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Improving $In_{0.37}Ga_{0.63}N$ MSM Photodetectors by Using a Recessed-Electrode Structure

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ABSTRACT

InGaN metal-semiconductor-metal photodetectors (MSM-PDs) with recessed electrodes were fabricated. When compared with the conventional planar MSM-PD, it was found that measured photocurrent and photocurrent-to-dark-current contrasting ratios are both much larger for a MSM-PD with recessed electrodes. With a 5V applied bias and an incidental light wavelength of 470 nm, it was found that the measured responsivities were 0.144 and 0.038 A/W for the MSM-PDs with and without recessed electrodes, respectively.
***Key Words*:** InGaN, MOCVD, MSM photodetectors, recessed electrodes

以凹槽式電極增進氮化鎵銦金屬-半導體-金屬光檢測器之功能

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摘　要

本文描述了凹槽式電極之氮化鎵銦金屬-半導體-金屬光檢測器（MSM-PD）的結構；並比較出具有凹槽式電極之光檢測器的光電流大小及其光暗電流比值均優於平面式電極之光檢測器。以波長為 470 奈米之入射光波照射在外加偏壓為 5 伏特之凹槽式電極光檢測器與平面式電極光檢測器上，量測其響應度分別為 0.144 以及 0.038 安培／瓦特。
關鍵詞：氮化鎵銦，金屬有機化學氣相沉積，金屬-半導體-金屬光檢測器，凹槽式電極

I. INTRODUCTION

III-V nitride semiconductors have a wurtzite crystal structure and a direct energy bandgap. At room temperature, the energy bandgap of AlInGaN varies from 0.78 to 6.2 eV. Therefore, III-V nitrides are useful for light emitters and photodetectors in this wavelength region. Indeed, nitride-based blue and green high brightness light-emitting diodes (LEDs) and laser diodes (LDs) [7, 12] are now commercially available. However, relatively few reports on nitride-based photodetectors can be found in the literature. Blue and ultraviolet (UV) photodetectors are important devices that can be used in various applications, such as high-density digital video disc (HD-DVD) and blue-ray DVD. Today, light detection in blue/UV region still uses Si photodetectors. However, it is known that the responsivity of Si photodetectors is limited by the high degree of surface recombination in this region. To date, various types of GaN-based photodetectors have been reported [2, 8, 9, 11]. Among them, GaN-based metal-semiconductor-metal photodetectors (MSM-PDs) have attracted much attention. Recently, Roberts et al. reported the fabrication of InGaN-based MSM-PDs with Au metal contact electrodes [10]. They successfully shifted the cut-off wavelength by changing the indium composition in the InGaN layers.

Although MSM-PDs have many advantages, transit time of photo-generated carriers often limits the response time of the MSM-PDs. To solve this problem, one can either scale down the distance between interdigitated electrodes or reduce active layer thickness to improve the detector response speed [13]. These methods, however, might also result in smaller detector responsivity. It is known that electric field in planar-type MSM-PDs is non-uniform. In other words, the electric field will become smaller with increasing depth. Thus, photo-generated carriers in the deep active region will need more time to reach the contact electrodes on the sample surface. Besides, some photo-generated carriers might not be collected by contact electrodes so as to result in a reduced photocurrent. In this letter, we report the fabrication of InGaN MSM-PDs with recessed gate electrodes. The optical and electrical properties of the fabricated detectors will also be discussed.

II. EXPERIMENT

Samples used in this study were all grown on c-face (0001) sapphire substrates by metalorganic chemical vapor deposition (MOCVD). Details of the growth have already been reported elsewhere [5]. The samples consists a 20-nm-thick GaN nucleation layer grown at 550^{o}C, a 2-μm-thick GaN layer grown at 1050^{o}C and a 0.5-μm-thick $In_{0.37}Ga_{0.63}N$ layer grown at 780^{o}C. From Hall measurements, it was found that electron concentration in the InGaN layer was 5×10^{17} cm^{-3}. Standard photolithography and inductive coupled plasma (ICP) etching were then performed to recess the samples to a depth of 230 nm. Ni/Au (100 nm/100 nm) Schottky contacts were subsequently deposited onto the recessed finger mesa by thermal evaporation and lift-off. The finger width and spacing of the interdigited contact electrodes were 7 μm and 10 μm. To achieve better sidewall contacts, non-self-aligned process was used during device fabrication. In other words, there was approximately 1 μm on each side of each electrode that is outside of the trench area to achieve better sidewall contacts. For comparison, conventional planar MSM-PDs without any recessed electrode structure were also fabricated. A Keithley-4200 semiconductor parameter analyzer was then used to measure the current-voltage (I-V) characteristics of the fabricated detectors both in dark and under illumination. For photocurrent measurements, a 150 Watt D_2 lamp was used as the light source. For spectral responsivity measurements, a 250W Xe lamp and a monochromator were used. The monochromatic light, calibrated with UV-enhanced Si photodetectors and an optical power meter, was collimated onto the photodetectors using an optical fiber.

III. RESULTS AND DISCUSSION

Figure 1 shows dark I-V curves for the MSM-PDs with and without the recessed electrodes. It can be seen that dark leakage current of the MSM-PD with recessed electrodes was larger than that observed from conventional MSM-PD. With a 5 V applied bias, it was found that dark leakage currents were 25 and 8 nA for the MSM-PDs with and without the recessed electrodes, respectively. Using thermionic emission theory [3], we found that Schottky barrier heights between InGaN and the metal contacts were 0.65 and 0.71 eV for the MSM-PDs with and without the recessed electrodes, respectively. The larger leakage current and smaller Schottky barrier height observed from MSM-PD with recessed electrodes should be attributed to the ICP induced damages during etching. It should be noted that dark current reaches saturation faster and seems to be relatively bias-independent for the MSM-PD with recessed electrodes. We believe these observations should be related to the enhanced electric field and the uniform electric field distributed through the gap space in the recessed electrode structure. Here, we defined the breakdown voltage as the voltage when the leakage current reached 1 mA. Using this definition, it was found that breakdown voltages were 36.5 and 26.5 V for the MSM-PDs without and with recessed electrodes,

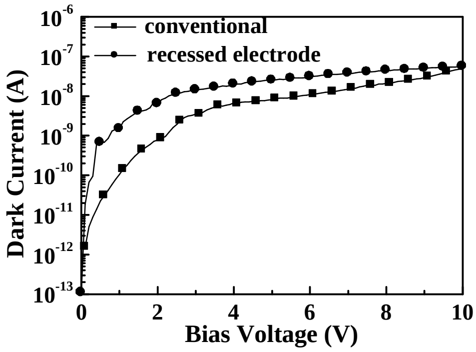

Fig. 1. Dark I-V characteristics of the MSM-PDs with and without recessed-electrodes

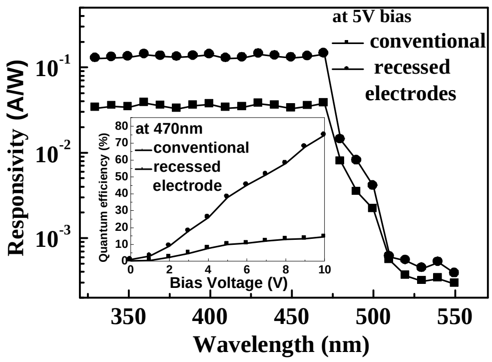

Fig. 3. The responsivity spectra of the conventional and recessed-electrode InGaN MSM-PDs under 5V bias

respectively. The smaller breakdown voltage observed from the recessed MSM-PD could again be attributed to the ICP induced surface damages [6].

Figure 2 shows measured photocurrents for the two MSM-PDs. It was found that photocurrent observed from the MSM-PD with recessed electrodes was larger than that of conventional MSM-PD by about two orders of magnitude. With a 5 V applied bias, it was found that photocurrent to dark current contrast ratios were 1650 and 50 for the MSM-PDs with and without the recessed electrodes, respectively. Although the more uniform electric field could result in a larger response for the MSM-PD with recessed electrodes, it is also possible that the much larger photocurrent is related to ICP etching. Previously, it has been shown by Carrano et al. [1] that much larger photocurrent can be induced by interfacial defects. After ICP etching, there should be a large number of surface states. With a much larger surface states after etching, there might be a photoconductive gain in the MSM-PD with recessed electrodes.

Figure 3 shows spectral responses of the fabricated MSM-PDs. It was found that the responsivities measured

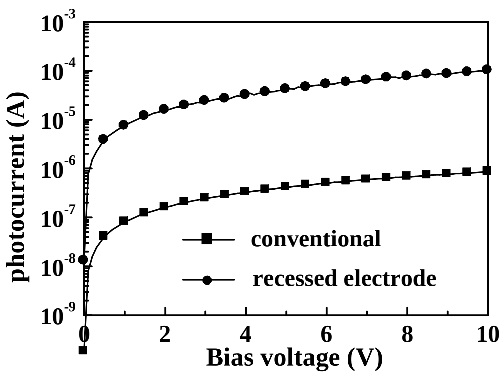

Fig. 2. Measured photocurrents of the MSM-PDs with and without recessed-electrodes

from both detectors were flat over the bandgap and exhibited sharp cutoff at the absorption edge. Since bandgap energies of $In_{0.37}Ga_{0.63}N$ and GaN are 2.626 and 3.42 eV, respectively [4], the sharp cutoff occurred at around 470 nm should related to the absorption of the $In_{0.37}Ga_{0.63}N$ layer and not the underlying GaN. The inset of figure 3 shows measured external quantum efficiency as a function of applied bias for the two different kinds of MSM-PDs. It was found that although measured external quantum efficiency increased with applied bias for both detectors, it increased much faster for the MSM-PD with recessed electrodes. Such a result suggests that there exists a large photoconductive gain in this device. As a result, we observed a much faster increase in external quantum efficiency in the inset of figure 3. Such a result also agrees well with the much larger photocurrent observed from the MSM-PD with recessed electrodes shown in figure 2. With a 5V applied bias and an incident light wavelength of 470 nm, it was found that measured responsivities were 0.144 and 0.038 A/W for the MSM-PDs with and without the recessed electrodes, respectively. The larger responsivity for the MSM-PDs with the recessed electrodes could again be attributed to the large photoconductive gain.

IV. CONCLUSIONS

In summary, InGaN MSM-PDs with the recessed electrodes were fabricated. Compared with the conventional planar MSM-PD, it was found that measured photocurrent and photocurrent to dark current contrast ratio were both much larger for the MSM-PD with the recessed electrodes. The responsivity and external quantum efficiency of MSM-PD with recessed electrodes were also found to be larger which could be attributed to the ICP etching induced photoconductive gain.

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