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Preparation Methods and Quantum Hall Effect of Graphene

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Abstract:

Graphene is a two-dimensional ultra-thin functional material. It has the characteristics of light weight, and it exhibits stable chemical properties. In recent years, it has become an excellent candidate material for the modification of various functional devices due to its excellent electrical performance. The performance of graphene is significantly influenced by the preparation method. Therefore, it is necessary to summarize the preparation methods of graphene. In addition, these functional devices typically operate in complex external environments, including magnetic fields, temperature fields, and electric fields. Therefore, studying the quantum Hall effect of graphene is of great significance for the use of graphene based devices. This article is written in order to provide a quicker understanding of this field. The preparation methods of graphene are briefly described. Among these methods, several industrialized methods of graphene production are also highlighted. Then, the progresses of quantum Hall effect in graphene are also presented. This work is of great significance for promoting the application of graphene based devices in complex external field environments.

Keywords: Graphene; quantum Hall effect; preparation.

1. Introduction

Since graphene was first observed under an electron microscope in 1962, a series of speculations have begun about it. It has been proven that two-dimensional materials could be stabilized at room temperature and pressure. Therefore, the graphene is getting a lot of attention and kicking off new technological developments [1-3].

Graphene exhibits extraordinary electrical conductivity, tens of times harder than steel and perfect two-dimensional planar structure. Besides, it also display excellent light transmission properties. Graphene has prefect symmetrical regular hexagonal structure which is very stable, and the connections between the individual carbon atoms are very flexible. Scientists have also developed many industrialized production methods for graphene, so that the mystery of graphene has been gradually unveiled. It has high strength and high conductivity. Meanwhile, it is also very light and thin. Therefore, graphene is well acknowledged to be employed in electronics, aerospace military, biological, new energy, and semiconductor.

In these applications, many graphene based devices require service in complex external field environments. In the energy field, graphene is expected to contribute greatly to the development of supercapacitors and lithium-ion batteries. Supercapacitor is an efficient system for storing and transferring energy. The large specific surface area, standardized porous structure, high conductivity and thermal stability of graphene make it the most promising electrode material. However, in some applications of graphene, it is necessary to transfer it to a suitable substrate, and the interaction with the substrate may cause partial alteration of graphene properties. Exploring the preparation of graphene is still of great significance.

There are many graphene based functional devices that need to be used in complex external working environments. In such a complex external environment, researchers often need to consider the quantum Hall effect (QHE) in materials. The quantum Hall effect is produced under the extreme conditions of strong magnetic field and low temperature.

Therefore, this work summarizes the preparation methods of graphene materials. Besides, the theoretical research, experimental observation and application status of graphene quantum Hall effect in recent years are introduced.

2. Preparation

2.1 Micromechanical Stripping Method

Andre Geim and Konstantin Novoselov created an innovative method to remove layers of graphite by using transparent tape. Firstly, the surface of flake graphite is etched by using plasma. Transparent tape is used to remove the layers. This step is repeated until a single or a few layers of graphene is prepared. The area from a few to a dozen micrometers and it is visible to the naked eye. Then, the graphene is dissolved in an organic solvent and the sample is spread on a silicon wafer for testing. The graphene crystal structure prepared in this way has a strong integrity and it is close to the ideal graphene. However, the sample area is too small and the yield is too low as the cumbersome operation for industrialized production.

2.2 Epitaxial Growth Method

By using a growth matrix, the epitaxial growth is a method of preparing high purity crystals. Thermal decomposition of SiC is the most common method of preparing graphene. The surface of the sample is first etched with oxygen or hydrogen. Then the sample surface is heated to 1000^{o}C by electron bombardment in an ultra-low vacuum environment. Afterwards, the SiC is heated to 1200-1600^{o}C to remove silicon from the (0001) surface of monolithic SiC. Then the graphene crystals are grown to form 1-3 layers of graphene sheets. In addition, Sutter et al. let the carbon atoms to approach the rare metal ruthenium at a temperature of about 1200^{o}C. The carbon atoms gradually penetrate into the interior of the ruthenium metal substrate. When the temperature drops to 850^{o}C, the carbon atoms gradually separate out of the ruthenium surface to form graphene sheets.

2.3 Chemical Vapor Deposition

Somani et al. preparing for graphene by vapor deposition on Ni foils using camphor as a carbon source. The basic principle is the process of utilizing the decomposition of a carbon sources at high temperatures, and the carbon atoms gradually form graphene on a catalyst substrate. There are basically five steps. Firstly, the graphene grows in the presence of a metal catalyst. Secondly, the polymers are spin-coated on graphene. Thirdly, the metal catalyst is corroded. Fourthly, the resulting polymer is transferred to the substrate. Finally, the polymer is dissolved in an organic solvent to obtain graphene. The two key factors in this method are temperature and catalyst. Ago and Zhou studied the growth of graphene on different crystalline surfaces of Cu and Ni. They found that the quality of graphene grown at single crystal interfaces is higher than that of polycrystalline metal. In this way, the graphene that has been manufactured is easily transferred to other substrates and retains its original optically electrical properties with few defects.

2.4 Oxidation-Reduction Method

The raw material of redox is graphite. There are two basic steps. The first step is divided into four processes. The first process is low temperature reaction, which is the oxidation of a strong acid. The next process is normal temperature reaction. In this process, the potassium permanganate causes further deep oxidation of sulphate-graphite interlayer compounds. Then, ultra-pure water is added with the releasing of heat due to the presence of strong acid. Ultimately, the layers of graphite oxide are peeled off by using ultrasonic method. The second step aims to use the reduction reaction to repair the basic structure of graphene that has been damaged during the oxidation process.

3. Quantum Hall Effect in Graphene

3.1 Quantum Hall Effect in Graphene

The universality of quantum Hall states can reveal detailed information about localized state energy levels and their densities in graphene devices. Tuan Khanh Chau et al. showed that the graphene quantum Hall effect is very robust [1]. The relationship between the quantum Hall plateau, Landau level, and the filling factor was carefully analyzed in order to reveal details of local states in the graphene device.

Researchers have analyzed the reasons for the anomalous broadening of the quantum Hall plateau observed in monolayer graphene devices. The cause of this anomaly can be attributed to localized states that are energetically located near the Dirac point in consideration of the relationship between the Landau level and filling factor. This localized state is like electrons trapped in a narrow energy range.

Experimentally, it has been demonstrated that graphene static strain can generate a pseudo-magnetic field with many Teslas. Researchers can observe several Tesla pseudo-magnetic fields oscillating at high frequencies under the premise that static distortion calculations are valid for aberrations of acoustic waves. This is a previously inaccessible electrodynamic system. Anita Bhagat et al. studied resistive oscillations induced by the quantum Hall effect which is generated by a time-dependent pseudomagnetic field [2]. At experimentally accessible frequencies and temperatures, these phenomena should be observed.

3.2 Integer Quantum Hall Effect in Graphene

In linear response Kubo formalism, the analytical expression for Hall conductivity of AAA-stacked triple layer graphene was obtained by Yawar Mohammadi et al. [3]. It is found that the values of the chemical potential and the magnetic field largely determine the quantization of Hall conductance. An explanation for this unusual quantization of the Landau level spectrum of AAA laminated triple layer graphene is also explored. Studies have shown that it has an AA stacking order. That is one of the features of multilayer graphene.

3.3 Quantum Spin Hall Effect in Graphene

A novel Gr/Ga Sb heterostructure with quantum spin Hall effect was proposed by Xinxin Wang et al. [4]. In addition, the gapless edge state of its nanoribbons also demonstrates the QSH effect. Besides, their bulk gaps and band inversions can be effectively enhanced by atmospheric strain engineering.

The results show an intrinsic bulk gap of 116 meV for Gr/(Ga)Sb and 125 meV for Gr/GaSb. By hydrogen passivation, the band gap of GaSb/Gr/GaSb can be extended to 147 meV. It can be used in ambient temperature. Because the band gap obtained is large enough. In addition, h-BN was found to be a suitable substrate. It can provide support for films and it does not disrupt the film quantum spin Hall effect. These results provide a viable approach for the design of Gr-based spintronic devices.

3.4 Quantum Vally Hall Effect in Graphene

Kyu Won Lee et al. using the density functional theory calculations and a tight-binding model [5]. Under the action of cross-edge transverse electric field, the gap-free edge states of zigzag edge graphene nanoribbons are investigated. If a transverse electric field exists at the vacuum-nanoribbon interface, the quantum valley Hall effect occurs. At lower electric fields, if a fringe potential of opposite sign exists on the opposite side, an additional quantum valley Hall effect is created. Even in the absence of a transverse electric field, the quantum valley Hall effect is catalyzed by asymmetric edge terminations. It is not the dangling bond but the terminating groups that cause the quantum valley Hall effect to produce an internal electric field.

4. Conclusion

This work mainly discusses the preparation methods of graphene. It also summarizes the theoretical research and practical application of graphene quantum Hall effect phenomenon in some fields in recent years. At present, the preparation method of graphene has been relatively enhanced. The industrial production technology is expected to be further optimized to reduce product costs. The understanding and researches on graphene and carbon materials is just kicking off. Graphene has many excellent properties, which can create unlimited possibilities in the field of science and technology. It is expected to trigger a new round of material revolution. It is believed that the carbon materials, represented by graphene, will write a strong mark in the long history of human civilization.

The quantum Hall effect is important in promoting the theoretical development and assisting the research of other disciplines. In this work, the practical application of quantum Hall effect in graphene materials and its promoting effect on theoretical development are revealed. It is believed that the quantum Hall effect will provide new solutions to the difficult problems in subatomic field, materials science, photonics and many other fields in the future.

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