Response Time Investigation Based on GaAs Position Sensitive Detector

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***Abstract*—This work reports on response times of a GaAs-based p-i-n Position-Sensitive Detector (PSD) operated in lateral and transverse photovoltaic modes. Visible light spots with wavelength values of 405, 532, and 638 nm were employed for measuring both static and dynamic properties of the proposed p-i-n PSD. The extracted sensitivity is 4.1 mV/mm for the 405 nm light with a power of 3 mW while it was 14.3 mV/mm for the 638 nm light. The measured nonlinearities were 1.0%~1.9%, 1.7%~2.25%, and 0.25%~1.25% for 405, 532, and 638 nm lights, respectively, with a power of 1 to 3 mW. Experimental results reveal that the shortest response time is available for the PSD tested with the 532 nm light.**

Keywords-GaAs HBT; p-i-n; photovoltaic; position sensitive detector; response time

I. INTRODUCTION

After finding of Lateral Photovoltaic Effect (LPE) [1], an important Position-Sensitive Detector (PSD) that has its output of Lateral Photovoltaic Voltage (LPV) changed linearly with light-spot position has been widely investigated by using various structures [2][8]. Effects of the LPE on Metal-Semiconductor (MS) structures have been reported to show PSD's sensitivities ranged from 12.4 to 28.8 mV/mm [2][4]. Currently, Si-based structures are preferred for low-cost infra-red PSDs. However, there has been little research about PSDs based on GaAs-based p-i-n structures [5][7] which are appropriate for visible-light positioning. In this work, a GaAs p-i-n structure being layer-compatible to the base-collector junction of an InGaP-GaAs Heterojunction Bipolar Transistor (HBT) was utilized to fabricate a visible-light PSD. Thus, it is possible to integrate a PSD with an HBT amplifier and hence to design a PSD circuit. In addition to wavelength and power dependences of sensing properties of the proposed GaAs p-i-n PSD, response times reflecting light-on and light-off were also addressed. Experiments and measurements about the proposed PSD are described in following section. In Section III, experimental results including key merits, such as sensitivity, linearity, and response time, are reported with theoretical discussion. Finally, conclusions are drawn.

II. EXPERIMENTS

Fig. 1 shows a cross-sectional view of the p-i-n structure used to fabricate a visible-light PSD. It was grown on a (100)-oriented semi-insulating GaAs substrate by a Metal-Organic Chemical Vapor Deposition (MOCVD) system and consisted of a n^+-GaAs layer (600 nm, $n^+=5\times10^{18}$ cm^{-3}), a n^--GaAs layer (600 nm, $n^-=1\times10^{16}$ cm^{-3}), and a p^+-GaAs layer (80 nm, $p^+=3\times10^{19}$ cm^{-3}) in sequence. Actually, it is layer-compatible with the base-collector-subcollector structure of a conventional InGaP-GaAs HBT. After defining an active region, AuGeNi was deposited as a common electrode (C) upon the exposed n^+-GaAs layer. Finally, AuZn was deposited to form two electrodes (A and B) upon the p^+-GaAs layer. A spacing between electrodes A and B is as long as 14 mm. Point O, the center between the electrodes A and B, is defined as origin of light-spot position (x=0). The light-spot position is positive (x>0) when the light spot is on the right side of point O. A voltage appearing between the electrodes A and B was measured as the LPV value while that between the electrodes A and C (or B and C) was measured as the Transverse Photovoltaic Voltage (TPV).

III. RESULTS AND DISCUSSION

Shown in Fig. 2(a) are the LPV values as a function of light-spot position for the p-i-n PSD tested with 405, 532, and 638 nm lights with a power of 3 mW. Common

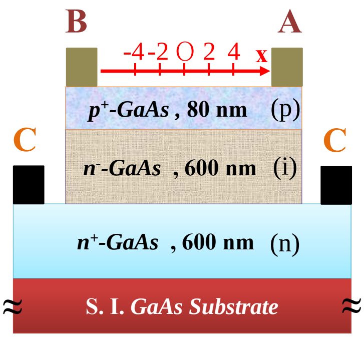

Figure 1. Cross-sectional view of a fabricated GaAs p-i-n PSD.

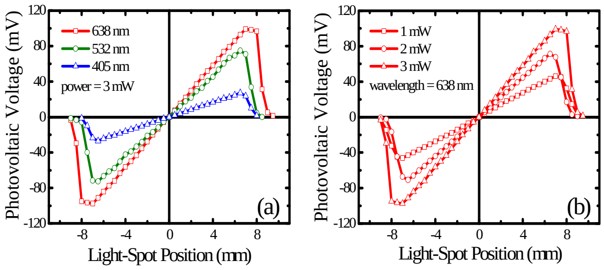

Figure 2. LPV values as a function of light-spot position for a PSD: (a) tested by 405, 532, and 638 nm lights with a power of 3 mW and (b) tested by a 638 nm light with a power of 1, 2, and 3 mW.

properties include: the LPV values are close to zero when the light spot is located at point O; if the light spot scans positively, LPV values also positively increase. On the contrary, they are negative when $x < 0$; maximum of the absolute LPV appears at $x \approx \pm 7$ mm; and moving the light spot beyond either the electrode A or the electrode B leads to abrupt decrease in the LPV. Two of the most important features associated with PSD's static sensing properties are sensitivity (S) and linearity. We find that the PSD tested by a 638 nm light has the highest S of 14.3 mV/mm as compared to those of 4.1 and 11.6 mV/mm by 405 and 532 nm lights. All nonlinearities obtained are below 2.5%, showing an excellent linear relationship with the light-spot position. Fig. 2(b) shows LPV values as a function of light-spot position for the p-i-n PSD tested by a 638 nm light with a power of 1, 2, and 3 mW. In addition to good linearity (> 98%), the sensitivity is enhanced from 6.7 mV/mm at 1 mW to 11.1 mV/mm at 2 mW and finally to 14.3 mV/mm at 3 mW. It is noticed that S is dependent on a number density of the initial electron-hole pairs. Thus, it is reasonable that (1) at the same power, the 405 nm light has the smallest S due to its least photons and (2) the larger power with more photons will lead to more initial electron-hole pairs. Experimental results are in good agreement with theoretical ones reported previously.

Fig. 3 shows wavelength dependence of response times of the GaAs p-i-n PSD in a lateral photovoltaic mode. The

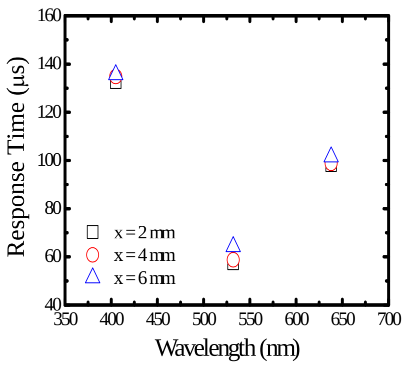

Figure 3. Wavelength dependence of response times of the PSD in a lateral photovoltaic mode.

parameter used is the light-spot position. It is found that the shortest response time is available for our PSD tested by a 532 nm light. Besides, we find that the light-spot position has no relevant effect on the response time. Thus, the swept time for holes and electrons reaching to p^+- and n^+-side layers, respectively, is considered to mainly determine the response time. When the 405 nm light spot is used, the swept time is dominated by electrons generated within the p^+- to i-GaAs region. On the contrary, it is dominated by holes generated in the deep i-GaAs region for the 638 nm light. Thus, a response time of 60±4 μs for the 532 nm light is the shortest time as compared to those of 134±2 and 99±2 μs for the 405 and 638 nm lights. Although response times of TPV values are not shown here, comparisons to those of LPV ones will also be addressed in this presentation.

IV. CONCLUSIONS

GaAs-based p-i-n PSDs have been fabricated for visible-light positioning. A PSD tested by a 3 mW 638 nm light shows a sensitivity of 14.3 mV/mm, resulting in a sensitivity-distance product of ≈200 mV. Nonlinearities obtained from the present PSD are smaller than 2.5%. Response times of the LPV values are 99±2, 60±4, and 134±2 μs when 638, 532, and 405 nm lights were used, respectively, that will be compared to those of TPV ones.

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