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AlGaN microdisks on top of supporting GaN columns fabricated using hydrogen environment anisotropic thermal etching

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Abstract

The AlGaN microdisks on top of supporting GaN columns were fabricated via etching process of an inductive coupled plasma reactive ion etching (ICP-RIE) and a hydrogen environment anisotropic thermal etching (HEATE). With the HEATE, GaN was selectively etched while the AlGaN layer was maintained, resulting in the AlGaN microdisk structures. The side length and thickness of the microdisks were approximately 1.5 μm and 100 nm, respectively. Such structures are expected to act optical resonator based on the whispering gallery mode. Under optically pumped condition, AlGaN microdisks exhibited lasing action at the wavelength of approximately 350 nm.

1. Introduction

Microstructures act as whispering gallery mode (WGM); light propagates around by total internal reflection at the boundary of the structures, [1] have been investigated as a potential candidate for applying high performance laser diodes owing to the high light confinement. Thus far, the sphere and disk structures have been investigated for the WGM resonators. Specially, microdisks acting as the WGM resonator with optical gain have been fabricated with semiconductor crystals by etching process [2,3] and crystal growth. [4,5] GaN-based [6,7] and ZnO [8,9] nano/microdisks via crystal growth have been demonstrated, and they exhibited lasing action owing to the symmetric structures and high quality crystallinity. Although the microdisk via crystal growth showed excellent optical properties, microdisks via etching process using various lithography techniques are easily designed the geometry. Thus, the microdisks via etching process are considered to be industrially practicable.

Thus far, the nitride-based microdisks via etching process depended on photo-electro-chemical (PEC) etching. [10] Using the PEC etching, band-gap selective etching enabled to form a microdisk and column which supported the microdisk at the center, indicating that most of the area of the microdisks were sandwiched by the air. With such structures, light is strongly confined vertically and laterally by the air and WGM, respectively. However, the microdisks via PEC etching have many challenges to overcome. Rough side-surface of the microdisks was formed by PEC etching owing to the mask erosion. The rough side-surface decreases the light confinement of the microdisk. The PEC etching is one of chemical wet etching process using strong alkaline aqueous solutions, indicating that it is difficult to control the etching ratio. In addition, some complicated layers were required to fabricate the microdisk by the PEC owing to realizing band-gap selective etching. [11,12]

In this study, we report on the demonstration of free-standing AlGaN microdisks fabricated via etching process of an inductive coupled plasma reactive ion etching (ICP-RIE) and a hydrogen environment anisotropic thermal etching (HEATE). [13] Using the HEATE, we demonstrated AlGaN microdisks supporting by a GaN column, and the technique solve the above issues. We show the fabrication process and optical properties evaluated by a room temperature photoluminescence measurement (RT-PL) of the AlGaN microdisks.

2. Experiment and results

Figure 1 shows the schematic illustration of fabricating process of the AlGaN microdisks. Commercially available templates were used to fabricate the AlGaN microdisks. With the templates, an AlGaN layer was grown on a GaN layer on a c-plane sapphire substrate by metal-organic chemical vapor deposition (MOCVD). At the first, SiO_2

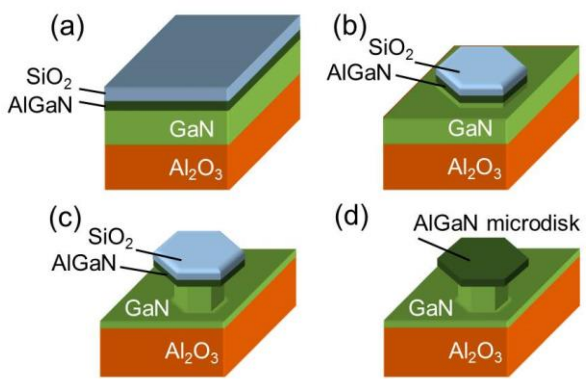

Fig. 1. The fabricating process of an AlGaN microdisk on top of a supporting GaN column

film (500 nm in thickness) was deposited on the substrate by use of a spattering process, and the SiO_2 mask-patterns on the AlGaN layer were formed by combination of electron-beam lithography (EBL) and ICP-RIE with CHF_3 and Ar gas. Using the SiO_2 mask, AlGaN was etched down to such depth to reach the GaN layer using the ICP-RIE with Cl_2, BCl_3 and Ar gas, and AlGaN microdisks were formed on the GaN layer (Fig. 1(b)). Subsequently, the substrates were etched by the HEATE technique. The substrates were set in a tube furnace, and the H_2 gas was flowed into the furnace and the temperature of the furnace was approximately 990 °C. Then, GaN was selectively etched, resulting in the AlGaN microdisk which was undercut, namely, supporting GaN columns was formed (Fig. 1(c)). At the last, remained SiO_2 layer was removed using the HF solution (Fig. 1(d)). Figure 2 shows the SEM image of the AlGaN microdisk on top of the supporting GaN column. The side length and thickness of the AlGaN microdisk were approximately 1.5 μm and 100 nm, respectively. As shown in Fig. 2, the supporting GaN column was seen through the AlGaN microdisk owing to the ultrathin structure, and the diameter of the top of the supporting GaN column was approximately 1.0 μm.

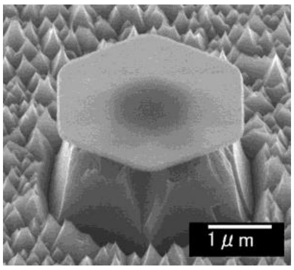

Fig. 2. Bird's-eye-view SEM image of AlGaN microdisk on top of supporting GaN column.

A RT-PL measurement was employed to characterize optical property of the AlGaN microdisks. In this experiment, a nitrogen laser whose wavelength, pulse width, and repetition rate were 337.1 nm, 900 ps, and 10 Hz, respectively, was used as an excitation source. Figure 3 shows the PL spectrum of the AlGaN microdisks on top of supporting GaN columns under the excitation density of approximately 12 MW/cm^2. Besides a broad spontaneous emission from the GaN, the sharp peaks appeared at wavelength range from approximately 350 nm to 355 nm. The full width at half-maximum (FWHM) of the sharp peaks are approximately 0.6 nm. These results indicate that AlGaN microdisk exhibited the lasing action caused by the WGM in the microdisk.

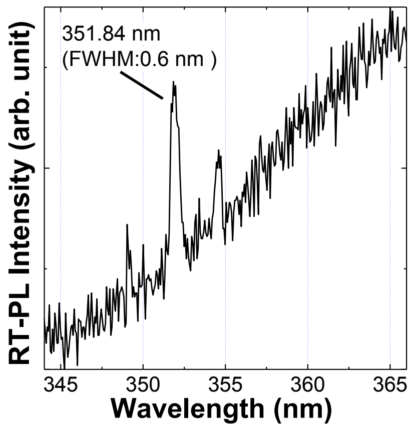

Fig. 3. PL spectrum of the hexagonal AlGaN microdisk on top of supporting GaN column at approximately 12 MW/cm^2.

3. Summary

The AlGaN microdisks on top of supporting GaN columns were fabricated via etching process of ICP-RIE and HEATE. The microdisks exhibited lasing action at the wavelength of approximately 350 nm under optically pumped condition. The optical microcavities of the microdisk via etching processes using HEATE can be applied to realizing ultra-violet laser diodes.

Acknowledgements

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