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Performance Improvement of GaN Metal-Semiconductor-Metal Photodetectors with Sputtered AlN Nucleation Layer

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1. INTRODUCTION

Recently, III-V nitride-based semiconductor materials have attracted considerable interest. Due to their characteristics, the III-V nitride semiconductors are frequently used to fabricate light emitting diodes (LEDs) and photodetectors (PDs). In fact, metal organic chemical vapor deposition (MOCVD) grown nitride-based LEDs prepared on sapphire substrates has already been extensively used in the full color displays, traffic light lamps and more. Besides, many researches have also focused their efforts on the fabrication of nitride-based ultraviolet (UV) PDs. UV PDs are important devices for fire detection, ozone layer monitoring, environmental field, and various commercial or military applications [1]. However, the crystal quality of GaN epitaxial layers prepared on sapphire substrate is poor due to the large mismatches in lattice constant between GaN and sapphire. And thus it will result in high threading dislocations (TDs) density in epitaxial layer. Many reports indicated that the TD density in the epitaxial layer can be reduced by using patterned sapphire substrates (PSS) or epitaxial lateral over growth (GLOG) [2-3]. However, all these techniques should take extra and complex process steps, which might result in a higher production cost. In our study, the GaN metal-semiconductor-metal (MSM) PD with sputtered AlN nucleation layer was fabricated and investigated, and was compared to MSM PDs prepared on normal sapphire substrate (NSS) and PSS.

2. EXPERIMENTS

Before the epitaxial growth, a 25-nm-thick ex-situ AlN nucleation layer was deposited onto the ***c***-plane (0001) sapphire substrate by RF sputter system, called the sputtered AlN nucleation layer. Then, for the epitaxy by MOCVD, a 2.5-μm-thick undoped GaN was grown onto the sputtered AlN nucleation layer. In contrast, a 10-nm-thick in-situ AlN nucleation layer was grown on the NSS and PSS by MOCVD. Then, a 2.5 and 4-μm-thick undoped GaN was also grown on in situ AlN nucleation layer for NSS and PSS, respectively. The pattern diameter, spacing, and height of the PSS were 3.5, 2, and 1.3 μm, respectively, which was fabricated by inductively coupled plasma reactive ion etching to etch sapphire coated the cone-shaped photoresist layer. For chips process, a Ni/Au (500/1500 Å) metal layer was evaporated as the Schottky contact electrodes. The optical and electrical properties of these three fabricated GaN MSM PDs were discussed in detail.

3. RESULTS AND DISCUSSION

Figure 1(a) and (b) show the double-axis XRD ω-scan rocking curves of the GaN film (002) and (102) plane for these three fabricated PDs, respectively. It was found that the intensity and full-width at half-maximum (FWHM) of the (002) and (102) plane rocking curves for the PDs with sputtered AlN nucleation layer was larger and narrower than those of NSS and PSS. The (002) plane rocking curves show the information about the screw dislocation density and the (102) plane rocking curves show the information about the mixed and pure edge dislocation densities [5]. According to the XRD results, it means that the dislocation density of GaN film can be effectively suppressed by using the sputtered AlN nucleation layer. Figure 2 shows the dark current–voltage (I–V) characteristics measured from the applied bias of 0 to 5 V for these fabricated GaN MSM PDs. It can be seen that the dark current of PD with sputtered AlN nucleation layer was the best performance than that of others. It is indicated that the leakage current can be effectively reduced by reducing the dislocation density which was preferential paths for leakage current conduction.

Figure 3 shows the spectral response characteristics measured from the fabricated GaN MSM PDs with PSS and sputtered AlN nucleation layer. It can be seen that an extremely sharp cut-off wavelength occurred at around 360 nm with a rejection ratio higher than 2 orders of magnitude for both devices. At an applied bias of 1 V, it was found that the best measured responsivity of PD with PSS and sputtered AlN nucleation layer were 0.0129 and 0.0168 A/W, respectively. The responsivity and cut-off characteristics of PD with sputtered AlN nucleation layer were better than those of PSS. This is because that the quantum efficiency of PD with sputtered AlN nucleation layer was better than that of PSS due to the reduction of the dislocation density which would result in more probability of carrier capture rate by defects.

Figure 4 shows noise power spectra of the fabricated GaN MSM PDs with PSS and sputtered AlN nucleation layer. For analysis of low-frequency noise at room temperature, the noise floor of our measurement system limited by the preamplifier was about 10^{-31} A/Hz. It was found that spectra measured from these PDs could be fitted reasonably well by the following equation:

$$Sn(f) = K(I^b/f^a) \qquad (1)$$

where Sn(f) is the spectral density of the noise power, K is a constant, I is the dark current, and b and a are two fitting parameters. From the measured curves, it was found the parameter a was almost equal to two throughout the measured frequency range. In other words, the low frequency noise in our devices was dominated by 1/f-type noise. With a 1 V applied bias, it was calculated that we achieved the detectivity (D∗) of 3.17×10^{11} and 1.49×10^{11} $cmHz^{0.5}W^{-1}$ from these fabricated GaN MSM PDs with PSS and sputtered AlN nucleation layer.

4. CONCLUSIONS

In summary, GaN MSM PD with sputtered AlN nucleation layer was fabricated and investigated. It was found that the FWHM of the (002) and (102) plane rocking curves for the PDs with sputtered AlN nucleation layer was better than NSS and PSS. The responsivity and cut-off characteristics of PD with sputtered AlN nucleation layer were better than those of PSS. This is because that the quantum efficiency of PD with sputtered AlN nucleation layer was better than that of PSS due to the reduction of the dislocation density. The low frequency noise in our devices was dominated by 1/f-type noise. The D∗ of these fabricated GaN MSM PDs with PSS and sputtered AlN nucleation layer were 3.17×10^{11} and 1.49×10^{11} $cmHz^{0.5}W^{-1}$, respectively.

ACKNOWLEDGMENT

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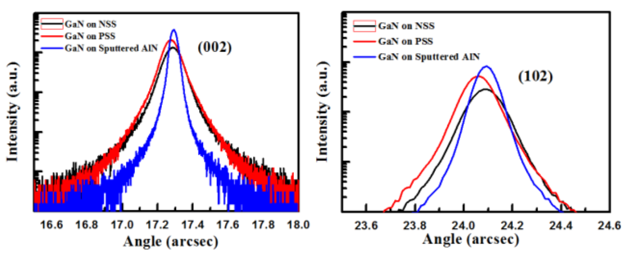


(a) (b)

Fig. 1 The XRD ω-scan rocking curves of the GaN film (a) (002) and (b) (102) plane

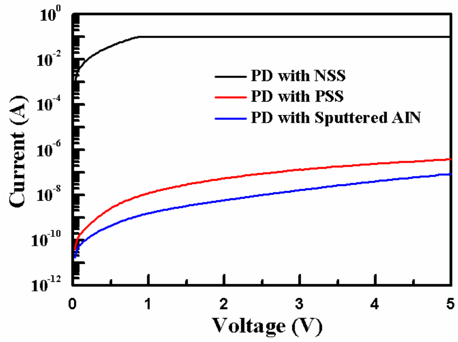


Fig. 2 The dark I –V characteristics of these fabricated GaN MSM PDs

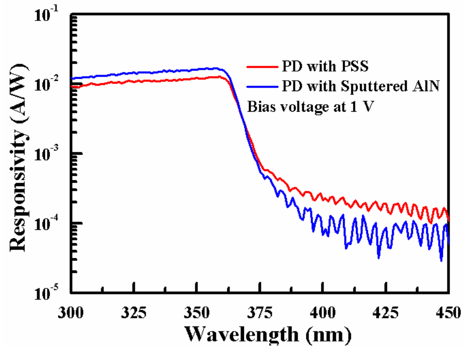
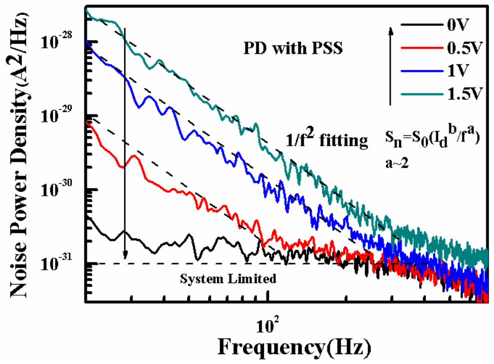
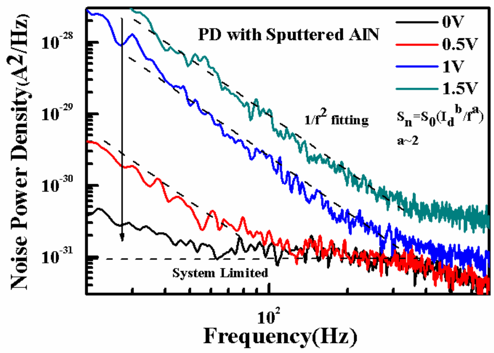


Fig. 3 The spectral response characteristics of GaN MSM PDs with PSS and sputtered AlN nucleation layer.



(a)



(b)

Fig. 4 Noise power spectra of the GaN MSM PDs with (a) PSS and (b) sputtered AlN nucleation layer.