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Experimental Investigation of Output Current Variation in Biased Silicon-based Quadrant Photodetector

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We report on the relationship between output current for quadrant photodetector (QPD) and bias voltage in silicon-based p-i-n (positive-intrinsic-negative) QPD examined using millisecond pulse laser (ms pulse laser) irradiation. The mechanism governing the relationship was further studied experimentally. The output current curves were obtained by carrying out QPD under different bias voltages (0-40 V) irradiated by ms pulse laser. Compared to other photodetectors, the relaxation was created in the output current for QPD which is never present in other photodetectors, such as PIN and avalanche photodetector (APD), and the maximum value of relaxation was from 6.8 to 38.0 μA, the amplitude of relaxation increases with bias value. The mechanism behind this relaxation phenomenon can be ascribed to the bias voltage induced Joule heating effect. With bias voltage increasing, the temperature in a QPD device will increase accordingly, which makes carriers in a QPD move more dramatically, and thus leads to the formation of such relaxation.

Keywords : Photodetectors, Laser-induced, Quadrant photodetector, Output current, Bias voltage
OCIS codes : (040.5160) Photodetectors; (040.6040) Silicon; (140.3330) Laser damage; (140.3440) Laser-induced breakdown; (140.3538) Lasers, pulsed

I. INTRODUCTION

Particularly in the past few years, photodetectors are widely applied with great advantage in various military and civilian areas, such as laser beam detecting [1], laser detection and ranging (LADAR) [2]. However, a photodetector is more likely to be damaged from absorbing energy in an optical system than other devices, when it is located at the focal plane of the optical system with laser energy high enough to influence its performance. Therefore, the study of laser-photodetector interaction has turned into an important part of scientific research.

Experimental research progress in the laser-photodiode interaction field has been reported. For example, Li and Wang *et al.* [3-5] studied the laser-induced damage threshold (LIDT) of silicon for various pulse duration lasers. The conclusion that the electrical degradation threshold increased with junction depth was found. Watkins *et al.* [6] studied the effect of morphological damage on electrical degradation of PIN photodiodes. Shaw [7] found that some photodiodes could restore initial responsiveness after laser irradiation. Moeglin [8] and Vest [9] focused on the relationship between responsiveness of a photodiode and laser fluence. Silicon photodiodes are devices used as detectors. Dong *et al.* [10] provided a new method for the study of the internal doping concentration for biased detectors with millisecond laser damage, and the C-V curve of APD was obtained by using a semiconductor analyser experimentally. Wang *et al.* [11-16] studied deeply the laser interaction with biased silicon-based APD on the basic of photodiode characteristics. They found that the Joule heat was created in an APD, and they obtained the output current for an APD and a PIN with the same trend, as shown in Fig. 1. In conclusion, the present experimental researches are mainly focused on the damage threshold of photodiodes

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and the output current for single-cell photodiodes. What is more noteworthy is that the influence of the parameters in the external circuit on its output current is not taken into account. However, in the process of using a photodetector, bias voltage is an important parameter. The effect of different external biased values on the output current of a photodetector need to be studied.

QPD [17, 18] is used to detect an optical spot position [19] in an optical system with many unique characteristics, for example, low noise, high sensitivity in detecting, high postural distinguishability, low detector error and low operating voltage [12]. However, there are few experimental studies about biased QPD irradiated by laser. In this paper, millisecond pulse laser-induced output current variation for biased silicon-based QPDs are investigated experimentally. The result shows that the output current curve generated

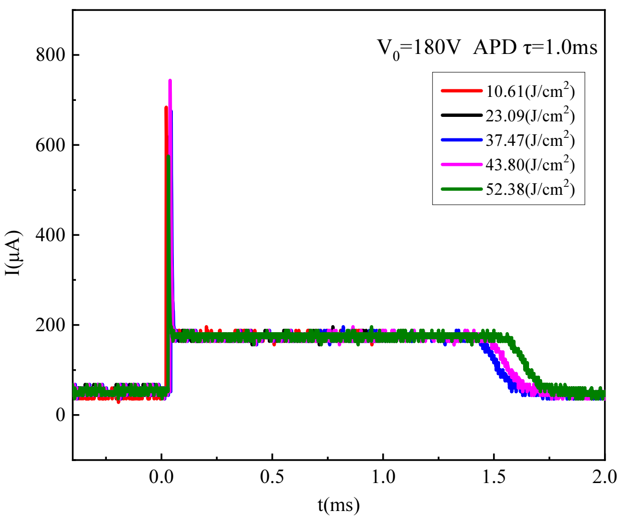

FIG. 1. The output current for an APD with 180 V versus laser fluence when irradiated with laser pulses under 1.0 ms.

relaxation after laser irradiation ended, the phenomenon was different from that for other photodiodes. the mechanism responsible for this phenomenon was the effect of temperature rise on the moving carrier.

II. EXPERIMENT

The experimental setup was shown in Fig. 2 [12]. An Nd: YAG laser (1064 nm) with a 10 *J* maximum output and 0.5 to 3.0 ms pulse width was used in the experiments. The pulse repetition rate was manually adjusted from 1 to 10 Hz. A beam-splitter was used to divide the laser beam, the output from the beam splitter was sent to an energy meter and to a focusing lens with a 15 cm focal length. In the experiment, the pulse width was set to 1.0 ms. The laser beam diameter is about 570 μm at the focal point. The laser beam center is located at the diagonal line on one cell (CELL 1) of the QPD. The laser fluence was kept in the range of 15-16 J/cm^2 under the electrical damage threshold. When the laser beam interacts with QPD, the temperature of the beam center was obtained by a pyrometer. Tektronix PWS2721 DC Power Supply was applied. The bias voltages were set at 0, 10, 20, 30, and 40 V under the operating voltage to analyze the influence of bias voltage on QPD. The oscilloscope was used to display the output current for the QPD. The experiment was performed at room temperature in air under normal atmospheric pressure.

The structure of a sample p-i-n QPD is shown in Fig. 3. QPD is coated by a Si_3N_4 standard antireflection film. The QPD was arranged with a heavily doped p-type region, n-type I-region, and a heavily doped n-type region. In contrast to other typical photodiodes, in a QPD the p-type region can be divided into four independent cells. The cross region of a QPD divides the p-type region into four independent cells which are connected with the I-region.

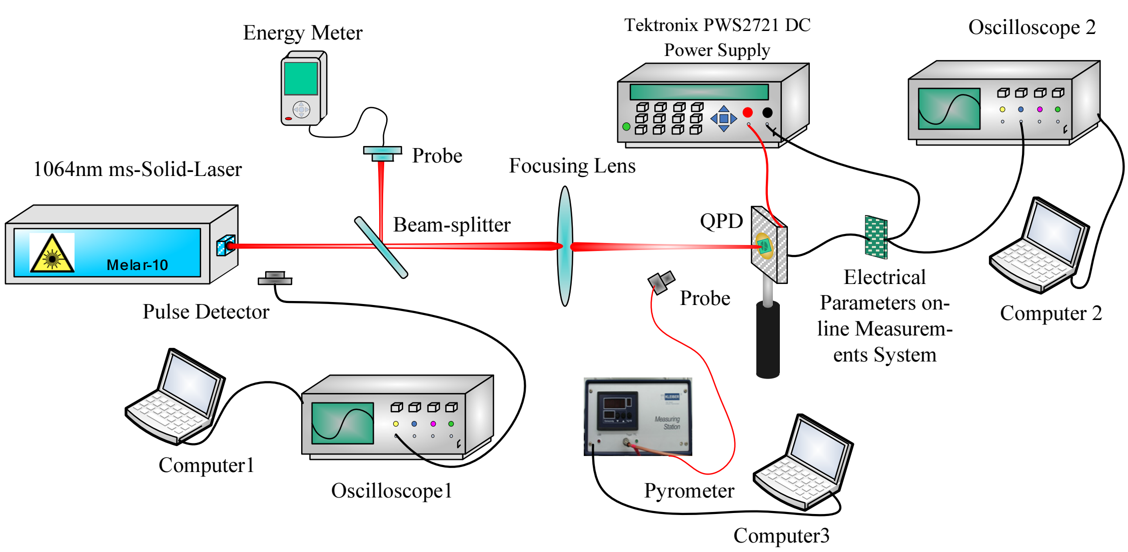

FIG. 2. Schematic showing the experimental setup.

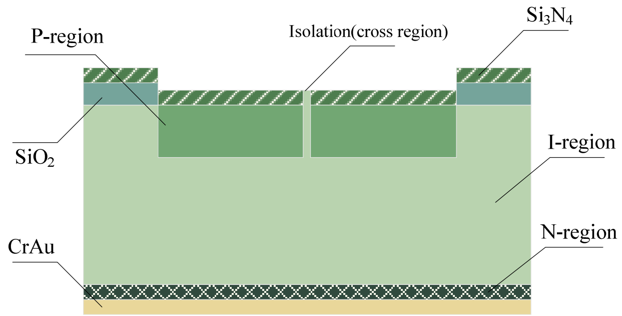

FIG. 3. Structure of a sample p-i-n QPD.

Moreover, the I-region of four cells and the cross region form a common substrate-layer together.

III. RESULTS

In the experiment, the output current for CELL 1 of QPD was measured when irradiated with 1.0 ms pulse laser at different bias voltages. The bias voltage was set at 0, 10, 20, 30, or 40 V, and the laser fluence was kept at about 15 J/cm^2. The experiment result is shown in Fig. 4.

When irradiated with 1.0 ms laser pulses at 15 J/cm^2, the 'Holding' current median was 13.2 μA, and the maximum value of relaxation in the output current for CELL 1 for QPD was 38.0 μA approximately when the bias voltage was set at 40 V. The 'Holding' current medians were 11.6 μA, 10.0 μA, 6.0 μA and 5.2 μA and the maximum values of relaxation were 31.6 μA, 18.8 μA, 9.2 μA and 6.8 μA approximately when the biased values were 30 V, 20 V, 10 V and 0 V, respectively. It is clear that the bias voltage in the external circuit impacts the output current for QPD during irradiation by ms pulse laser. So, it can be summarized that both the 'Holding' current median value and the maximum value of the relaxation in the output current for CELL 1 of QPD increase as bias voltage. Therefore, the bias voltage value in the external circuit has a great influence on the output current for the cell of the QPD irradiated by ms pulse laser, the output signal analysis and accurate positioning ability of QPD can be improved. The relaxation amplitude in the output current for CELL 1 of the QPD could also be suppressed by adjusting the bias voltage during laser irradiation.

However, as shown in Fig. 1, this relaxation in the output current has never been obtained for an APD or a PIN after laser irradiation [12, 16]. Therefore, we considered that this phenomenon could be explained only by the internal structure of a QPD and its interaction with bias voltage.

IV. DISCUSSION

According to the QPD's property, there is a main factor leading to the rise of QPD amplitude of relaxation: Joule heat and laser heating. When laser fluence is fixed, the effect of the ms pulse laser on a QPD is constant. When there is bias voltage in the external circuit, the laser-induced carrier is swept away by the electric field formed rapidly in the external circuit, and a large instantaneous current is formed inside the QPD, which leads to more Joule heat. Joule heat affects the internal temperature rise of the QPD directly. So, the higher temperature the QPD rises to, the greater the carrier move per unit time, the more obvious the relaxation phenomenon that will be generated [20, 21]. Therefore, at 40 V, the extent of relaxation in output current for CELL 1 of QPD irradiated by laser is the highest.

As shown in Fig. 4, the 'Holding' current median value increases as the bias voltage in the external circuit, the reason for this result is the mentioned potential difference at ends of the p-n junction. In addition, the hole and electron can be swept, and respectively accumulate at the ends of the p-n junction, resulting in the potential difference formed at the p-n junction [21, 22]. The potential difference also increases as the external biased value increases, and it can affect the 'Holding' current. Therefore, when the bias voltage value is set at 40 V, the 'Holding' current for CELL 1 of the QPD is higher than for the others.

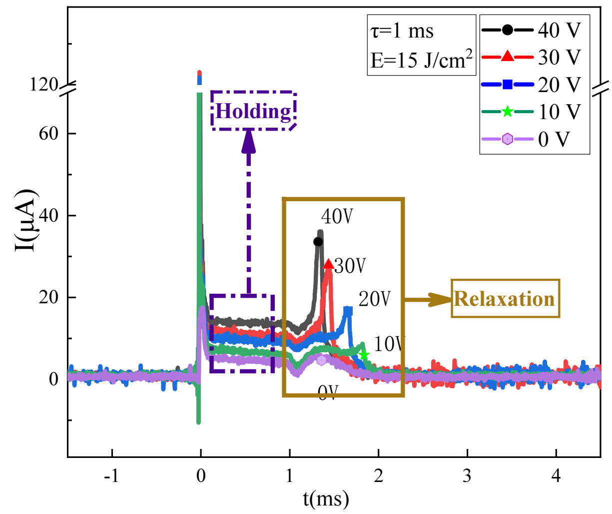

FIG. 4. The output current for CELL 1 of QPD versus bias voltage when irradiated with laser pulse of 15 J/cm^2 and 1.0 ms.

V. CONCLUSION

In conclusion, the output current for the laser beam-located cell of the QPD is studied experimentally when a biased silicon-based p-i-n QPD is irradiated by ms pulse laser. This result shows that the relaxation amplitude in the output current for CELL 1 of the QPD increases with the bias voltage value, the reason is that the output current variation could reflect the change of carrier movement, when the bias voltage is set in the external biased circuit, the temperature rises in a QPD, leading to violent carrier movement. The amplitude increases with the bias voltage because the carrier moves more violently. 'Holding' current median value increases with the potential difference at the p-n junction caused by the increase of bias voltage. Therefore, this result fills the vacancy in the biased QPD irradiated by ms pulse laser, through the research of this present work, it lays a foundation for the unusual behavior of QPD in the external biased circuit, and it offers the basis for further study of detector anti-damage research.

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