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Study on Responsivity of Photodetector Corresponding to Resistivity Difference

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Abstract

This article discussed the responsivity of quadrant detector corresponding to resistivity difference.Silicon wafers of various resistivity are used to make quadrant detectors, and the responsivity of these detectors are measured.There sultsindicate that the better responsivity under low working voltage is corresponding to a higher resistivity.

Keywords

Resistivity; Photodetector; Responsivity.

1. Introduction

A silicon photodetector photosensitive chip is a photon detector that can convert the photon radiation received by the detector into electrical parameters such as current and voltage that are easier to directly measure. Silicon photodetector photosensitive chip is based on the photoelectric effect of silicon material to detect light radiation. The process is that incident photons directly transfer energy to electrons, causing the electrical properties of the material to change [1]. Silicon four-quadrant detector is a common photoelectric sensor, which has the characteristics of high responsivity, short response time, high position resolution, and wide spectral response range [2]. Photoelectric detection system has a wide range of applications, especially in the application of laser guidance has been very mature. For example, in 1991, the US Air Force first used a missile code-named "Copperhead"[3,4], in which the laser pointer used a silicon four-quadrant detector as a laser receiver. The hit accuracy of the copperhead can reach 0.4 m. The "Rahat" gun-launched missile developed by Israel's MBT Company, the important light-receiving module of its missile head is also a silicon four-quadrant photoelectric detector.

Among the parameters that affect the performance of the detector, the impulse responsivity is very important to the performance of the photosensitive chip. This is because in the field of laser guidance, improving the responsivity means increasing the range of the missile, which can hit farther targets. Strategically Get a huge advantage. Therefore, how to improve the impulse responsivity of the photosensitive chip is an important task.

2. Principle of the Photosensitive Chip

The working mechanism of photosensitive chips is mainly to use the photovoltaic effect of silicon materials. When the photosensitive chip is illuminated, as long as the photon energy E is not less than the forbidden band width Eg of the silicon material, the photons will interact with the electrons and transfer the photon energy to the electrons. After the electrons obtain enough energy, they can transition to the conduction band, while A hole appears in the original position, forming an "electron-

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hole" pair, and these electron holes can participate in conduction. Therefore, the conductivity of the silicon material changes, and the resulting current is formed under the action of the bias voltage, and the incident light energy is converted into electricity.

When the laser irradiates the photosensitive surface of the four-quadrant photodetector, due to the existence of the isolation groove, the laser spot will be divided into four parts A, B, C, and D, as shown in Figure 1. When a laser beam illuminates the photosensitive surface, the light energy of the four parts is converted into electrical signals respectively, and the output electrical signals pass through the back-end processing circuit to obtain the center position of the laser spot. When used for laser-guided weapons, it is necessary to integrate the four-quadrant detector with the servo drive device. By adjusting the tail in the device, the deviation of the laser spot center from the coordinate origin can be continuously reduced until the spot center coincides with the coordinate origin, that is, four The quadrant detector is facing the tracking target. In this way, the target can be locked, and the requirements such as guidance and hitting the target can be completed.

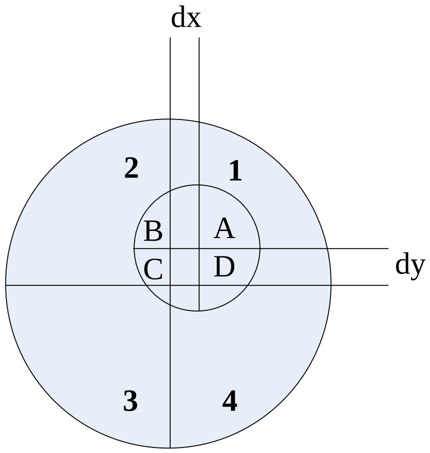

Figure 1. Surface spot of four-quadrant photodetector

3. Analysis of Influence of Silicon Wafer Resistivity on Impulse Responsiveness of Photosensitive Chips

The responsivity of the photodetector reflects the ability of the photodetector to convert the optical signal into an electrical signal, which is defined as: under the irradiation of the incident light of a certain power and a specific wavelength, the photocurrent IP generated by the photodetector and the optical power of a specific wavelength The ratio of P, the formula is expressed as:

$$R = \frac{I_p}{P} = \frac{q\lambda_0}{hc}\eta_0 = \frac{q\lambda_0}{hc}(1-R_f)e^{-\alpha(\lambda)d}(1-e^{-\alpha(\lambda)w}) \tag{1}$$

Where q is the electron charge, is the quantum efficiency, h is Planck's constant, λ is the wavelength of the incident light, and c is the speed of light.

It can be seen from the formula that the responsivity of the photodetector is related to the quantum efficiency and the incident wavelength. To improve the DC responsivity of a certain wavelength, it is necessary to improve the quantum efficiency of the wavelength.

The responsivity value calculated by this formula actually refers to the responsivity of the photodetector photosensitive chip under the illumination of a specific wavelength of DC light, but in practical applications, especially in laser guidance applications, the detector uses pulsed pulses. Light is used to illuminate the surface of the photosensitive chip of the silicon photodetector. Since the pulse width used is only 10ns to 20ns, and the duty cycle is usually 1‰ to 1%, the photons are incident into the photosensitive chip of the silicon photodetector to generate photogenerated carriers (electrons). -hole pair), because the irradiation time is too short, the photogenerated carriers have not reached the saturation state, and the periodic pulsed laser has already entered the state without light, as shown in Figure 2.

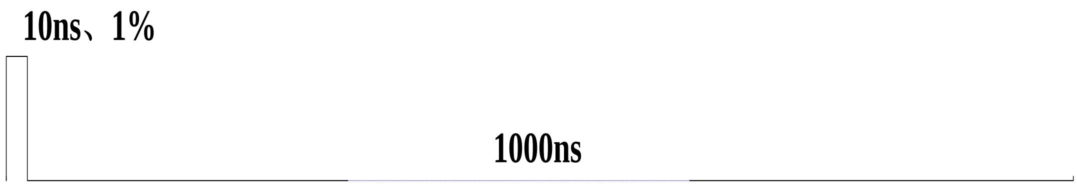

Figure 2. Schematic diagram of pulsed laser with 1% duty cycle

In addition, the silicon four-quadrant photodetector usually works at a relatively low voltage, which is between the pass-on voltage and the carrier saturation drift velocity voltage. The photogenerated carriers have not yet reached the saturation drift velocity under the bias voltage, so the measured The narrow pulse width pulse responsivity of the photodetector photosensitive chip is only 20% to 50% of the DC responsivity.

The minority carrier lifetime of a silicon wafer is closely related to the resistivity, as shown in the following formula,

$$\tau_p = \left[7.8\times10^{-13}N_D + 1.8\times10^{-31}{N_D}^2\right]^{-1} \tag{2}$$

$$\tau_n = \left[3.45\times10^{-12}N_A + 9.5\times10^{-32}{N_A}^2\right]^{-1} \tag{3}$$

The higher the resistivity of the silicon wafer, the longer the corresponding minority carrier lifetime. Similarly, the lifetime of the photogenerated carrier is also longer. Under the same working voltage, the distance it travels per unit time is farther, reaching the silicon four. The more photogenerated carriers at the positive and negative poles of the quadrant photodetector, the higher the responsivity.

4. Comparison of Photosensitive Chips Prepared with Different Resistivity of Silicon Wafers

In the experiment, 3 groups of silicon wafers with different resistivities (each group of 5 pieces) were selected for the preparation of photosensitive chips. The resistance tester is a destructive test, so after each group of silicon wafers are tested by a four-point probe tester, a piece with moderate resistivity is selected for the extended resistance test, and then the remaining 12 silicon wafers are formed into a batch for simultaneous testing. Preparation of photosensitive chips.

The four-probe test results of the three groups of silicon wafers are shown in Table 1:

Table 1. Four-probe test results

Group 1		Group 2		Group 3	
No	Resistivity/Ωcm	No	Resistivity/Ωcm	No	Resistivity/Ωcm
L1	5210	M1	12036	H1	18753
L2	5348	M2	11824	H2	17941
L3	5384	M3	11079	H3	17352
L4	5105	M4	13214	H4	18628
L5	5277	M5	12443	H5	18424

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Select L2, M1, and H5 respectively to test the expansion resistance. The test results are as follows:

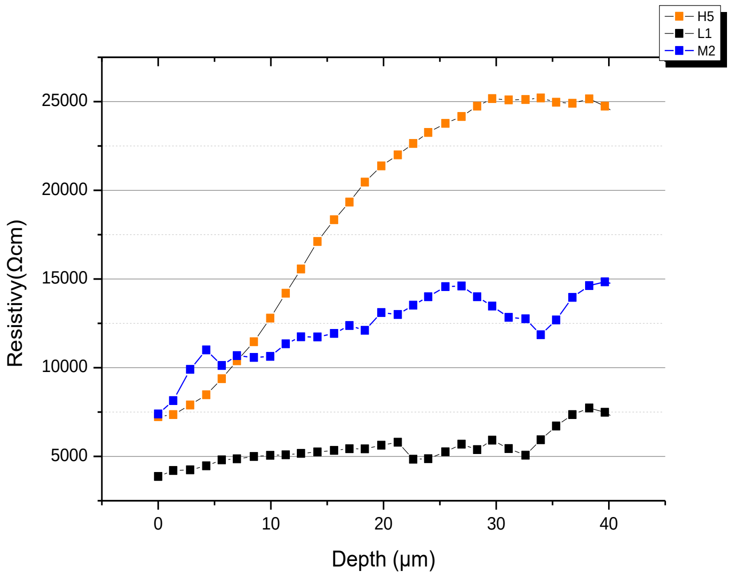

Figure 3. Extended resistance test curve of L2, M1, H5

Table 2. The average value of expansion resistance of L2, M1, H5

Average resistivity of L2 silicon wafer 0~30μm	5464.99Ωcm
Average resistivity of M1 silicon wafer 0~20μm	12274.98Ωcm
Average resistivity of H5silicon wafe 0~40μm	18854.09Ωcm

The remaining 12 silicon wafers are prepared together for photosensitive chips. After the preparation is completed, the qualified photosensitive chips on each silicon wafer are selected for the pulse responsivity test. The test adopts the circuit shown in the figure below, where the pulse light source wavelength is 1060nm, The pulse width is 20ns, the period is 1ms, the average power is 200nW, the resistance value of the sampling resistance is 55.4Ω, and the test voltage is 50V.

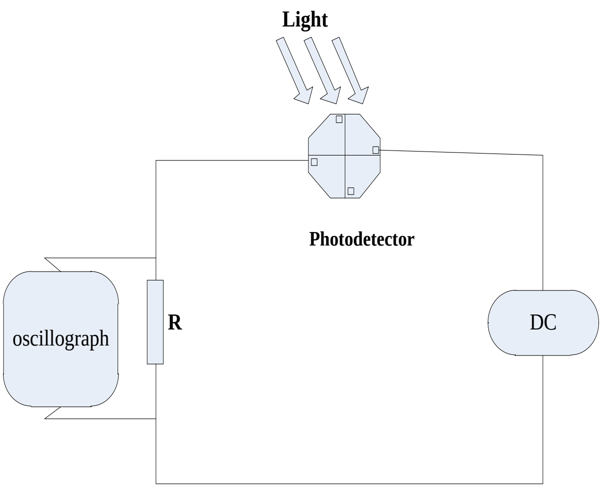

Figure 4. Schematic diagram of impulse responsivity test

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The pulse responsivity test results of 12 photosensitive chips with different resistivity under 50V bias are as follows:

Table 3. 1064nm optical impulse responsivity test results

Group 1		Group 2		Group 3	
No	Impulse Responsiveness(A/W)	No	Impulse Responsiveness(A/W)	No	Impulse Responsiveness(A/W)
L1	0.052	M2	0.1404	H1	0.1794
L3	0.0541	M3	0.1393	H2	0.1689
L4	0.0489	M4	0.1414	H3	0.1689
L5	0.053	M5	0.1404	H4	0.1775
Mean	0.052	Mean	0.14037	Mean	0.17367

5. Conclusion

Starting from the working principle of the photosensitive chip, the theoretical analysis of the narrow pulse width pulse response of the photosensitive chip by the resistivity of the silicon chip is carried out, and three groups of silicon wafers with different resistivity are used to prepare the same photosensitive chip. Practical experiments have come to the conclusion that the higher the resistivity of the silicon chip, the higher the pulse responsivity of the narrow pulse width of the photosensitive chip.

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