Extended Abstracts of the 2016 International Conference on Solid State Devices and Materials, Tsukuba, 2016, pp849-850

PS-9-07

Ultrafine (≤10nm) InGaN quantum structures fabricated by hydrogen environment anisotropic thermal etching (HEATE)

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

[1] Sophia University
[2] Sophia Nanotechnology Research Center
7-1, Kioi-cho, Chiyoda-ku, Tokyo 102-8554, Japan
Phone: +81-3-3238-3532 E-mail: kikuchi@sophia.ac.jp

Abstract

Ultrafine InGaN/GaN nanostructures with lateral dimension of around 10 nm were artificially fabricated by hydrogen environment anisotropic thermal etching (HEATE). The minimum dimensions of InGaN single quantum wires embedded in GaN nanowalls were 8-nm in width and 3-nm in thickness, and those of hexagonal InGaN single quantum disks embedded in GaN nanopillars were 10-nm in diameter (opposite sides distance) and 3-nm in thickness. The InGaN/GaN nanostructure arrays without any post treatment exhibited clear room temperature photoluminescence (RT-PL) emission, suggesting a low process damage of HEATE. The RT-PL of the ultrafine InGaN quantum structures showed remarkable dependency on the lateral dimension in the rage of 10 to 40 nm.

1. Introduction

Position and size controlled ultrafine semiconductor nanostructure is an attractive material for various fields such as basic research, practical application of light emitting devices and future applications such as quantum information processing [1]. InGaN nanostructures has particularly favorable properties of visible light emission and room temperature operation due to wide bandgap energy. We have investigated a novel GaN etching technique named hydrogen environment anisotropic thermal etching (HEATE) [2] suitable for nanostructure fabrication. HEATE is a low-damage GaN selective etching technique using SiO_2 masks based on thermal decomposition reaction of GaN in a low-pressure H_2 environment at high-temperature around 850~1100 °C. In this study, we report on fabrication of InGaN/GaN ultrafine nanostructures having InGaN layers of 8~10-nm in lateral dimension and room temperature photoluminescence (RT-PL) characteristics.

2. Experiments

An InGaN/GaN single quantum well (SQW) wafer grown by a metal-organic chemical vapor deposition were used as a starting material. The wafer has a structure of p+GaN(10nm) /p-GaN(10nm)/GaN(5nm)/InGaN(3nm)/GaN(10nm)/n-GaN (50nm)/n-AlGaN(2um)/u-GaN(4um) on a (0001)Al_2O_3 substrate as shown in Fig.1. Because AlGaN is difficult to etch under conventional HEATE condition, the AlGaN layer was used for an etching stop layer. After the formation of circular and stripe shaped 150-nm-thick SiO_2 nanomasks with various size and pitch in each 50-μm square area on the surfaces of the epitaxial layer via electron beam lithography and dry etching with a CF_4/O_2 mixed gas, the samples were heated at 900 ºC under the hydrogen pressure of 100 Pa for 25 minutes. Finally, exposed area were selectively etched by HEATE and GaN/InGaN/GaN nanostructures were formed.

3. Results

Fig. 2 shows a bird's eye view SEM image of 300-nm-pitch InGaN/GaN nanowall array along a-axis and an inset is magnified image of a nanowall edge. A schematic shape of the fabricated nanowall is shown in Fig. 4 (a). The height of nanowall is about 88 nm and the sides were consisted of two {n0_n1} facets. The slanted angles at lower and higher part of nanostructures were evaluated to be about 60º and about 85º from cross sectional TEM images of other sample fabricated at 1000 °C. It was carefully evaluated from the SEM images that the top width of narrowest nanowall was about 5 nm and the width of InGaN QW was 8 nm. That is ultrafine InGaN single quantum wire (SQWR) was successfully fabricated. Fig.3 shows the SEM image of 400-nm-pitch InGaN/GaN nanopillar array and an inset is magnified image of a pillar. A schematic shape of the nanopillar also shown in Fig. 4 (b). The upper region of nanopillar is surrounded by six {n0_n1} (n>3) equivalent facets. The minimum diameter (opposite side distance) of the single hexagonal InGaN quantum disk (SQD) was evaluated to be 10 nm. The lateral dimension of the ultrafine nanostructures were controlled by sidewall etching under SiO_2 mask region. Fig.5 shows RT-PL spectra of nanowall array with InGaN SQWRs width of 8~10 nm and nanopillar array with InGaN SQDs diameter of 10~12 nm. The intensity was normalized by emission area. These ultrafine InGaN nanostructures showed clear PL emission at room temperature without any passivation, suggesting the low etching damage. The peak wavelength of InGaN SQWRs and SQDs are 438 and 425 nm, respectively. Those showed large blue-shift from the original wavelength of 445 nm of as grown wafer. There are some possible reasons of blue-shift such as strain relaxation at the edge of nanostructure, indium desorption and/or migration at high-temperature, and quantum shift in lateral direction. Fig.6 shows peak wavelength of

InGaN nanostructures as a function of the lateral size. The wavelength of SQDs are shorter than that of SQWRs due to larger side edge area of SQDs. It can be note that both SQWRs and SQDs showed steep blue-shift below 20 nm. Fig. 7 shows PL intensity normalized by emission area as a function of nanostructure size. The intensity increased with reducing the size and maximized around at 15nm in width. These remarkable PL behavior of ultrafine InGaN nanostructures will be discussed.

4. Conclusions

Ultrafine InGaN nanostructures (SQWRs and SQDs) with lateral dimension of 8~10 nm were successfully fabricated by HEATE technique. The as fabricated nanostructures showed clear RT-PL emission, suggesting low-etching damage of HEATE process. The RT-PL intensity and peak wavelength of ultrafine nanostructures with lateral size of 8~40 nm showed remarkable size dependency.

References

[1] M. Holmes, K. Choi, S. Kako, M. Arita, and Y. Arakawa, Nano Letters, 14 (2014) 982.

[2] R. Kita, R. Hachiya, T. Mizutani, H. Furuhashi and A. Kikuchi, Jpn. J. Appl. Phys. 54 (2015) 046501.

Acknowledgements

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

Fig. 1. Schematic layer structure of epitaxial wafer used for ultrafine InGaN quantum structures fabrication by HEATE process.

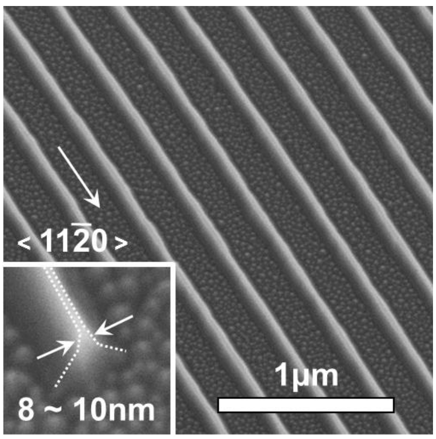

Fig. 2. Bird's eye view SEM image of 300-nm-pitch InGaN/GaN nanowall array along a-axis.

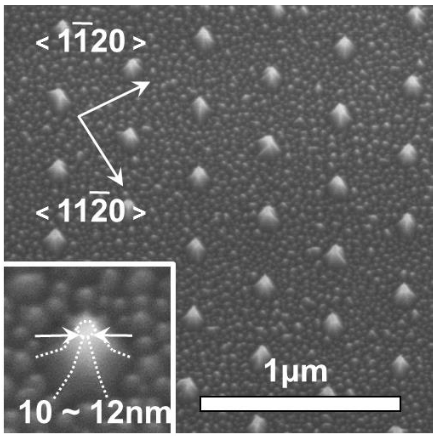

Fig. 3. Bird's eye view SEM image 400-nm-pitch InGaN/GaN nanopillar array.

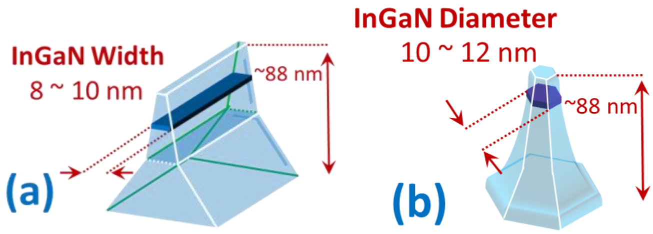

Fig. 4. schematic shape of the fabricated nanowall (a) and nanopillar (b).

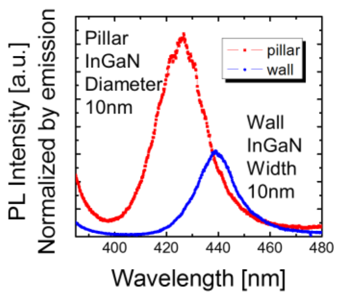

Fig. 5. RT-PL spectra of nanowall array with InGaN SQWRs width of 10 nm and nanopillar array with InGaN SQDs diameter of 10nm.

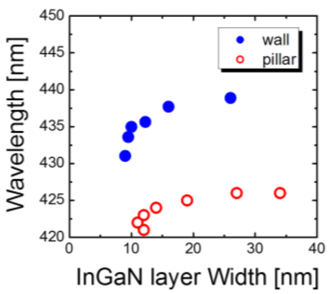

Fig. 6. Peak wavelength of InGaN nanostructures as a function of the lateral size.

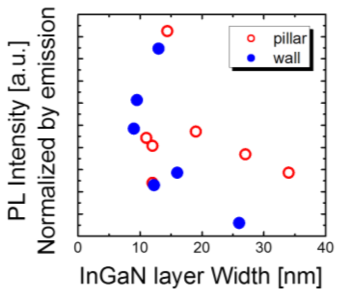

Fig. 7. PL intensity normalized by emission area as a function of nanostructure size.