Study of Gas Sensor with Carbon Nanotube Film on the Substrate of Porous Silicon

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ABSTRACT

A new method of obtaining extremely high electric field in a very small region near the tip of carbon nanotube, with diameter of nanometer order, is studied. This method makes the self- sustaining dark discharge voltage decreased to that of less than 220v, which is the safe range. The carbon nanotube array film is used as the cathode, to form a new kind of gas sensor based on the gas discharge. The discharge current of the gas, at the room temperature and the atmospheric pressure, increases from the order of nanoampere[1] to that of microampere. So, the sensitivity of the gas sensor is increased a great many. The electric characters of several gases at the atmospheric pressure are studied in this paper. The self-sustaining dark discharge voltages of different gases are different, and so are the discharge currents. Then, the gas variety and the gas concentration can be recognized. The porous silicon is made and selected as the substrate for carbon nanotubes to grow on. This can improve the adhesion of carbon nanotube on the substrate, so the lifetime of the cathode can be prolonged.

INTRODUCTION

There are many kinds of gas sensors, which all have their own shortcomings. For example, semi-conductor gas sensors have high sensitivity, but they work at high temperature, so they can not be used to measure the flammable gas and the gas easy to explode. The gas sensor based on the gas discharge, proposed in this paper, has high sensitivity, and works at room temperature and atmospheric pressure. This kind of gas sensor recognizes the various gases in the high electric field by different electric conductance. If gas has the stable electric conductance at room temperature and atmospheric pressure, high voltage is needed to supply enough high electric field. The carbon nanotube (CNT), with diameter of nanometer order (Fig1), fine electric conductance and high mechanical intensity, is used to obtain high electric field round the tip of CNT with the supply voltage of several hundred volts. So, gas round the tip of CNT will have stable self-sustaining discharge.

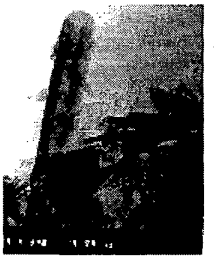

Fig1. Carbon nanotube

1. Preparation of CNT array film cathode with the substrate of porous silicon

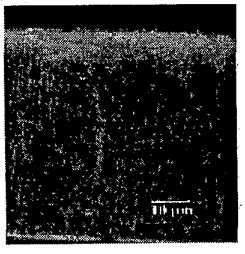

Fig2a. Carbon nanotube array

The porous silicon (PS) slice is used as the substrate to improve the adhesion of CNT and prolong the lifetime of the device. PS with multiple structure of micrometer order and nanometer order is studied and prepared by chemical method of hydro-thermal iron ion etching on the mono-crystalline silicon[2]. The carbon nanotube grows on PS by pyrogenation method, and CNT array (Fig2a) film is obtained, which is used as the cathode. The iron slice is used as the anode, and the electrode structure is shown as Fig2b. This kind of electrode is used to form a new kind of gas sensor based on the gas discharge.

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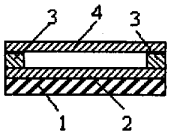
2. Gas conductance theory in the high electric field in a very small region

The electric field intensity on the surface of the CNT tip has relation to the applied voltage U, between cathode and anode, and the curvature radius of tip R_0[1]: $E_r = U/R_0$. Then, when R_0 is 10nm, a high electric field intensity of 2×10^{10}v/m will be obtained with the supplied voltage of 200v. And the high electric field intensity will be obtained in a small region with several nanometers from the tip surface.



1. substrate of porous silicon (cathode)
2. carbon nanotube film (cathode)
3. insulation strip
4. anode (iron slice)

Fig2b. Carbon nanotube electrode

When U increases to a certain value U_s, viz. the breakdown voltage of gas, the discharge current will increase rapidly, which means that gas is break down. Because the CNT is used as the cathode, the high electric field intensity is obtained with low voltage. So, U_s decreases greatly to the safe range of less than 220v.

3. Experiments and results

The experiment on the adhesion of CNT was done. When the voltage U increased to 800v, the CNT film on the PS slice didn't flake off, while a small part of the CNT film on the normal silicon slice did when U increased to 500v. This demonstrates that the adhesion of CNT on PS slice is stronger than that of CNT on silicon slice.

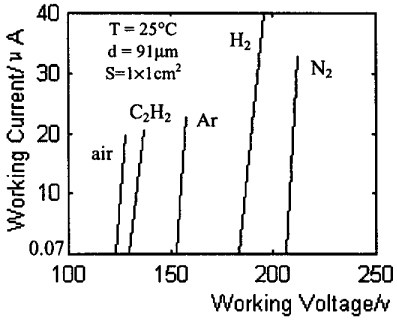


Fig3. I-V characters of single gas of several kinds measured by the gas sensor

The electric conductance of single gas at the atmospheric pressure is studied in the experiments. The volt-ampere characters of 5 kinds of gas are shown in Fig3. The experiment result shows that, when the conditions of the electrode area S, the distance d between cathode and anode and working temperature T are constant, the electric conductance of different kinds of gas are different, which means that the breakdown voltages are different and the discharge currents are different. In comparison with the result of the reference[1], the breakdown voltage of air decreases from 372v[1] to 128v, while the discharge current increases from 30nA[1] to 20μA. The breakdown voltage of N_2 decreases from 488v[1] to 212v, while the discharge current increases from 50nA[1] to 33μA. The breakdown voltage decreases more than 1 time, and is less than 220v, which is the safe range. The discharge current increases from the nanoampere order to the microampere.

4. Discussion

Different kinds of gas under the same experimental conditions have different electric conductance. So, the theory of gas sensor based on gas discharge is feasible. The tip of CNT, with curvature radius of nanometer order, is used to obtain high electric field intensity, therefore, the voltage U_s for self-sustaining discharge of gas decreases greatly. The CNT array film is used as the cathode, so the discharge current increases greatly. The new kind of gas sensor increases the sensitivity greatly. And the field of sensor will be a new application field for nano-material.

REFERENCE

[1] Dai Pinghu, Ling Baoming. Study of A New Gas Sensor Based on Electrical Conductance of Gases in A High Electrical Field. Chinese Journal Of Scientific Instrument, Vol.19, No.3, 1998.

[2] Li Xinjian, Zhu Deliang, Chen Qianwang, Zhang Yuheng. Strong And Nondegrading Luminescent Porous Silicon Prepared By Hydrothermal Etching, Applied Physics Letters, Vol.74, No.3, 1999.