

Photocurrent Characteristics of Gate/Body-Tied MOSFET-Type Photodetector with High Sensitivity

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Abstract

In this paper, the photocurrent characteristics of gate/body-tied (GBT) metal-oxide semiconductor field-effect transistor (MOSFET)-type photodetector with high sensitivity in the 408 nm – 941 nm range are presented. High sensitivity is important for photodetectors, which are used in several scientific and industrial applications. Owing to its inherent amplifying characteristics, the GBT MOSFET-type photodetector exhibits high sensitivity. The presented GBT MOSFET-type photodetector was designed and fabricated via a standard 0.18 μm complementary metal-oxide-semiconductor (CMOS) process, and its characteristics were analyzed. The photodetector was analyzed with respect to its width to length (W/L) ratio, bias voltage, and incident-light wavelength. It was confirmed experimentally that the presented GBT MOSFET-type photodetector has over 100 times higher sensitivity than a PN-junction photodiode with the same area in the 408 nm – 941 nm range.

Keywords: Gate/body-tied, Photodetector, MOSFET, Sensitivity, PN-junction photodiode, Wavelength

1. INTRODUCTION

As a tool for acquiring image information, a highly integrated and high-efficiency complementary metal-oxide-semiconductor (CMOS) image sensor can use various peripheral circuits for additional functions and has the advantage of low cost. Consequently, they are being used in various fields, and related research is being actively conducted [1-3]. Recently, among the main research fields of CMOS image sensors, photodetectors with high sensitivity have been actively studied with regard to their scientific and industrial applications, such as in light detection and ranging (LiDAR), time-of-flight (ToF), 3D imaging and fluorescence lifetime-imaging-microscopy systems [4-7].

Single photon avalanche photodiodes (SPADs), which operate in an avalanche mode above the breakdown level, have

been used for similar purposes. SPADs can be fabricated using the CMOS technology, however, they have the disadvantage of possessing a large pixel area and requiring a high supply voltage. Moreover, to manufacture a high-resolution image sensor based on SPADs, quenching circuits and time-to-digital converter circuits are essential, making the signal processing complicated [8-11].

In this paper, a gate/body-tied (GBT) metal-oxide semiconductor field-effect transistor (MOSFET)-type photodetector possessing a small pixel area and requiring a low supply voltage with high sensitivity in the 408 nm – 941 nm range is presented. Previously, it was confirmed that the GBT MOSFET-type photodetector exhibits high sensitivity to blue (473 nm), green (533 nm) and red (633 nm) light, owing to its inherent amplifying characteristics [12]. In this study, a GBT MOSFET-type photodetector was designed and fabricated via a standard 0.18 μm CMOS process. In the analysis, the photocurrent characteristics of the GBT MOSFET-type photodetector with respect to source voltage, width to length (W/L) ratio, and incident-light wavelength were measured. In addition, the photocurrent characteristics were compared with those of a PN-junction photodiode with the same area in the 408 nm-941 nm range.

2. PRINCIPLE OF OPERATION

Fig. 1 shows the vertical structure of a GBT MOSFET-type

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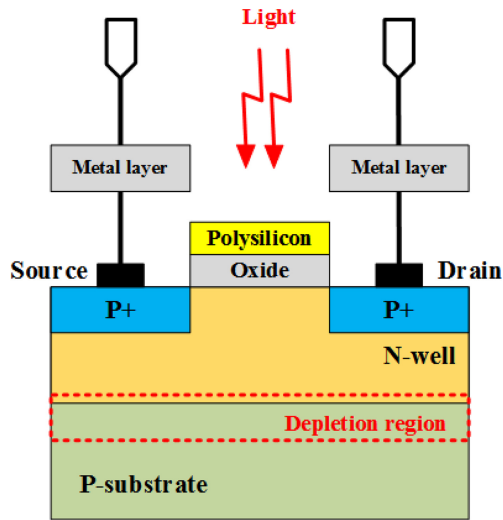


Fig. 1. Vertical structure of GBT MOSFET-type photodetector.

photodetector. The photodetector is designed such that the gate node and the body node are physically connected. The area of the photodetector, excluding the gate, is shielded by a metal wire. The gate consists of polysilicon. As a result, light strikes only the gate region of the photodetector. Some photons of short wavelengths are absorbed in the polysilicon gate, resulting in the reduction of sensitivity, whereas photons with long wavelengths are mostly absorbed by the substrate. The incident light entering through the gate of the photodetector generates electron-hole pairs in the depletion region. The holes drift toward the channel and P substrate, and the electrons accumulate in the N-well owing to the high potential barrier. These accumulated electrons reduce the potential barrier of the N-well, which cause a negative gate voltage of photodetector, because the gate is connected to the N-well. Because of decrease in the gate voltage, a channel is formed and current flows through the channel. In addition, the accumulated electrons generate a negative voltage in the N-well, and a positive feedback to the gate through the gate/N-well connection is created. The photocurrent of the GBT MOSFET-type photodetector is highly amplified by this positive feedback mechanism [13-15].

Fig. 2 (a) shows the symbol of a single GBT MOSFET-type photodetector for measuring the photocurrent. To measure the photocurrent (I_{ph}) generated by the light incident on the active region of the photodetector, the GBT MOSFET-type photodetector was designed with the structure presented in Fig. 1(a). Fig. 1 (b) shows the layout of the photodetector. The gate node of the photodetector depicted in Fig. 2 was designed to be physically tied with the body node.

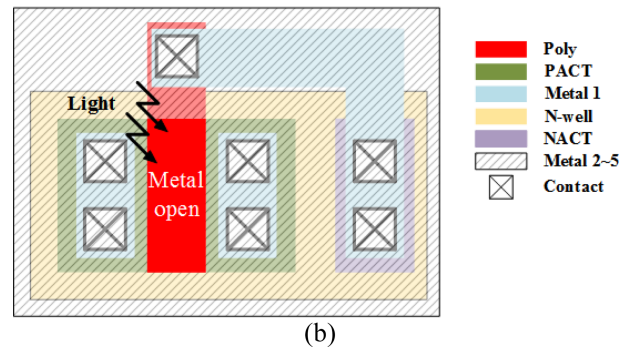
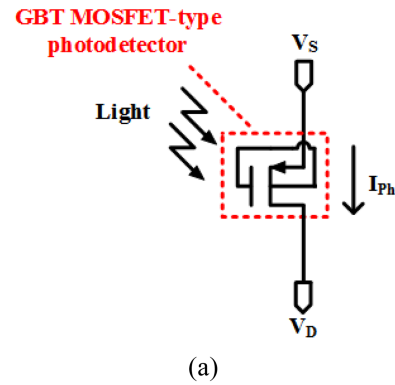


Fig. 2. (a) Symbol of GBT MOSFET-type photodetector for measuring the photocurrent and (b) layout of the GBT MOSFET-type photodetector.

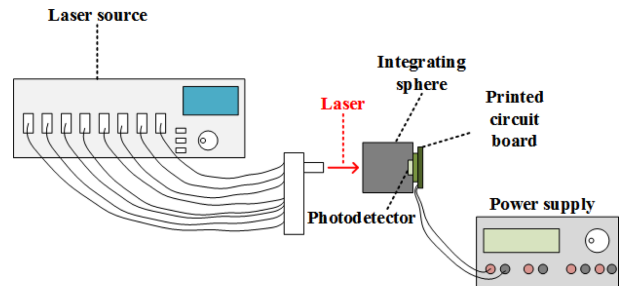


Fig. 3. Experimental environment for photocurrent measurement of photodetectors.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

Fig. 3 shows the experimental environment for photocurrent measurement of photodetectors. Using a laser source, the incident light was emitted with a total of 8 wavelengths: 408 nm, 489 nm, 521 nm, 639 nm, 726 nm, 785 nm, 854 nm, and 941 nm. In the setup, the light from the laser source enters the integrating sphere, inside which repeated Lambertian reflections occur. The reflected light has a uniform distribution and is incident on the photodetector. The photodetector was fabricated using the

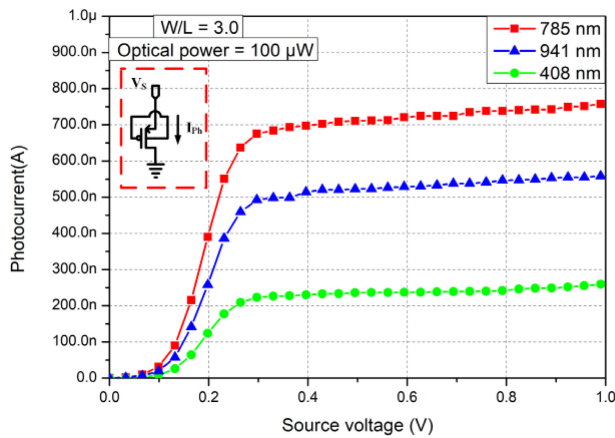


Fig. 4. Photocurrent-measurement results with respect to the source voltage of GBT MOSFET-type photodetector for various wavelengths.

standard $0.18\text{ }\mu\text{m}$ CMOS process. Threshold voltage of the fabricated p-channel MOSFET operating in the enhancement mode was -0.4 V .

The GBT MOSFET-type photodetector is essentially a MOSFET. The voltage between the source and drain nodes (V_{SD}) determines the operating region of the photodetector. In this region, a photocurrent is generated by the light incident at the photodetector. Therefore, to use the GBT MOSFET-type photodetector as a photodetector, it is essential to analyze its characteristics with respect to V_{SD} . In addition, a general characteristic of a MOSFET-type photodetector is that the output signal is affected by the W/L ratio of the device. Therefore, it is essential to analyze the photocurrent characteristics of the GBT MOSFET-type photodetector with respect to the W/L ratio.

Fig. 4 shows photocurrent-measurement results with respect to the source voltage of the photodetector for various wavelengths. As a light source, output light wavelengths of 408 nm, 785 nm, and 941 nm of the laser source were used. The optical power of the three wavelengths was measured as $100\text{ }\mu\text{W}$ under the same conditions as above. It can be observed in Fig. 4 that among the three wavelengths tested, 785 nm generated the greatest photocurrent in the photodetector. Therefore, it can be inferred that the sensitivity is the highest when the wavelength of the light incident on the GBT MOSFET-type photodetector is 785 nm.

Table 1 shows various widths and lengths and the corresponding W/L ratios of the GBT MOSFET-type photodetector with the same area ($4\text{ }\mu\text{m}^2$). Fig. 5 shows the photocurrent-measurement results with respect to the source voltage of the photodetector for various W/L ratios. It can be

Table 1. Various widths and lengths and the corresponding W/L ratios of GBT MOSFET-type photodetector with the same area ($4\text{ }\mu\text{m}^2$).

	Width	Length	W/L
TEG 15	$3.465\text{ }\mu\text{m}$	$1.155\text{ }\mu\text{m}$	3.0
TEG 14	$2.83\text{ }\mu\text{m}$	$1.415\text{ }\mu\text{m}$	2.0
TEG 13	$2\text{ }\mu\text{m}$	$2\text{ }\mu\text{m}$	1.0
TEG 12	$1.415\text{ }\mu\text{m}$	$2.83\text{ }\mu\text{m}$	0.5
TEG 11	$1.155\text{ }\mu\text{m}$	$3.465\text{ }\mu\text{m}$	0.3

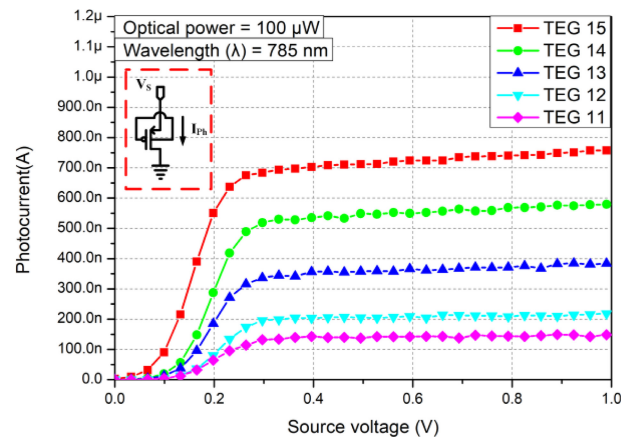


Fig. 5. Photocurrent-measurement results with respect to the source voltage of GBT MOSFET-type photodetector for various W/L ratios.

observed that as the W/L ratio of the photodetector increased from 0.3 to 3.0, the generated photocurrent increased from approximately 148 nA to 757 nA. Therefore, the sensitivity of the GBT MOSFET-type photodetector can be increased by adjusting its W/L.

Fig. 6 shows (a) the photocurrent-measurement results of the GBT MOSFET-type photodetector with respect to the wavelength of the incident light and (b) the photocurrent-measurement results of a PN-junction photodiode with respect to the wavelength of the incident light. Table 2 lists: (a) the photocurrent measurements of the GBT MOSFET-type photodetector (I_{GBT}) and that of the PN-junction photodiode (I_{PN}) with the same area, and (b) the corresponding wavelengths of the incident light.

To measure the photocurrent, the source voltage of the GBT MOSFET-type photodetector and PN-junction photodiode of the same area were measured at 1 V and reverse bias 1 V, respectively. In the case of the PN-junction photodiode, the measured photocurrent at the full wavelength ranged from approximately 1.95 nA to 5.63 nA, and that for the GBT MOSFET-type photodetector, the photocurrent is about 259 nA to 757 nA. On comparing these two photocurrent measurements, it

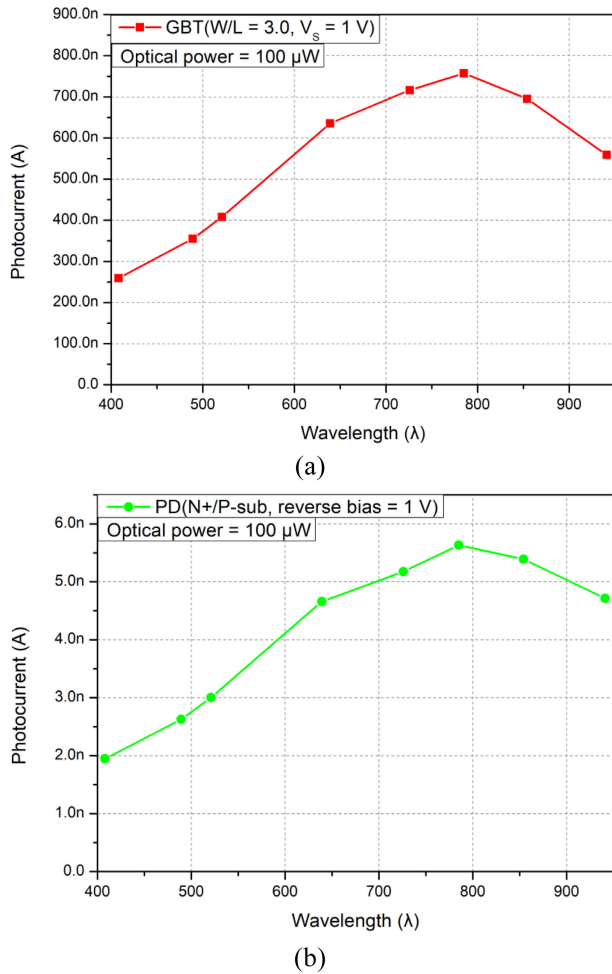


Fig. 6. (a) Photocurrent-measurement results of the GBT MOSFET-type photodetector with respect to incident-light wavelength and (b) photocurrent-measurement results of a PN-junction photodiode with respect to incident-light wavelength.

Table 2. Photocurrent of the GBT MOSFET-type photodetector (I_{GBT}) and that of the PN-junction photodiode (I_{PN}) with the same area with respect to incident-light wavelength.

Wavelength	I_{GBT}	I_{PN}	Ratio ($I_{\text{GBT}}/I_{\text{PN}}$)
408 nm	259 nA	1.95 nA	133
489 nm	355 nA	2.63 nA	135
521 nm	408 nA	3.00 nA	136
639 nm	636 nA	4.66 nA	136
726 nm	717 nA	5.18 nA	138
785 nm	757 nA	5.63 nA	134
854 nm	695 nA	5.39 nA	129
941 nm	559 nA	4.71 nA	119

was confirmed that the optical properties of the GBT MOSFET-type photodetector were excellent at a wavelength of 408 nm – 941 nm.

4. CONCLUSIONS

In this study, a GBT MOSFET-type photodetector was designed and fabricated via a standard 0.18 μm CMOS process. The characteristics of the photocurrent with respect to the source voltage, width to length (W/L) ratio of the photodetector, and wavelength of the incident light were evaluated through measurements. In addition, the photocurrent characteristics of the photodetector with high sensitivity at a wavelength of 408 nm – 941 nm was measured and compared with those of a PN-junction photodiode.

It is known that the responsivity of a Si PN-junction photodiode is typically 0.3 A/W to 0.5 A/W. Because, in this study, the photocurrent of the GBT MOSFET-type photodetector was found to be over 100 times greater than that of the PN-junction photodiode with the same area, the responsivity of the photodetector is estimated to be over 30 A/W. Therefore, the presented photodetector can be useful for several applications; particularly, those requiring high sensitivity in the visible and near infrared (NIR) range.

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