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

Broad Section B

Title of Project : Physics and Functions of Van der Waals Heterostructures

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Keyword : Two-dimensional materials, Van der Waals heterostructures, nonlinear phenomena, magnetism, field effect

【Purpose and Background of the Research】

Recent progress of materials science has uncovered that monolayer or a few layer materials can exist and exhibit peculiar properties that are distinct from their bulk counterpart. Nowadays so called two-dimensional (2D) materials have grown one of the largest field in materials science. Van der Waals (vdW) heerostructures, formed by laminating different 2D materials, are revolutionary materials, because they do not require any lattice matching which used to be a prerequisite in the conventional epitaxy.

The purpose of this research is to fabricate a variety of vdW heterostructures and to discover novel properties and functions that are impossible to realize in single materials.

In particular we focus on two subjects. One is the symmetry control of vdW heterostructures, and their nonreciprocal transport and anomalous photovoltaic effects. The second is the novel superconducting and magnetic phases arising from the proximity effects at the vdW heterointerfaces.

【Research Methods】

The project employ both the transfer lamination methods and molecular beam epitaxy (MBE) methods. The former includes stacking of monolayer materials with twisted angles, which allow us fabrication of materials that never exit in nature. That former allows us to fabricate monolayer materials that are hardly cleaved with large areas. We are also able to combine these two methods for making new vdW heterostructures.

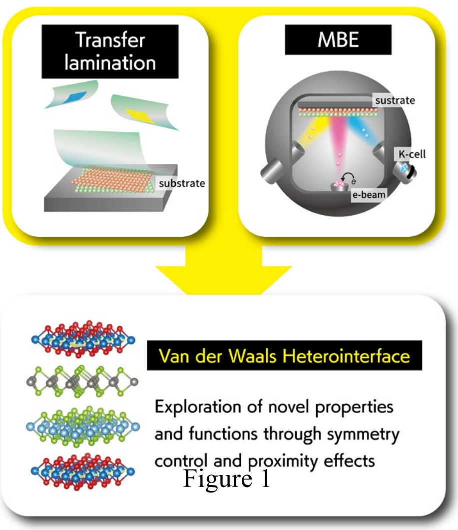

Figure 1

【Expected Research Achievements and Scientific Significance】

First, we fabricate a variety of vdW heterostructures taking the advantage of wealthy materials family with controlled symmetry. For instance, when we make a vdW heterostructure using materials of three-fold symmetry and two-fold symmetry, the heterostructure loses its rotational symmetry. When the structure is formed in such a way that the mirror axes of the two 2D materials coincide with each other, the in-plane dipole emerges. Such a controllability is substantially increased by introducing twisting angles. With this symmetry reduced system, we measure the nonlinear transport properties, including nonreciprocal transport and anomalous photovoltaic effect. With these, we clarify the effect of quantum phases in the momentum space, such as Berry connection, Berry curvature, and Berry curvature dipole.

Second, we aim at realizing new magnetic and superconducting phases originated from the proximity of distinct states of matter as well as elementary particles in neighboring materials. Particularly, in optics, we will focus on the exciton-magnon interaction in the vdW interface, which have been investigated in single materials so far. This offers a new opportunity to apply the vdW interfaces to the highly efficient conversion from microwave to visible light.

【Publications Relevant to the Project】

- Enhanced intrinsic photovoltaic effect in tungsten disulfide nanotubes, Y.J. Zhang, T. Ideue, M. Onga, F. Qin, R. Suzuki, A. Zak, R. Tenne, J. H. Smet and Y. Iwasa, *Nature*, **570**, 349 (2019).
- Bulk rectification effect in a polar semiconductor T. Ideue, K. Hamamoto, S. Koshikawa, M. Ezawa, S. Shimizu, Y. Kaneko, Y. Tokura, N. Nagaosa & Y. Iwasa, *Nature Physics*, **13**, 578 (2017).

【Term of Project】 FY2019-2023

【Budget Allocation】 154,600 Thousand Yen

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