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Characterization of GaN on GaN LED by HVPE method

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The selective area growth light emitting diode on GaN substrate was grown using mixed-source HVPE method with multi-sliding boat system. The GaN substrate was grown using mixed-source HVPE system. Te-doped AlGaN/AlGaN/Mg-doped AlGaN/Mg-doped GaN multi-layers were grown on the GaN substrate. The appearance of epi-layers and the thickness of the DH was evaluated by SEM measurement. The DH metallization was performed by e-beam evaporator. n-type metal and p-type metal were evaporated Ti/Al and Ni/Au, respectively. At the I-V measurement, the turn-on voltage is 3 V and the differential resistance is 13 Ω. It was found that the SAG-LED grown on GaN substrate using mixed-source HVPE method with multi-sliding boat system could be applied for developing high quality LEDs.

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Key words: LED, Hydride vapor phase epitaxy, Selective area growth, Double heterostructure, GaN, III-V.

Introduction

Recently, the interest of the using light-emitting diode (LED) for display and illumination applications has been growing steadily over the past few years. LEDs are already applied in various fields such as traffic signal, display back light unit, and lamps due to many advantages such as high efficiency, high durability, and eco-friendly because of absence of mercury content [1-2].

The group III-V nitride semiconductors are attracting much attention for high efficiency optoelectronic device applications whose emission wavelength ranges from green to ultraviolet light due to their wide band gaps [3-4]. Specially, ultraviolet light applied various fields such as chemical detector, sterilization, counterfeit money detector and etc [5-6]. For this reason, one of the III-V nitride semiconductors AlGaN-based LEDs which can emit ultraviolet light is being focused. In order to fabricate the AlGaN-based LEDs, the high quality AlGaN epitaxial layer is necessary.

Most of GaN-based electric and photonic device structures have been grown on foreign substrates, such as sapphire due to the low cost acceptable device performance [7-8]. However, it is well known that the large lattice mismatch between GaN-based epitaxial layer and sapphire substrate leads to high density of threading dislocations in III-V epitaxial layers and the thermal conductivity of sapphire (0.23 W/cm K) is very poor than that of GaN (2.1 W/cm K) [9-10]. If the GaN-based epitaxial layer grows on GaN substrate, it can decrease the density of threading dislocation due to the decrease in the lattice mismatch between the substrate and the epitaxial layer. For these reasons, the GaN substrates grown by HVPE method were used as a substrate for this work.

The major method for fabricating III-V nitride based LEDs is a metal organic chemical vapor deposition (MOCVD) process. Generally, the conventional process for fabricating GaN-based LEDs and other devices, dry etching is an essential step due to the high bond energy (8.92 eV/atom) of GaN [11]. The dry etching method such as reactive ion etching (RIE) uses plasma for etching, which causes the electrical, physical damage and high process cost [11]. Conventional hydride vapor phase epitaxy (HVPE) system is difficult to grow the multi layers. The reason for HVPE system for the double heterostructure (DH) growth has complicated innards because of supplies for Al and doping sources. In addition, it is difficult to control the growth rate of HVPE system due to high growth rate. However, the mixed-source selective area growth (SAG)-HVPE LED with multi-sliding boat system has simple innards, a simplification process and lower cost than conventional LED process.

In this paper, we fabricated the SAG-LED on GaN substrate using mixed-source HVPE method with multi-

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sliding boat system and studied about the characterization of this SAG-LED. The SAG-LED consists of a Te-doped AlGaN cladding layer, an AlGaN active layer, a Mg-doped AlGaN cladding layer, and a Mg-doped GaN layer. This DH was continuously grown by the mixed-source HVPE method with multi-sliding boat system. Morphology and the thickness of DH grown on GaN substrate were evaluated. The DH was metalized using by e-beam evaporator and measured the I-V and electroluminescence (EL).

Experiment

GaN substrate for the DH growth was prepared using HVPE system where Si mixed with metallic Ga in a graphite boat and grown on sapphire substrate. The temperature of source zone and growth zone were stabled at 900 and 1090 °C, respectively. After the growth of GaN substrate, the SiO_2 deposited on GaN substrate for the patterning of SAG using RF sputter. The GaN substrate which had SAG pattern placed in the middle part of the growth zone of the HVPE system.

Fig. 1 shows the schematic of multi-sliding boat system. The mixed-source with multi-sliding boat for the DH growth prepared as follows: four wells in multi-sliding boat were filled with Te-Al-Ga, Al-Ga, Mg-Al-Ga and Mg-Ga metallic mixed-sources, respectively, and soaked in a furnace at 900 °C for 1 hour. After prepared the substrate and multi-sliding boat, these were loaded at the middle of growth zone and source zone, respectively. The quartz tube for supplies HCl gas was inserted in a hole at the top plate of multi-sling boat. The quartz tube for supplying NH_3 gas was placed on the top plate of multi-sliding boat and the end of this quartz tube was near the substrate. The HCl gas flowed over the metallic mixed-source for the growth of Te-doped AlGaN (n-clad) layer. After growth of n-clad layer, the HCl gas flow was stopped and the cover was moved to close first well and open the second well. Then HCl gas was flowed over the Al-Ga metallic mixed-source for the growth of AlGaN (active) layer. The DH was grown on GaN substrate on this way. The carrier gas was N_2 and NH_3 gas used for supplying nitride. The HVPE system set the source zone temperature at 900 °C and growth zone temperature at 1090 °C during the growth. After complete the DH growth, an appearance of SAG on GaN substrate and the thickness of DH and substrate were evaluated by a scanning electron microscopy. Metallization was performed with e-beam evaporator. Ni/Au was evaporated for n-type metals and Ti/Al was evaporated for p-type metals.

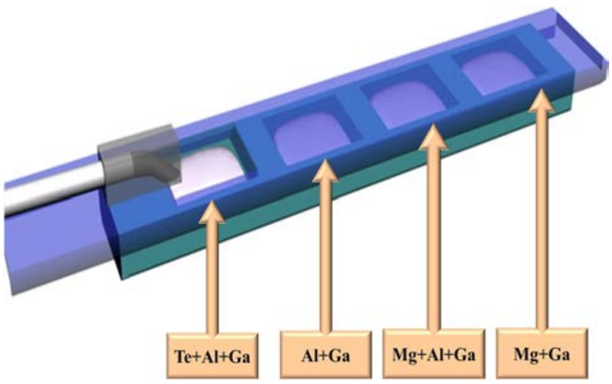

Fig. 1. The schematic of multi-sliding boat system.

Results and discussion

n-GaN substrate was grown by doping with Si because the undoped-GaN substrate has higher resistance than n-GaN. Fig. 2 shows the result of Hall effect measurement of GaN substrate at 300 K. The average and standard deviation of carrier concentration of our substrate were 6.4×10^{16} and 2.2×10^{16} cm^{-3}, respectively. But the general concentration of undoped-GaN layer is 10^{16}~10^{17} cm^{-3} and n-GaN is 10^{17}~10^{19} cm^{-3} [8, 12-14]. It means that our substrate is similar to undoped-GaN even though we intended to grow n-GaN. Our previous work reported that carrier concentration of a Te-doped AlGaN layer measured at 300 K by Hall effect measurement was 1.1×10^{18}~8.0×10^{18} cm^{-3} [15] and hole concentration of Mg-doped GaN layer was 1.5×10^{16}~3.2×10^{16} cm^{-3}[13]. From these results, the carrier concentrations of n-clad layer and p-clad layer are estimated to be in these ranges.

Fig. 3 shows the SEM images of DH grown on GaN substrate. Fig. 3(a) is the top-view image of the SAG-DH on GaN substrate, showing that the SAG-DH was successfully grown by mixed-source HVPE method with multi-sliding boat system. Fig. 3(b) and (c) are the side view of DH on GaN substrate, showing that the thickness of GaN substrate and DH are 450 and 10 μm, respectively.

Fig. 4 shows the schematic structure of the SAG-LED grown on GaN substrate by the mixed-source HVPE method with multi-sliding boat system and metallized by an e-beam evaporator.

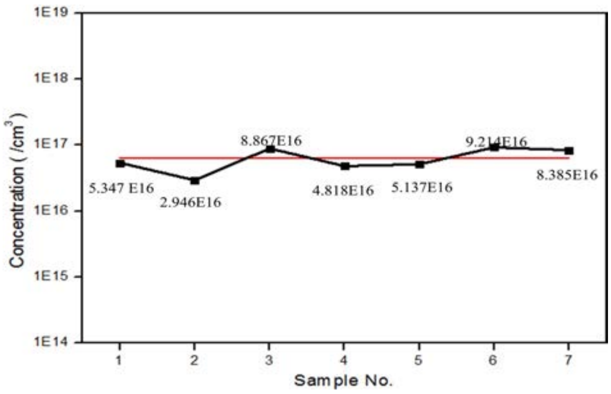

Fig. 2. The result of Hall effect measurement.

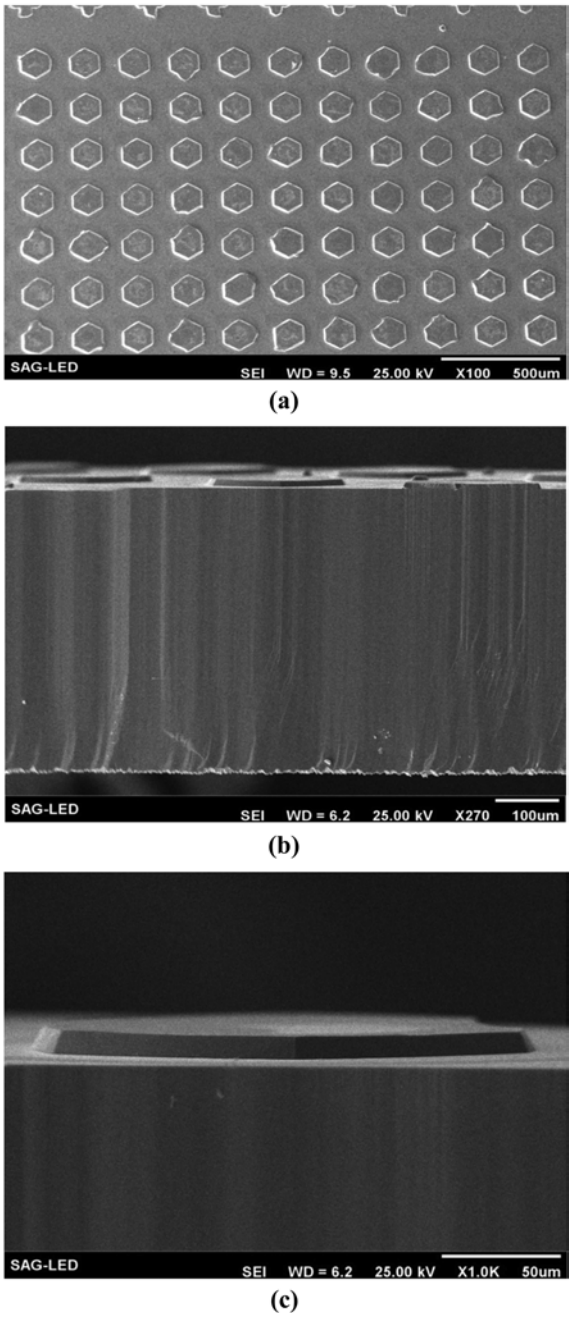

Fig. 3. The SEM images grown on GaN substrate. (a) top-view, (b) side view with low magnification and (c) side view of DH on GaN substrate.

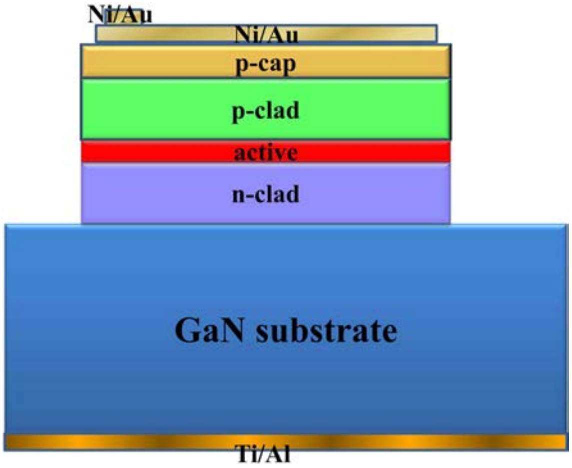

Fig. 4. The schematic structure of SAG-LED.

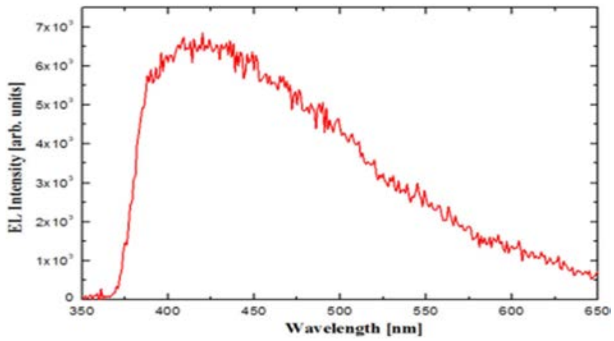

Fig. 5. The EL spectrum of the SAG-LED.

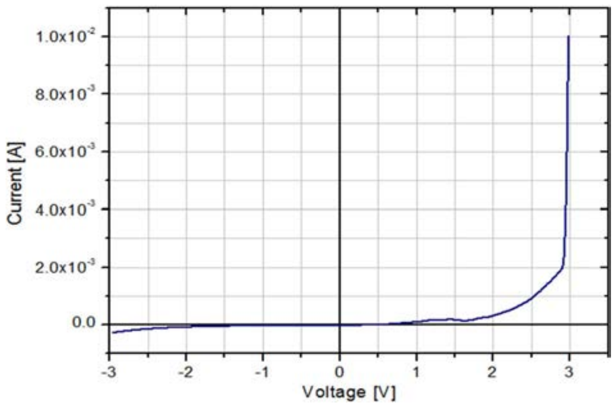

Fig. 6. The I-V curve of the SAG-LED.

The SAG-LED emitted bluish light at an injection current of 30 mA at room temperature and the EL spectrum in Fig. 5 shows that the main peak is 420 nm. These results reveal that the emitting light color is deep blue. However, the wavelength is longer than general AlGaN-based LEDs. Because the wavelength of LEDs with AlGaN as an active layer is shorter than 400 nm. This result is assumed to be attributed to the low composition of Al in Al and Ga mixed source. Therefore, if Al compositions become higher when Al and Ga are mixed together, the LED with shorter wavelength could be obtained. In conventional growth of AlGaN layer using HVPE method, AlN is concentrated because the chemical reaction between NH_3 and Al chloride forms faster than NH_3 and Ga chloride [9, 16]. This is the reason why we assume that the spectrum of EL has a tail is attributed to partial concentration phenomenon of AlN in AlGaN layer. Fig. 6 shows I-V charateistics measured. The trun-on voltage is 3 V and differential resistance is 13 Ω in I-V curve.

From this result, the electrical property of the SAG-LED is evaluated to be fine. These results mean SAG using mixed-source HVPE method with multi-sliding boat system of DH on GaN substrate was successfully and it can be applied in development of high quality LEDs.

Conclusion

The SAG-LED on GaN substrate was performed by mixed-source HVPE method with multi-sliding boat system. The result of Hall effect measurement of GaN substrate shows that the obtained substrate was undoped-GaN. However, the resistance of undoped-GaN is higher than n-GaN. SEM images show that the SAG was successful and the thickness of GaN substrate and DH were 450 μm and 10 μm, respectively. The EL measurement result shows that the main peak is about 420 nm, indicating that SAG-LED is emitting deep-blue light. The turn-on voltage and differential resistance at the I-V curve are 3 V and 13 Ω, respectively. These results mean that the device has a high performance LEDs. It could be concluded that that the mixed-source HVPE method with multi-sliding boat system is possible to be one of the growth methods of -nitride LEDs for high quality emitting diodes.

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