식각 손상된 InGaN/GaN 다중 양자우물 발광 다이오드의 전기적 특성 회복

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Improvement of Etch-Damaged Electrical Properties of InGaN/GaN Multiple Quantum Well Light-Emitting Diodes

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Ⅰ. INTRODUCTION

GaN-based nitrides are attracting much attention as suitable materials for optoelectronic applications in the visible and ultraviolet energy regions.[1] The recent rapid progress of the research on the nitrides has realized superbright blue and green InGaN single quantum well (SQW) light emitting diodes (LEDs)[2] and room temperature (RT) pulse oscillation of InGaN multiple quantum well (MQW)[3] and SQW[4] laser diodes (LDs). All of the LEDs and a majority of the LDs have a ridge waveguide structure in which the mesas are formed by a dry etching technique. Hence, the fabrication of these GaN-based optoelectonic devices depends largely on dry etching. Plasma etching techniques have been predominantly used in the patterning of the III-nitrides. Recently, the most significant advancement in dry etching of the III-nitrides is the utilization of high density plasmas such as inductively coupled plasmas (ICPs) and electron cyclotron resonance (ECR) systems, in which plasma density (or the ion flux) and ion energy are controlled independently. Several research groups reported etch characteristics of the III-nitrides using the high density plasmas for epitaxially grown films.[5,6] However, plasma-induced damage often occurs under conditions of high ion flux and energetic ion bombardment.

Plasma-induced damage can include lattice defects (or dislocations) and formation of dangling bonds on the surface mainly due to energetic ion bombardment, sidewall damage, hydrogen passivation, polymer deposition and etch products deposition, and unequal removal rate of group III and group V elements. Several research groups reported the dry etch damage results for InN, InGaN and InAlN,[7] GaN Schottky diodes,[8] and GaN MESFET.[9] However, very little work has been reported for the InGaN/GaN MQW LED structures. The plasma-induced damage can affect the electrical properties of the LEDs and LDs, such as forward and reverse voltages.

In this paper, we report the improvement of etch-damaged electrical properties of the InGaN/GaN MQW LEDs grown by metal-organic chemical vapor deposition in terms of surface treatment.

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Ⅱ. EXPERIMENTAL

$In_xGa_{1-x}N$/GaN multiple quantum well LED structures were grown on c-plane sapphire substrate by metal-organic chemical vapor deposition system. Trimethylgallium (TMGa), trimethylindium (TMIn), ammonia (NH_3), and silane (SiH_4) were used as the precursors of Ga, In, N, and Si, respectively. Before growing the nitride films, the substrates loaded into the reactor were thermally cleaned in hydrogen atmosphere at 1200 ^oC for 10 min. A GaN nucleation layer of 25 nm thickness was grown on the cleaned substrate at 560 ^oC, and a 4-μm-thick GaN:Si was then grown at 1130 ^oC. Figure 1 shows the InGaN/GaN MQW LED structure grown at 750 ^oC, having a 6-period InGaN(2.5 nm)/GaN(8 nm) quantum well structure. A 0.25-μm-thick Mg-doped p-GaN was grown finally at 1090 ^oC on the top of MQWs.

For fabrication of the InGaN/GaN MQW LED chips, the processing procedures were summarized as: 1) SiO_2 film was deposited by PECVD onto the epiwafer as the etch mask before ICP mesa etching, 2) ICP etching was carried out to form mesa structure with Cl_2/Ar discharges, 3) Au(5 nm)/Ni(7 nm) bi-layer for p-ohmic metal was deposited by e-beam evaporation and lift-off, then alloyed at 500 ^oC, and 4) Ti(30 nm)/Al(70 nm) bi-layer for n-type contact was deposited and patterned by lift-off. Etching was performed in a planar-type inductively coupled plasma (ICP) system in which the ICP source operated at 13.56 MHz. Surface morphologies of the fabricated MQW LEDs were analyzed with atomic force microscopy (AFM). The I-V characteristics of the InGaN/GaN MQW LEDs were measured with a semiconductor parameter analyzer (HP 4155A).

Ⅲ. RESULTS AND DISCUSSION

Figure 2 shows the effect of surface treatment on current-voltage *(I-V)* characteristics at room temperature of the InGaN/GaN MQW LEDs along with (a) annealing before etching, (b) annealing after etching, and (c) annealing and KOH treatment after etching as a function of ICP source power at 100 W rf chuck power, 10 mTorr, and 50 % Cl_2. Annealing was carried out under N_2 at 930 ^oC for 30 sec by RTA system. We can see substantial improvements, especially the operating voltage, with annealing and KOH treatment after etching and before metallization. This is attributed to a substantial improvement in surface morphology, as shown in Fig. 3. The root-mean-square (rms) showed 1.273 nm for as-grown, 1.248 nm for KOH treatment for 10 min, 0.583 nm KOH treatment for 20 min. Although not shown, the ICP-induced damage of the InGaN/GaN MQW LEDs has been studied in terms of *I-V* properties, together with etch rate and surface morphology. We observed the physical degradation of the sidewall along with the rougher surface morphology deteriorated the *I-V* properties. The experimental results led to a conclusion that the forward voltage was more sensitive to the surface roughness and the reverse voltage was strongly affected by the sidewall contamination.[10] We can also see disappearance of OH bonding on surface with annealing after etching from the FT-IR measurement, as shown Fig. 4.

Ⅳ. CONCLUSIONS

The improvement of etch-damaged electrical properties of InGaN/GaN MQW LEDs grown by metal-organic chemical vapor deposition has been studied in terms of surface treatment. Annealing and KOH treatment after etching and before metallization recovered the electrical properties substantially. This is due to improvement in surface morphology with annealing and KOH treatment after etching and before metallization. Therefore, we were able to improve the electrical properties with annealing and KOH treatment after etching.

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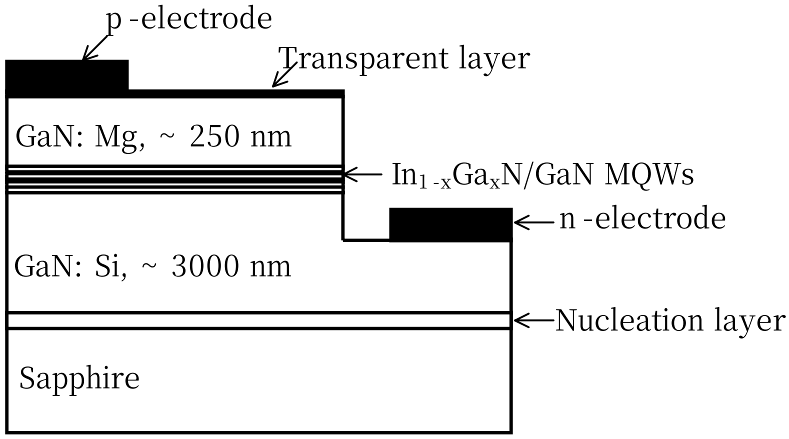

Figure 1. Schematic diagram of InGaN/GaN MQW LED structure.

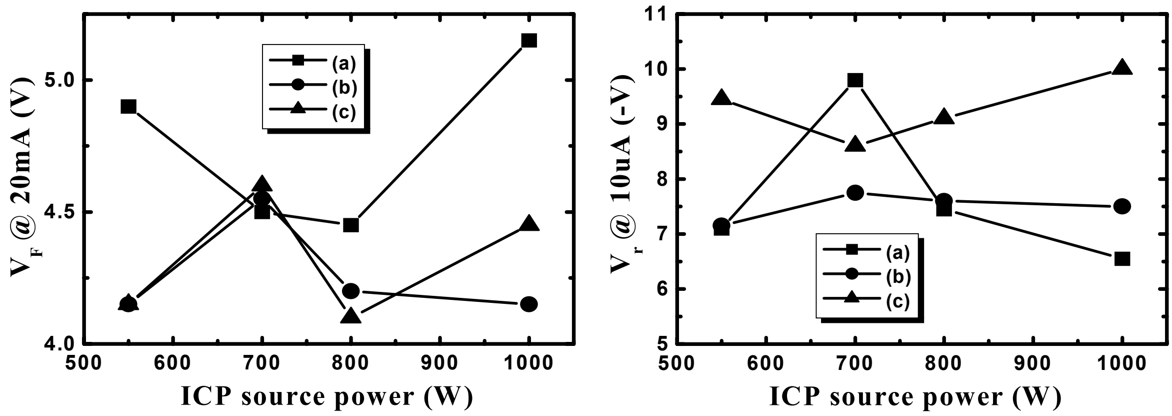

Figure 2. Forward (left) and reverse (right) voltages of InGaN/GaN MQW LED structures at room temperature with surface treatment as a function of ICP source power: (a) activation + etching + metallization, (b) etching + annealing + metallization, and (c) etching + annealing + KOH treatment + metallization, respectively.

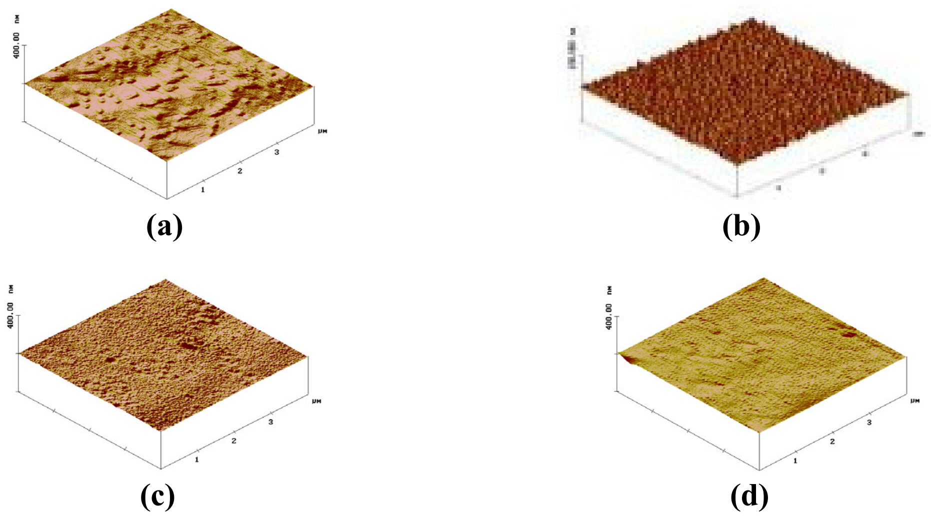

Figure 3. AFM images of effects of KOH treatment on surface morphology.
(a) as-grown, rms: 1.273 nm, (b) etched, no treatment, rms: 1.963 nm, (c) treatment for 10 min, rms: 1.248 nm, and (d) treatment for 20 min, rms: 0.583 nm, respectively.

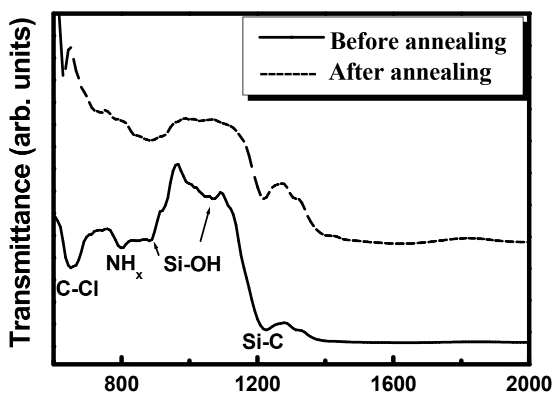

Figure 4. FT-IR spectra of InGaN/GaN MQW LEDs with and without annealing after etching.