Control Of Surface Morphology In Photoelectrochemical Etching Of Gan

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Photoelectrochemical etching processes have proven to be effective, low-damage wet etching approaches for GaN and related materials.[1-3] However, compared with dry etching techniques[4] the PEC etching processes reported to date often result in rough etched surfaces,[1-3] while smooth surfaces are preferable for many electronic and optoelectronic devices. In this work, we report our recent investigation of the surface morphology of GaN after PEC etching. We find that considerable control over the surface roughness can be exerted through selection of the electrolyte concentration and illumination intensity, as well as through the use of an applied bias voltage during etching.

For etching studies, a metal mask consisting of 150 nm thick Ti was deposited on the GaN sample surface by electron beam evaporation and patterned using a lift-off process. The GaN samples were mounted in an electrochemical cell, in which a tungsten probe tip was used to contact the Ti metal on the sample, and a platinum wire was inserted in the KOH electrolyte to act as the cathode. A Keithley sourcemeter between the tip and the Pt cathode monitors the PEC etching current and supplies the voltage bias if required. The UV light source is a 1000 W mercury-xenon short arc lamp.

Figure 1 (a) shows a typical PEC-etched surface obtained by etching in 0.05 M KOH solution for 24 min. A high density of whisker-like structures forms; the same surface morphology has previously been observed by other researchers.[2-3] In comparison, Fig. 1(b) shows the PEC-etched surface obtained in 0.0025 M KOH solution for 24 min, with a mirror placed below the electrochemical cell to increase illumination intensity. As shown in Fig. 1 and Table 1, higher illumination intensity and lower electrolyte concentration result in considerably smoother surfaces and a much reduced density of whiskers. This trend is consistent with the qualitative description of Youtsey et al.[5]

In our experiments, GaN samples ($n{\sim}6x10^{16}cm^{-3}$) grown on sapphire by MOCVD are used, thus a high dislocation density in the epitaxial GaN is expected.[6] It has been verified that dislocations in GaN act as nonradiative recombination centers.[7] Consequently, a non-uniform density of holes at the surface arises from the combination of a spatially uniform electron-hole pair generation rate under UV illumination and rapid hole recombination at dislocation sites. As a result, selective etching between dislocated and defect-free GaN results in whisker morphology due to the sensitivity of the PEC etch rate to surface hole concentration. Consequently, one possible approach that has been proposed to achieve smooth and whisker-free etched surfaces is to reduce the variation in the hole concentration by using high illumination intensity to saturate the recombination centers.[5] On the other hand, as shown in Table 1, we have observed that reducing the electrolyte concentration also suppresses whisker formation independent of hole concentration. Our XPS analysis of GaN surfaces before and after etching (Fig. 2) shows that oxide forms during PEC etching, and is more slowly dissolved in lower concentration solutions.[8] The resulting residual oxide slows the etching of defect-free GaN, suppressing the selective etching which leads to rough surfaces. Consequently, a lower whisker density is achieved.

Figure 3 shows the result of PEC etching in 0.0025 M KOH solution with a +0.65 V bias applied between the tungsten tip and the Pt cathode. The surface morphology is improved to an rms roughness of 0.5 nm, and whisker formation is almost entirely eliminated. The applied positive bias helps to extract electrons from the UV illuminated area and increases the energy band bending at the GaN-electrolyte interface, thereby inducing a higher hole concentration at the GaN surface.

We have investigated several mechanisms for morphology control in PEC etching. A combination of oxide-mediated PEC etching in lower-concentration electrolytes and bias-enhanced etching has been found to produce the smoothest surfaces.

References

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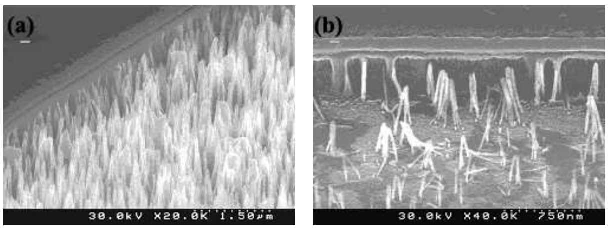

Fig. 1. PEC-etched GaN in (a) 0.05 M KOH for 24 min and (b) 0.0025 M KOH for 60 min with mirror.

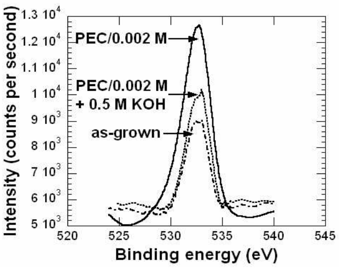

Fig. 2. Detail of oxygen (O 1s) XPS analysis.

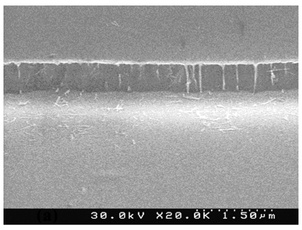

Fig. 3. PEC-etched GaN in 0.0025 M KOH for 30 min under +0.65 V bias voltage.

	KOH Electrolyte Concentration (M)			
	0.0025	0.0025	0.01	0.05
Etch Time and Configuration	30 min +0.65 V	1 hr mirror	24 min	24 min
Density ($x10^9$ cm^{-2})	~0	~1.5	~30	>200

Table 1. Density distribution of whisker-like structures.