Extended Abstracts of the 2016 International Conference on Solid State Devices and Materials, Tsukuba, 2016, pp791-792

PS-7-03

Passivation effect of ozone water treatment of InGaN/GaN nanostructures fabricated by hydrogen environment anisotropic thermal etching (HEATE)

Kohei Ogawa[1], Tomoya Mizutani[1], Shun Ishijima[1], Yusuke Namae[1], Akihiro Matsuoka[1], Akihiko Kikuchi[1,2]

[1]Sophia University
[2]Sophia Nanotechnology Research Center
7-1, Koi-cho, Chiyoda-ku, Tokyo, Japan
Phone: +81-3-3238-3532 E-mail: kikuchi@sophia.ac.jp

Abstract

We investigated the effect of saturated ozone water (SOW) treatment on the optical properties of InGaN/GaN multiple quantum well (MQW) nanostructures fabricated by a hydrogen environment anisotropic thermal etching (HEATE). Because the HEATE is nearly damage-free etching technique for InGaN/GaN nanostructure, the surface treatment effect is easy to investigate. After the removal of surface native oxide by a buffered oxide etching (BOE), the InGaN/GaN MQW nanostructures were dipped in SOW from 5 to 120 minutes. For the case of 30 min SOW treatment, the integrated PL intensity increased about 80 %, the PL lifetime increase from 0.65 to 1.9 nsec, and the PL peak wavelength shifted from 435 to 428 nm, compared with those after BOE. These results suggest that SOW treatment effectively reduces the surface non-radiative recombination by forming widegap oxide layer. The blue shift of PL wavelength also suggests the increase of compressive strain of InGaN layer by covering the nanostructures with oxide layer.

1. Introduction

GaN based nanostructure is an attractive material for realization of high performance and high functional optoelectronic devices owing to its strain relaxation effect, high-density integration capability, ultra-small volume of active region, and so on. It is well known that the surface non-radiative recombination deteriorates the device performance especially for smaller nanostructures due to larger surface to volume ratio. The surface passivation is an essential technique for realizing high-performance nanostructure devices. We have investigated a novel low damage GaN etching technique named hydrogen environment anisotropic thermal etching (HEATE) [1] which is based on thermal decomposition reaction of GaN in a low-pressure H_2 environment at high-temperature around 800~1100 ºC. Recently, we have confirmed by high-resolution TEM observation that the etched facets of GaN and InGaN by HEATE keep crystallinity until the outermost surface, that is any amorphous region which formed by physical impact during etching process was observed. Because the HEATE is nearly damage-free etching technique for InGaN/GaN nanostructure, the surface treatment effect is easy to investigate.

In this study, we investigated the surface passivation effect of saturated ozone water (SOW) treatment on the optical properties of InGaN/GaN MQW nanopillars fabricated by HEATE. The room temperature photoluminescence (RT-PL) and time-resolved PL (TR-PL) measurements were carried out to evaluate the optical properties.

2. Experiments

An InGaN/GaN multi quantum well (MQW) blue LED epitaxial wafer grown on Al_2O_3 PSS substrate by a metal-organic chemical vapor deposition were used as a starting material. The wafer had six pairs of InGaN/GaN MQW sandwiched by p-GaN and n-GaN/n-AlGaN cladding layers as shown in Figure 1. The designed thicknesses of InGaN quantum well, GaN barrier are 3 nm and 10 nm, respectively. Because AlGaN is difficult to etch under conventional HEATE condition, the n-AlGaN layer was employed as etching stop layer. After the formation of 100-nm-thick circular SiO_2 nano-masks, the samples were heated at 1050 ºC at the hydrogen pressure of 10 Pa for 10 min in a tubular furnace to decompose the exposed GaN area by HEATE process. Figure 2 shows SEM top view images of InGaN/GaN nanostructures fabricated by HEATE with average diameters of (a) 42 nm and (b) 79 nm. Both nanopillars were aligned in triangular lattice with 200 nm pitch.

Immediately after the buffered oxide etching (BOE) using buffered hydrofluoric acid (BHF) to remove the surface native oxide of MQW nanopillars, the RT-PL and TR-PL were measured using He-Cd laser (λ=325 nm) and InGaN short pulse laser diode (λ=375 nm), respectively, as excitation sources. Following to these procedures, the samples were dipped in SOW, then measured the RT-PL spectra and TR-PL characteristics. The SOW treatment time was changed into 5, 30 and 120 minutes.

3. Results and discussion

Figure 3 shows the PL decay curves of nanopillars with InGaN diameter of 42 nm after BOE and SOW treatments. The PL decay was fastest for the case of after BOE with the lifetime of 0.65 nsec. After the SOW treatment of 5 and 30 min, the lifetime increased to 1.0 and 1.9 nsec, respectively, and saturated at 120 min. The increase in room temperature lifetime suggested the reduction of non-radiative recombination. Supporting the lifetime results, the integrated PL intensity after 30 min SOW treatment was about 80% increased from that after BOE as shown in Figure 4. The PL peak wavelength shifted from 435 to 428 nm by 30 min SOW treatment.

Figure 5 shows PL decay curves of InGaN MQW nanopillars with different InGaN diameters of (a) 42 nm and (b) 79 nm before and after 30 minutes SOW treatment. The lifetime clearly increased after SOW treatment for both cases. It is also note that smaller nanopillar showed faster lifetime, because of larger surface to volume ratio. We also confirmed that surface oxidation layer by SOW treatment easily removed by BOE and PL characteristics had reproducibility.

These results suggest that SOW treatment effectively reduces the surface non-radiative recombination by forming widegap oxide layer such as Ga_2O_3. The blue shift of PL wavelength also suggests the increase of compressive strain of InGaN layer by covering the nanostructures with oxide layer.

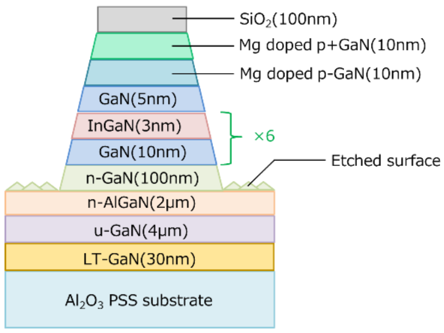

Fig.1 Schematic diagram of InGaN/GaN nanostructure fabricated by HEATE process.

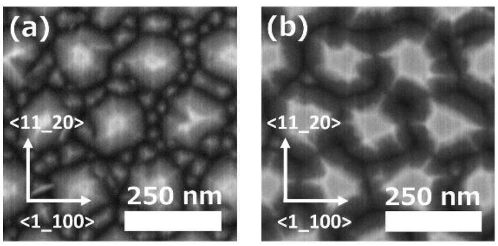

Fig.2 SEM top view images of InGaN/GaN nanostructures with InGaN diameter of (a) 42 nm and (b) 79 nm fabricated by HEATE.

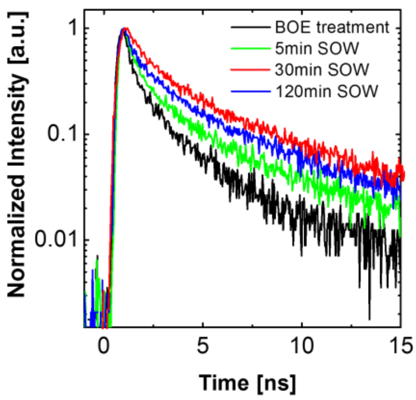

Fig.3 RT-PL decay curves of MQW nanopillars with InGaN diameter of 42 nm after BOE and SOW treatment.

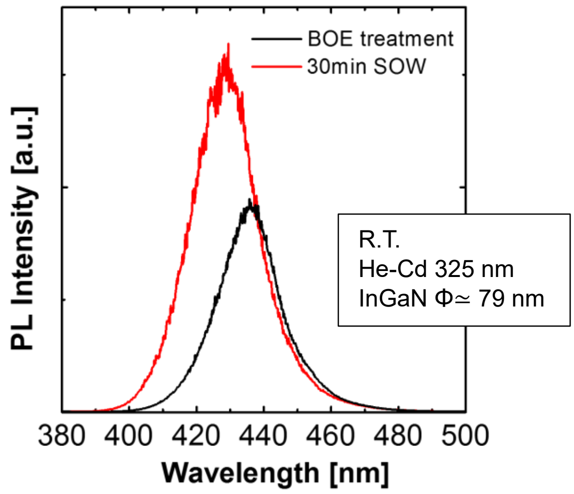

Fig.4 The PL spectrum after BOE treatment and 30 min SOW treatment.

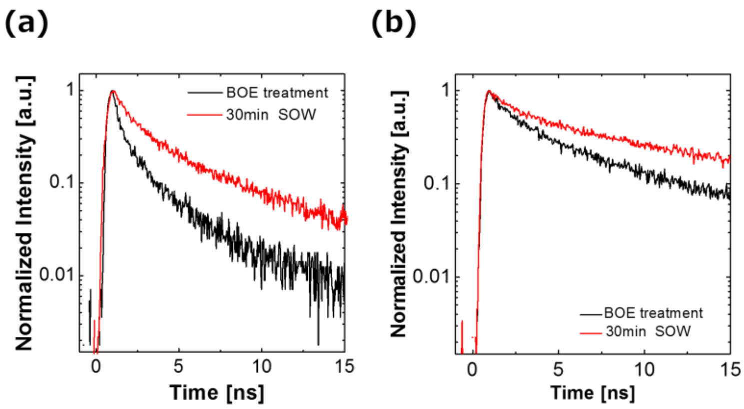

Fig.5 PL decay curves of InGaN MQW nanopillars with InGaN diameters of (a) 42 nm and (b) 79 nm before and after 30 minutes SOW treatment.

4. Conclusions

We investigated the saturated ozone water treatment for the InGaN MQW nanopillars. It was confirmed that the SOW treatment is an effective passivation technique to suppress the surface non-radiative recombination. The RT-PL intensity was 80% increased by 30 minutes SOW treatment. The RT-PL lifetime was increased from 0.65 to 1.9 nsec by the SOW treatment. It was also considered that this passivation technique can be used for digital etching of GaN because the oxidation reaction for Ga is saturated and Ga_2O_3 film can be etched by BHF.

Acknowledgements

This work was partially supported by Grant-in-Aid for Ex-ploratory Research No. 16K14260.

References

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