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

Exploring materials science based on embedding low-dimensional electronic states

Principal Investigator	National Institute for Materials Science, Research Center for Materials Nanoarchitectonics, Group Leader KITAURA Ryo　　Researcher Number:50394903
Project Information	Project Number : 23H05469　　Project Period (FY) : 2023-2027 Keywords : 2D materials, artificial atoms, quantum technology

Purpose and Background of the Research

●Overview of the research

The arrangement of atoms in materials determines their properties. While it is possible to create materials with desired properties by arranging atoms, it is challenging to do so with microscopic particles like atoms. Various methods have been proposed, but they come with limitations. To overcome this issue, we are focusing on two-dimensional materials and artificial atoms. Our approach involves embedding atom-like states, made up of multiple atoms, in two-dimensional materials. We aim to produce new materials with diverse properties and conduct research on their properties.

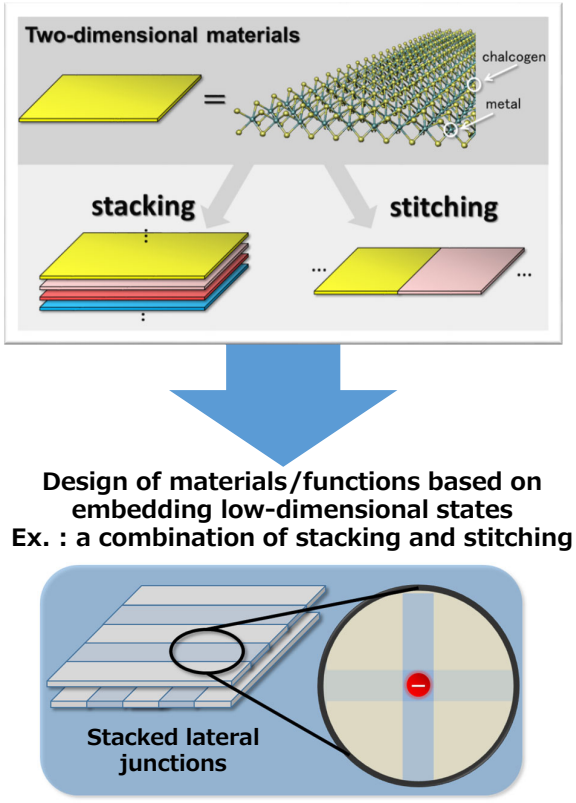

Figure 1. Image of embedding low-dimensional states

The picture on the left shows a layer of transition metal dichalcogenide that is less than one billionth of a meter thick. By stacking and stitching these materials, we can create new materials that have never been seen before. This is interesting because it allows us to embed atomic-like states in two-dimensional materials.

For example, a structure based on stacking and stitching is shown at the bottom of the left Figure. Where the ribbons cross, atom-like states emerge. As the fabrication technique improves, we'll be able to arrange these states the way we want.

The above structures are only a few examples. By designing structures with two-dimensional materials as the matrix, a wide variety of array systems can be realized. This research aims to design various structures using the techniques and to open up new materials science.

● Methods

First, we will develop the nanostructure fabrication method using MOCVD and manipulation techniques. The fabricated structures will then be subjected to a variety of advanced techniques to investigate their optical and electrical properties in detail. For this purpose, their optical and electrical properties will be investigated by attaching metal wires and shining laser light on them.

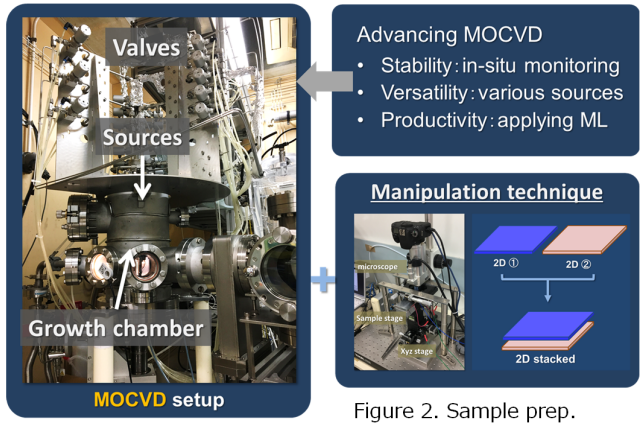

Figure 2. Sample prep.

Expected Research Achievements

●Research Question

The research question in this work is

> Will the new “designer artificial atoms in 2D materials" be a new platform for condensed matter science and quantum technology?

In this work, we will demonstrate
(1) the effectiveness of the artificial atomic arrangement method
(2) function creation
We will answer the research questions by performing the above things.

(1): we will demonstrate that "artificial atomic arrangement" is possible by using a two-dimensional material as a matrix by advancing the above-mentioned MOCVD method and manipulation technology, and by using advanced processing technology as well.

(2): Devices (a structure with wiring for applying voltage or measuring current) will be fabricated with microfabrication techniques. Unique phenomena of the array pattern can be expected to emerge. For example, electrons trapped in artificial atoms are expected to lead to new technologies (quantum technologies) that make use of their mysterious properties based on quantum mechanics.

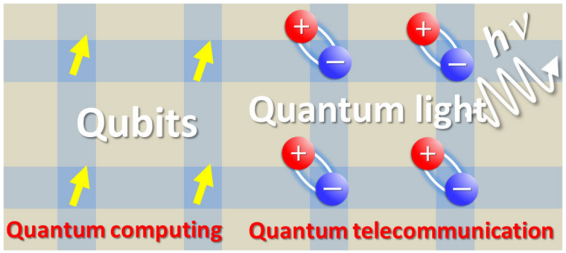

Figure 3. for Quantum technologies

For example, as shown in the left Figure, when an electron or an exciton is confined, it could be used as a quantum bit at the heart of a quantum computer and as a tool for quantum cryptographic communication, which is in principle secure.

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