JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. **5** No 2, 02001(3pp) (2013)
ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том **5** № 2, 02001(3cc) (2013)

Characterization of GaN Nanorods Fabricated Using Ni Nanomasking and Reactive Ion Etching: A Top-Down Approach

Ashutosh Kumar[1,*], Michael Latzel[2], C. Tessarek[2], S. Christiansen[2], R. Singh[1,†]

[1] *Department of Physics, Indian Institute of Technology Delhi, Hauz Khas, 110016 New Delhi, India*
[2] *Max Planck Institute for the Science of Light, 24, Günther-Scharowsky-Str. 1/Bau, 91058 Erlangen, Germany*

(Received 15 February 2013; published online 04 May 2013)

Large thermal mismatch between GaN surface and sapphire results in compressive stress in Gallium Nitride (GaN) layer which degrades the device performance. Nanostructuring the GaN can reduce this stress leading to reduction in Quantum Confined Stark Effect. Aligned GaN nanorods based nanodevices have potential applications in electronics and optoelectronics. This paper describes the fabrication of GaN nanorods using Ni nanomasking and reactive ion etching. The morphology of GaN nanorods was studied by field emission scanning electron microscopy. The optical properties of GaN nanorods were studied by Cathodoluminescence (CL) spectroscopy. CL results revealed the existence of characteristic band-edge luminescence and yellow band luminescence.

Keywords: GaN, Nanorod, Nanomasking, Reactive-ion etching, Cathodoluminescence, Band-edge luminescence, Yellow band luminescence.

PACS numbers: 81.16. – c, 81.16.rf, 78.67. – n, 78.60.Hk

1. INTRODUCTION

Semiconductor nanostructures have recently emerged as the leading material for the fabrication of electronic [1-2] and optoelectronic devices [3]. Over the last decade, use of Gallium Nitride (GaN) nanostructures for high power transistors [4] and solid state lightning [5-7] is an interesting area for researchers. The main reason behind these interests is the fact that nanostructuring can reduce the compressive stress in GaN layer grown over sapphire leading to reduction in Quantum Confined Stark Effect. Also, due to direct and wide band gap of GaN, its nanostructures can be used for high temperature and high power electronic devices applications [8]. GaN nanorods based nanodevices do have some advantages as compared to bulk GaN based devices which are listed below [9-11]:

– High surface to volume ratio: increase in active area for LEDs and solar cells.

– Strain relaxation in GaN nanorods: increase in radiative recombination efficiency in multiple quantum wells (MQWs) due to reduction in quantum confined stark effect.

– Growth of MQWs on non-polar planes: increase in radiative recombination efficiency in MQWs and wavelength stability.

– Reduction in threading dislocation density: increase in performance of nanodevices.

GaN nanorods can be fabricated using top-down and down-top approach. The down-top approach which is a self organized growth technique includes catalyst assisted Vapor-Liquid-Solid (VLS) growth, catalyst free or self-induced growth and selective area growth on nano-patterned substrate. GaN nanorods are generally synthesized using VLS mechanism which was first developed by Wagner and Ellis [12] in 1964. Han et al. [13] in 1997 was the first to demonstrate successfully the fabrication of GaN nanowires. VLS growth methods do have disadvantages of requiring highly specific growth conditions to increase the on-axis growth rate while minimizing the lateral growth rate. This can lead to non-optimal material quality and less flexibility in material design such as doping and heterostructures.

For fabrication of a device using 1D GaN nanostructure, it is essential to develop a process to make contacts to individual nanowires or nanorods as well as array of nanowires or nanorods which lacks in VLS mechanism. One solution to this problem is top-down approach where GaN nanorods can be fabricated by etching GaN layer using nanomasks. This approach includes methods like conventional photolithography, e-beam lithography, self-organized nanomasking or nanosphere lithography [14, 16-17]. In these techniques, dry etching methods like as RIE-ICP are used to obtain high aspect ratio. High aspect ratio of nanorods can be achieved using techniques like e-beam lithography or photolithography but these techniques have limitations in nanofabrication over large area substrates. However, techniques like self-assembled nanomasking and nanosphere lithography are cost effective and applicable to nanofabrication over large area substrates. Ramesh et al. [15] demonstrated blue shift in Photoluminescence (PL) emission peak as well as improvement in PL internal quantum efficiency in GaN nanoLED fabricated using top-down approach as compared to as grown down-top GaN nanoLED. An enhancement of PL intensity and blue shift of PL emission peak (which indicates the strain relaxation) in GaN nanorods fabricated using top-down approach are also reported by various groups [16-17].

So in this work, we employed a top-down approach for the fabrication of GaN nanorods using nanomasking and reactive ion etching (RIE) for nanoelectronics and optoelectronics applications.

* ashutosh.kumar@physics.iitd.ac.in
† rsingh@physics.iitd.ac.in

2. EXPERIMENTAL

The samples used in this study were cut from nominally undoped GaN wafer of thickness about 2 µm grown on c-plane sapphire substrate by metalorganic chemical-vapor deposition (MOCVD) technique. GaN nanorods were fabricated using top-down approach by Nickel (Ni) nanomasking and reactive ion etching. Prior to nanorods fabrication, samples were ultrasonically cleaned in trichloroethylene, acetone and isopropanol respectively at 70 ºC. The samples were then dipped in 1:1 HCl for 2 min to remove the native oxides. Finally the clean samples were rinsed with deionized water and blown with dry nitrogen. A SiO_2 layer of thickness about 100 nm was deposited over n-GaN using sputtering followed by sputter deposition of Ni metal film. Then rapid thermal annealing (RTA) was performed at 800 ºC for 60 sec under nitrogen ambient to produce Ni metal nano-islands. In next step, reactive ion etching (RIE) of SiO_2 was performed followed by selective RIE of n-GaN layer. SiO_2 layer was selective etched using CF4 plasma while selective etching of GaN layer was performed using Cl_2/Ar plasma. Finally to fabricate GaN nanorods, Ni and SiO_2 were etched using HF for 60 sec. The HF etching also removes any other contaminants. The schematic for fabrication of GaN nanorods using Ni nanomasking and reactive ion etching is shown in Fig. 1.

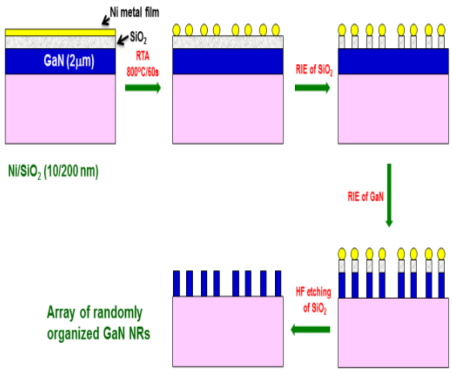

Fig. 1 – Schematic diagram for fabrication of GaN nanorods using Ni nanomasking and reactive ion etching technique

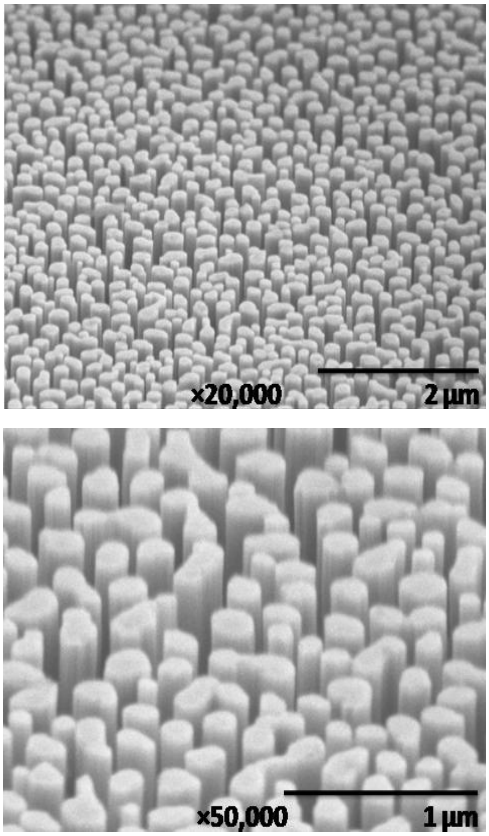

Fig. 2 – FESEM image of GaN nanorods at two different magnifications (× 20,000 and × 50,000)

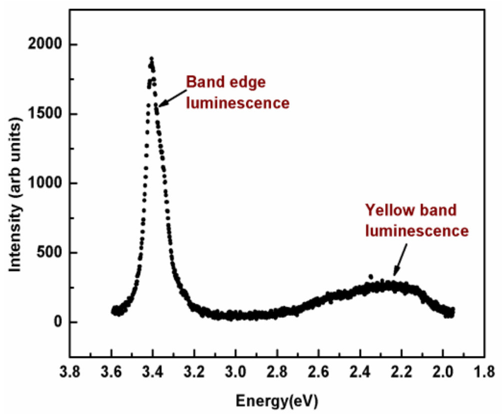

Fig. 3 – CL spectrum of GaN nanorods at room temperature from mapped region showing two peaks which corresponds to band-edge luminescence (at 3.4 eV) and yellow band luminescence (centred about 2.3 eV)

3. RESULTS AND DISCUSSION

3.1 Morphological Studies of GaN Nanorods

The shape and morphology of the GaN nanorods were observed using field emission scanning electron microscopy (FESEM). The side view image of GaN nanorods fabricated using top-down approach taken at different magnification (× 20,000 and × 50,000) is shown in Fig. 2a, b. From the side-view secondary electron image of the GaN nanorods cluster, the diameters of the nanorods on the sapphire substrate were about 100 to 250 nm. High vertical alignment of these nanorods is also clear from secondary electron images.

3.2 Cathodoluminescence Studies

Cathodoluminescence (CL) measurements were also performed in order to investigate the light emission properties of GaN nanorods. The CL measurements reported here were performed at room temperature using standard CL measurement set-up with accelerating voltage of 5 kV and electron beam current of 20 µA. Fig. 3 shows the CL spectrum of GaN nanorods from the mapped region.

The CL spectrum shows a stronger peak from GaN band edge luminescence at 3.4 eV (364 nm) and an additional broad peak centred about 2.3 eV (550 nm) which is commonly known as yellow band luminescence (YL). Both the peaks are characteristics of the GaN nanostructures and also earlier reported in GaN

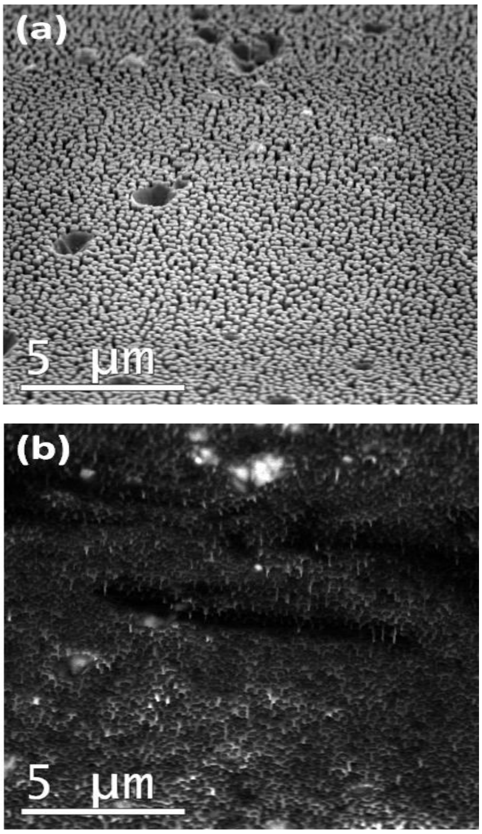

Fig. 4 – (a) FESEM image and (b) corresponding panchromatic CL image of GaN nanorods

nanostructures fabricated from down-top approach [18-19]. The existence of YL indicates that there is a deep level located at about 2.3 eV below conduction band edge and recombination of conduction electrons through this deep level can give yellow emission

A plan-view integrated panchromatic CL image from GaN nanorods acquired with an accelerating voltage of 5 kV and electron beam current of 20 μA is shown in Fig. 4a, b. Fig. 4a shows the FESEM image of GaN nanorods and Fig. 4b shows the corresponding panchromatic CL image. It is clear that CL intensity is not uniform and shows strong contrast between dark and bright regions. The bright spots in the image represent high CL emission intensity while dark spots represent low emission intensity. The non-uniform CL emission is associated with the presence of extended crystalline defects such as dislocations which can act as the radiative centers. However, comparison between monochromatic CL imaging at 364 nm and 550 nm can give more information about these defects which is a matter of future investigation.

4. CONCLUSIONS

A different route for the fabrication of highly vertically aligned GaN nanorods on c-plane sapphire is reported in this study. We fabricated GaN nanorods using a top-down approach by nanomasking and reactive ion etching. The FESEM images indicated the GaN nanorods with diameter ranging between 100-250 nm were grown via top-down approach. FESEM images also indicated the highly vertical alignment of these nanorods. The CL analysis confirmed the formation and high optical properties of GaN nanorods. These studies give us more understanding about the fundamental properties of GaN nanomaterials and provide useful information in the application of GaN nanorods-based devices.

AKNOWLEDGEMENTS

Ashutosh Kumar is grateful to Council of Scientific and Industrial Research (CSIR) India for Senior Research Fellowship. The authors are thankful to Prof. Vikram Kumar for his valuable suggestion during this work. The authors (A.K. and R.S) are thankful to Department of Information Technology, Govt. of India for setting up Nanoscale Research Facility at IIT Delhi.

REFERENCES

1. Y. Xia, P. Yang, Y. Sun, Y. Bu, B. Mayers, B. Gates, Y. Fin, F. Kim, H. Yan, *Adv. Mater.* **15**, 353 (2003).
2. J. Appenzeller, J. Knoch, T.M. Bjork, H. Riel, H. Schmid, W. Riess, *IEEE T. Electron Dev.* **55**, 2827 (2008).
3. X. Duan, Y. Huang, Y. Cui, J. Wang, C. M. Lieber, *Nature* **409**, 66 (2001).
4. Y. Huang, X. Duan, Y. Cui, C.M. Lieber, *Nano Lett.* **2**, 101 (2002).
5. S. Nakamura, T. Mukai, M. Senoh, *Appl. Phys. Lett.* **64**, 1689 (1994).
6. J. Zhu, L. Wang, S. Zhang, H. Wang, D. Zhao, J. Zhu, Z. Liu, D. Jiang, H. Yang, *J. Appl. Phys.* **108**, 074302 (2010).
7. C.J. Neufeld, C. Schaake, M. Grundmann, N.A. Fichtenbaum, S. Keller, U.K. Mishra, *phys. status solidi c* **4**, 1605 (2007).
8. L. Nguyen, *Gallium Nitride Nanowires*, COSMOS (2012).
9. T. Fujii, Y. Gao, R. Sharma, E.L. Hu, S.P. DenBaars, S. Nakamura, *Appl. Phys. Lett.* **84**, 855 (2004).
10. C. Huh, K.-S. Lee, E.-J. Kang, S.-J. Park, *J. Appl. Phys.* **93**, 9383 (2003).
11. H.W. Huang, J.T. Chu, C.C. Kao, T.H. Hseuh, T.C. Lu, H.C. Kuo, S.C. Wang, C.C. Yu, *Nanotechnology* **16**, 1844 (2005).
12. R.S. Wagner, W.C. Ellis, *Appl. Phys. Lett.* **4**, 89 (1964).
13. W. Han. S. Fan, Q. Li, Y. Hu, *Science* **277**, 1287 (1997).
14. S. Li, A. Waag, *J. Appl. Phys.* **111**, 071101 (2012).
15. V. Ramesh, A. Kikuchi, K. Kishino, M. Funato, Y. Kawakami, *J. Appl. Phys.* **107**, 114303 (2010).
16. C.H. Chiu, T.C. Lu, H.W. Huang, C.F. Lai, C.C. Kao, J.T. Chu, C.C. Yu, H.C. Kuo, S.C. Wang, C.F. Lin, T.H. Hsueh, *Nanotechnology* **18**, 445201 (2007).
17. H.W. Huang, J.T. Chu, T.H. Hsueh, M.C. Ou-Yang, H.C. Kuo, S.C. Wang, *J. Vac. Sci. Technol. B* **24**, 1909 (2006).
18. S.O. Kucheyev, M. Toth, M.R. Phillips, J.S. Williams, C. Jagadish, *Appl. Phys. Lett.* **79**, 2154 (2001).
19. H.D.P. Schenk, S.I. Borenstain, A. Berezin, A. Schön, E. Cheifetz, S. Khatsevich, D.H. Rich, *J. Appl. Phys.* **103**, 103502 (2008).