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Low Temperature p-GaN rough layer on $In_{0.23}Ga_{0.77}N$/GaN MQW LEDs

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1. Introduction

Wide bandgap III-nitride semiconductors are important devices that can be used in many important applications. Although nitride-based LEDs and LDs are already commercially available [1-4], there are still many problems that need to be solved. For nitride-based LED applications, growth temperature of the top p-GaN layer is important. It has been reported that the optical and structural properties of the active multiquantum well (MQW) could be degraded when a high temperature grown p-GaN contact layer is deposited onto the low-temperature grown InGaN/GaN MQW. On the other hand, surface morphology of the top p-GaN layer also plays an important role in the performance of nitride-based LEDs. It is known that the external quantum efficiency of LEDs depends on the refractive index and morphology of the top surface layer. In other words, we might be able to enhance the LED output intensity by changing the morphology of the top p-GaN layer. In this study, we prepared p-GaN layers grown at different temperatures. Carrier concentration and surface morphology of these samples will then be evaluated and reported. Nitride-based LEDs with top p-GaN layers grown at different temperatures will also be fabricated. The optoelectronic properties of these fabricated LEDs will also be discussed.

2. Experiments

Nitride-based LEDs with top GaN layers grown at different temperatures were fabricated. The InGaN/GaN MQW LED structure consists of a 30nm-thick GaN nucleation layer grown at 560°C, a 4μm-thick Si-doped GaN n-cladding layer grown at 1050°C, an $In_{0.23}Ga_{0.77}N$/GaN MQW active region grown at 700°C and a 0.3μm-thick Mg-doped GaN cap layer grown at different temperatures. The MQW active region consists 5 periods of 3nm-thick $In_{0.23}Ga_{0.77}N$ well layers and 10nm-thick GaN barrier layers. The surface of the as-grown LED epitaxial layers was then partially etched until the n-type GaN layer was exposed. Ni/Au contact was subsequently evaporated onto the p-GaN contact layer to serve as the p-electrode. On the other hand, Ti/Al/Ti/Au contact was deposited onto the exposed n-type GaN layer to serve as the n-type electrode, to complete the fabrication of the LEDs. The schematic diagram of $In_{0.23}Ga_{0.77}N$/GaN MQW LEDs used in this study is shown in figure 1.

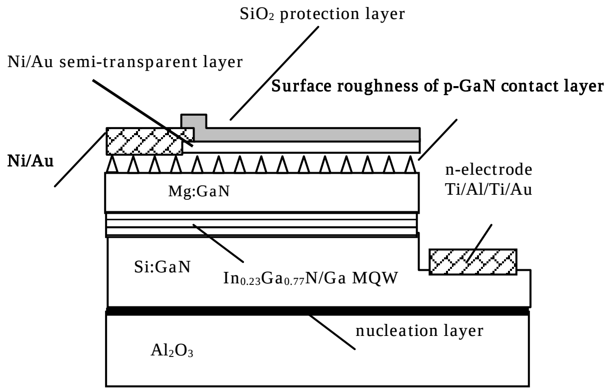

Fig. 1 Schematic diagram of $In_{0.23}Ga_{0.77}N$/GaN MQW LEDs with a rougher p-GaN contact layer.

3. Results and Discussion

Figure 2 shows measured carrier concentration and resistivity of the three p-GaN epitaxial layers grown at different temperatures. It can be seen that by lowering the growth temperature to 800°C, we could achieve a high hole concentration of $1.6\times10^{18}cm^{-3}$ and a low resistivity of 4.2 ohm-cm from the p-GaN epitaxial layers. The high hole concentration is probably due to the high activation efficiency of Mg when we reduce the p-GaN growth temperature to 800°C. As the growth temperature was increased to 900°C, we found that hole concentration was reduced and the resistivity of the p-GaN layer was increased. It was also found that although hole concentrations of the 900°C-grown and 1000°C-grown samples were about the same, the resistivity of the 1000°C-grown sample again became smaller. Such a smaller resistivity is probability could be attributed to the better crystal quality and thus a higher hole mobility when the p-GaN growth temperature was increased to 1000°C. Among the three samples, it should be noted that we achieved the highest hole concentration and the smallest resistivity from the 800°C-grown p-GaN. Such a result suggests that we should be able to reduce the LED operation voltage by using a low 800°C-grown p-GaN cap layer, instead of the conventional high 1000°C-grown p-GaN cap layer.

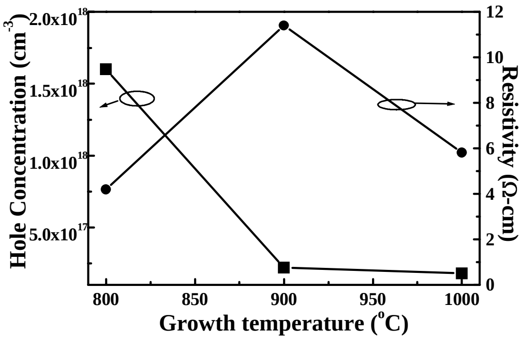

Fig. 2 The carrier concentration and resistivity as a function of the growth temperature of p-GaN layer.

Scanning electron microscope (SEM) image of the 800°C-grown p-GaN epitaxial layer was rough. Such a rough surface could be attributed to the fact that Ga atoms might not have enough energy to migrate to proper sites at low temperatures. Thus, lateral growth rate of GaN will become smaller due to the smaller Ga diffusion length at low temperatures [5]. As a result, surface morphology of the p-GaN samples grown at 800°C was much rougher, as shown in figure 3.

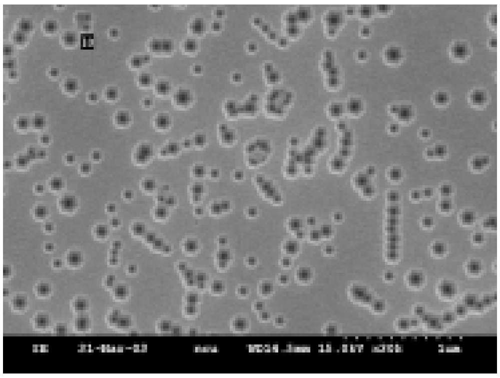

Fig. 3 Scanning electron microscope (SEM) image of $In_{0.23}Ga_{0.77}N$/GaN MQW LEDs at 800°C p-GaN growth.

Figure 4 shows intensity-current (L-I) characteristics of nitride-based LEDs with an 800°C-grown p-GaN cap layer (i.e. LEDI) and a 1000°C-grown p-GaN cap layer (i.e. LEDII). At low injection currents, it can be seen that the output intensity of these two LEDs increased linearly with the injection current. However, LED output intensities seem to saturate slightly for both devices when the injection current is further increased. Under the same injection current, it was found that EL intensity of LEDI with an 800°C-grown p-GaN cap layer was much larger than that of LEDII with a 1000°C-grown p-GaN cap layer. As shown in figure 4, it was found that the 20 mA output intensities were 80 mcd and 42 mcd for LEDI and LEDII, respectively. In other words, we could enhance the LED output intensity by more than 90% with the low 800°C-grown p-GaN cap layer, as compared to the conventional high 1000°C-grown p-GaN cap layer. The exact reasons of the much larger luminous intensity of LEDI were not clearly yet. We believe such an enhancement could be attributed to the higher hole concentration and the rough surface of the 800°C-grown p-GaN cap layer. With a high hole concentration, we should be able to achieve a better carrier spreading, which is helpful in enhancing the LED output intensity. On the other hand, we believe surface roughness could also enhance the LED output intensity, since we should be able to achieve a larger total surface area for light emitting. A rough surface might also result in at least a partial reduction in the total internal reflection. Thus, we could achieve a much larger LED output intensity for samples with a 800°C-grown p-GaN cap layer.

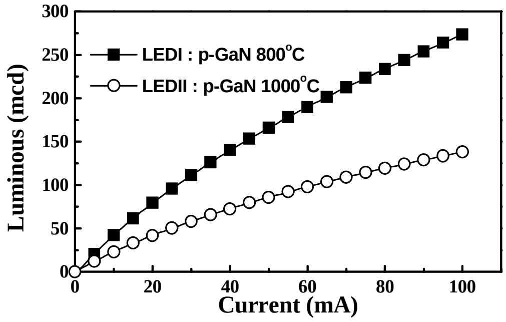

Fig. 4 L-I characteristics of the $In_{0.23}Ga_{0.77}N$/GaN MQW LEDs with different temperature p-GaN contact layer.

4. Summary

In summary, Mg doped p-GaN epitaxial layers prepared at different temperatures were prepared and characterized. It was found that we could achieve a higher hole concentration and a rough surface by reducing the growth temperature down to 800°C. $In_{0.23}Ga_{0.77}N$/GaN MQW LEDs with such a low 800°C-grown p-GaN cap layer were also fabricated. It was found that we could enhance the LED output intensity by more than 90% with the low 800°C-grown p-GaN cap layer, as compared to the conventional high 1000°C-grown p-GaN cap layer.

Acknowledgements

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