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Study on Graphene Field Effect Tube Photoelectric Sensor

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Abstract: *As a special device that converts the measured physical quantity into electrical signal or other signal output according to specific rules, the sensor becomes the nerve ending connecting the natural world and the electronic world. Photoelectric sensors, as an important branch of sensors, play a central role in applications such as optical communication, imaging and detection, as electronic systems perceive external eyes. At present, the main sensor products in the market have defects such as limited detection wavelength, low responsivity and complex structure. In view of these problems and practical needs, combined with the advantages of graphene with wide detection wavelength range, high influence and high electron mobility, this paper proposes a graphene field effect tube photoelectric sensor with silicon nitride protective layer, and its preparation process, environmental stability test and photoelectric response characteristics are studied and analyzed. The results have potential application value. Graphene field effect transistor photoelectric sensor has many excellent characteristics, such as wide detection band, high response, good environmental stability and easy preparation and integration. It provides a new research idea for MEMS photoelectric sensor and has a very broad application prospect.*

Keywords: *Graphene, photoelectric sensors, silicon oxide, terahertz, silicon nitride protective layer*

1. Introduction

As a special device that converts the measured physical quantity into electrical signal or other signal output according to specific laws, the sensor becomes the nerve ending connecting the natural world and the electronic world. In general, the signal collected by the sensor is converted into electrical signals, which are read after subsequent storage, amplification, calculation, transmission and other processing. As the beginning of the signal processing process, the sensitivity and accuracy of information acquisition determine the reaction speed and reaction accuracy of the whole subsequent system for external perception. According to the statistics provided by the World Semiconductor Trade Statistics Association, the third quarter of 2017[1] data show that the global semiconductor sales in the third quarter of 2017 reached USD 107.9 billion, up 10 % from the second quarter of USD 97.9 billion. Therefore, with the rapid development of science and technology, as an important node of intelligent equipment and information technology interacting with the outside world, the development of sensor technology has been paid more and more attention.

Since its discovery, graphene has attracted wide attention and carried out a lot of research in many fields such as energy storage, biochemistry, environmental protection and optoelectronics due to its unique physical structure and excellent physical properties. In terms of photoelectric detection, graphene can absorb all the light from ultraviolet to terahertz band due to its unique zero-gap energy band structure to generate photoexcited carriers. In addition, graphene also has a series of advantages such as ultra-fast carrier mobility, wavelength-independent absorption, low dissipation, and tunable optical properties of electrostatic doping. Therefore, graphene is an almost ideal photoelectric detection material. Combined with the excellent characteristics of graphene, it is expected to solve the problems of existing photoelectric sensors to study and prepare photoelectric sensors with graphene as photosensitive material.

2. Properties of Graphene and Their Applications in Photoelectric Field

2.1 Properties of Graphene

Graphene was obtained by repeatedly stripping highly oriented pyrolytic graphite with tape[2] and verified to be a zero band gap bipolar semiconductor material.[3] In terms of electrical properties, the highest carrier mobility of graphene can reach 250000. Compared with the carrier mobility of silicon, graphene is more than 100 times higher. Since the electrons in graphene have no effective mass, the intense lattice vibration generated at high temperature will not have a great impact on the electron scattering of graphene, so it will not reduce the carrier mobility of graphene, that is, the carrier mobility of graphene will not change with temperature.[4]

In terms of chemical properties, graphene has a large specific surface area with its unique two-dimensional structure. In addition, micro doping (physical or chemical doping) on the surface of graphene can significantly change the conductivity of graphene. The chemical properties of graphene are stable, and the surface has a certain adsorption capacity for charged particles.[5]

In terms of thermodynamics, the thermal conductivity of graphene can reach 5000 W / mK, which is five times higher than that of diamond composed of the same elements.

In terms of optics, graphene can absorb the vertical incident light of visible and infrared light waves, and the reflected light intensity is less than 0.1 %. However, due to the structure of its single atomic layer, the absorption rate is only 2.3 %. The properties of graphene can be changed by doping the graphene surface to meet the application requirements.[6]

2.2 Application of graphene in optoelectronics

In many graphene optoelectronic applications, photovoltaic cells are one of the more mature applications. Graphene can be used as transparent conductive film, carrier transmission channel, photoactive material and catalyst in photovoltaic equipment.

Graphene is also often used in photoelectric detectors. Most photodetectors use the internal photoelectric effect, and the spectral bandwidth is affected by the material absorption rate. The absorption range of graphene can range from ultraviolet to terahertz, so the graphene photodetector can work in a very wide wavelength range.

Graphene can also be used in terahertz devices for terahertz detection and frequency conversion. The electrical and optical properties are regulated by external electric field or optical pumping.[7] This possibility makes single-layer graphene and few-layer graphene controllable for infrared radiation and terahertz radiation. Thus, the application equipment that may be derived includes regulator, filter, converter, beam splitter and polarizer.[8]

3. Design of graphene field effect tube photoelectric sensor

3.1 Principle Analysis of Graphene Photoelectric Sensing

The sensing range of the graphene field effect tube photoelectric sensor can be from visible light to terahertz wave, and its sensing principle is the result of the combined action of three working principles. These three working principles are photovoltaic effect, photoelectric effect and plasma resonance.

Photovoltaic effect is that the electrons in graphene are excited by light wave radiation to produce in-band or inter-band step, and then produce photocurrent. The relevant information of the incident light signal can be obtained by measuring the current signal at both ends of the conductive channel.

The photothermoelectric effect makes use of the strong correlation between electrons to make the photocarrier excited under terahertz radiation rapidly increase temperature. Since the temperature of the lattice changes slowly, changing the temperature of the photoexcited carrier can quickly drive the diffusion of electrons in the conductive channel. The relevant information of terahertz signal can be obtained by measuring the current signals at both ends of the conductive channel.

Plasma resonance is the plasma excitation in the conductive channel of the field effect tube caused by terahertz radiation, which forms resonance in the conductive channel. The relevant information of terahertz signal can be obtained by measuring the voltage or current signal in the conductive channel.

3.2 Structure design of graphene field effect tube device

(1) Buried grid structure

Different from the back-grating graphene field effect tube, the liquid-grating graphene field effect tube structure can directly use the measured solution as the gate medium, thus effectively improving the regulation efficiency of gate pressure.

In order to overcome the low efficiency of gate pressure regulation and the complexity of liquid gate structure design, this paper adopt the buried gate structure, as shown in figure 1.

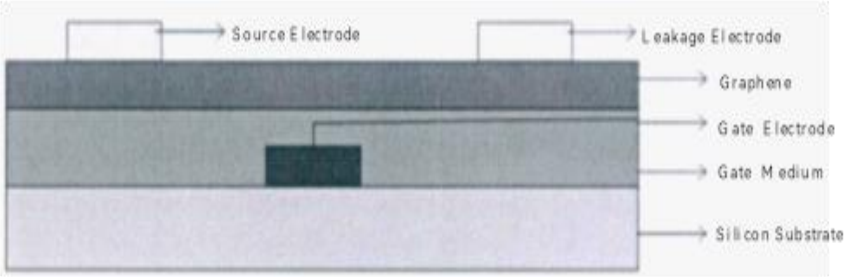

Figure 1: The schematic of buried-gate structure graphene field effect transistor structure

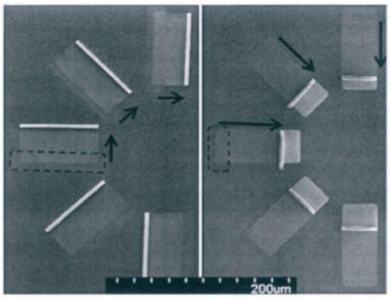

Figure 2: The image of silicon nitride double stress layer self-assembled

(2) Stress layer base

In this paper, in addition to the design and preparation of graphene field effect tube photoelectric sensor and its performance test, we also try to use the stress film self-assembly technology to optimize the planar structure of graphene field effect tube, that is, using the stress layer as the base skeleton of the device, the planar device is self-assembled into a three-dimensional device. Preparation of stress layers, as shown in figure 2.

3.3 Layout Design of Graphene Field Effect Tube

Due to the limitations of specific process flow, process level and engraved relationship, we need to follow certain design rules in the process of drawing layout. The minimum metal wire width, minimum metal spacing, tolerance between different masks and minimum slot width are required for the design rules of self-assembled graphene field effect tubes. Combined with the current process conditions in the laboratory and theoretical design, the layout design rules of self-assembled graphene field effect tube are determined as follows: minimum metal wire width: 6μm; minimum metal spacing: 4μm ; tolerance between different masks : 2μm; minimum groove width : 100μm.

The layout of the photoelectric sensor of the graphene field effect tube has a total of six layers, in which the partially transparent plate with pattern and the partially opaque plate without pattern becomes the dark field plate, and the partially opaque plate with pattern and the partially transparent plate without pattern becomes the bright field plate.

The alignment marks are set on the left and right sides of each independent unit chip. Rough alignment markers, fine alignment markers and fat and thin markers are set in alignment markers. In the process of lithography nesting, the lithography plate is aligned with the coarse alignment mark on the chip first, and the magnification of the observation is increased, then the fine alignment mark is used for alignment. After exposure and development, according to the fat and thin marks to determine the lithography process exposure and development time is appropriate.

4. Preparation of Graphene Field Effect Tube and Silicon Nitride Film Covering Process

4.1 Preparation process of graphene field effect tube

(1) Making sacrificial layer. Clean silicon wafer, use lithography, magnetron sputtering technology and stripping technology to prepare sacrificial layer.

(2) Making stress layer. Silicon nitride double-stress layer was prepared by plasma enhanced chemical vapor deposition technology, photolithography technology and reactive ion etching technology, and graphically.

(3) Fabrication of gate electrode. The gate electrode was prepared by lithography, magnetron sputtering and stripping techniques.

(4) Making dielectric layer. The SiO2 dielectric layer was prepared by plasma enhanced chemical vapor deposition technology, photolithography technology and reactive ion etching technology, and graphically.

(5) Transfer and graphical graphene. Transfer graphene material to dielectric layer and stress layer. Graphene without photoresist cover was etched by oxygen plasma etching technology with photoresist as barrier layer, and then the photoresist on the surface of graphene was cleaned by acetone to complete the transfer and graphics of graphene.

(6) Making source and drain electrodes. The gate electrode and leakage electrode were prepared by lithography, thermal evaporation or electron beam evaporation and stripping technology.[9]

4.2 Silicon Nitride Film Covering Process

Firstly, silicon nitride thin film was deposited on the surface of photoelectric sensor of graphene field effect tube by plasma enhanced chemical vapor deposition technology, with a thickness of 30 nm.

Then, lithography is performed on the independent cell chip that completes the film deposition. Use negative photoresist to leave the electrode plate figure out. After the chip was placed in a quartz box, it was placed in a high-temperature drying cabinet and dried at 120 ℃ for 30 min. After drying, take out the quartz box, drop into0.5mL hexamethyldisiloxane, photoresist adhesive treatment, the process lasted for10minutes. After the treatment, the negative photoresist NR9 - 3000PY was spin-coated on the surface of the chip using a bench leveler KW-4A. The rotational speed was set to be 700 r / min at low speed for 9 seconds, 4000 r / min at high speed for 40 seconds. After spin coating, the chip is placed on the hot plate and baked at 120 ℃ for 90 seconds to reinforce the photoresist. After homogenizing, Nanguang 2 - inch lithography machine was used to overprint and expose the independent unit chip. After adjusting the chip position and focus, the source electrode and the leakage electrode lithography plate are placed to align the coarse alignment and fine alignment of the left and right alignment marks. After the markers on both sides were aligned, they were exposed for 90 seconds. After exposure, the chip was placed on the hot plate and baked again at 120 ℃ for 90 seconds to further strengthen the photoresist. After baking, develop, develop liquid model RD-6, develop time is 70 seconds. After the development, the ionized water was used to wash out the residual developer rapidly, and then the chip surface was observed by optical microscope. Observe the alignment mark position and fat thin mark to determine whether exposure and development is appropriate.

After lithography, the chip front was etched by reactive ion etching machine NE-550 H for 10 to 11 seconds. The silicon nitride deposited on the electrode surface is etched in the etching process so that the subsequent external wiring can be wired.

After etching, the etched chip is immersed in acetone for 5 to 10 minutes, depending on the microscopic observation. If the color is too deep, the immersion time can be extended to 10 to 20 minutes.

After soaking, rinse the acetone attached to the chip surface with alcohol, and blow the alcohol with nitrogen. Then, the chip is put into the plasma degumming machine to continue the degumming process, the processing time is usually 10 minutes to 30 minutes. After the plasma degumming machine is processed, the chip surface is observed again by an optical microscope. If there is still photoresist residue, the plasma degumming machine is used to continue the degumming operation, and the processing time is from 15 min to 20 min each time. Repeat this process until the photoresist is completely removed.

5. Photoelectric Performance Test of Graphene Photoelectric Sensor

5.1 Photoelectric response test.

(1) Test system construction

Before using the graphite diluted liquid gate field effect tube device for photoelectric performance testing, we need to build a test circuit first. According to the structure of graphene field effect transistor, we design the test circuit. The source electrode and leakage electrode of the device are connected to the positive and negative ends of Agilent B2911 A semiconductor parameter tester. Since the response current generated by the graphene field effect tube irradiated by incident light should be tested in the circuit, no voltage is applied between the source electrode and the drain electrode. After the incident light is turned on, the leakage current is read by the semiconductor parameter tester. When the response current changes with the gate voltage, the positive electrode of the DC voltage source is connected to the gate of the graphene field effect tube, and the negative electrode is connected to the negative electrode of the semiconductor parameter tester. There is still no voltage applied between the source electrode and the leakage electrode. The current between source electrode and drain electrode is read by semiconductor parameter tester, and the change with gate voltage is observed.

(2) Photoelectric response test in visible range

Firstly, the incident light at 514 nm was tested using a graphene field effect tube. The power of incident light is measured by an optical power meter, and the maximum power of incident light is 4.0 mW. Under different incident light power, the response current of graphene field effect tube to 514 nm light is obtained, such as figure 3. The gate voltage is applied to the gate electrode, and the response current of the graphene field effect tube under different gate voltage is measured. The change of the response current with the gate voltage is analyzed, such as figure 4. It can be seen that both positive and negative voltages can amplify the response current. In contrast, the increase in negative voltage is greater. The analysis data show that when the gate voltage is − 2 V, the maximum responsivity is 1.03 mA / W. In addition, the response current at different positions in the conductive channel of graphene field effect tube was tested, such as figure 5. As the position of the conductive channel irradiated by the incident light changes, the response current also changes. The two points with the maximum response current are on both sides of the gate electrode in the middle of the conductive channel. The reason for this phenomenon is that the source electrode and the drain electrode of the graphene field effect tube designed in this paper are symmetrical. When the range of incident light is large, the current generated on both sides of the source electrode and the drain electrode is equal and the direction is opposite, which will offset each other. When the light strikes on both sides of the gate electrode, the power of the incident light in the conductive channel is larger. At the same time, the incident light focuses on the side of the source electrode or the leakage electrode, which makes the current collected by the electrodes on both sides biased, that is, the response current intensity becomes larger.

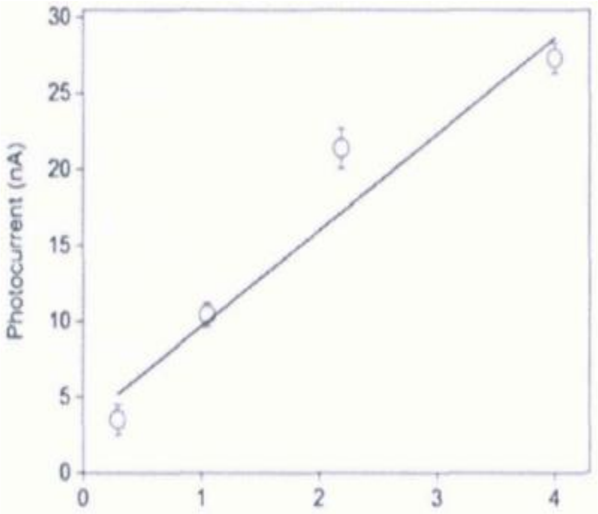

Figure 3: The photoelectric response of graphene FET to 514nm light to graphene FET changes with different power

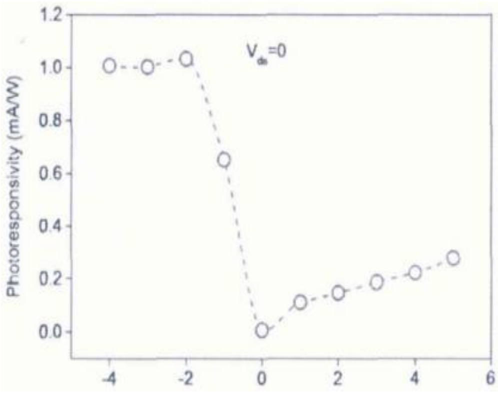

Figure 4: The photoelectric response of graphene FET to 514nm light as a function of gate voltage

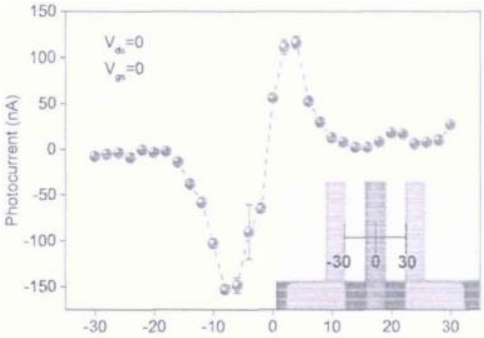

Figure 5: The photoelectric response of graphene FET to 514nm light changes with incident light position

After the photoelectric test of 514 nm visible light, 633 nm and 785 nm visible light were tested. The photoelectric response of graphene field effect tube under different power and different gate voltage were tested, such as figure 6 and figure 7. It can be seen that the graphene field effect tube designed in this paper has a response to the incident light wave in the visible band, and has a linear relationship with the incident light power. By applying voltage to the gate electrode, the response current can be amplified and regulated. Among them, the maximum response to 633 nm incident light is 1.2 mA / W, and the maximum response to 785 nm incident light is 6.3 mA / W.

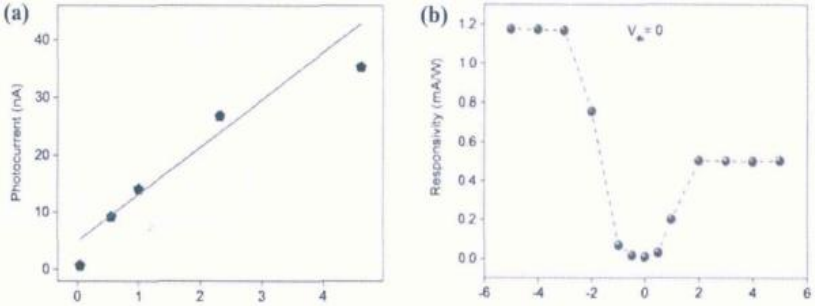

Figure 6: The photoelectric response of graphene FET to 633nm light

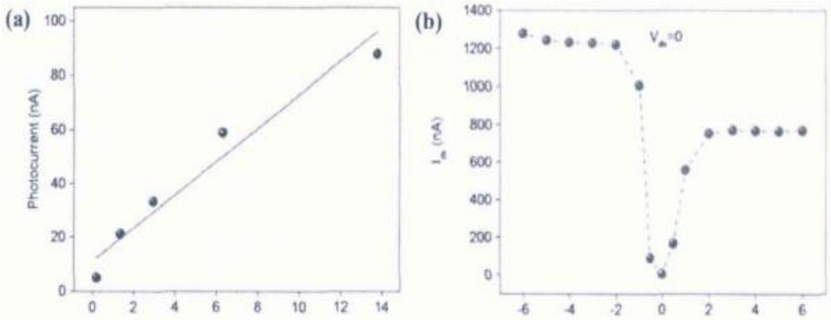

Figure 7: The photoelectric response of graphene FET to 785nm light

5.2 THz response test.

After the photoelectric test of the incident light in the visible light band, the graphene field effect tube is used to test the response of the incident microwave in the terahertz band. Similar to the test circuit structure of visible light photoelectric test, the terahertz wave response test also connects the source electrode and the drain electrode of the device to the positive and negative ends of the semiconductor parameter tester Agilent B2911 A, as shown in figure 8(a). During the test, after the incident light is turned on, the leakage current is read by the semiconductor parameter tester. Terahertz laser generator is used as the incident light source for testing, and the incident light wave is periodically on-off. The response current is observed by semiconductor parameter tester, as shown in figure 8(b). It can be seen that the graphene field effect tube also has a response current to the incident light wave in terahertz band, but the response intensity is relatively weak. The incident wave power is 63 mW, and the corresponding response is 0.254 mA / W. Compared with the visible wave segment, the response is still too small.

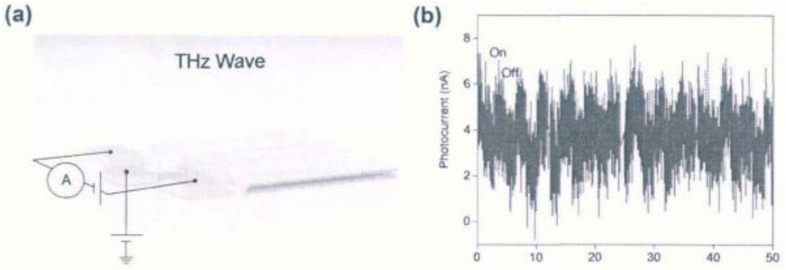

Figure 8: The schematic and test real-time variation of test circuit of THz wave with graphene FET

6. Conclusion

This paper mainly introduces the unique structure and excellent properties of graphene, and its application in the field of optoelectronics. As an important branch of sensor, photoelectric sensor plays a key role in the application of optical communication, imaging and detection. In order to meet the requirements of wide detection range, high responsivity, good environmental stability and easy preparation and integration, a buried-gate graphene field effect transistor photoelectric sensor based on silicon nitride double-stress layer, silicon dioxide as the dielectric layer and graphene as the sensitive material is fabricated in this paper, which provides a new direction and attempt for the development of photoelectric sensors and has a wide application prospect. The main work of this paper is as follows:

(1) The properties of graphene and its related applications in the field of optoelectronics are introduced in detail. The main research work and innovation points of this paper are summarized.

(2) The structural design of the graphene field effect tube photoelectric sensor is introduced in detail, and the corresponding preparation process and layout design are preset according to the actual process conditions.

(3) The preparation process of graphene field effect tube was introduced in detail, and the influence of film coverage on the protection of graphene devices and the related process are introduced.

(4) The photoelectric response of graphene photoelectric sensor was tested at different wavelengths. It is verified that the graphene field effect tube photoelectric sensor has a response current to the incident light in the visible light band and the incident light in the terahertz band, and the response current changes with the change of the incident light power, and the two show an approximate linear relationship. The voltage applied to the gate electrode can also amplify and regulate the response current.

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