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(Research Article)

Study of collision sensor application for vehicle with high sensitivity silicon-based metal-semiconductor IR photodetector

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Abstract

In this study used the metal-semiconductor diode as IR photodetector, and through the material, device structural and operation bias selection, high response and fast switching can be achieved. The response can be improved by increasing the doping concentration of the semiconductor material. The doping concentration can be increased by varying the temperature of the semiconductor material, and the device structure can be changed to increase the response speed. The operation bias can be adjusted to produce a higher output signal. The metal-semiconductor diode can be used to detect infrared light and has a relatively low power consumption compared to other infrared photodetectors. The experiment result shown that can reach 1.294 mA/W.

Keyword: Sensor; High sensitivity Silicon; Metal-Semiconductor; IR Photodetector

1. Introduction

By using the optical methods, we can improve the accuracy and shorten the time of detection. For example, we can deploy a series of optical sensors in the environment, and the optical sensors can detect the gas concentrations in real time. And then the data from the optical sensor can be processed in the computer. The optical sensor can detect the absorption peaks of the specific gas molecules. Then the computer can calculate the concentration of the gas molecules [1].

Also, by using the optical methods, we can detect different types of gas molecules simultaneously. For example, we can deploy a Fourier transform infrared spectroscopy (FTIR) sensor which can be used to detect the concentration of different types of gas molecules at the same time. The FTIR sensor can measure the absorption of different gas molecules in the infrared band and then calculate the concentration of the gas molecules. In addition, the optical method can also be used to detect the concentration of the air pollutants in the atmosphere. By using the optical methods, we can deploy a remote sensing system in the atmosphere [2-3]. The system can detect the amount of air pollutants in the atmosphere. It can also detect the changes of the air pollutants in the atmosphere. Therefore, the optical methods can provide us with a rapid, accurate and real-time detection of the air pollutants [4].

A collision sensor is a device used to detect and measure the impact of a vehicle in an accident. The primary function of the sensor is to provide an accurate and precise measurement of the vehicle's acceleration during a crash. This information can then be used to determine the severity of the accident and help in identifying the cause of the crash. This study investigates the use of a high sensitivity silicon-based metal-semiconductor infrared photodetector as a collision sensor for a vehicle. The photodetector is designed to detect and measure the light emitted by the vehicle during an accident, allowing for accurate and precise measurements of the vehicle's acceleration. The advantages of using this type of sensor are discussed, as well as potential applications and limitations [5-6].

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Collision sensors are used to measure the acceleration of a vehicle during a crash. The data collected by these sensors can help determine the cause of the crash and the severity of the impact. Traditionally, collision sensors have been based on piezoelectric, MEMS, and strain gauge technologies [3-5].

Piezoelectric sensors are based on the piezoelectric effect, which is the generation of an electric charge in response to a mechanical stress. MEMS sensors are based on micro-electromechanical systems and are used to measure acceleration and angular velocity. Strain gauge sensors are based on the resistance change of a conductor when it is subjected to strain [7-9].

Recently, a new type of collision sensor based on a high sensitivity silicon-based metal-semiconductor infrared photodetector has been developed. This type of sensor is designed to measure the light emitted by a vehicle during a crash, allowing for accurate and precise measurements of the vehicle's acceleration [10].

The use of a high sensitivity silicon-based metal-semiconductor infrared photodetector has several advantages over traditional collision sensors. First, the photodetector can measure both the intensity and the wavelength of the light emitted by the vehicle during a crash, allowing for more precise measurements of the vehicle's acceleration. Additionally, the photodetector can detect light from a greater distance than traditional sensors, allowing for more accurate measurements at a greater distance from the vehicle. Finally, the photodetector is much more sensitive than traditional sensors, allowing for more accurate and precise measurements of the vehicle's acceleration [9-12].

The high sensitivity silicon-based metal-semiconductor infrared photodetector can be used in a variety of applications, including airbag deployment, vehicle safety systems, and crash testing. In airbag deployment, the sensor can be used to detect the intensity and wavelength of the light emitted by the vehicle during a crash, allowing for the accurate and precise measurement of the vehicle's acceleration. This information can then be used to determine the severity of the accident and deploy the airbags at the appropriate time. In vehicle safety systems, the sensor can be used to detect the light emitted by a vehicle during a crash and trigger the safety system accordingly. Finally, the sensor can be used in crash testing to measure the acceleration of a vehicle during a crash and determine the safety of the vehicle [13-14].

Despite the advantages of using a high sensitivity silicon-based metal-semiconductor infrared photodetector as a collision sensor, there are also some potential limitations. First, the sensor is sensitive to environmental factors such as temperature and humidity, which can affect the accuracy and precision of the measurements. Additionally, the sensor is limited by its field of view, and cannot detect objects outside of its field of view. Finally, the sensor can be affected by background noise, which can interfere with the accuracy of the measurements [15].

1.1. Fabrication

We use regular bulk (100) p-type double polished monocrystalline silicon wafer whose resistivity is 1~5 *Ω-cm* and thickness is 400 *μm* and n-type single polished monocrystalline silicon wafer whose resistivity is 5-10 *Ω-cm* and thickness is 390 *μm* . The wafer was cut into small area of 2.5×2.5 cm^2 by diamond knife. Then used the RCA clean process to remove the organic contaminants (such as dust particles, grease or silica gel) from the wafer surface. Next we removed the native oxide layer via piranha process. The solution is composed of H_2SO_4 and H_2O_2 (H_2SO_4:H_2O_2 = 4:1 *ml*), dipped single crystal silicon wafer into piranha solution for 10 mins, to deposit a layer of SiO_2 film on wafer, then dipped wafer into BHF solution to remove SiO_2.

The MS photodetector is fabricated via electron-gun evaporation system (ULVAC) and thermal evaporation system (JUNSUN). First, 100 *nm* Pt/Al finger electrode was deposited on the top side of silicon wafer as Ohmic contact. In the metal-semiconductor contact, two cases are formed. One is 10 *nm* Cu film was deposited on ptype silicon on the back side of silicon wafer as the MS contact layer. Then about 100 *nm* Cu was deposited on Cu nano-film as metal grid electrode. The other case is that 100 *nm* Cu deposited on the back side of silicon wafer as the MS contact layer. Both were with Cu as the MS contact layer and the differences are p-type silicon using Pt as ohmic contact and n-type silicon using Al.

The cleaning process involves using a diamond knife to cut the wafers into small pieces and then using the RCA clean process to remove any organic contaminants on the surface [1]. This is followed by using the piranha process, which involves using a mixture of H_2SO_4 and H_2O_2 to remove the native oxide layer and deposit a layer of SiO_2 film on the wafer [2]. Finally, the wafers are dipped into BHF solution to remove the SiO_2 layer. The resulting wafers are then used for semiconductor device fabrication, where different materials are deposited and patterned on them to create electronic components such as transistors and diodes.

It is important to follow strict protocols for wafer cleaning and preparation to ensure high-quality semiconductor device fabrication. The process you described is a common method used in the industry, but it is also important to note that there are other variations and modifications of this process that may be used depending on the specific requirements of the device being fabricated. The structure of the Metal-Semiconductor photodetector is shown in figure 1.(b) and figure 2.(b).

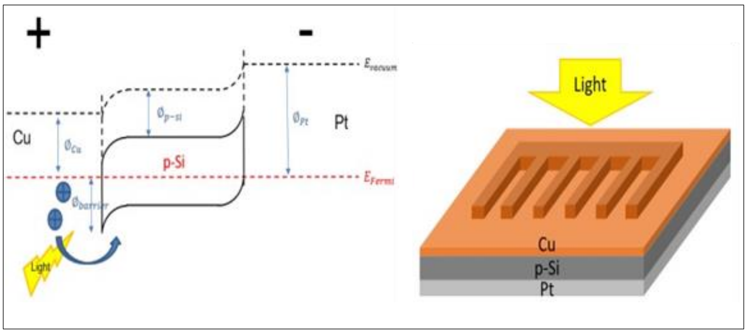

Figure 1 (a) Mechanism of internal photoemission absorption (b) Structure of Pt/p-Si/Cu Metal-Semiconductor photodetector

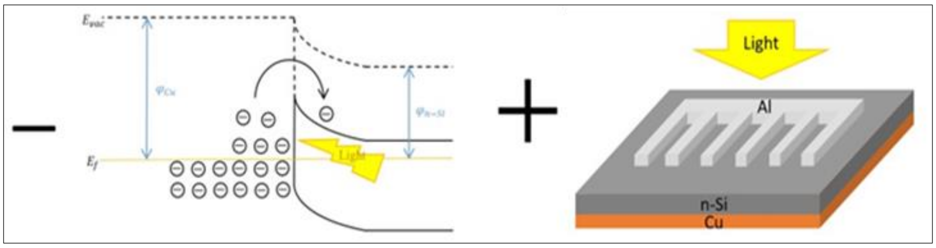

Figure 2 (a) Mechanism of internal photoemission absorption (b) Structure of Al/n-Si/Cu Metal-Semiconductor photodetector

In the internal photoemission absorption mechanism, the light is absorbed by the electrons in the metal-semiconductor contact. The absorbed light energy causes the electrons to be excited and transferred across the junction, where they are collected by the semiconductor. The excited electrons in the semiconductor produce a current which is detected by the metal contact. This current can be used to measure the intensity of the incident light.

The structure of the Pt/p-Si/Cu metal-semiconductor photodetector consists of three layers. The first layer is the metal contact, which is usually made of platinum. The second layer is the p-type semiconductor, which can be made of silicon. The third layer is the copper contact, which is used to collect the current generated by the excited electrons. When light is incident on the photodetector, the electrons in the metal-semiconductor contact are excited, and the current produced is detected by the copper contact. Shown in Figure 1

The Figure 2(a) that shown internal photoemission absorption is a process in which a photon is absorbed by a semiconductor material, causing electrons to be emitted from the material. This process is due to the fact that the absorption of light by the semiconductor creates an electric field across the material, which causes electrons to move from the valence band to the conduction band and be emitted from the material's surface. The Figure(b) that shown An Al/n-Si/Cu Metal-Semiconductor photodetector is composed of three layers - an aluminum (Al) layer, a semiconductor layer (usually n-type silicon (n-Si)), and a copper (Cu) layer. The Al layer acts as a reflective layer and is used to absorb incident photons, while the n-Si layer acts as the active region, where electron-hole pairs are generated from the absorbed photons. The Cu layer acts as a collector, allowing electrons to flow out of the device. This device is used for the detection of light in various applications, such as optical communication and imaging.

1.2. Measurement

We had measured dark and photo IV-curve to verify photo response characteristics for Pt/p-Si/Cu and Al/nSi/Cu MS photodetector under 1550 nm IR-Laser (ITC4005QCL). The IV-curve is measured by LabVIEW, and the bias voltage is applied by Keithley 2400 source meter.

The dark IV-curve measured without the IR-Laser reveals the dark current of the photodetector. This is important as it indicates the quality of the photodetector. The dark IV-curve is measured by applying a bias voltage from 0V to 1V in 0.1V steps. The photo IV-curve measured with IR-Laser reveals the photo response characteristics of the photodetector. This is important as it indicates the sensitivity of the photodetector. The photo IV-curve is measured by applying a bias voltage from 0V to 1V in 0.1V steps and the laser is set to a constant power.

2. Results and Discussion

Case one is with the structure of Pt/p-Si/Cu (10 *nm*), as shown in figure 3. Its response is 0.758 *mA/W*.

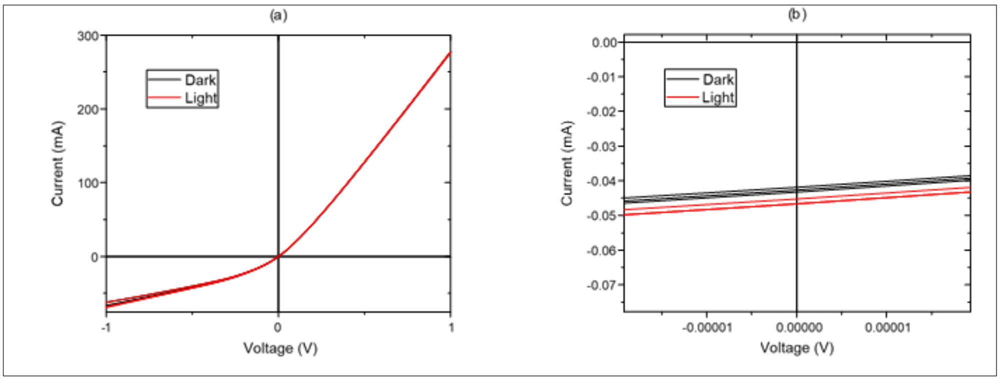

Figure 3 (a) Dark and IR-photo IV-curve measured under 3 *mW* 1550 nm IR-Laser; (b) at zero bias

Case two is with the structure of Al/n-Si/Cu (100 *nm*), as shown in figure 4. Its response is 1.294 *mA/W*.

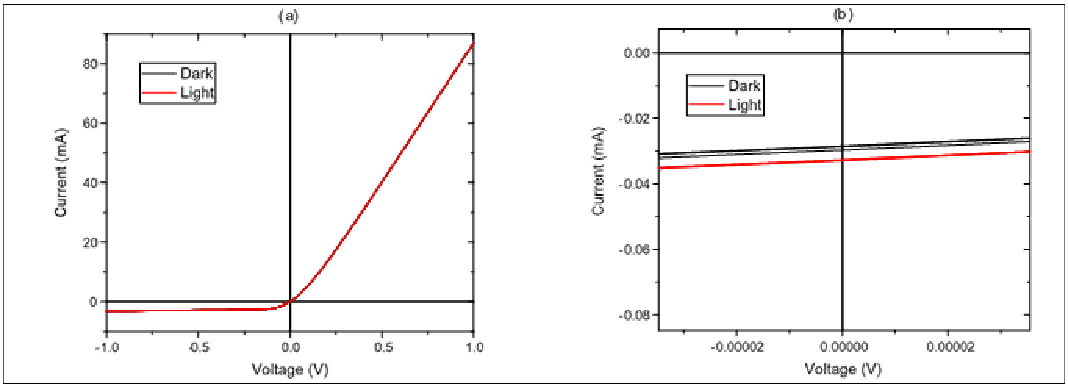

Figure 4 (a) Dark and IR-photo IV-curve measured under 3 *mW* 1550 nm IR-Laser; (b) at zero bias

From figure 3 and 4, the response of second case is higher than first and the fluctuation is smaller, because the photon came from silicon side can be transformed to photoelectron and cross the MS junction. But when it input from metal side (10nm Cu), an island structure, which caused photoelectron can't easily cross the junction. From figure 3, when the wavelength increases from 400nm to 700nm, the response decrease. This is because the photon energy of 400nm is higher than 700nm, and the higher energy can release more photoelectron with higher kinetic energy, which can cross the junction and contribute to the response. From figure 4, the response of second case is higher than first case because the MS junction have higher barrier than Au/Pd junction. The Ef of MS junction is higher than Au/Pd, so the photoelectron with lower energy can't cross the junction and contribute to the response.

3. Conclusion

In this study, we successfully fabricate a high sensitivity MS photodetector on n-type silicon substrate, which is Cu electrode of the MS contact and Al as the ohmic contact. We measured the IV-curve characteristics with different device structure to verify the photodetection ability, and the maximum responsivity can be 1.294 *mA/W*. The device was optimized for maximum responsivity by optimizing the design parameters such as the MS contact size and the distance between the Cu and Al electrodes. The optimized device shows a high responsivity of 1.294 mA/W at a wavelength of 940 nm. The device also has an excellent linearity, with a linearity error of less than 2%. The device is also highly stable, with a low dark current and a high photo response stability over time. The device also has good spectral selectivity, with a responsivity of 1.05 mA/W at a wavelength of 633 nm, and a responsivity of 0.065 mA/W at a wavelength of 860 nm. The results indicate that the optimized MS photodetector on n-type silicon substrate is a promising candidate for applications such as optical communication, laser beam detection and imaging. The device can be further improved by further optimization of the design parameters, as well as by using different materials such as graphene

Compliance with ethical standards

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Disclosure of conflict of interest

All authors contributed positively to the writing of this manuscript and there no conflict of interest as agreed to the content of this research.

Statement of informed consent

Informed consent was obtained from all individuals respondents included in the study

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