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Analysis and characterization of GaN nanostructure by electrochemical etching

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Nanostructured GaN layers have been fabricated by electrochemical and laser-induced etching (LIE) processes based on n-type GaN thin films grown on the Si (111) substrate with AlN buffer layers. The effect of varying current and laser power density on the morphology of the GaN layers is investigated. The etched samples exhibited a dramatic increase in photoluminescence intensity as compared to the as grown samples. The average diameter of the GaN crystallites was about 7–10 nm, as determined from the PL data The Raman spectra also displayed stronger intensity peaks, which were shifted and broadened as a function of etching parameters. A strong band at 522 cm^{-1} is from the Si (111) substrate, and a small band at 301 cm^{-1}, due to the acoustic phonons of Si. Two Raman active optical phonons are assigned h-GaN at 139 cm^{-1} and 568 cm^{-1}due to E2 (low) and E2 (high) respectively.

Keywords: GaN; analysis, Characterization.

1. INTRODUCTION

Wide-gap Ⅲ—V nitride semiconductors such as GaN are most promising for blue or ultraviolet (UV) emitting devices. For the fabrication of GaN nanostructure-based devices, it is important to control the size of nanocrystals as well as to develop a reliable means of monitoring the size distributions of the nanocrystallites in these luminescent materials. In recent years, processing techniques for III—V nitrides' nanostructures have been successfully established, especially for crystal growth. Several have attempted to investigate compound semiconductors nanostructure such as GaAs, GaP and GaN [1–5] while the most suitable etching method is still not concrete because of the excellent chemical stability and high hardness of these compounds. Plasma etching [6] and reactive ion etching (RIE) [7,8] have mainly been applied so far to etching of III—V nitride crystals. With these processes, however, damage by ion or plasma bombardment is a serious problem.

In this work, the fabrication of nanostructured porous GaN by electrochemical etching and laser-induced etching has been attempted. Laser processing has the advantages of not causing damage or contamination, as well as of special selectivity with high resolution and high efficiency; however, there are few reports on the laser processing of III—V nitride crystals. The studies on the fundamental properties of these nanostructures are very important due to their unique structural and optical properties relative to the bulk form of the corresponding material.

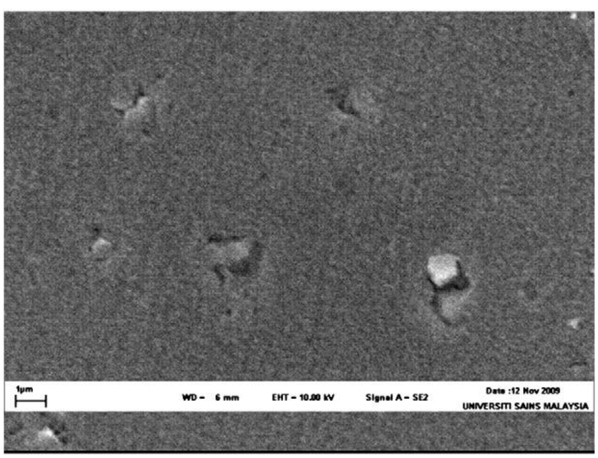

Figure 1 SEM image of as grown GaN/AlN/Si (111).

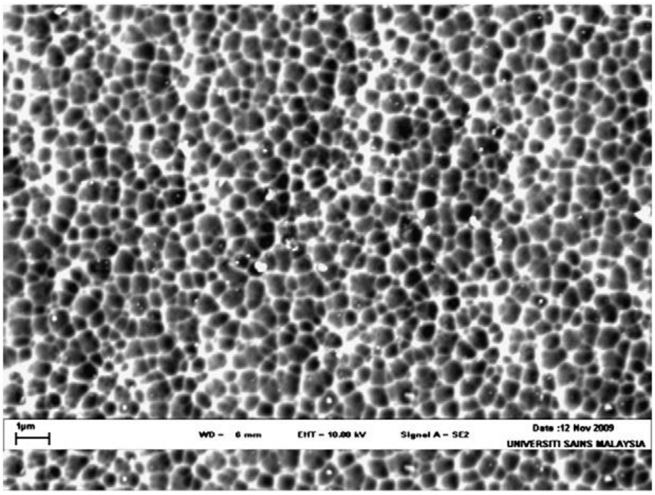

Figure 2 SEM image of nanostructured GaN prepared by electrochemical etching.

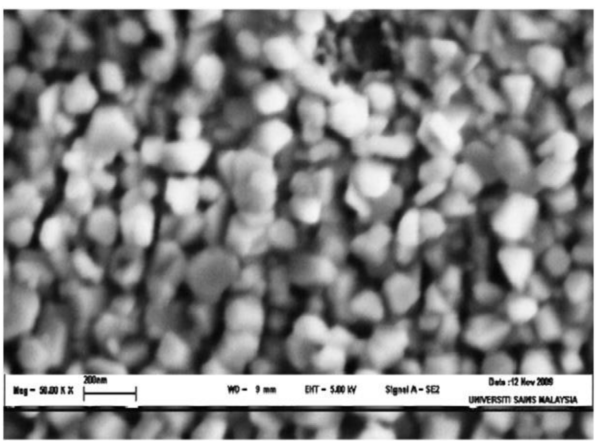

Figure 3 SEM image of nanostructured GaN prepared by laser-induced etching.

GaN epilayer was grown on top of the buffer layer for 60 min with the substrate temperature set at 845 °C. The GaN samples with (0002) orientation, a carrier concentration of 2.1×10^{19} cm^{-3}, and a thickness of 0.47 um were placed in an electrolyte solution with ethanol 99.999%: HF40%, all in a ratio of 5:1 applied with a current density of 75 mA/cm^2 and an etching duration of 45 min for the electrochemical etching process, and for the laser- induced etching, a power density of 38 W/cm^2 from a laser diode (λ= 635 nm, 1.90 eV) was applied. The etching duration was 45 min. The processes were carried out at room temperature. Surface morphology and structural properties of the samples were characterized by using scanning electron microscopy (SEM). Photoluminescence (PL) measurement was also performed at room temperature by using, He—Cd laser (λ= 325 nm), and Raman scattering has been investigated using Ar + Laser (λ = 514 nm).

2. RESULTS AND DISCUSSION

Fig. 1 shows the SEM image of the as grown GaN sample. The as grown samples exhibited a relatively smooth surface morphology. Pits were found on the GaN surface but with a small ratio as compared to resulted in the formation of pores over structures with different sizes. The etched surface became hexagonal, and pores over structures are confined to smaller size. In addition, the pore walls were very thin with some short thin tips at the top as shown in Fig. 2. When the etch rate is too large, the grain boundaries are etched significantly slower than the centre of the crystals. This leads to a hexagonal, rough morphology [10]. On the other hand, the surface morphology of the sample obtained after the laser-induced etching process shows deep and extremely thin pores as shown in Fig. 3. This is due to variation in the penetration depth of the laser beam. Photoluminescence (PL) spectra showed blue shift luminescence of the etched samples relative to the as grown. The band edge emission wavelength shifted from 362.0 to 335.0 nm for the electrochemically etched sample, and to 346.5 nm for the laser-induced etched sample. The average diameter of the GaN crystallites was about 7–10 nm, as determined from the PL data by using the effective mass theory. Assuming infinite potential barriers, the E_g of the 3D confined GaN were obtained as [11].

3. CONCLUSIONS

In summary, GaN nanostructures have been fabricated by two different etching techniques. The as grown MBE samples exhibited a relatively smooth surface morphology. The etched surface became hexagonal, and pore structures were confined to smaller size. The quantum confinement effects are considered to control the mechanism of the luminescence in the nanocrystallites. The broadening of the band gap energy occurs with the decrease in the crystallite size. The blue shift luminescence is attributed to charge carrier quantum confinement. The Raman spectra for the etched samples revealed shifted and broadened peaks relative to the as grown GaN which can be attributed to the quantum confinement effects on the electronic wave function of the GaN nanocrystals.

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