Physics of tomorrow realized by two-dimensional materials

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A key for the brighter tomorrow is the materials and the physics on it. Today, we are facing many environmental issues. Since the industrial revolution, we have been damaging the ecosystem, polluting the Earth, and causing global warming. There are many issues caused by humankind. That is why resolving these issues is also a task for humankind. Then, what is the issue for physics to fight against? For example, restoring the ecosystem is hard for physics. To handle the issue, we need a deep understanding of biology. How about the pollution? To solve it, it is essential to convert harmful compounds into harmless compounds. To tackle this issue, chemistry is better rather than physics. Then, what should we do to stop global warming? We need to reduce energy consumption by improving efficiency paying attention to thermodynamics. Yes, this is an issue physicist to solve. As we have been tackling the problem of thermodynamics and efficiency since the 19^{th} century. Global warming is an issue for physics.

The next question is how to fight against it, and what is the key to solve them. When you hear the word physics, what comes to your mind. It might be quantum physics, astrophysics, mechanics, electromagnetism, and so on. Today, there are quite a lot of fields in physics, and ultimately, all this universe is the field of physics. Among them, condensed physics is one of the most promising candidates. In specific, the physics on the materials is important. The reason is as follows. To apply physics into our daily life, we need to implement it into devices such as home appliances, solar panels. As they are made with various materials, studying the physics on the materials will leads to improving their performance and reducing energy consumption. Thus, material physics is important. Moreover, in contrast to the ideal system such as vacuum, we need to respect the many-body effect in the materials. The many-body effect triggers many intriguing phenomena. Among them, famous examples which won the Nobel prize are superconductivity, topological physics, and laser. In complicated systems, we can design the system to obtain the desired functionalities. We can effectively change the mass, dimensionality, electric charge and so on. To obtain desired properties, it is more favorable to have many choices of system. If we have many choices, we can choose the best system among the candidates. Hence, in order to utilize the condensed matter physics in our daily life, the diversity of systems and controllability are quite important.

One of the most straightforward approaches to increase the variety of materials is the combination. Combining different materials of different properties, we can fabricate new materials with desired properties.

However, it is not easy to find these materials. In the 20th century, the main approaches were alloys and superlattice. Alloys are the materials which different metals are melt and mixed into brand-new material. As it is melted once, it is not easy to control the microscopic structure. On the other hand, in certain groups of metals, we can control the structure very finely and make ordered structures. This is the so-called superlattice. In this system, we can obtain ordered structures, but we need to pay attention to the affinity of materials. Therefore, the variety was limited.

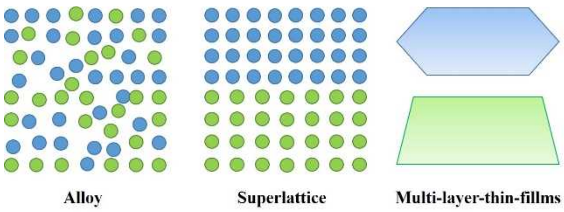

Fig. 1 Schematic picture of alloy, superlattice and multi-layer-thin-films. Different color means different substances

Recently, the systems of thin films attract much attention. In 2004, Novoselov, Geim, and their collaborators discovered that we can split graphite into graphene sheets using Scotch tape [3-4]. Graphene is a kind of two-dimensional material, and it was quite surprising that we can obtain this kind of material in such a simple process. After this discovery, it has been fabricated many two-dimensional materials by many groups. These materials also have a variety of properties. One has magnetism, one breaks a symmetry, and one possesses the Dirac cone (one of the gapless structures in the energy spectra). By stacking them, it is possible to make multi-layer-thin films with a variety of properties.

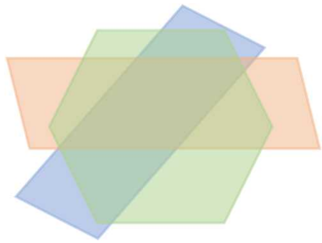

Fig. 2 : Schematic picture of multi-layer-thin-films. Difference of colors and shapes shows different materials. We can stack different layers like freely. By arranging stacking

In addition to the variety of films, there are more advantages. As these films are coupled with quite weak force so-called van-der Waals, we can easily change the stacking structure of them. This is not possible in stiff materials such as alloys and superlattices, for each site is strongly coupled. Therefore, in the multi-layer-thin-film systems, we can choose stacking structure and combination of films freely.

One success of these systems is the magic angle graphene [6]. We stack two sheets of graphene at a certain twist angle. Then, the electronic band structure changes, and high-temperature superconductivity is induced. This explicitly shows that we can endow the films with different functionalities without changing materials.

In summary, for the brighter tomorrow, we need to solve environmental issues. Especially, global warming and energy consumption is the issue physicists to solve. This is a problem of thermodynamics and they have been studying it since the 19th century. We can utilize our knowledge and experimental technique to make high-efficient devices and innovative materials. To realize the phenomena proposed theoretically to solve it, the material plays a central role. In the 21st century, it has been discovered we can make two-dimensional systems in a simple procedure, and it is a promising candidate for the devices in of next generation. Therefore, these two-dimensional materials are promising.

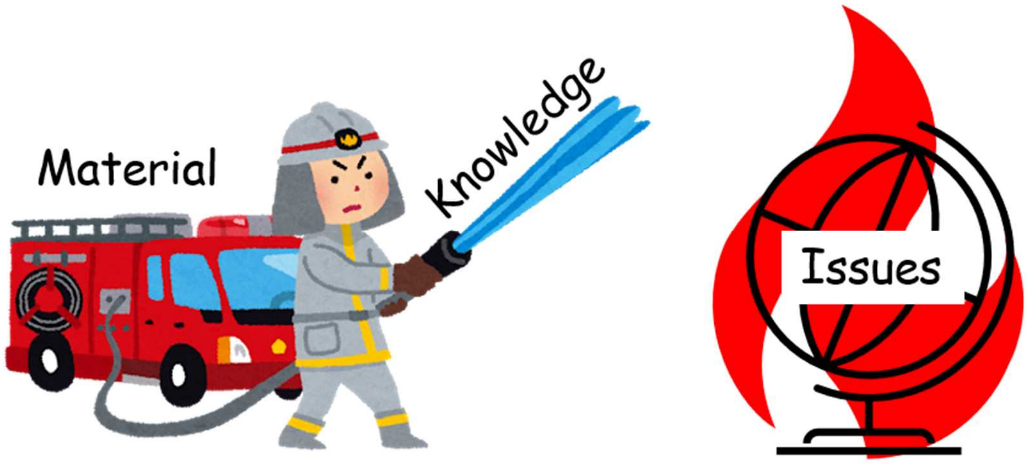

Fig. 3 : We fight against global warming by the knowledge of physics (water) and the application with materials (fire truck)

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