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GaN-Based Schottky Barrier Photodetectors With a 12-Pair Mg_xN_y-GaN Buffer Layer

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Schottky barrier diodes are key elements for the realization of nitride-based electronic devices such as high electron mobility transistors and UV photodetectors (PDs). However, crystal quality of the GaN epitaxial layers prepared on sapphire substrate is poor due to the large mismatches in lattice constant and thermal expansion coefficient between GaN and sapphire. These mismatches could result in a significant number of threading dislocations (TDs) in the epitaxial layers, leading to abnormal large leakage currents in nitride-based devices [1]. Therefore, GaN-based Schottky barrier PDs with the 12-pair Mg_xN_y-GaN buffer layers were fabricated in order to solve this problem.

Samples were grown on c-plane sapphire substrates using metalorganic chemical vapor deposition. Two kinds of nucleation layers were first deposited, including 2-pair Mg_xN_y-GaN buffer layer (PD_A) and a conventional single low temperature (LT) GaN nucleation layer (PD_B), followed by a 2 μm thick Si doped GaN layer and a 0.3 μm thick unintentionally doped GaN active layer. Schottky devices were then fabricated using 15 nm Ti/100 nm and 40 nm Ni/100 nm Au served as Ohmic contacts and Schottky contacts, respectively. The Ohmic contacts were annealed at 600℃ for 8 min. We kept the diameter of the fabricated devices with circular Schottky contact at 400 μm.

Figure 1 plots asymmetrical (1 0 -1 2) XRD rocking curves for the two samples. It was found that full-width-half-maximum (FWHM) of the (1 0 -1 2) XRD peaks of PD_A and PD_B were 439 and 509 arcsec, respectively. The samller asymmetrical XRD FWHM observed from PD_A indicates that crystal quality of the GaN epitaxial layer with a 12-pair Mg_xN_y-GaN buffer layer is higher.

Figure 2 shows room temperature current-voltage (I-V) characteristics for the two fabricated PDs. It can be seen clearly that the reverse leakage current of PD_A was substantially smaller than that of PD_B. The significant six orders of magnitude reduction in reverse leakage current observed from PD_A should be contributed to the use of 12-pair Mg_xN_y-GaN buffer layer which can effectively suppress the generation of TDs. In the forward bias region, it was found that thermionic-emission potential barriers were 1.44 and 1.04 eV, respectively, for PD_A and PD_B. It was also found that the ideality factors of PD_A and PD_B were 1.28 and 2.03, respectively. These values all suggest that we can achieve a more ideal Schottky barrier behavior from PD_A with 12-pair Mg_xN_y-GaN buffer.

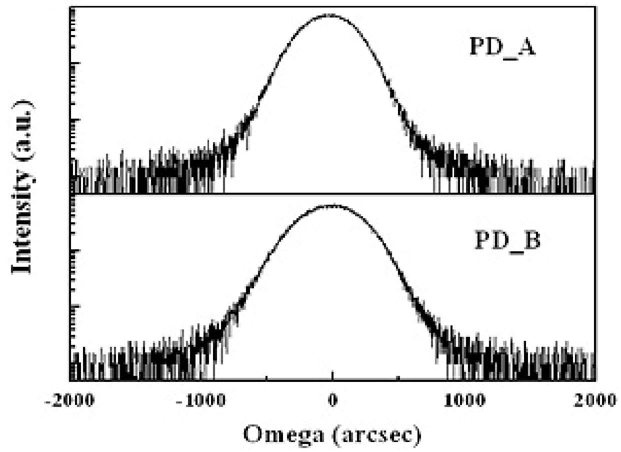

Figure 1 Asymmetrical (1 0 -1 2) XRD rocking curves for the two samples.

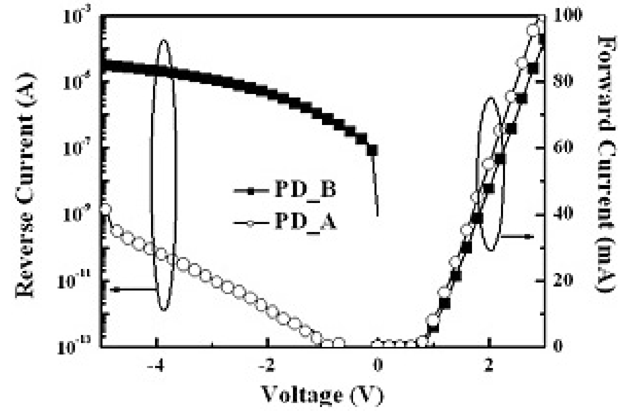

Figure 2 Room temperature I-V characteristics for the two fabricated PDs.

Figures 3 shows spectral responsivity of the two fabricated PDs. With an incident light wavelength of 360 nm and an applied bias of -5 V, it was found that measured responsivities of PD_A and PD_B were 0.097 and 0.551 A/W which corresponds to external quantum efficiencies of 33.47% and 190.12%, respectively. Noted that the -5V bias responsivity of PD_B corresponds to an external quantum efficiency which is larger than 100%. This result suggested the existence of photoconductive gain [2] in PD_B. Here, we define UV-to-visible rejection ratio as the responsivity measured at 360 nm divided by the responsivity measured at 500 nm. With this definition, it was found from figures 3 that UV-to-visible observed from PD_A was three orders of magnitude larger than that of PD_B, when biased at -5 V.

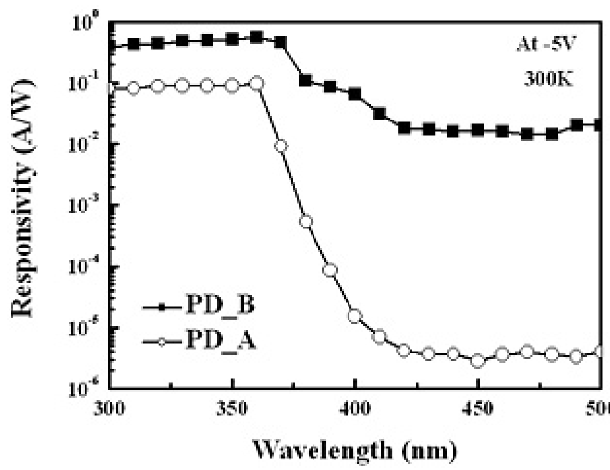

Figure 3 Room temperature spectral responsivity of both fabricated PDs biased at -5V.

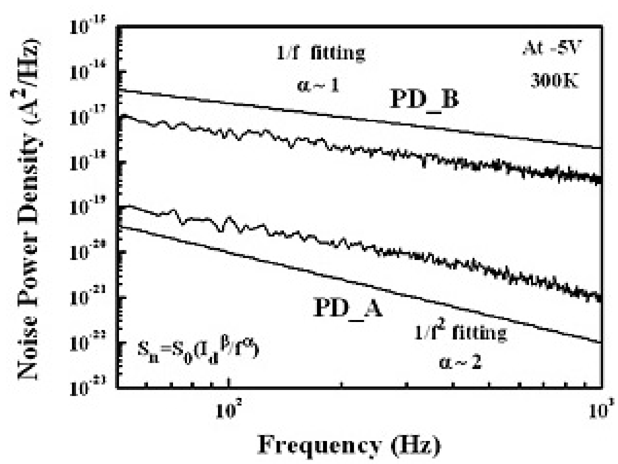

Figure 4 Measured noise power spectra of both fabricated PDs biased at -5V.

Figures 4 shows measured noise power spectra of the two fabricated PDs biased at -5 V. It was found that both curves of the two devices can be well fitted by Hooge-type equation [3]:

$$S_n(f) = S_0 \frac{I_d^{\beta}}{f^{\alpha}} \tag{1}$$

where I_d is the dark current, f is the frequency, $S_n(f)$ is the spectral density of noise power, S_0 is a constant, α and β are two fitting parameters. According to the noise curves obtained, as shown in figure 4, $1/f^2$-noise (α=2) indicatively appears as a dominant noise mechanism in PD_A while 1/f-noise (α=1) is dominant in PD_B. Here, we assumed $S_n(f) = S_n(1\ Hz)$ for f <1 Hz. Thus, the noise equivalent power (*NEP*) and the normalized detectivity, D^*, could be determined by:

$$NEP = \frac{\sqrt{\langle i_n \rangle^2}}{R} \quad (2)$$

$$D^* = \frac{\sqrt{A}\sqrt{B}}{NEP} \quad (3)$$

where *R* is the responsivity of the PDs, *A* and *B* are the area of the device and the bandwidth, respectively. For a given bandwidth of 1 kHz and a device area of 2.12×10^5 μm^2, with a -5 V applied bias, D^* and *NEP* for PD_A were 1.5×10^7 cmHz$^{0.5}$W^{-1} and 9.73×10^{-8} W, respectively. At the same bias, D^* and *NEP* for PD_B were 8.22×10^6 cmHz$^{0.5}$W^{-1} and 1.77×10^{-7} W, respectively. These values indicate that we can also achieve a lower noise level and a larger detectivity by using the 12-pair Mg_xN_y-GaN buffer layer.

In summary, GaN-based Schottky barrier PDs with conventional single LT GaN buffer layer and with 12-pair Mg_xN_y-GaN buffer layer were both fabricated. It was found that we could reduce TD density and correspondingly improve the crystal quality of the devices by using the 12-pair Mg_xN_y-GaN buffer layer. It was also found that we can reduce noise level and enhances detectivity of GaN-based PDs by the 12-pair Mg_xN_y-GaN buffer layer.

References

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