Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, Nagoya, 2002, pp. 854–855

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GaN-Based Light-Emitting Diodes With Si-doped $In_{0.23}Ga_{0.77}N$/GaN Short-Period Superlattice Tunneling Contact Layer

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1. Introduction

Poor ohmic contact at metal/p-GaN interface is the major problem that led to light emitting devices (LEDs) with limited performance and reliability. Thus, it is required to reduce contact resistance and improve contact reliability so as to achieve high performance nitride-based LEDs. Conventional GaN LEDs use semi-transparent Ni/Au as the p-contact material [1-2]. However, the operation voltage of GaN LEDs with Ni/Au p-contact is still high due to the high contact resistance resulting from the highly resistive top p-GaN layer. Recently, Jeon *et al.* demonstrated a lateral current spreading at n-GaN layer in LED structure with a GaN tunnel junction [3]. T. Takeuchi *et al.* also demonstrated that holes can inject through GaN:Si^{++}/InGaN:Mg^{++} tunnel junction in GaN LEDs [4]. In this study, we prepared InGaN/GaN MQW LEDs with an n^+-$In_{0.23}Ga_{0.77}N$/GaN short-period superlattice (SPS) top layer. Instead of highly resistive p-GaN as the top contact layer, we could thus use n^+-p tunneling junction to form a low voltage drop top contact. We will show that the tunneling junction is an effective method to reduce LED operation voltage. A detailed study of contact properties of n^+-p tunneling junction and the optoelectronic properties of GaN LEDs with n^+-p tunneling junction will be reported.

2. Experiments

Both conventional GaN MQW LEDs and GaN MQW LEDs with n^+-p tunneling junction were prepared by metalorganic chemical vapor deposition (MOCVD). Detailed of the growth procedure could be found elsewhere. The structure of LED with n^+-p tunneling junction was similar to those reported in reference [1] to reference [4]. In the following, we call the conventional GaN MQW LED as LEDI and the GaN MQW LEDs with n^+-p tunneling junction LEDII.

3. Result And Discussion

Figure 1 shows the measured sheet carrier concentration as a function of temperature for these two LEDs. It was found that the sheet hole concentration of conventional GaN was about $3.9\times10^{13}cm^{-2}$ at room temperature (RT). In contrast, the sheet electron concentration of GaN LED with Si-doped n^+-$In_{0.23}Ga_{0.77}N$/GaN (5Å/5Å) SPS structure was about $3.7\times10^{15}cm^{-2}$. Such a value was at least two orders higher than the hole concentration in Mg-doped p-type GaN. This can be attributed to the smaller bandgap energy of $In_{0.23}Ga_{0.77}N$/GaN and the low activation energy of Si in $In_{0.23}Ga_{0.77}N$/GaN. As can be seen from figure 1, the activation energy of Si in InGaN is almost 0meV. In general, one can achieve good ohmic contacts from highly doped semiconductors that carrier can across the metal/semiconductor interface through thermionic emission or tunneling. Thus, we should be able to achieve good ohmic contacts from InGaN/GaN MQW LEDs with an n^+-$In_{0.23}Ga_{0.77}N$/GaN short-period superlattice (SPS) top layer since SPS could provide a high carrier concentration, as shown in figure 1.

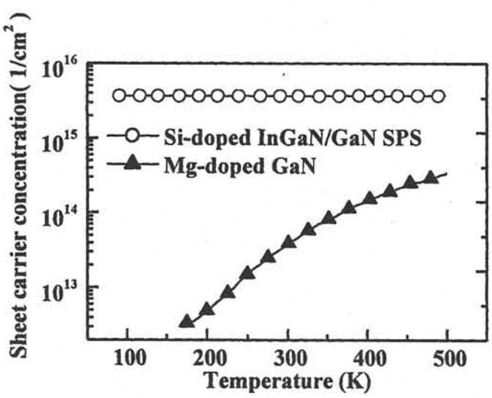

Fig.1 Sheet carrier concentration of a p-GaN layer and an n^+-p SPS tunneling junction structure.

Figure 2 shows the dynamic resistance of the two InGaN/GaN MQW LEDs. It can be seen that the series resistances are about 40Ω and 11Ω for LEDI and LEDII, respectively. We believe the lower series resistance for LEDII is attributed to good current spreading of top SPS contact layer and the lower contact resistance of anode electrode. High series resistance can result in a severe heating effect and a large leakage current especially under high current injection. The heating effect will accelerate the degradation of electrode and thereby influences the device reliability [5-6].

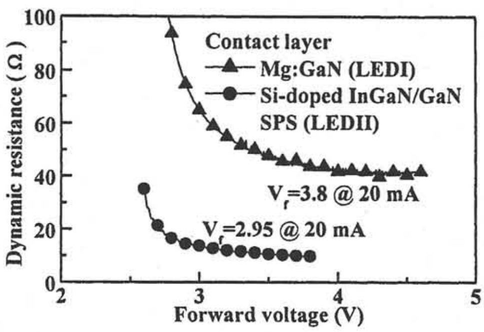

Fig.2 The dynamic resistance depends on the applied voltage for LEDs at forward operation.

Figure 3 shows life test of relative luminous intensity measured from these two LEDs, normalized to their respective initial readings. During life test, both LEDs were driven by a 50 mA current injection and the temperature was controlled at 80°C. It was found that the luminous intensity decayed by 34% for LEDI after 739 hours. For LEDII, the luminous intensity only decayed by 26%. The fast degradation of LEDI could again be attributed to the severe heating effect and large leakage current in this sample. As a result, the lifetime of LEDI is shorter, as can be seen from Fig. 3. In contrast, the lifetime of LEDII is longer due to its smaller contact resistance. One can expect that such a SPS reversed tunneling contact layer can also be applied to nitride-based laser diodes (LDs) and we expect that GaN LDs with SPS will also have a longer lifetime.

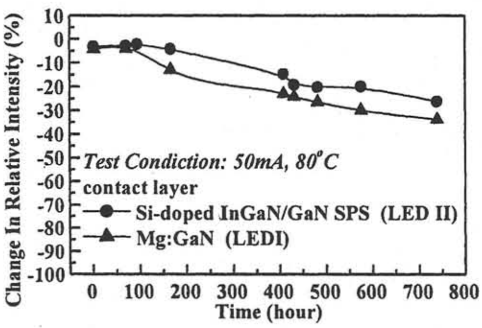

Fig. 3 Life test of relative luminous intensity measured from these three LEDs, normalized to their respective initial readings.

4. Summary

In summary, the electrical properties of uniformly Si-doped n^+-$In_{0.23}Ga_{0.77}N$/GaN SPS structure were measured and compared with conventional Mg-doped GaN films. Temperature-depend Hall measurement for this structure shows high sheet electron concentration. Experimental results indicate that we can achieve LEDs with a lower series resistance of around 11 Ω, which was much smaller than the 40 Ω series resistance observed from conventional LED. The LED with n^+- $In_{0.23}Ga_{0.77}N$/GaN SPS tunneling top contact layer also exhibits a longer lifetime.

Acknowledgements

The authors would like to acknowledge the financial support from the National Science Council for their research grant of NSC 90-2215-E-008-043and NSC 90-2112-M-008-046.

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