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Magnetic confinement of electrons in carbon based materials

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Abstract: A carbon-based topological material which shows anomalous Hall effect at room temperature was found in this study. The topological material with long-range ferromagnetic order was transformed into micro particles with single magnetic domain structure first. Then the micro particles were combined in a special manner to form a micro magnetic mirror, showing the microelectromagnetic confinement of anomalous Hall effect. By controlling the generation and elimination of the confined magnetic field, the electrons can be confined and released. This carbon-based topological material can change the current electricity storage mode of a battery which transforms chemical energy to electric energy and greatly increases the electricity storage density per unit volume.

Key Word: carbon-based topological materials; anomalous Hall effect; magnetic confinement; magnetic domain

0. Introduction

Materials are one of the foundations of the industrial revolution. The past industrial revolutions show that the development of materials has played an extremely important role in addition to scientific progress. In 2013, scientists found the material with anomalous Hall effect at low temperature, meaning an incredible quantum phenomenon in zero magnetic field. This material must meet **three** very harsh conditions: (1) It has topological characteristics in its energy band and thus conductive one-dimensional edge state; (2) it has a long-range ferromagnetic order; and (3) it is internally insulating and non-contributive to conductivity. Therefore, the study on the materials with anomalous Hall effect is very important in condensed matter physics. In particular, the anomalous Hall effect at room temperature always is the focus of research. In 2014, it was found during the study on the conductivity of carbon-based materials in this paper that the "sandwich" structure of ferromagnetic metal insulation material between the two single graphite sheets can show anomalous Hall effect at room temperature. The material is named "carbon-based

nest" according to the sandwich structure. The material shows two basic characteristics: (1) anomalous Hall effect at room temperature produced by the spontaneous magnetization of the material itself independent of the external strong magnetic field, i.e. the quantum Hall state realized in zero magnetic field; and (2) quantum confinement effect. For general materials, when the continuous energy band becomes a discrete energy level, the ground state energy level moves upward, so the absorption spectrum blue shifts. However, for this material, the magnetic dipole moves upward in the ground state energy level in the low-dimensional structure or nanostructure, so the absorption spectrum red shifts.

During the application of the material with anomalous Hall effect at room temperature, it is found that micro electromagnetic confinement can be realized by changing the spontaneous magnetization conditions of the material. Different from that chemical energy transforms to electric energy first and then electric energy re-transforms to chemical energy, microelectromagnetic confinement is an ideal electricity storage method to achieve the real electrolyte-free solid-state battery. During chemical energy transformation and charge & discharge, the substance on the surface of the plate electrode gradually becomes loose, so the energy decays rapidly over time and the service life is relatively short. Microelectromagnetic confinement leads to no loose substance on the surface of the plate electrode. The charge & discharge occur during spontaneous magnetization and demagnetization. In other words, electric energy is stored by magnetic energy. Therefore, microelectromagnetic confinement has the characteristics of slow energy decay and long service life. In preliminary analysis, the structural size of the magnetic confinement body and the maximum electronic confinement limit of a single magnetic confinement body show that microelectromagnetic confinement has greater electricity storage density per unit volume than chemical energy transformation.

1 Anomalous Hall Effect of Carbon-based Topological Materials at Room Temperature

In this paper, microelectromagnetic confinement was mainly discussed because of similar material and manufacturing method to anomalous Hall effect. The differences between anomalous Hall effect and microelectromagnetic confinement is

ferromagnetic insulation material between two single graphite sheets for the former and combination of single graphite sheet and ferromagnetic insulation particles for the latter. Spontaneous magnetization occurs in both anomalous Hall effect and microelectromagnetic confinement. In addition, microelectromagnetic confinement is found on the basis of anomalous Hall effect. Therefore, the anomalous Hall effect of the carbon-based topological materials was briefly described.

Carbon-based topological material is a "sandwich" topological structure with ferromagnetic metal insulation material between two single graphite sheets, which has two-dimensional edge conductivity and long-range ferromagnetic order [1,2] and shows anomalous Hall effect at room temperature. The Vander Pauw method can be used to simply measure the anomalous Hall voltage by applying 1~30 v adjustable voltage to two opposite angles or sides of a quadrate, which is 1 mm thick and 2 cm long and wide, respectively, using the other two opposite angles or sides for detection of Hall voltage. The Hall voltage is shown in Fig. 1A, and the experimental results are shown in Fig. 1B.

Fig. 1A Diagram of Anomalous Hall Voltage

Fig. 1B Input Voltage V_0 versus Hall Voltage U_0

It can be seen from Fig. 1B that the spontaneous magnetization of the carbon-based topological material shows the anomalous Hall effect at room temperature; with the increasing input voltage V_0 between 1V and 18V, between 18V and 21V, and between 21V and 30V, Hall voltage U_0 increases linearly, decreases, and plateaus (i.e. magnetic saturation), respectively. The input voltage, V_0 , and current, I , continue to increase, and U_0 is a constant, showing the basic characteristics of anomalous Hall effect.

2. Electromagnetic Confinement Fundament and Experiment

A magnetic mirror must be created so that microelectron has the same magnetic

confinement as the macroplasma [3]. It is found that the material has so small linearity that the size effect of one-dimensional conductor appears when it is close to the structure of single magnetic domain particles [4, 5] and the electromagnetic barrier is generated in a transverse magnetic field and electric field. Accordingly, the microelectromagnetic confinement phenomenon is found in accordance with the principle that single domain particles are combined to form a magnetic mirror.

Similarly, the single-sided graphite sheet structure approximate magnetic domain particles with one-dimensional edge state conductivity, as shown in Fig. 2A, grew on the particle material by the same method to ferromagnetic metal insulation material between two graphite sheets with anomalous Hall effect. Fig. 2B shows the particle distribution under an X-ray scanning megaloscope. A magnetic mirror composed of some particles can be observed from Fig. 2B.

2.1 Magnetic Mirror Formation and Fundament:

Each single magnetic domain particle is isolated by an organic insulating liquid with a simple structure. Any angles of the particles are connected to form a one-dimensional conductor, as shown in Fig. 2A (Black represents one-dimensional conductor.).

Fig. 2A Magnetic Mirror (Four single domain particles)

Fig. 2B Particle Distribution

Fig. 2A illustrates a magnetic mirror formed from connection of four approximate

single domain particles. Before formation of a magnetic mirror, the current I tunnels a one-dimensional conductor to form an oblique cross magnetic field. The particles a and b form magnetic mirrors, while the particles c and d form no magnetic mirror. With the increase of magnetic field of particles a and b, the one-dimensional conductor of the particles c and d has higher electromagnetic barrier than that of the particles a and b due to the transverse magnetic field [6]. (One-dimensional conductor is unstable for interaction of electron lattices [8] and always forms electric and magnetic barriers especially under size effect). The transverse magnetic field prevents the movement of electrons in the one-dimensional conductor of the particles c and d. The electrons running in the energy band of one-dimensional conductor of the particles c and d are confined in the magnetic mirror. If the voltage continues to increase, the potential energy of electrons will increase and the barrier width will narrow [7], and some electrons will pass through the magnetic mirror. When there is an electric field, the electric and magnetic barriers will be superimposed together. The linear function conforms to $F(x) = y$. If the voltage continues to increase after magnetic energy saturation, the potential energy of electron gas makes the barrier width zero, so the material becomes a one-dimensional conductor. The magnetic saturation voltage is defined as the breakdown voltage (See 2.2.1 in Experiment). Therefore, with increasing voltage below the breakdown voltage, the magnetization speed increases, and the number of the bound electrons in the magnetic mirror increases. The saturation limit of the bound electrons is directly proportional to the distance between the particles a and b and the magnetic field intensity of the mirror image. When the magnetic field intensity of the particles a and b decreases or disappears, the bound electrons jump to the conduction band of the one-dimensional conductor, and the electrons flow to form a current.

2.2 The electromagnetic confinement was confirmed by the following experiments and data.

2.2.1 Experiment on Electromagnetic Barrier in One-Dimensional Conductor

A certain number of approximate single magnetic domain particles with one-dimensional conductivity were well stirred in organic insulating liquid, evenly spread on a quadrate insulating plate. The approximate single magnetic domain particles on the insulating plate randomly arranged and the one-dimensional conductor randomly connected. Electrodes were added at both ends to make an experimental plate. 0V~50V DC voltage was applied to both ends of the electrodes to test the current at different voltages, as shown in Fig. 3.

Fig. 3 Electromagnetic Barrier of One-Dimensional Conductor

With increasing voltage V from 0V to 7V, the current I increases to 5.5 mA, the intensities of magnetic and electric fields reach the width of the electromagnetic barrier that can prevent the movement of the electrons, so the current drops to zero instantly, i.e. there is no current in the one-dimensional conductor. When the voltage increases to 11V, the potential energy of the electrons increases, the width of the electromagnetic barrier narrows, some electrons tunnels, the magnetic field intensity further increases, the width of the electromagnetic barrier increases, and the current drops to zero instantaneously, forming a short electrical pulse. When the voltage continues to increase, several electrical pulses occur, as shown in Fig. 3. When the voltage continues to increase to 37 V at the magnetic saturation of the ferromagnetic insulation material, the current instantly increases by the factor of 1.5. If the voltage is kept unchanged or increased, a lot of heat is generated so that the material is functionally destroyed. Therefore, this voltage is called breakdown voltage. If the power is quickly switched off and on at $V_0 > 3V$ and any voltage below the breakdown voltage, the electrical pulses in Fig. 3 appear, indicating that the electrical barrier disappears when the power is off and appears again under the action of the magnetic barrier when the power is on. The experiments prove that the electric barrier and the magnetic barrier are superimposed. The experimental data are related to the size of the experimental plate and spreading thickness. The data prove only the electromagnetic barrier produced by the one-dimensional conductor in the electric and magnetic fields.

2.2.2 Electromagnetic Induction Experiment:

The material was prepared by the method in 2.2.1 and evenly spread till the thickness of 0.1 mm on the insulating plate which is 0.2 mm thick and 2 cm wide and

long, respectively. Electrodes were added at both ends. The material was even spread till the thickness of 0.1 mm on the other side of the insulating plate. Electrodes were added at both ends. 12V/50Hz alternating electromagnetic field was applied to one side of the material as side A, and the induced electromotive force and resistance were measured on the other side as side B. The one-dimensional conductor in the material was randomly connected, as shown in Fig. 4. The test results show that there is no induced electromotive force on side B. The resistance of side B gradually increases from originally 1.1k Ω to 1.8k Ω . The resistance gradually returns to 1.5k Ω when the electric field is removed and to the original value of 1.1 K Ω when an external magnetic field is used for repeated demagnetization.

The experiments prove that under the induction of alternating electromagnetic field, a barrier of one-dimensional conductor under the size effect and magnetic field increases the resistance of the material during alternating generation and elimination of the alternating magnetic field on the induction side. The resistance of the material is greater than the original value because the magnetic field and the generated barrier are partially maintained at a moment when the external alternating electromagnetic field stops.

Fig. 4 Diagram of Electromagnetic Induction Experiment

2.2.3 Electromagnetic Confinement Experiment:

The material was prepared by the method in 2.2.1 and evenly spread till the thickness of 0.1 mm on the graphite plate which is 0.2 mm thick and 0.5 cm long and wide, respectively. One end of the graphite plate was used as an electrode. Its structure was observed under a microscope, as shown in Fig. 2A. Then it was covered with another graphite plate of the same size as the other electrode. (When the material was evenly spread, a pseudo structure naturally formed in Fig. 2A existed internally, so a weak electromagnetic confinement phenomenon occurred in case of power connection).

In the first step, 3V DC voltage was applied between the two electrodes for 20 s before disconnected.

In the second step, the current at both ends was immediately detected to be 5 μ A, and zero in about 1 s. (Due the self demagnetization effect of soft magnetic potential, the magnetic confinement established in an electric field disappeared).

In the third step, the current of 28 μ A, which was generated when the magnet with the magnetic field intensity of 0.2 T gradually approached to about 5 cm, dropped to zero in 2 s; the current of 16 μ A was produced in the subsequent current the reverse magnetic pole experiment (the magnetic field of the single magnetic domain particles that created the magnetic mirror disappeared); no current was produced when the magnet approached again.

The analysis of the above experimental data shows that electromagnetic confinement exists in the structure in Fig. 2A, i.e. the electrons are confined in the magnetic mirror. When the external strong magnetic field has an opposite polarity to the single magnetic domain particles in the material, the magnetic mirror field is eliminated or reduced. Thus, the magnetic confinement disappears or decreases and the confined electrons release and form a current.

2.2.4 Charge & Discharge Test:

When the magnetic mirror disappears, the movement direction of the electrons depends on the degenerate state when they are confined [7], so some of the electrons are scattered after the electrons at each magnetic mirror point are unconfined. The material, such as Ni₂O₃, etc., added or coated on the plate electrode to form a potential difference, forms a potential difference with the single magnetic domain particles to guide the scattered electrons. Thus, after the magnetic field is weakened or eliminated, the electrons enter the energy band more slowly, the potential difference (voltage) increases, and the electric power increases.

Experimental method: The prepared material was evenly spread on the graphite plate, as shown in Fig. 2A, and covered with another graphite plate of the same size or Ni₂O₃ coated plate electrode. The two electrode plates were connected to the DC power supply. The charge and discharge test was conducted at the voltage of 5V~28V. Fig. 5 shows the charge at 5V, 8V, 10V, 12V, 14V,... 28V, discharge to 5 mA, and the time of discharge from 5mA to 3mA.

Fig. 5 Charge at 5V~28V and Discharge to 5mA and 3mA

Fig. 5 shows that the higher the charging voltage, the longer the time, S^* , (in second) of discharge to 5 mA and 3mA, indicating that the higher the voltage, the higher the magnetization speed, and the higher the charge speed. Within the saturation limit of magnetic confinement, the more electrons confined by the magnetic mirror lead to the more softly magnetized particles, the more magnetic mirrors after the charging voltage disconnection, and the bigger quantity of stored electricity.

3. Conclusion

(1) In Fig. 2A, the magnetic mirror composed of the approximate single magnetic domain particles has no conditions for anomalous Hall effect and long-range ferromagnetic order, which have different spontaneous magnetization conditions. Therefore, it is only recognized as a micro magnetic mirror, microelectromagnetic confinement, formed under anomalous Hall effect.

(2) Some measures must be taken for arrangement so that the material has the structure shown in Figure 2A, which is the most important for the material.

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