Extended Abstracts of the 2004 International Conference on Solid State Devices and Materials, Tokyo, 2004, pp. 550-551

P6-5L

Nitride-based light emitting diodes with nanostructured silicon contact layers

C. H. Kuo[1] and S. J. Chang[2]

[1] South Epitaxy Corporation, Hsin-shi 741, Tainan, Taiwan
[2] Institute of Microelectronics & Department of Electrical Engineering, National Cheng Kung University, Tainan 701, Taiwan
Phone:+886-6-2757575ext62391 Fax:+886-6-2761854
Email: changsj@mail.ncku.edu.tw

1.Introduction

III-V nitrides have some unique properties, such as wide direct band gap, high thermal conductivity and high chemical stability. These properties have attracted tremendous attention in recent years. High performance optical devices such as light emitting diodes (LEDs) and laser diodes (LDs) have both been developed using GaN-based materials grown on sapphire substrates[1-2]. For most commercial nitride-based LEDs, an Mg-doped GaN layer was used as the top p-contact layer while Ni/Au was used as the semi-transparent p-metal[2-5]. However, it has been shown that the transmittance of Ni/Au is only around 60-75%. In order to solve this issue, one can use highly transparent indium-tin-oxide (ITO) to replace Ni/Au. However, it has been shown that ITO can only form Schottky contacts on p-GaN. Very recently, we reported the fabrication of nitride-based ITO LEDs with an n^+-short period superlattice (SPS) tunnel contact layer[6]. It has been shown that we can simultaneously achieve a reasonably small specific contact resistance and a high upper contact transmittance by using such a combination. However, we need to control the growth of the n^+-SPS carefully. In this study, we use a low resistive nanostructured silicon contact layer to replace the n^+-InGaN/GaN SPS tunneling contact layer. The properties of the fabricated nitride-based ITO LEDs with a nanostructured silicon contact will also be discussed.

2. Experiments

The InGaN/GaN multi-quantum well (MQW) LEDs used in this study were all grown by metalorganic chemical vapor deposition(Veeco E300 MOCVD). Details of the growth procedures are already been reported elsewhere[3-6]. Figure 1 schematically depicts the ITO LED with a nanostructured silicon contact layer proposed in this study. The nanostructured silicon layer was grown at 750^{o}C using diluted SiH_4 and H_2 as the source materials. During the growth of this layer, the flow rates of SiH_4 and H_2 were kept at 40 sccm and 60 slm, respectively. Atomic force microscopy (AFM) was then used to characterize surface morphologies of the samples. Surfaces of the samples were then partially etched until the n-type GaN layers were exposed. An ITO layer was subsequently evaporated onto the sample surfaces to serve as the upper contacts. On the other hand, Ti/Al/Ti/Au contacts were deposited onto the exposed n-type GaN layers to serve as the n-type electrodes. The epitaxial wafers were then lapped down to about 90 nm. We then used scribe and break to complete the fabrication of 300 μm×300 μm blue InGaN/GaN LED chips. For comparison, ITO LEDs with an n^+-SPS tunnel contact layer and with only p-GaN cap layer were also fabricated. Current-voltage (I-V) characteristics of these fabricated devices were then measured at room temperature by an HP4156 semiconductor parameter analyzer.

3. Result And Discussion

Figures 2(a) and 2(b) show AFM images of the ITO LED with an n^+-SPS tunnel contact layer. It can be seen that surface of this sample is smooth with a root-mean-square (RMS) roughness less than 3.3 nm. Figures 3(a) and 3(b) show AFM images of the ITO LED with a nanostructured silicon contact layer. It can be seen that surface of this sample is much rougher with a RMS roughness larger than 15.7 nm. Figure 4 shows I-V characteristic of the fabricated LEDs. It was found that the 20 mA forward voltages measured from the LEDs with ITO on p-GaN and ITO on n^+-SPS contact layers were 6.01 and 3.25 V, respectively. Similar results have also been reported previously. In other words, the operation voltage measured from the LEDs with ITO on p-GaN cap layer was much higher than those measured from the other two LEDs. Such a large operation voltage can be attributed to the Schottky contact formed when ITO was deposited directly onto p-GaN. On the other hand, the much smaller operation voltage observed from the LED with ITO on n^+-SPS can be attributed to the facts that ITO forms good ohmic contact on n-GaN, carriers can tunnel through the n^+-p junction and carriers can spread out easily in the in-plane directions.

As also shown in figure 4, it was found that the 20 mA forward voltage measured from the LED with ITO on nanostructured silicon contact layer was 3.26 V, which was almost identical to that observed from LED with ITO on n^+-SPS contact layer. We believe that some of the Si atoms might diffuse into p-GaN so as to form a highly doped thin n^+-GaN layer. Thus, we can also significantly reduce the LED operation voltage without growing the complicated SPS structure. It should be also be noted that we should also achieve a much larger LED output intensity with the rough surface of nanostructured silicon layer, since photons generated in the active region should have multiple chances to be emitted with such a rough surface. Details of the optical properties of the LED with ITO on nanostructured silicon contact layer will be reported separately.

4. Summary

In summary, nitride-based LEDs with ITO on p-GaN, ITO on n^+-SPS and ITO on nanostructured silicon contact layers were fabricated. It was found that surface of the nanostructured silicon layer was very rough. It was also found that the 20 mA forward voltages measured from the LEDs with ITO on p-GaN, ITO on n^+-SPS and ITO on nanostructured silicon contact layers were 6.01, 3.25 and 3.26 V, respectively. The small operation voltage observed from the LED with nanostructured silicon contact layer is probably due to the formation of a highly doped thin n^+-GaN layer.

Reference

[1] T. Mukai, M. Yamada and S. Nakamura, vol. 37, no. 11B, pp. L1358-L1361, December 1998.

[2] S. Nakamura, T. Mukai and M. Senoh, Appl. Phys. Lett. 64 (1994) 1687

[3] C. H. Kuo, S. J. Chang, Y K. Su, J. F. Chen, L. W. Wu, J. K. Sheu, C. H. Chen and G. C. Chi, IEEE Electron. Dev. Lett., Vol. 23, No. 5 , pp. 240-242, May 2002

[4] S. J Chang, C. H. Kuo, Y. K. Su, L. W. Wu, J. K. Sheu, T. C. Wen, W. C. Lai, J. F. Chen, and J. M. Tsai, IEEE JSTQE, Vol. 8, No. 4 , pp. 744-748, July/August 2002

[5] C. H. Kuo, S. J. Chang, Y. K. Su, J.F. Chen, J. K. Sheu, J. M. Tsai, IEEE Trans. Electron Devices, Vol. 50, No. 2 , pp. 535-537, February 2003

[6] C. H. Kuo, S. J Chang, Y. K. Su, R. W. Chuang, C. S. Chang, L. W. Wu, W. C. Lai,, J. F. Chen, J. K. Sheu, H. M. Lo and J. M. Tsai , Materials Science and Engineering B 106, pp. 69-72, 2004

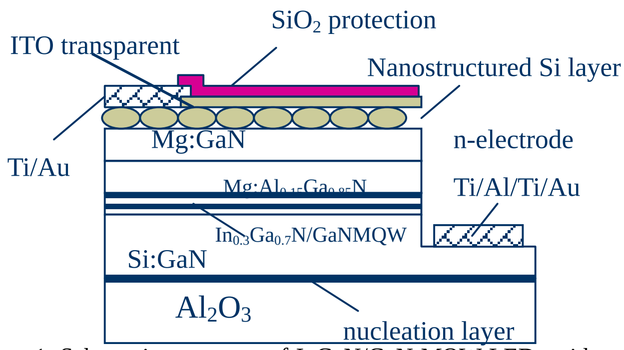

Figure 1. Schematic structures of InGaN/GaN MQW LEDs with nanostructured silicon contact layers.

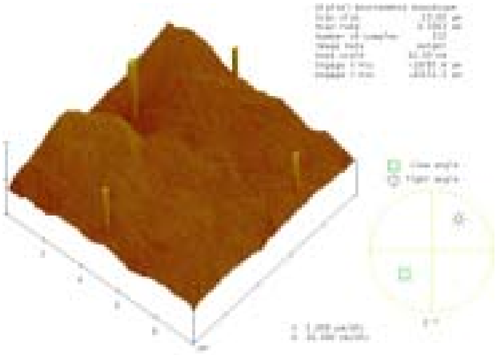

Figure 2. AFM images of the InGaN/GaN MQW LED with n^+-SPS contact layer.

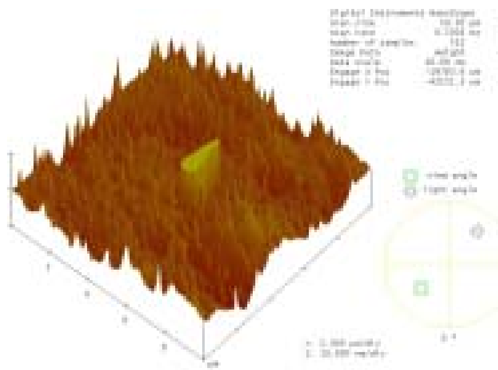

Figure 3. AFM images of the InGaN/GaN MQW LED with a nanostructured silicon contact layer.

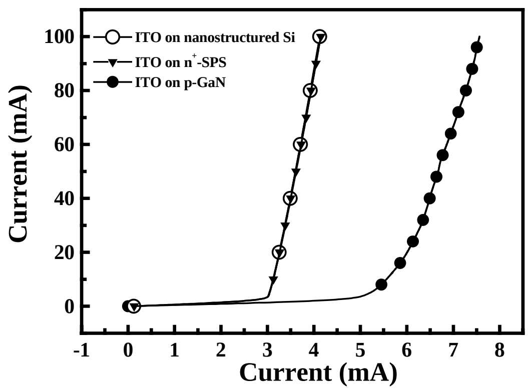

Figure 4. I-V characteristics of the fabricated nitride-based LEDs with different contact layers.