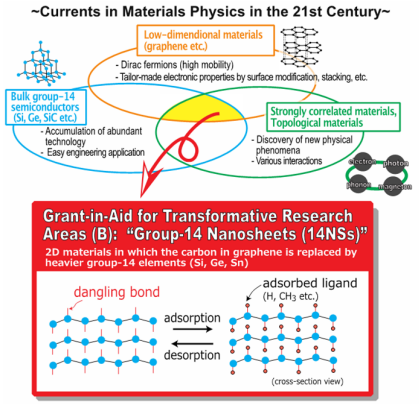

Figure 1. Summary of our project

●Background

The existence of 14NSs was predicted in 1994. Although they remained a figment of the imagination for a long time, all 14NSs have been successfully synthesized. However, the intrinsic properties of the carrier transport have unfortunately been known because they are synthesized on thick metals.

From the fundamental research perspective, no researcher has attempted to break away from the synthesizing on metals; very few calculations are closely aligned with experiments, and the research has been limited to the pursuit of profound physical models. In other words, the research seems to be diverging without a unified approach. From the applied research perspective, 2D materials of Ge and Sn (germanene and stanene) are listed as innovative materials in the "International Roadmap for Devices and Systems (2022 Edition)," a roadmap for Si semiconductor integrated circuits. However, the Si semiconductor community is rather conservative thus and negative about introducing materials in the budding stage. At this rate, it is difficult to clarify their physical properties and discuss the application possibility; thus, no lasting progress in 14NSs research can be expected.

To improve and strengthen the academic level of this community, we must quickly graduate from the first stage, where research has been conducted according to everyone's taste. We need to establish a common infrastructure that will enable us to gather wisdom from across disciplines and mutually utilize our research results. It is also essential to set the direction of 14NSs research. We will promote research to solve these issues and become the 14NSs flagship. That is our project.

Expected Research Achievements

In this project, we will (1) further develop the 14NSs synthesis method we have developed so far, (specifically, working on controlling the layer numbers and stacking arrangement), (2) identify their crystal structures, chemical bonds, and electronic states, and (3) measure their novel physical properties before any other researchers in the world. In the long-term, (4) to provide new material design guidelines to pioneer the future of applied physics based on 14NSs to the domestic/ international community and industry. In addition, we will not only explore the novel physical properties and mechanisms of each quantum (e.g., electrons, photons, magnons, phonons, etc.) expressed in 14NSs, but also develop the device process technology that will be indispensable for their application.

X00: Administrative Group
Leader: KUROSAWA Masashi
Co-investigator: ANDO Yuichiro, KAWANAGO Takamasa, ARAIDAI Masaaki

A01: Synthesis Group
Leader: KUROSAWA Masashi (Semiconductor Engineering, Thermoelectric Materials)
Co-investigator: OHTA Akio (Interface Science)

B01: Characterization Group
Leader: ANDO Yuichiro (Spin Physics)
Co-investigator: YUHARA Junji (Surface Science)

C01: Application Group
Leader: KAWANAGO Takamasa (Device Engineering)

D01: Theoretical Group
Leader: ARAIDAI Masaaki (Computational Materials Science)
Co-investigator: YAMAKAGE Ai (Topological Properties)

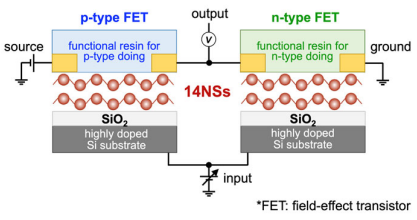

Figure 2 Schematic illustration of 14NSs CMOS circuit (Low static power consumption device).

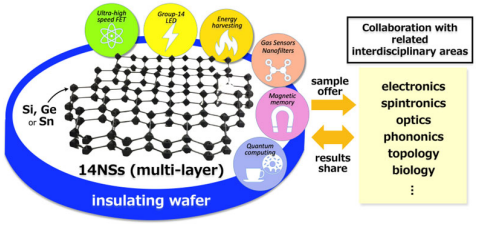

Figure 3 A conceptual illustration of project prospects after FY 2027.

Homepage Address, etc.	Group-14 Nanosheets Website https://alice.xtal.nagoya-u.ac.jp/14ns/