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AlGaN UV-B Photodetectors on AlN/sapphire template

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1. Introduction

Recent progress in developing AlGaN based ultraviolet (UV) photodetectors (PDs) has demonstrated their great potential as an alternative to the traditional UV sensing devices, such as photomultiplier tubes (PMTs) and Si UV detectors, which are high cost, unstable or inefficiency.[1-6] AlGaN UVB photodetectors with the long-wavelength cutoff in the region of 280~320 nm are of interest for a variety of applications. Topics include ozone layer monitoring, medical and chemical analyses, combustion and flame detection, UV curing detection, phototherapy control, and personal exposure monitors etc.[7] A key issue limiting the performance of the state-of–art AlGaN UVB PDs is the cracks and/or high-density defects present in the AlGaN active epilayer, due to the lattice and thermal mismatch between the AlGaN and the underlying epilayer. The recent achievement of AlN(≥1 μm)/sapphire template is expected to improve this problem. In this work, we report the high–performance $Al_{0.3}Ga_{0.7}N$ UVB Schottky photodiode fabricated on AlN/sapphire template.

2. Device fabrication

The epitaxial structure was grown on AlN (1μm)/sapphire template by MOCVD method using NIPPON SANSO SR2000 system. The epilayers consisted of a 1 μm-thick Si-doped n^+-$Al_{0.3}Ga_{0.7}N$ layer followed by a 0.5 μm unintentionally doped $Al_{0.3}Ga_{0.7}N$ active layer. The growth temperature and pressure are 1180 ℃ and 100 torr, respectively. For comparison, another set of $Al_{0.3}Ga_{0.7}N$ layer on GaN/sapphire structure was also grown on sapphire. The epitaxial structure includes a 30 nm GaN buffer layer grown at 500 ℃, a subsequent 2 μm i-GaN layer grown at atmosphere and 1180 ℃, and a 0.2 μm unintentionally doped $Al_{0.3}Ga_{0.7}N$ active layer grown at 120 torr and 1180 ℃. A thicker active layer is expected, but with the occurrence of cracks in our samples based on GaN/sapphire structure.

X-ray diffraction measurements showed that the full width at half magnitudes (FWHMs) of the (004) and (204) rocking curves are 247 and 564 arcsec for $Al_{0.3}Ga_{0.7}N$ on AlN/sapphire template and 362 and 789 arcsec for $Al_{0.3}Ga_{0.7}N$ on GaN/sapphire, indicating high crystalline quality of the epilayers on AlN template.

Figure 1 depicts the schematic cross-section structures of the two devices. Mesa structures were defined by reactive ion etching (RIE) using BCl_3 gas. Ohmic contacts were formed with e-beam deposited Ti/Al/Ni/Au. The transparent Schottky-contact dots with a diameter of 200 μm were formed with Pt/Ni (70/15 Å) layers, which was deposited using e-beam evaporation and a standard lift-off process. Probe pads were deposited with Ni/Au bilayer.

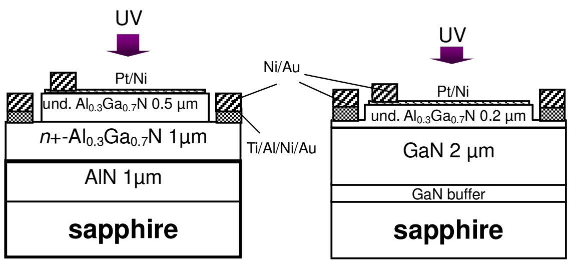

Fig. 1 Schematic cross-section of the UVB AlGaN Schottky photodiodes fabricated on (a) AlN/sapphire template and (b) GaN/sapphire.

3. Results and Discussion

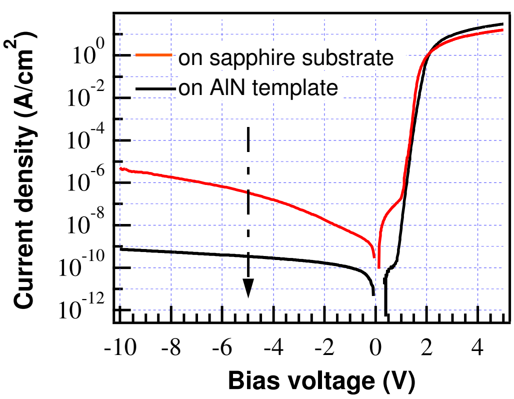

Fig. 2. Dark current-voltage characteristics of the $Al_{0.3}Ga_{0.7}N$ Schottky PD fabricated on AlN/sapphire template and GaN/sapphire structure.

Dark current-voltage (I-V) characteristics of the Schottky PDs were measured with an Agilent 4156C precision semiconductor parameter analyzer. As shown in Fig.2, for the device fabricated on AlN/sapphire tenmplate, the leakage current is only 2.4 pA at -5 V bias, corresponding to a current density of 3.3×10^{-10} A/cm². This value is about three orders lower than that of the $Al_{0.3}Ga_{0.7}N$ PDs fabricated on GaN/sapphire structure, which is ~ 3.4×10^{-7} A/cm^2. We ascribe this lower leakage current density to the high crystalline quality of the $Al_{0.3}Ga_{0.7}N$ epilayers on AlN template.

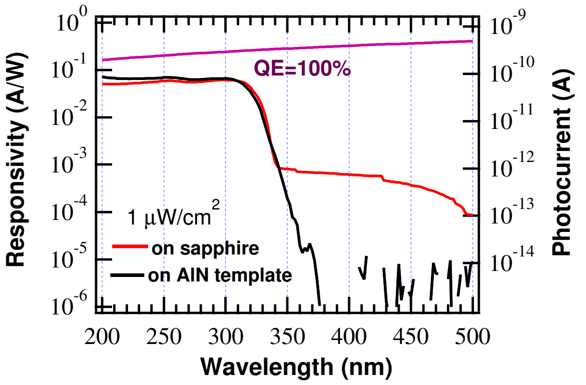

Fig. 3. Spectral responsivities of the zero-bias UVB Schottky PDs under the constant irradiation intensity of 1 μW/cm^2.

The spectral responses of the photodiodes were measured using a lamp source consists of halogen, xenon and D2 lamp, a monochromator and a Electrometer in the wavelength range of 500~200 nm. The constant irradiation intensity was corrected with PMT unit, while the absolute values of responsivity were determined using a calibrated Si detector. For the device fabricated on AlN/sapphire template, as seen from Fig. 3, the sharp cutoff presents at the band edge of $Al_{0.3}Ga_{0.7}N$. The rejection ratio is more than four orders of magnitude by λ=360 nm. At a bias of -5 V, the photoresponse is 54.4 mA/W under an irradiation density of 1 μW/cm^2 with a wavelength of 300 nm, giving the external quantum efficiency (QE) of 26%. For the photodiodes constructed on GaN/sapphire structure, the band-edge cutoff wavelength and the peak responsivity are almost same as those of the photodiode on AlN template. The rejection ratio, however, is only two orders of magnitude by 360 nm. We speculate that the lager leakage current combined with the long-wavelength response arising from the *i*-GaN layer contribute to this lower rejection ratio.

Due to its superior characteristics, a large size UVB Schottky photodiode fabricated on AlN template with active area of 4×4 mm^2 was used to detect the flame from a lighter. Figure 4 demonstrates the photoresponses to lighter flame under the background with and without room light, respectively. It is shown that the UVB photodiode has a clear photoresponse to the lighter flame and also slightly responses to the room light.

4. Conclusions

We have demonstrated the AlGaN UVB Schottky-PDs fabricated on AlN/sapphire template with improved performance of low dark current and high UVA and visible rejection ratio, as compared with those fabricated on GaN/sapphire structure. Dark current density as low as 3.3×10^{-10} A/cm^2 at -5 V bias and zero-bias external QE of 26% at 300 nm were achieved. The capability for detecting the flame of lighter is demonstrated by the photodiode with the large active-area of 4×4 mm^2.

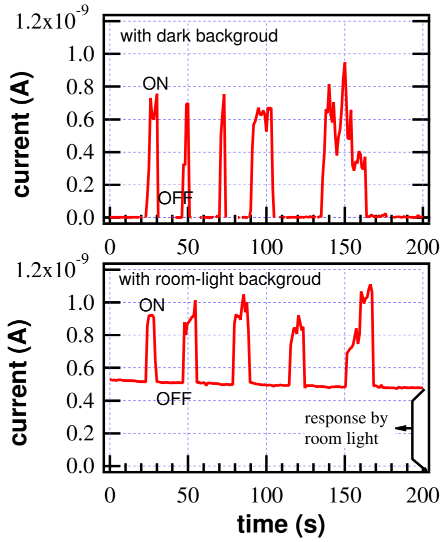

Fig. 4. Photoresponses to lighter flame detected by a zero -bias UVB Schottky PD fabricated on AlN template with the active area of 4×4 mm^2, placed ~15 cm apart.

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References

[1] J. C. Campbell, C. J. Collins, M. M. Wong, U. Chowdhury, A. L. Beck, and R. D. Dupuis, Phys. Stat. Sol. A. **188**, 283 (2001).

[2] C. J. Collins, U. Chowdhury, M. M. Wong, B. Yang, A. L. Beck, R. D. Dupuis, and J. C. Campbell, Electron. Lett. **38**, 824 (2002).

[3] N. Biyikli, O. Aytur, I. Kimukin, T. Tut, and E. Ozbay, Appl. Phys. Lett. **81**, 3272 (2002).

[5] C. Pernot, A. Hirano, M. Iwaya, T. Detchprohm, H. Amano and I. Akasaki, Jpn. J. Appl. Phys., **39**, L387 (2000).

[6] J. D. Brown, J. Matthews, S. Harney, J. C. Boney, J. F. Schetzina, J. D. Benson, K. V. Dang, T. Nohava, W. Yang, and S. Krishnankutty, MRS Internet J. Nitride Semicond. Res. **5S1**, W1.9 (2000).

[7] E. Muñoz, E. Monroy, J.L. Pau, F. Calle, F. Omnès, and P. Gibart, J. of Phys. : Cond. Matter. **13**, 7115 (2001).