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Optically pumped lasing action around unusual wavelength of 390 nm in hexagonal GaN microdisks fabricated by rf-MBE

Tetsuya Kouno,[1,*] Masaru Sakai,[2] Katsumi Kishino,[3] and Kazuhiko Hara[1]

[1]Shizuoka University, 3-5-1 Johoku, Naka-ku, Hamamatsu-shi, Shizuoka-ken 432-8011, Japan
[2] University of Yamanashi, 4-3-11 Takeda, Kofu, Yamanashi 400-8510, Japan
[3]Sophia University, 7-1 Kioi-cho, Chiyoda-ku, Tokyo 615-8510, Japan
*E-mail: tetsuya.kouno@gmail.com

1. Introduction

Semiconductor microdisk structures have attracted much attention as ultra high-Q optical resonators with the resonant mechanism of whispering gallery mode (WGM), in which light is strongly confined in the resonator by total internal reflection (TIR) at the outer wall of the resonator medium as shown in Fig. 1, resulting in an extremely high Q factor. It is, therefore, expected for them to be applied to high performance semiconductor lasers, optical switches, and ultra-sensitive sensors [1-4]. Especially, the WGM micro- and nano-resonators composed of wide-gap semiconductors such as GaN, AlN, and ZnO are promising for the applications to ultra-sensitive label-free sensors for bio-chemical, monitoring molecules and cells owing to their material properties; the transparency for UV light and chemical stability. In addition, it is important that the micro-cavities with small gain volume are composed of high-quality crystals. In this sense, high crystalline quality GaN and ZnO micro- and nano-crystals via crystal growth have been studied in order to obtain superior optical properties and tiny cavity characteristics [5-11]. We also have fabricated the GaN-based WGM resonators using rf-MBE, and so far achieved the formation of the high-quality GaN hexagonal microdisks on m-plane GaN substrates as shown in Fig. 2 [12].

In this study, we found that there were GaN microdisks showing unusual lasing wavelengths around 390 nm. We discuss the origin of the optical gain of that by investigating the crystal structure.

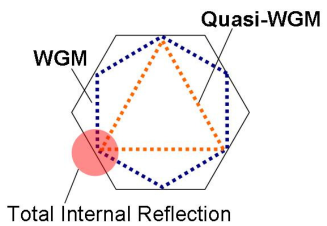

Fig. 1. The schematic diagram of resonant systems in the hexagonal configuration

2. Experiment and Result

We fabricated the GaN hexagonal microdisks by means of crystal growth with rf-MBE on Ti thin films deposited m-plane GaN substrates. Prior to the growth, the Ti thin film surface was nitrided under the active nitrogen-beam irradiation at approximately 400 °C for 10 min. First, GaN nanocolumns were grown on that at 890 °C, where small pits in the Ti film functioned as the crystal nucleation sites. Subsequently, the substrate temperature was gradually decreased from 890 to 850 °C in 1.5 h and, then maintained at 850 °C for 1.5 h. During the growth at 850 °C, the lateral growth of GaN was enhanced, which produced the GaN hexagonal microdisks. The microdisks with a diameter of several micrometers were formed on the tops of the GaN nanocolumns of approximately 300 nm in diameter. The thickness and side length of GaN hexagonal microdisks were approximately 200 nm and 1-2 μm, respectively (Fig. 2). As the GaN microdisks had a hexagonal top surface, the microdisks considered to be crystallized in the wurtzite structure with the surface towards the c-direction. It should be noted here that the c-plane GaN hexagonal microdisks were grown in nearly parallel to the m-plane GaN substrate. However, the direction of side facets of GaN microdisks randomly aligned. These results indicate that the crystalline direction of GaN microdisks was not related to that of the underling m-plane GaN substrate. The reason is under investigation at present.

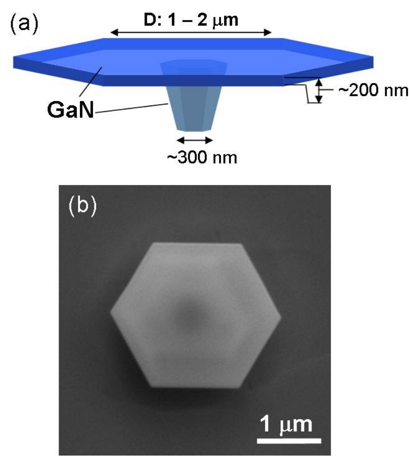

Fig. 2. (a) Schematic diagram of the GaN hexagonal microdisk, and (b) SEM image of the surface of the typical GaN microdisk.

Figure 3 shows the emission spectra of the two GaN microdisks excited by the 355 nm line from a THG Nd:YAG laser with intensities higher than the threshold. We noticed that there are GaN microdisks showing unusual wavelength lasing actions around approximately 390 nm as shown in Fig. 3 (a). Typically, the lasing wavelength was around 370 nm as shown in Fig. 3(b), reflecting the band gap energy of the wurtzite GaN crystal, 3.4 eV. The difference in the lasing wavelength leads us to consider that the other optical gain (not of GaN wurzite crystals) emitting around 390 nm should be existed in the specific GaN microdisk crystals. Then, the cross-sectional TEM observation was performed for the two-kinds of hexagonal microdisks, whose lasing wavelengths were observed around 390 and 370 nm (Fig. 4). As shown in these images, a different-phase thin layer (stacking fault) was observed in the middle place of GaN microdisks showing laser action around 390 nm wavelength (in Fig. 3(a) and 4(a)), whereas no such structure was observed in the GaN microdisk showing laser action around 370 nm wavelength (in Fig. 3(b) and 4(b)). Considering that the band gap energy of cubic GaN is approximately 3.2 eV, we have speculated that cubic phase GaN thin layers were included near the stacking faults in the GaN wurtzite crystals, resulting in the generation of optical gain. In the scheme, the optically generated carriers are accumulated in the cubic-phase GaN layer with the narrower bandgap, providing the optical gain. To support this proposal, however, further investigations should be needed.

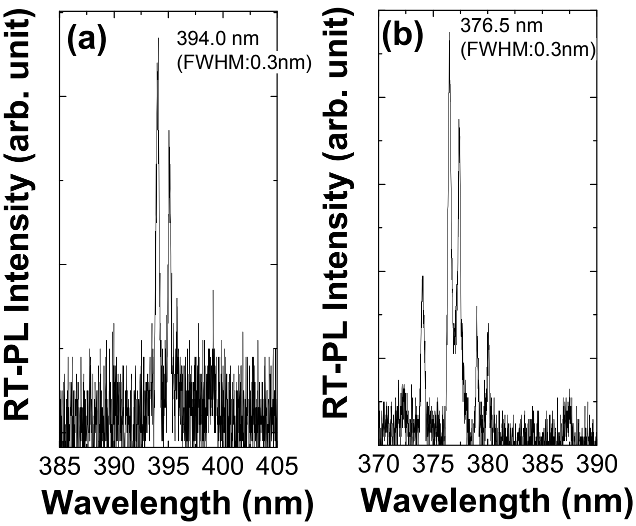

Fig. 3. The optically pumped lasing spectra from GaN microdisks

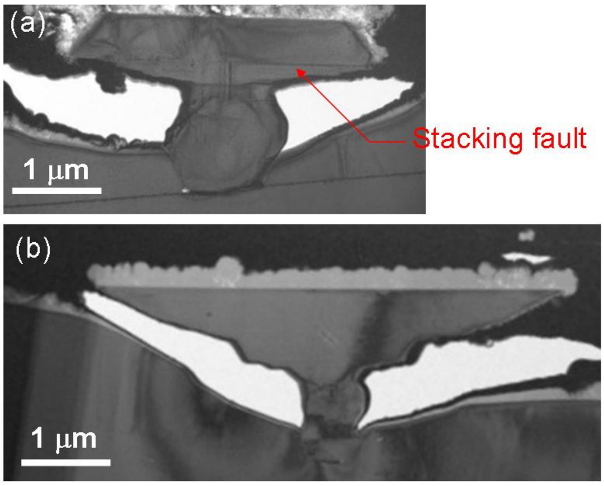

Fig. 4. The TEM images of GaN microdisks; (a) the GaN microdisk showing lasing actions around 390 nm wavelength, and (b) the GaN microdisks showing lasing actions around 370 nm wavelength.

3. Conclusions

We found that the GaN hexagonal microdisks operated in unusual wavelength laser action around 390 nm, and we proposed that the inclusion of cubic-phase thin layer into the GaN hexagonal microdisks resulted in the gain of that by the observation of cross-sectional TEM. With the prospects, it suggested the possibility of the first demonstration of optically pumped laser actions of cubic-phase GaN thin films integrated into hexagonal microdisks. In addition, the existence of two-type hexagonal microdisks will provide the clue as to clarify the growth mechanism, why the peculiar GaN hexagonal microdisks are prepared.

Acknowledgements

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