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Investigation of AlGaN MSM Photodetectors with Low-Temperature AlN Cap and Recess Etched layers

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1. Introduction

III-V nitride semiconductors have a wurtzite crystal structure and a direct energy bandgap. At room temperature, the energy bandgap of AlGaN varies from 3.4 to 6.2 eV. Therefore, AlGaN is useful for ultra-violet (UV) light emitters and photodetectors in UV wavelength region. Ultraviolet (UV) photodetectors (PDs) are important devices that can be used in various applications, such as flame detection, astronomy detection, pollution monitoring, and space communications [1]. To date, various types of GaN-based PDs have been reported [2-4]. Among them, GaN-based metal-semiconductor-metal photodetectors (MSM-PDs) have attracted much attention. In order to achieve a high performance AlGaN MSM PD, it is necessary to reduce dark current, which is originated from carrier leakage occurred at the metal/semiconductor interface. Previously, it has been shown that one can significantly reduce gate leakage in GaN-based devices by utilizing a low temperature (LT) GaN layer [5]. Similar concept could also be applied to AlGaN-based devices. It is known that LT AlN exhibits an ultra-high resistivity, which cannot be reduced even with thermal annealing. Such a semi-insulating property makes LT AlN suitable to serve as the top layer of MSM PDs. It is known that electric field in planar-type MSM-PDs may 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. Thus, some photo-generated carriers might not be collected by contact electrodes so as to result in a reduced photocurrent. We have reported the fabrication of InGaN MSM-PDs with recessed gate electrodes by ICP etching [5] and the photocurrent can be further enhanced. Thus, the performance of AlGaN-based MSM-PDs can be also effectively improved by using this recess etching technique. In this letter, the optical and electrical properties of nitride-based MSM PDs with a recess etched layer and LT AlN cap layers are reported.

2. Experimental and Result Discussions

The AlGaN MSM photodetectors in this experiment were all epitaxial grown on c-face (0001) sapphire substrates by metalorganic chemical vapor deposition (MOCVD) system. A 25 nm-thick low temperature GaN nucleation layer was deposited as 550 ℃ and followed by the growth of 1μm-thick unintentional doped GaN as the buffer layer to reduce the dislocations. The nominally undoped 200 nm-thick $Al_{0.16}Ga_{0.84}N$ was grown on the undoped GaN. After conventional cleaning procedure, the recess etching was done using the inductively coupled plasma (ICP) dry etching technology. The etching depth was 100 nm. Then, we fabricated the structures capped with a 20 nm-thick LT grown AlN layer by using MOCVD re-grown technique. To evaluate the effect of LT grown cap layer, structure without cap layer was also demonstrated. The growth temperature of the LT grown AlN layer was set at 500 ℃. Afterwards, Ni/Au (10/35 nm) was deposited as metal contacts on sample with and without recess etching by thermal evaporation, respectively. The contacts of the device form two inter-digitated, fork-shaped electrodes. The schematic structure was shown in Fig.1.

Room temperature current-voltage (I-V) characteristics of the fabricated AlGaN MSM PDs were then measured by an HP4156 semiconductor parameter analyzer in dark, as shown in figure 2. Under reverse bias, it was found that the dark current was near a constant of around 1×10^{-12} A for AlGaN MSM-PDs with the LT-AlN cap layer. In contrast, dark current of conventional AlGaN MSM-PDs was at least four orders of magnitude larger, and increased rapidly as the bias voltage increased. This could be attributed to the fact that the highly resistive LT AlN cap layer could result in a thicker and higher potential barrier, as compared to conventional MSM-PDs. In addition, leakage current in AlGaN MSM PDs with this LT AlN cap layer was much smaller and less dependent on the applied bias. It can also be seen that dark leakage current of the MSM-PDs with ICP recess etched was lightly larger than that observed from MSM-PDs only with an LT layer. The larger leakage current observed from MSM-PDs with ICP recess etched should be attributed to the ICP induced damages during etching. It should be noted that dark current seems to be relatively bias-independent for the MSM-PDs with ICP recess etched. We believe these observations should be related to the enhanced electric field and the uniform electric field distributed through the gap space in the recess etched structure.

Figure 3 shows the I-V characteristics of AlGaN MSM-PDs under illumination. It was found that photocurrent of MSM-PDs with LT-AlN layer was much smaller than that of conventional sensor, since most incident photons were absorbed by the LT AlN cap layer and only few photo generated carriers could contribute to photocurrent. It was also found that photocurrent observed from the MSM-PDs with ICP recess etched was larger than that of conventional MSM-PD by about one order of magnitude. Although the more uniform electric field could result in a larger response for the MSM sensor with ICP recess etched, it is also possible that the much larger photocurrent is related to ICP etching. Previously, it has been shown by Carrano et al. [7] 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-PDs with ICP recess etched.

Figure 4 shows spectral responses of the fabricated MSM-PDs. It was found that the responsivities measured from three PDs exhibited sharp cutoff at the absorption edge. Since bandgap energies of $Al_{0.16}Ga_{0.84}N$ is 3.875 eV, the sharp cutoff occurred at around 320 nm should related to the absorption of the $Al_{0.16}Ga_{0.84}N$ layer.

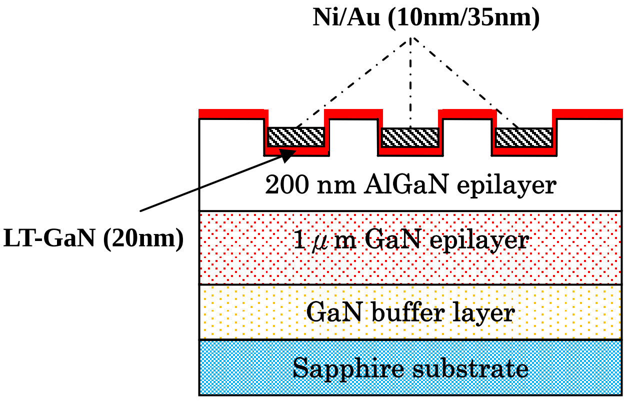

Fig. 1 The schematics structures of AlGaN MSM-PDs with LT-AlN cap layer and recess etched layer.

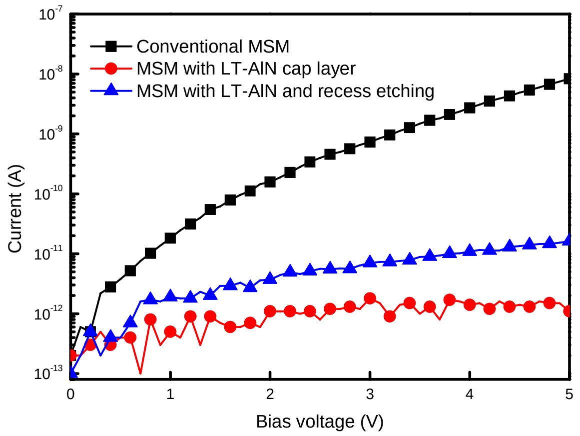

Fig. 2 The Dark I-V characteristics of AlGaN MSM-PDs with LT-AlN cap layer and recess etched layer.

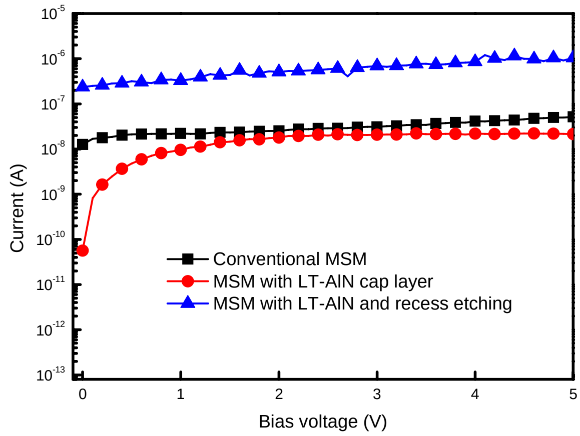

Fig. 3 The illuminated I-V characteristics of AlGaN MSM-PDs with LT-AlN cap layer and recess etched layer.

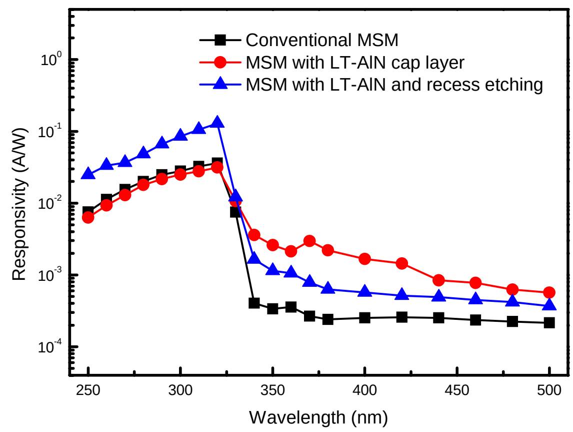

Fig. 4 The spectral response of AlGaN MSM-PDs.

3. Conclusions

In summary, AlGaN MSM-PDs with the LT-AlN layer and ICP recess etched layer were fabricated. Compared with the conventional MSM-PDs, it was found that measured photocurrent was much larger for the MSM-PD with with the LT-AlN layer and ICP recess etched layer. The responsivity of MSM-PD with the LT-AlN layer and ICP recess etched layer were also found to be larger which could be attributed to the ICP etching induced photoconductive gain.

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