Preparation Of Carbon Nanotube Transistors and Their Applications in Integrated Circuits

Bowen Wang *

School of Physics, Nanjing University, Nanjing, China

* Corresponding Author Email: 211840094@smail.nju.edu.cn

Abstract. Carbon nanotube is nanoscale tubular structure composed of carbon atoms. It has been widely used in electronics, medicine, and environmental science, due to its excellent mechanical properties. Among them, the application of carbon nanotubes in transistors is a promising research direction. Therefore, exploring the preparation of carbon nanotube transistors and their applications in integrated circuits has become a hot research direction in recent years. This article focuses on the structure, preparation process, and various issues of carbon nanotube field-effect transistors. Burning and removal of metallic carbon nanotubes were discussed, as these impurities are generated Inevitably during the production process. Then the article introduces three methods of fabricating conductive channels. The last part of the article, the electrical properties of carbon nanotube field-effect transistors were reviewed. The superior electrical properties of carbon nanotubes are highlighted. In addition, the change in electrical properties caused by two types of deformation, axial deformation and rotational deformation are also discussed.

Keywords: Carbon nanotubes, burn off, conductive channels, electrical properties.

1. Introduction

In the past two decades of the 20th century, the development of integrated circuits was very rapid. Many electronic products and mechanical structures manufactured based on integrated circuits entered the lives of people. Among them, mobile phones and computers have become an inseparable part of life. Integrated circuits have achieved unprecedented efficiency in information transmission through the application of various electronic components. Therefore, research on integrated circuits is of great importance to modern society. Exploring precise electronic chips is urgently needed.

Transistors, as the basic unit of chips, play various roles in the chip, including detecting, amplifying current and transmitting signals. Most transistors have the characteristics of small size, fast response speed, and high response accuracy. Besides, transistors also have the advantage of low energy consumption compared with equivalent electronic tubes. This is the reason why they can be widely used in precision devices such as chips. The most important basic unit in chips is the transistor. Carbon nanotube transistors, which has small size and high performance, is a hot research topic at present [1,2].

There are various types of carbon nanotube transistors, mainly including carbon nanotube field-effect transistors and carbon nanofilm transistors. In this work, the nanotube field-effect transistors were reviewed. The selection of transistor structure and preparation process would be highlighted. The difficulties and solutions during preparation would be discussed.

2. Preparation of Nanotubes

2.1. Single Walled Carbon Nanotube Field-effect Transistor

The structure of single-walled carbon nanotubes (SWNTs) field-effect transistors has been continuously optimized. The bottom gate of single-walled carbon nanotube transistors consists of a Si bottom gate layer of 10-100nm, two electrodes, SiO2 layer, and single-walled carbon nanotubes which were built on the two electrodes [3]. Conductive channels are formed on the constructed carbon nanotubes. However, the problem of high contact resistance at the connection between single-walled carbon nanotubes and the two poles, result in high demand for electrode voltage. One of the optimization methods for the bottom gate structure is to penetrate single-walled carbon nanotubes deep into the electrodes at both ends. However, this method would bring about pollution in the subsequent steps [3]. Compared with the above mentioned two structures, the top gate structure is more enclosed. Moreover, the transistor structure can be independently controlled in integrated circuits due to the presence of a separate gate above the top gate structure [4].

In the above-mentioned carbon nanotube transistor structure, metallic carbon nanotube impurities that are not required for the experiment will be prepared during the preparation process. Therefore, how to remove the impurities is also a problem which need to be solved.

2.2. Burning and Removal of Metallic Carbon Nanotubes

In the process of producing carbon nanotubes, metallic carbon nanotube impurities are generated. These metallic carbon nanotubes cannot be effectively adjusted by controlling the voltage manually. During the experimental preparation process, the impurity is usually removed by burning [3,5,6]. Due to the semiconductor properties of carbon nanotubes, when a high voltage is applied, the current carrying electrons will be quickly depleted. Therefore, they can be burned off by increasing the voltage. The charge carriers on the semiconductor carbon nanotubes could be deplete by increasing the gate voltage, thus cutting off the semiconductor carbon nanotubes temporarily. Then, a sufficiently high drain voltage should be applied. During this process, it is shown that when V increases to a certain voltage, the current passing through the carbon nanotubes sharply decreases, indicating that the metal carbon nanotubes are rapidly burning away at this time [6]. It is reported that the current switching ratio of the transistor before burning is only 10, while the current switching ratio after burning can reach up to 10^4~10^6, indicating that the burning process can greatly improve the performance of carbon nanotubes [3].

2.3. Formation of Conductive Channels

After the problem of preparation is solved, it is important to discuss how to drop carbon nanotube droplets on the electrodes of a transistor accurately and conveniently. Therefore, how to form carbon nanotube conductive channels between the electrodes of a transistor would be highlighted in this part. There are three ways to form conductive channels: atomic force microscope (AFM) probe manipulation, alternating current (AC) electrophoresis, and chemical vaper deposition (CVD) growing [3].

2.3.1 AFM probe manipulation

The AFM probe will change the contact force between the probe and the sample surface based on the height change of the liquid on the transistor surface. This principle can be used to maintain the force of the probe at a selected value [7-8]. In the actual experimental operation, single walled carbon nanotubes are dropped onto the substrate. The AFM probe is moved to the appropriate position, and the electrodes at both ends are connected. Whether the single walled carbon nanotubes can be dragged by the AFM probe in the experiment depends on the attraction between the single walled carbon nanotubes and the probe, as well as the ratio of van der Waals force between the carbon nanotubes and the substrate. When the attraction between carbon nanotubes and AFM probes is greater, the probes can drag the carbon nanotubes. The advantage of using AFM probes to create conductive channels lies in their high precision, which can determine whether the conductive channels are formed between the two electrodes accurately. However, the possibility of bending or damaging carbon nanotubes when moving the probes are also increased.

2.3.2 AC electrophoresis

This method utilizes the properties of the electric field. The droplets of single walled carbon nanotube will be polarized under the action of an electric field [9]. The polarized single walled carbon nanotubes will rotate and translate under the action of alternating current. Through this motion, the motion of single walled carbon nanotubes could be controlled. In the experiment, a small amount of pretreated single-walled carbon nanotube liquid is dropped onto the substrate. Then, an AC bias voltage is applied between the two electrodes. Afterwards, observe the change in resistance between the electrodes. When the resistance suddenly decreases to a few hundred kΩ, a conductive channel is formed between the two electrodes.

AC electrophoresis is more convenient. However, it also has limitations. Before the experiment, both ends of the metal electrodes must be prepared. In addition, only the worst bottom gate structure can be used.

2.3.2 CVD growing

The CVD growing method is based on the chemical vapor deposition method to prepare single-walled carbon nanotubes [10-11]. In the experiment, a certain concentration of catalyst is arranged on the substrate, and the experimental environment is heated to a temperature of about 900oC. A carbon source gas containing carbon compounds is used. Through chemical reactions, single-walled carbon nanotubes can be formed.

Compared to the first two preparation processes, CVD has a shorter existence time, a wider range of applications, and better prospects. It can be applied to top grid structures with better structures. There are still impurities such as amorphous carbon and catalyst particles [3].

2.4. Electrical Properties of Carbon Nanotube Field-effect Transistors

2.4.1 Electrical properties of carbon nanotubes

As The differences between the new type of transistor and traditional silicon transistor lies in the newly added single walled or multi walled carbon nanotube section. Therefore, understanding the electrical properties of carbon nanotubes is very important. Carbon nanotubes are tubular objects formed by a carbon monolayer. The difference between single walled and multi walled carbon nanotubes lies in the number of layers of carbon monolayer that form the pipeline. Single walled carbon nanotubes are the most commonly used among carbon nanotubes.

The electrical properties of single-walled carbon nanotubes can be divided into two categories: metallic properties and semiconductor properties. Both types of carbon nanotubes have very broad application prospects. To distinguish between these two types, carbon nanotube index (n, m) are needed. These parameters contain information such as the diameter and helicity of carbon nanotubes. Based on this information, the electrical properties of carbon nanotubes can be determined. The specific judgment method requires the following formula: n-m=3q, where q is limited to an integer. If the carbon nanotube index satisfies this formula, it is metallic. Otherwise, semiconductor property could be found in this kind of carbon nanotube [11]. Semiconductor type carbon nanotubes can be used to construct FETs. From the formula, it can be inferred that 1/3 of carbon nanotubes are metallic and 2/3 are semiconductor type. In general, both two types could be produced in experiments, and specific methods should be used to remove them according to needs.

2.4.2 Properties brought by deformation of carbon nanotubes

It has been found that deformation can effectively change the properties of carbon nanotubes [12]. As it was mentioned above, the carbon nanotube index can indicate the electrical properties of carbon nanotubes. When the carbon nanotubes were stretched and twisted, the metallic and semiconductor properties could be changed [12]. In this work, the electrical changes caused by deformation in serrated carbon nanotubes and armchair carbon nanotubes will be introduced.

When the carbon nanotube index of serrated carbon nanotubes is (17, 0), (18, 0) or (19, 0), as tension and compression change along the axis, deformation in this direction obviously does not affect the axial properties of carbon nanotubes [13]. However, it will cause a significant change in the band gap by affecting the electronic structure. At this point, carbon nanotubes will transition from their original semiconductive form to a metallic form. And when the three types of carbon nanotubes undergo deformation, their respective energy gap changes are basically the same. When n is 3s+1 (s is a positive integer), semiconductor type carbon nanotubes can be compressed to become metal type ones. Similarly, when n is 3s-1, semiconductor type carbon nanotubes can be stretched to become metal type. When n is exactly 3s, metal type carbon nanotubes can be compressed to become semiconductor type. And torsional deformation also has an impact on three different types of serrated carbon nanotubes. Unlike axial deformation, the regularity of torsional deformation is very weak. With the change of torsional angle, carbon nanotubes will transform between the semi conductive and metallic forms.

For armchair shaped carbon nanotubes, the effect of axial deformation is relatively small. Moreover, the effect of torsion on the energy gap of armchair shaped carbon nanotubes is very small. When axial deformation occurs, it hardly undergoes any transformation. In addition, the effect of torsional deformation on armchair shaped carbon nanotubes is similar to that on serrated carbon nanotubes.

3. Conclusion

In summary, this article mainly summarizes the preparation and properties of carbon nanotube transistors. The firing method of metal type carbon nanotubes were highlighted. In addition, several methods that can manufacture conductive channels, such as AFM, AC and CVD growth, were also studied. In the future, the transistor structure in electronic products will become smaller and smaller. Compared to transistors made of silicon, transistors made of carbon nanotubes will have more obvious advantages in this trend. Although there have been many research achievements in carbon nanotube transistors nowadays, the potential of carbon nanotube transistors is far beyond that.

References

[1] IBM Research Division. Carbon nanotube transistors and logic circuits. Physical: B, 2002,323: 6-14.

[2] IBM Research Division. Manipulation of carbon nanotubes and properties of nanotube field-effect transistors and rings. Microelectronic Engineering, 1999,46: 101-104.

[3] HUANG Haiyan, CHEN Changxin, ZHANG Yafei. Research on the preparation process of single-walled carbon nanotube field-effect transistors. Micro nano electronic technology, 2008,(02): 78-82.

[4] Yang M H, Teo K B K. Advantages of top-gate, high k dielectric carbon nanotube field-effect transistors. Applied Physics Letters, 2006, 88: 113507.

[5] SeidelR, Graham A P, Unger E, et al. High-current nanotube transistors. Nano Letters, 2004, 4: 831-834.

[6] ZHAI Chunxue, WANG Ruozheng, MA Chao, YIN Tieen, WU Zhihua, ZHAO Lili, CHEN Jian, ZHANG Zhiyong, DENG Zhouhu. Preparation and characteristics of carbon nanotube-oriented network field-effect transistors. **Journal of Northwest University** (Natural Science Edition), 2011,41(06): 976-980.

[7] Roschier L, Penttila J. Single-electron transistor made of multiwalled carbon nanotube using scanning probe manipulation. Applied Physics Letters, 1999, 75 (5): 728-730.

[8] BASKI A A. Fabrication of nanoscale structures using STM and AFM [M]. Academic Press, 2002.

[9] Smith P A, Nordquist C D, Jackson T N. Electric-field assisted assembly and alignment of metallic nanowires. Appl Phys Lett, 2000, 77 (9): 1399-1401.

[10] Kong J, Son H T. Synthesis of individual single walled carbon nanotubes on patterned silicon wafers. Nature, 1998, 395 (29): 878-881.

[11] Angelucci R. Growth of carbon nanotubes by Fe-catalyzed chemical vapor processes on silicon-based substrates. Physical: E, 2007, 37: 11-15.

[12] LIU Hong, YIN Haijian, XIA Shuning. Electrical properties of deformable carbon nanotube field-effect transistors. Acta Physical Sinica, 2009, 58(12): 8489-8500.