Surface KOH treatment in AlGaN-based photodiodes

W.-H. Lan, K.-C. Huang and K.F. Huang

KOH treatment is investigated as a method to improve the I-V characteristics of AlGaN-based photodiodes. The defects in the photodiode may enhance the dark current, and cause photocurrents with incident photon energy less than the absorption edge. With the KOH treatment in the process, the defects and whisker-like features could be reduced. High rejection ratio in the spectral responsivity could be achieved. The KOH treatment is a good method to reduce the surface defects in AlGaN-based photodiodes.

Introduction: Applications for wide-bandgap nitrides include emitters in light-emitting diodes (LEDs), laser diodes (LDs), photoconductive detectors and photovoltaic detectors in the blue-ultraviolet (UV) range of the spectrum. Since GaN is quite hard to etch, fabrication of these GaN-based optoelectronic devices depends on the inductively coupled plasma reactive ion etching (ICP-RIE) method. Several groups have studied the GaN defect induced by the ICP etching process [1–3]. It is known that energetic ion bombardment-induced damage in the ICP etching process may lead to deterioration in the optical and electrical properties of the semiconductor [4–7]. The leakage current is generally used to characterise ICP-etched GaN samples, as well as breakdown voltage [8–12].

In this Letter we study the effect of surface KOH treatment for AlGaN-based photodiodes after ICP etching process. The current behaviours for as-grown and KOH-treated samples are studied. The spectral responsivity for both samples is also studied. From this, the effect of KOH treatment and the surface defects are discussed.

Experimental procedure: Visible-blind AlGaN-based photodiodes were grown on sapphire substrates by metal organic chemical vapour deposition (MOCVD). The epitaxial structure consists of a sapphire substrate with a low temperature GaN nucleation layer, 2 µm of undoped GaN, 2 µm of n^+-GaN (2×10^{18} cm^{-3}), 50 nm of n-GaN (5×10^{17} cm^{-3}), 300 nm of undoped $Al_{0.13}Ga_{0.87}N$, and 50 nm of p^+-GaN (5×10^{17} cm^{-3}). Samples were then etched to the n^+GaN region by ICP etching process with standard photolithography process. For KOH treatment samples were then immersed in the boiling KOH solution for 80 s, rinsed in DI water and dried by nitrogen gas. The procedure for both the as-grown and the KOH-treated samples was then as the following. The Ni/Au contacts on the p-type layer are formatted with photolithography technology and subsequently annealed in a furnace at 550°C for 10 min in air. A SiO_2 layer was then deposited by plasma-enhanced chemical vapour deposition (PECVD) to serve as the antireflection coating as well as the surface passivation layer. The Ti/Al/Ti/Au metals as the n-type contacts were then patterned by standard lift-off process. The diode area is 1×10^{-3} cm^2. The current-voltage (I-V) measurements of AlGaN-based photodiodes were characterised by a Hewlett-Packard 4156 semiconductor analyser. Spectral responsivity of the AlGaN-based photodiodes was measured by a Xenon arc lamp and a monochrometor (SPX1000). All the optical systems were calibrated using a UV-enhanced silicon photodiode.

Results and discussion: Fig. 1*a* shows scanning electron microscopy (SEM) images of the AlGaN-based photodiodes for the as-grown sample after etching to the n^+-GaN region. Owing to poor protection of the photoresist during the etching process or the poor property of AlGaN and p-GaN, the sidewall with whisker-like features [13] for the as-grown sample can be observed on top of the n^+-GaN layer after the ICP etching process. These whisker-like features may result from mix and edge dislocations [14], the diameter being around 50–100 nm [15]. Thus, some leakage currents through these whisker-like features can be expected. After the KOH treatment, these whisker-like features can be removed [16] as shown in Fig. 1*b*. Under the smoother surface on the edge, a more uniform electric field can be achieved and less leakage current on the edge can be expected.

Fig. 2 shows current-voltage (I-V) characteristics for the AlGaN-based photodiodes without ('as-grown' sample) and with the KOH treatment ('KOH-treated' sample). For the KOH-treated sample, a lower dark current could be observed and the photocurrent is also near a constant at various bias voltages. For the as-grown sample, a dark current increased as reverse bias increased. Under illumination (330 nm, 0.7 µW), for the as-grown sample, the current increased with bias. Some leakage paths in parallel with the diode may be formed in the as-grown sample [17]. Compared to a stable current for the KOH-treated sample, these defects may be characterised as surface defects. To clarify the defects effect, with the illumination of photon energy less than the absorption edge, the results of the sample illuminated were studied. Fig. 3 shows the I-V characteristics illuminated with a wavelength of 400 nm (2.8 µW). The I-V curve of the KOH-treated sample taken in the dark and under the illumination is almost the same. Yet, for the as-grown sample, some currents under illumination could be observed. Since the incident photon energy is less than the bandgap, these currents could be characterised as the defect-assisted photocurrent. Thus, lower surface defects could be expected for the KOH-treated sample.

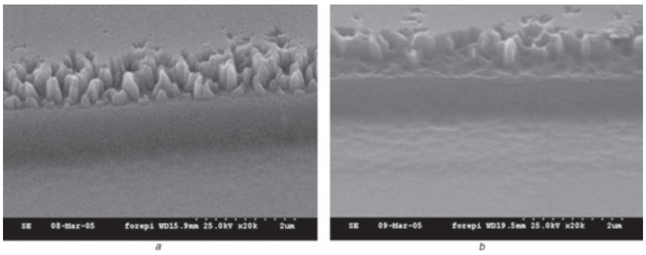

Fig. 1 *Scanning electron microscopy images*

a SEM image of AlGaN-based photodiodes for as-grown sample after etching to n^+-GaN region
b SEM image of AlGaN-based photodiodes for KOH-treated sample after etching to n^+-GaN region

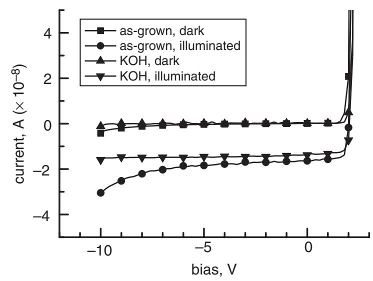

Fig. 2 *Current-voltage characteristics for as-grown and KOH-treated samples under illumination (0.7 µW) with wavelength 330 nm*

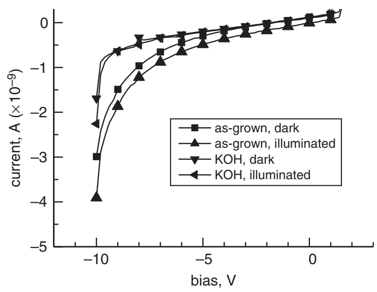

Fig. 3 *Current-voltage characteristics for as-grown and KOH-treated samples under illumination (2.8 µW) with wavelength 400 nm*

Fig. 4 shows the spectral response of as-grown and KOH-treated samples under 0 V and reverse bias 10 V. The cutoff wavelength is around 335 nm as the absorption of $Al_{0.13}Ga_{0.87}N$ (3.7 eV) for both samples. The responsivity is 0.023 and 0.021 A/W for both the as-grown and KOH-treated samples at a wavelength of 330 nm. For the KOH-treated sample, there is less surface defect as discussed above, and less responsivity in the rejection band at 0 V can be observed in the Figure. Under higher reverse bias, the defect-assisted current may be enhanced, and may increase the responsivity in the rejection band. For the as-grown sample, some extra defect levels around 3.4 eV (360 nm) can be observed at reverse bias 10 V. For the KOH-treated sample, there is no such level in this case, as shown in Fig. 4.

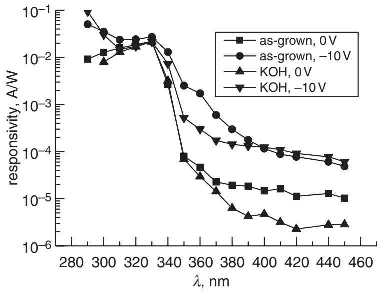

Fig. 4 *Spectral responsivity for as-grown and KOH-treated samples at different biases*

Conclusions: The surface effects of AlGaN-based photodiodes with the KOH treatment after the ICP etching process have been investigated. The characteristics of reverse bias current are studied. Under illumination (400 nm, 2.8 μW), for the as-grown sample, the photocurrent can be observed. When the incident photon energy is less than the absorption edge, these currents could be characterised as the defect-assisted photocurrent. With the KOH treatment in the process, the defects and whisker-like features could be reduced. High rejection ratio in the spectral responsivity could be achieved. The KOH treatment is a good method for improving the devices characteristics in AlGaN-based photodiodes.

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