

A Novel Chemical Lift-Off Process based on Embedded Nano-rods Template

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1. Introduction

In recent years, light emitting diodes (LEDs) have been attracted great attention for application on high-power and high-brightness lighting source, especially for GaN-based LED.¹ At high current level operations, heat generation will increase the junction temperature rapidly, and reduce the device performance, such as lowering the internal quantum efficiency (IQE) and shorting the device lifetime.¹ Owing to low cost and highly latticematch to GaN, sapphire has become the most commonly used substrates for GaN epitaxial growth. However, sapphire is poor in its thermal and electrical conductivity. Now therefore, in consideration of increasing the performance at high-power operation, fabricating a freestanding GaN substrate by several different techniques had been reported in many literatures.²⁻⁴ The laser lift-off (LLO) technique is the most popular way to separate the GaN from the sapphire substrate.² Even so, the LLO technique is still have many drawbacks such as, high-cost and low-throughput, large thermal stress, laser-induced damage. In order to solve these problems, chemical lift-off (CLO) technique is an alternative way to fabricate a free-standing GaN substrate using for the vertical type LEDs manufacture.³⁻⁴ In this study, we report a simple approach to successfully separate GaN film from its substrate without harming the material quality.

2. Experiment

In this work, the GaN samples prepared to carry out the CLO process were grown on c-plane sapphire substrates by metal organic chemical vapor deposition (MOCVD) systems. A low-temperature growth GaN nucleation layer followed by a 1- μm -thick undoped GaN, and a 1- μm -thick Si-doped ($3 \times 10^{18} \text{ cm}^{-3}$) n-GaN layer were grown. Then, we created a array of n-GaN nano-rods by using nanoimprint process. The nano-rod arrays were 12-fold symmetry distributed on the entire substrate with a average nano-rod diameter of 350 nm, the nearest neighboring circle distance of 550 nm, and an etch depth of about 1 μm . Next, nano-rods template was covered by SiO₂ layer, which was fabricated by the spin-on-glass (SOG) process, and then backed on the furnace. In order to provide a regrowth template, a ICP etching was used to exposed the top surface of the n-GaN nano-rods, followed a 4- μm -thick Si-doped ($3 \times 10^{18} \text{ cm}^{-3}$) n-type nano-epitaxial lateral overgrowth (NELO) GaN, ten-pairs InGa_{0.15}N/GaN MQWs, and a 0.17- μm -thick Mg-doped

($6 \times 10^{17} \text{ cm}^{-3}$) p-GaN were deposited onto the terrace of n-GaN nanostructure. The NELO technique was applied in order to improve the crystalline quality. Subsequently, a chip size of 300 mm \times 300 mm was defined by a laser scribing process and the covered SiO₂ layer was removed using buffered Oxide Etcher (BOE). The sample structure was schematically shown in Fig. 1(a). Finally, the chemical lift-off (CLO) process were performed in different etching conditions, including the concentrations of KOH-ethylene glycol solution (molarity of 0.95M, 2.2M, 5.3M, 12.1M, and 20.4M) and process temperature (70 °C and 120 °C). All the samples were etched for at 20 minutes.

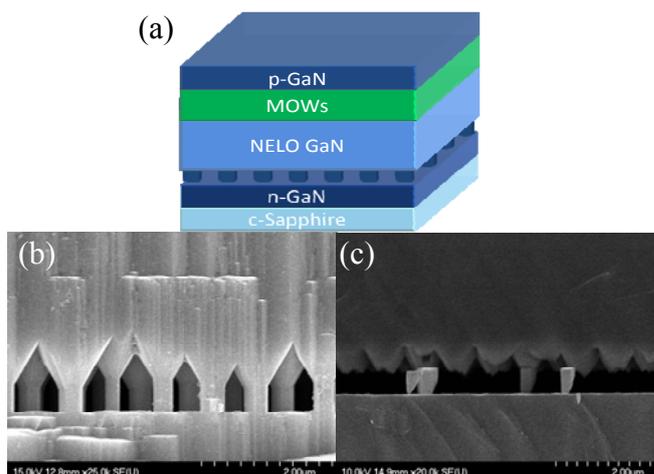


Fig. 1 (a) Schematic of sample structure, and the SEM images of GaN after (b) HT & HC (c) LT&LC KOH-ethylene glycol solution etching.

3. Results and Discussion

Fig. 1(b) shows the SEM image of etched GaN sample at high temperature (HT) of 120 °C and high concentration (HC) of 20.4M. In this image, triangular-shaped voids were formed over the space between n-GaN nano-rods. The etching behavior can be explained by polarity-selective chemical etching, which had been demonstrated in other literature.⁵⁻⁶ In KOH solution, the -c-plane was etched with extremely fast rate compared with other planes, whereas the +c-plane remained still (ie. the Ga-polar could prevent the surface from further etching). Then, isosceles triangles with

{11-22} planes had been formed above the inter-space of n-GaN nano-rods. On the other hand, fig. 1(c) reveals the observation of etched GaN sample at low temperature (LT) of 70 °C and low concentration (LC) of 0.95M. Obviously, etching result was different from the etching behavior of HT and HC as mention above. Reduction of etching rate was observed and majority of nano-rods were etched and broken at the regrowth interface.

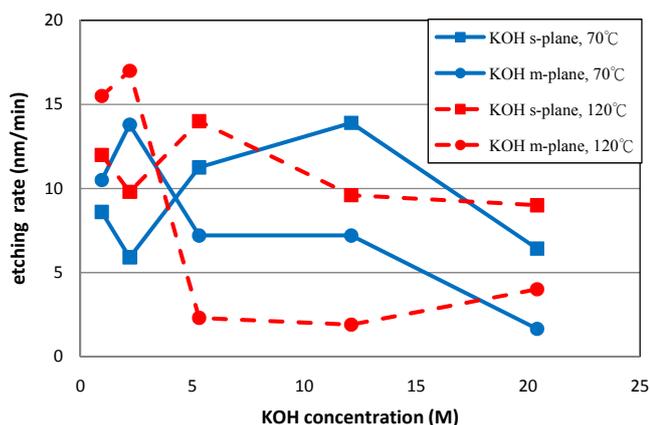


Fig. 2 The etching rates in different etching conditions of s-plane and m-plane, respectively.

In order to identify the etching behavior of NELO GaN in KOH-ethylene glycol solution, a series etching condition was performed. The etching rates of m-plane {10-10} and s-plane {11-22} were investigated in Fig. 2. A significant phenomena was found at solution temperatures of 70 °C (the solid line) and 120 °C (the dash line). In higher concentration (molarity of 5.3M, 12.1M, and 20.4M) KOH solution, the etching rates of s-plane (square points) were faster than those of m-plane (circle points). On the contrary, the etching rates of the m-plane increase rapidly in lower concentration (molarity of 0.95M, and 2.2M) KOH solution etching, especially at the temperature of 120 °C. The mechanism is under investigating, and a possible reason to explain this etching behavior is attributed to the stress. Stress induced nano-rod breaking at the regrowth interface while its diameter became thinner and thinner during the KOH etching. In addition, it is worth noting that possible damage on active region during CLO process. Therefore, the higher etching ratio of m-plane to s-plane was preferred.

As shown in Fig. 3(a), we successfully separated individual GaN chips from sapphire substrate after KOH-ethylene glycol solution of 70 °C and 0.95M. The NELO GaN epilayer was transferred by 3M blue tape. Furthermore, a nanostructure textured surface was obtained in our CLO chip which is revealed in Fig. 3(b). Once this CLO technique applied to LED device process after appropriate pattern designing, it will greatly improve the device performance through increasing the light extraction effi-

ciency.

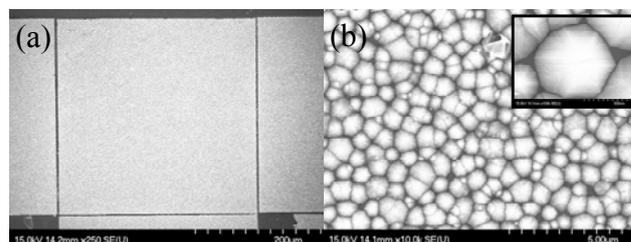


Fig. 3 SEM image of bottom surface of (a) a whole release NELO GaN chip. (b) a textured bottom surface of NELO GaN epilayer.

4. Conclusions

In summary, we have demonstrated an navol CLO process based on embedded nano-rods template. At HT and HC etching condition of KOH-ethylene., the polarity-selective etching behavior was dominated. It is explained that the etching rates of s-plane were faster than those of m-plane under HC and HT etching condition. However, it is much desirable for CLO under LT and LC etching condition. As a result, a nanostructure texture surface was formed on the n-GaN surface. Our CLO technique is a promising way to separate the GaN from the sapphire substrate, specifically the nanostructure texture surface of GaN epilayer is believed to improve the light extraction efficiency of III-nitride LEDs.

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References

- [1] E. F. Schubert, *Light-Emitting Diode, 2nd edition* (2006).
- [2] C. F. Chu, F. I. Lai, J. T. Chu, C. C. Yu, C. F. Lin, H. C. Kuo, and S. C. Wang, *J. Appl. Phys.* **95**, (2004) 3916
- [3] H. Goto, S. W. Lee, H. J. Lee, H.J. Lee, J. S. Ha, M. W. Cho, and T. Tao, *Phys. Stat. Sol. (c)* **5, 6**, (2008) 1659
- [4] C. F. Lin, J. J. Dai, G. M. Wang, and M. S. Lin, *Appl. Phys. Exp.* **3**, (2010) 092101
- [5] D. Li, M. Sumiya, K. Yoshimura, Y. Suzuki, Y. Fukuda, and S. Fuke, *Phys. Status Solidi A* **180**, (2000) 357
- [6] M. Itoh, T. Kinoshita, C. Koike, M. Takeuchi, K. Kawasaki, and Y. Aoyagi, *Jpn. J. Appl. Phys.* **45**, (2006) 3988
- [7] K. Y. Zang, Davy W. C. Cheong, H. F. Liu, H. Liu, J. H. Teng, and S. J. Chua, *Nanoscale Res. Lett.* **5**, 1051 (2010)