Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp717-718

Epitaxial-Lateral-Overgrowth of Gallium Nitride for Embedding the Micro-Mirror Array

Hao Ming Ku[1], Chen Yang Huang[1, 2], Chen Zi Liao[2] and Shiuh Chao[1,*]

[1]Institute of Photonics Technologies, National Tsing Hua University,
Hsinchu, Taiwan, 30013, R.O.C.
[2]Electronics and Opto-electronics Research Laboratories,
Industrial Technology Research Institute, Hsinchu, Taiwan, 31040, R.O.C.
[*]Phone: +886-3-5731151, Fax: +886-3-5720348, E-mail: schao@ee.nthu.edu.tw

1. Introduction

Light extraction efficiency of conventional GaN-based LED is limited by the total internal reflection between the high refractive index semiconductor light emitting material and the surrounding low refractive index material. Methods such as photonics crystals [1], patterned sapphire [2], Bragg reflector [3], were proposed to enhance the light extraction efficiency. On the other hand, internal quantum efficiency of the light emitting materials and devices is limited by defect density in the GaN, and the epitaxial-lateral-overgrowth(ELOG) process was found to be useful in reducing the dislocation density in the GaN[4][5]. We have proposed [6] to use the micro-mirror-array (MMA) that is embedded in the ELOG-GaN as the light extraction enhancement structure. In this report, we will give our current analysis results on the ELOG process of GaN that bury the MMA. The effect of process temperature and gas pressure on the lateral/vertical growth rate of the ELOG process will be given. GaN/InGaN multiple quantum well (MQW) light emitting structure was fabricated on top of the enhancement structure, nearly double the wall-plug efficiency over the conventional LED was obtained.

2. Fabrication process and results

Fabrication process of the MMA structure was reported[6] and it is summarized as follows: Ta_2O_5/SiO_2 multi-layer dielectric films were deposited alternately by ion-beam-sputter to form high reflective mirror on the 2.56μm GaN template that was deposited on a c-plane sapphire substrate, as shown schematically in Fig. 1(a). Photolithography method was used to form hexagonal array pattern on the SU-8 photo-resist that was spin-coated on top of the Ta_2O_5/SiO_2 multi-layer. The hexagon pattern was coincided with the c-plan hexagon of the underlying GaN template and sapphire, as shown schematically in Fig. 1(f). Inductive-coupled-plasma(ICP) etching with CF_4/Ar mixed gas was applied to transfer the array pattern to the Ta_2O_5/SiO_2 multi-layer down to the interface of the GaN template and the Ta_2O_5/SiO_2 multi-layer, as shown in Fig. 1(b)(c) schematically and in Fig. 2(a)(b) with the SEM picture. ELOG process of GaN was then applied to embed the MMA. Process parameters for the ELOG is given in Table I from Ref [6]. The fifth step in Table I was crucial to the lateral growth. We have changed the process temperature and the total pressure of the fifth step, without changing the ratio of the gas mixture, and measure the lateral/vertical growth rate. The temperature was changed from 1150℃ to 1180℃ and the total gas pressure was change from 200mbar to 500mbar. The lateral growth rate was obtained, referring to the inset of Fig. 4, by dividing the lateral width w by the process time of the fifth step. The vertical growth rate was obtained by dividing the vertical thickness d by the process time of the fifth step. Fig. 3 shows the SEM pictures of the ELOG GaN at intermediate stage of the fifth step. Fig. 4 shows the vertical/lateral growth rates versus temperature and pressure. The vertical rate was decreased with increasing temperature and increasing pressure. The lateral rate was increased with increasing temperature and decreasing pressure. The results suggests that if we wish to cover larger area MMA, it is desirable to have high lateral rate and low vertical rate, and therefore, to operate the ELOG at higher temperature and lower pressure.

On top of the enhancement structure, we then fabricated MQW InGaN/GaN epitaxial structure, which was composed of 600nm thick Si-doped n-type GaN, followed by 10 pairs of GaN(2nm)/InGaN(2nm) electron blocking layers, 5 pairs of GaN(13nm)/InGaN(3nm) MQW, 200nm thick Mg-doped p-type GaN, 10nm thick heavy Mg-doped p^+-type GaN. Mesa structure, 300μm×300μm square, was then formed and followed by Ti(100nm)/Au(300nm) for p-contact, Ti(200nm)/Al(600nm)/Ti(200nm)/Au(200nm) for n-contact and Ni(0.5nm)/Au(4nm) for transparent p-contact. Fig. 5 and 6 shows the photoluminescence spectra and the optical output power vs. electrical input power for the samples with and without the enhancement structure, respectively. It is clear that nearly double the wall-plug efficiency was obtained.

3. Conclusions

We showed the effect of temperature and pressure on the ELOG process for embedding a MMA in GaN. We demonstrated that nearly double the wall-plug efficiency can be obtained for the MQW-LED with the MMA structure.

References

[1] J.J. Wierer, M.R. Krames, J.E. Epler, N.F. Gardner, M.G. Craford, J.R. Wendt, J.A. Simmons, and M.M. Sigalas, Appl. Phys. Lett. **84** (2004) 3885.
[2] D.S. Wuu, W.K. Wang, K.S. Wen, S.C. Huang, S.H. Lin, S.Y.

Huang, C.F. Lin, and R.H. Horng, Appl. Phys. Lett. **89** (2006) 161105.
[3] Y.S. Zhao, D.L. Hibbard, H.P. Lee, K. Ma, W. So, and H. Liu, J. Electron. Mater., **32** (2003) 1523.
[4] A. Sakai, H. Sunakawa, and A. Usui, Appl. Phys. Lett. **71** (1997) 2259.
[5] A. Usui, H. Sunakawa, A. Sakai, and A.A. Yamaguchi, Jpn. J. Appl. Phys. **36** (1997) L899.
[6] C.Y. Huang, H.M. Ku, W.T. Liao, C.L. Chao, J.D. Tsay, and S. Chao, Opt. Express. **17** (2009) 5624.

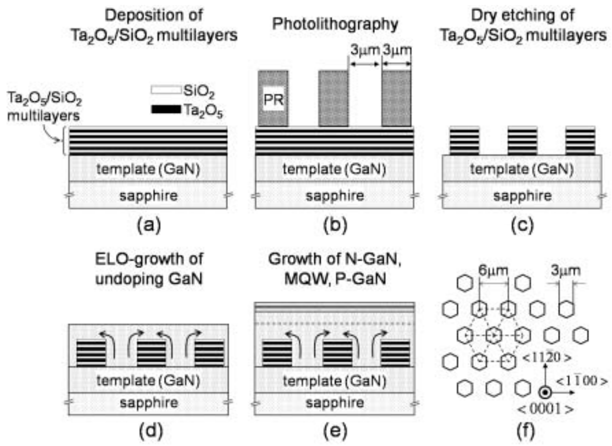

Fig. 1 MMA fabrication process schematics (a) deposition of multi-layer, (b) lithography, (c) etching process, (d) ELO growth, (e) growth of light emitting layers (f) top view of the array pattern

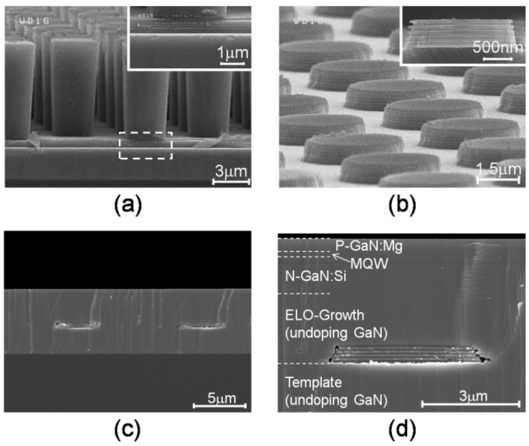

Fig. 2 SEM pictures of (a) 2-D PR pattern on multi-layer, (b) 2-D MMA, (c) ELO growth of GaN, (d) Growth of MQW.

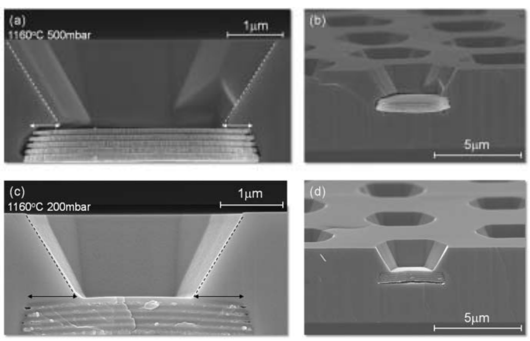

Fig. 3 SEM picture of ELO growth at 1160℃ (a)(b) gas pressure is 500mbar (c)(d) gas pressure is 200mbar

Table I MOCVD process parameters [6]

Process Step	Temp. (℃)	Pressure (mbar)	Group III Gas Reactive+ Carrier (sccm)	Group V Gas Reactive+ Carrier (sccm)	Process time
1.Heating clean	1200	200	H_2:15000	H_2:15000	5min
2.Nucleation	500	950	TMGa:10+ N_2:15000	NH_3:2500+ N_2:500	8min
3.Anneal	1200	500	H_2:15000	H_2:6000	3min
4.Growth GaN	1160	500	TMGa:32+ H_2:15000	NH_3:5500+ H_2:500	90min
5.ELO GaN	1180	200	TMGa:32+ H_2:15000	NH_3:5500+ H_2:500	120min

sccm: cubic centimeters per minute at standard temperature and pressure.
TMGa: trimethyl gallium.

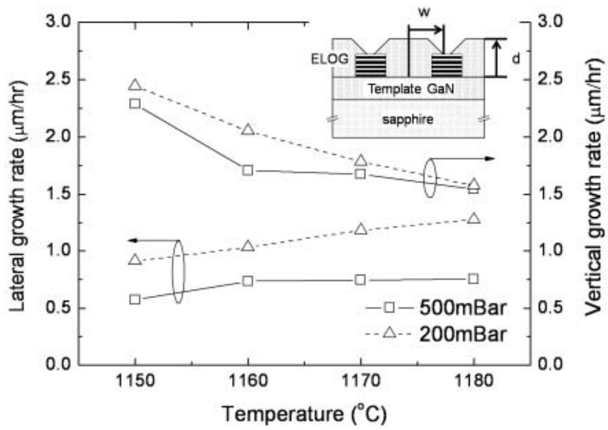

Fig. 4 Lateral growth rate and vertical growth rate vs. temperature and pressure

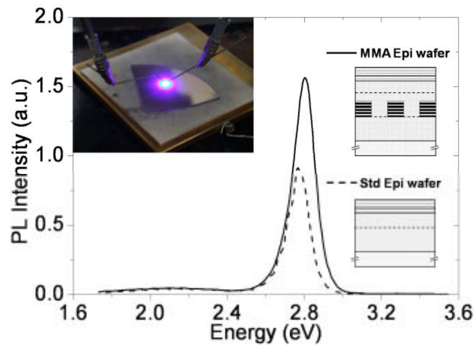

Fig. 5 Photoluminescence spectra for the samples with and without the enhancement structure

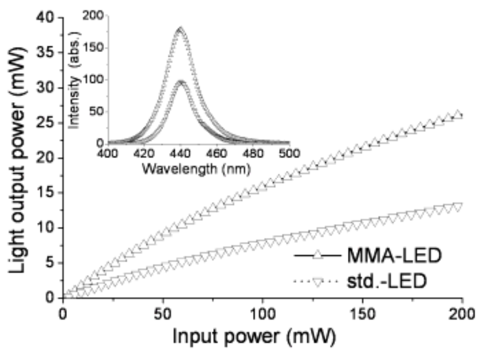

Fig. 6 Optical output power vs. electrical input power for the samples with and without the enhancement structure