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Enhanced UV photodetector responsivity in porous GaN by Pt assisted electroless etching

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High quality unintentionally doped n-type GaN layers were grown on Si(111) substrate using high temperature AlN as buffer layer by radio frequency (RF) nitrogen plasma-assisted molecular beam epitaxy (MBE). This paper presents the structural and optical studies of porous GaN sample compared to the corresponding as grown GaN. Metal-semiconductor-metal (MSM) photodiode was fabricated assamples. For as grown GaN sample, this detector shows a sharp cut-off wavelength at 362 nm. A maximum responsivity of 0.258 A/W was achieved at 360 nm. For the porous GaN sample, this detector shows a sharp cut-off wavelength at 364 nm. A maximum responsivity of 0.771 A/W was achieved at 363 nm. MSM photodiode based on porous GaN shows enhanced (3x) magnitude of responsivity relative to as grown GaN MSM photodiodes. Enhancement of responsivity can be attributed to the relaxation of the compressive stress and reduction of surface pit density in the porous sample.

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1. Introduction

Ultraviolet (UV) photodetectors are important devices that can be used in various commercial and military applications. For example, visible-blind UV photodetectors can be used in space communications, ozone layer monitoring and flame detection. To my knowledge, only few approaches have been reported with regard to the metal-semiconductor-metal (MSM) photodiode fabricated on porous GaN films.

The fabrication of porous semiconductors has stimulated much research interest recently. The unique physical properties of the porous layer such as, high surface area, shift of bandgap and efficient luminescence are among the special features which show promise in some of the sensing applications [1,2]. The research in porous GaN is strongly driven by the superior physical properties such as the excellent thermal, mechanical and chemical stability, as well as the potential shift of the bandgap [3], moreover, it has been reported that porous GaN can be used as intermediate layer for the reduction of substrate induced strain [4,5]. Since bulk GaN in wafer size is not available, GaN thin film usually is grown on poor lattice and thermal mismatch foreign substrates which will result in high residual stress and eventually lead to high density of structural defects. Porous GaN shows promise as a growth template for epitaxial re-growth; this could reduce the density of structural defects significantly and allows the growth of residual-free epitaxial GaN layers. Comparatively, the study of porous GaN is still in the early stage, many fundamental properties are not well-established.

In this work, porous GaN was prepared by Pt assisted electroless chemical etching for 60 minutes. The morphological, structural and optical properties of as grown and porous GaN samples were characterized by scanning electron microscopy (SEM), high resolution X-ray diffraction (HR-XRD), and photoluminescence (PL). Also reported is our attempt to fabricate and characterize metal-semiconductor-metal (MSM) photodiode based on these films.

2. Experimental details

The unintentionally doped n-type GaN film grown on Si(111) substrate was used in this study. The thickness of GaN film is about 0.06 μm with carrier concentration of ~4.0×1019 cm^{-3} as determined by Hall Effect measurement. The wafer was then cleaved into few pieces. Prior to the metallization, the native oxide of the sample was removed in the 1:20 $NH_4OH:H_2O$ solution, followed by 1:50 $HF:H_2O$. Subsequently boiling aqua regia (3:1 $HCl:HNO_3$) was used to etch and clean the sample.

Porous GaN in this work was generated by Pt assisted electroless etching. Two narrow stripes of Pt with thickness of about 200 nm were deposited on the GaN sample by using sputtering system. The samples were then etched in a solution of 4:1:1 $HF:CH_3OH:H_2O_2$ under illumination of an UV lamp with 500 W power for 60 minutes. After chemical treatment, the samples were removed from the solution and rinsed with distilled water; followed by the removal of the residual Pt by ultrasonic cleaning. The morphological, structural and optical properties of as grown and porous GaN samples were characterized by scanning electron microscopy (SEM), high resolution x-ray diffraction (HR-XRD), and photoluminescence (PL).

For the MSM photodiodes, the structure of the MSM photodiode consists of two interdigitated Schottky contacts (electrodes) with finger width of 230 μm, finger spacing of 400 μm, and the length of each electrode was about 3.3 mm. It consists of 4 fingers at each electrode. Nickel (Ni) is used as the Schottky contact metal for all the fabricated devices due to its high metal work function (ϕm = 5.15 eV) [6] and its availability in our lab. Thermal evaporation method is employed for all the Ni Schottky contact formation by using a metal mask. For the wafer cleaning process prior to metallization of the contact metal, the samples were dipped in a 1:20 NH_4OH:H_2O solution for 15 s followed by a 10 s dip in a 1:50 HF:H_2O solution. Then, it was rinsed with distilled water and blown dry with normal gas blower.

The typical resistance of the MSM is about 10 kΩ. The spectral response was measured using a tungsten lamp, a monochromator, a chopper and a lock-in amplifier. The spectral responsivity of the UV detectors has been determined.

3. Results and discussion

The morphology of the as grown and porous GaN films were characterized by plan-view scanning electron micrographs (SEM). As seen in Fig. 1, the porous area is very uniform, with pore diameter in the range of 80-110 nm. It should be noted that the porous GaN generated by electroless etching technique does not necessarily has identical morphological evolution. Diaz et al [7,8] prepared their porous GaN samples by platinum assisted electroless etching, and found that, at short etch time (< 15 min), a rich network of small pores were formed. However for longer etch times, a ridge-valley-like morphology was obtained.

In order to examine the quality of the films, ω/2θ scan of XRD rocking curve (RC) for (0002) plane was carried out. Fig. 2 shows the ω/2θ scan of the XRD RC of (0002) plane for the as grown and porous GaN/Si(111). It is interesting to note that the FWHM of porous GaN sample increases compared to the as grown sample, however, the amount of increase was small. Change of peak positions was relatively insignificant for the (0002) diffraction plane. This can be explained by the relatively narrawer statistical size distribution of the pores.

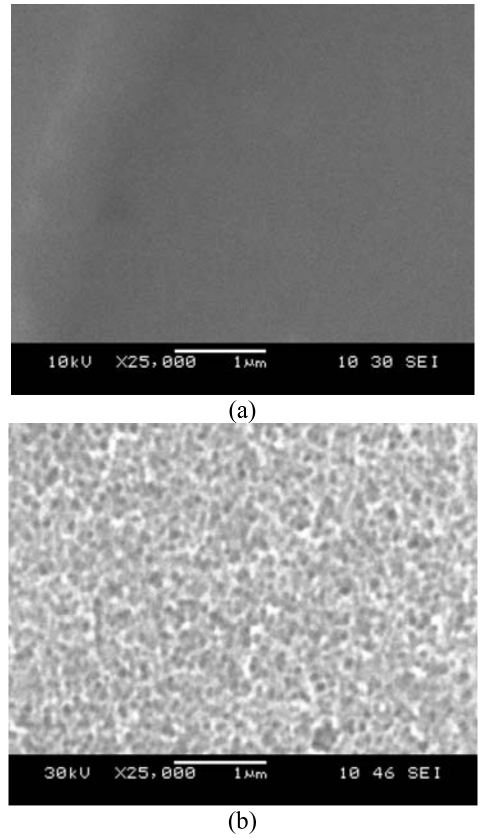


Fig. 1. SEM images of the samples. (a) As grown, (b) Etched for 60 min.

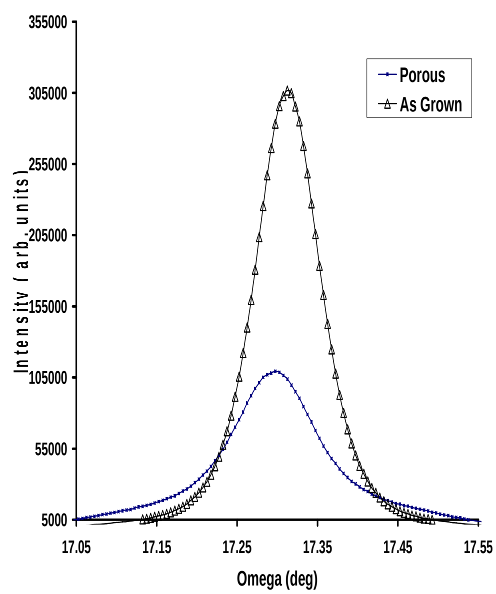


Fig. 2. X-ray diffraction (XRD) rocking curve (RC) of (0002) plane for as grown and porous GaN grown on Si(111) substrates.

Fig. 3 illustrates the room temperature PL spectra of as grown and porous GaN samples. The porous GaN samples were observed to be red-shifted relative to the as-grown sample. The red-shift is due to the relaxation of the compressive stress in the porous samples. The amplification of porosity-induced PL intensity could be explained by the extraction of strong PL by light scattering from the sidewalls of the GaN crystallites [9]. However, it could be also ascribed to the optical microcavity effect which is inherent to porous GaN areas characterized by strong light scattering. It has been known that optical mode density could be altered by interference due to the optical environment [10].

The spectral responsivity data for the as grown and porous GaN MSM detector are illustrated in Fig. 4. Photodetector responsivity was measured as a function of the incident light wavelength, which was from a high-pressure tungsten lamp with a 5V bias. For as grown GaN-based MSM, the detector shows a sharp cut-off wavelength at 362 nm, with a maximum responsivity of 0.258 A/W achieved at 360 nm.

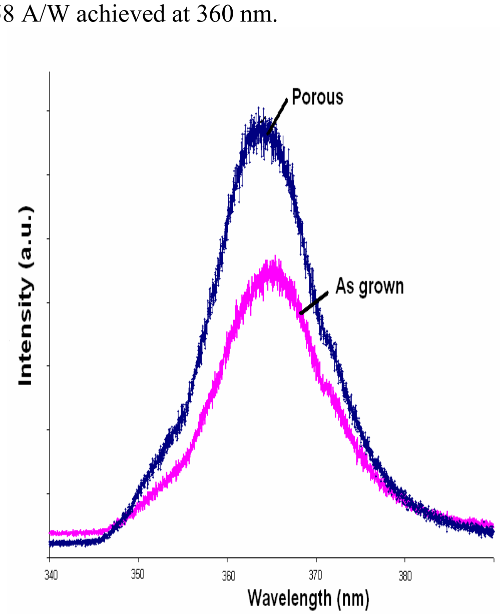
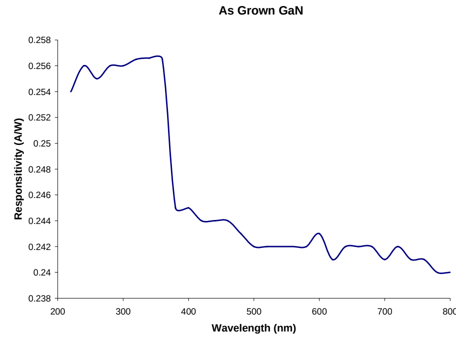
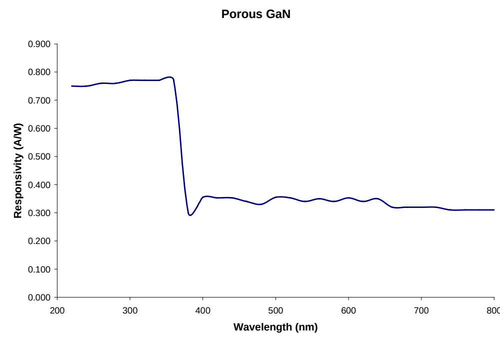


Fig. 3. The near band edge PL spectra of the samples measured at room temperature: As grown and etched under 60 min.

For porous GaN MSM detector, a sharp cut-off wavelength at 364 nm with a maximum responsivity of 0.771 A/W was achieved at 363 nm. Both of the detectors show a little decrease in responsitivity in UV spectral region. MSM photodiode based on porous GaN shows enhanced (3x) magnitude of responsivity relative to the as grown GaN MSM photodiode. The response below the band gap obviously comes from the energy levels in the forbidden band, just like those in the photoluminescence, which mainly depends on defects and impurities in GaN films. The studies show that porosity in GaN films could influence the structural and optical properties of the material, suggesting several advantages of porous GaN in photodetector applications.



(a)



(b)

Fig. 4. The responsivity as a function of wavelength for MSM detector: (a) As grown, (b) Porous GaN

4. Conclusion

The properties of UV photodetectors based on GaN epilayers grown on Si(111) substrates using RF-MBE were investigated. Porous GaN in this work was generated by Pt assisted electroless etching. The porous area is very uniform, with pore diameter in the range of 80-110 nm. Metal-semiconductor-metal (MSM) photodiode was fabricated on the samples. MSM photodiode based on porous GaN shows enhanced (3x) magnitude of responsivity relative to as grown GaN MSM photodiodes, suggesting advantages of porous GaN in photodetector applications.

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