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Lasing Action in a Micro Optical Cavity with Wurzite/Zinc-Blende GaN Crystal Phase Nano Hetero-Structures

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Abstract: GaN microdisks exhibiting lasing action at unusual wavelength of approximately 390 nm was found, and the origin of the optical gain was revealed by the crystal analysis by TEM measurements. With TEM analyses, wurtzite / zinc-blende GaN crystal phase nano hetero-structures were observed in the microdisks, the thickness of the zinc-blende GaN crystal inclusion was 2-7 ML at the observed area. We considered that these were not the simple stacking faults, but the wurtzite / zinc-blende / wurtzite quantum wells. Thus, the structures worked as an optical gain and resulted in the unusual behavior.

1. Introduction

The crystal phase hetero-structures of semiconductors such as a wurtzite (WZ)/zinc-blende (ZB)/WZ quantum well, are attracting much attention as the new concept of the quantum structures. The structures have great potential to realize bandgap engineering with single material systems, indicating reduction of the cost or process to fabricate quantum devices and realizing quantum wells with low lattice mismatch. In the basic research field, the crystal growth techniques to control the crystal phase systems have been studied with InP nanowires[1)] and InAs nanowires[2)]. For the III-nitrides of GaN, ZB phase inclusions are grown in a WZ crystal as a stacking fault. Using the system of the crystal phase hetero-structure, GaN nanowires with the WZ/ZB/WZ type-II quantum wells of crystal phase hetero-structures were demonstrated, and the peak energy of photoluminescence with different thickness of the ZB inclusion layers were inevstigated[3)]. Theoretical approaches predicted that the excitons bound to the systems with GaN show an higher binding energy than the bulk case despite of the type-II[4)]. According to the reports, the systems only with GaN have potential to realize the LEDs and LDs emitting approximately from 360 nm to 400 nm wavelengths. However, the structures with large area of micro-region and high quality crystallinity to reach lasing actions, have not been demonstrated at room temperature.

In our progress of research, we demonstrated optically pumped lasing actions at unusual wavelength of approximately 390 nm from GaN microdisks as an optical micro-cavity supported by Whispering Gallery Mode (WGM) family[5)]. At the stage, we discussed the optical gain in relation to the ZB GaN inclusion in WZ GaN crystal, but the crystal structures of them did not clearly understood. In this report, we clarified the crystal structures in the GaN microdisk exhibiting unusual lasing action.

2. Experiment and Result

The GaN microdisk with side length of approximately 1.0 μm shown in Fig. 1 (a) SEM image was investigated. The microdisk was fabricated by radio-frequency plasma-assisted molecular beam epitaxy (rf-MBE). The detail of the growth procedure is shown in ref. 6. The room temperature photoluminescence (PL) spectrum of the microdisk is shown in Fig 1 (b). In the PL experiment, the microdisk was excited by a 355-nm-wavelength line from an Nd: YAG laser, whose pulse width and repetition rate was 5 ns and 20 Hz, respectively. The laser was focused on to a spot with approximately 6 μm diameters to excite single microdisk, and the power density was approximately 1 MW/cm^2. The peak wavelength of the lasing peak and full width half maximum for the PL spectrum are 390.7 nm and 0.15 nm, respectively. As we discussed in ref. 5, the top-surface geometry of the microdisk is hexagonal, so we assumed that the microdisk consist of WZ GaN crystal, whose band gap is approximately 3.4 eV. Then, the lasing wavelength was unusual in this case. Here, we considered that the band gap energy of Zinc-blende GaN is approximately 3.2 eV. We have speculated that zinc-blende phase GaN thin layers were included near the stacking faults in the GaN wurtzite crystals, resulting in the generation of optical gain.

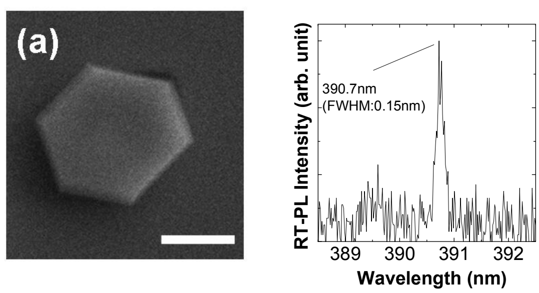

Fig. 1 (a) SEM top view image of the GaN microdisk, the scale bar is 1 μm. (b) The PL spectrum obtained by the microdisk shown in (a).

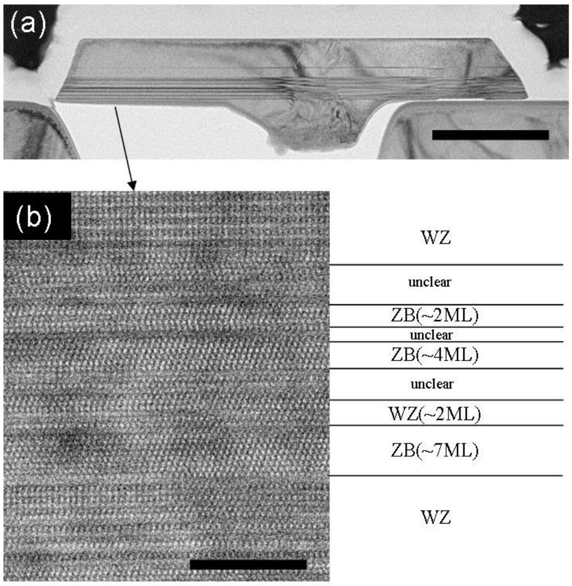

Fig. 2 (a) TEM cross-sectional image of the microdisk shown in Fig. 1(a) with 50,000 magnifications, the scale bar is 500 nm. (b) TEM image at the part of the thinlayers with a different phase structures with 5,000,000 magnifications, the scale bar is 5 nm.

In this study, the TEM measurement was employed to clarify the crystal structure in this microdisk exhibiting unusual lasing behavior. In the TEM image with 50,000 magnifications shown in Fig. 2 (a), the thin layers with a different phase structures are observed in the microdisk. The magnified image at the point is shown in Fig. 2 (b); the TEM image with 5,000,000 magnifications. From the analysis, the different phase crystal nano structures of WZ and ZB crystal were confirmed. At this observation area, WZ/ZB (2 to 7 ML)/WZ crystal phase nano hetero-structures were confirmed. The structure are not the simple stacking faults, but can consist of type-II quantum wells of WZ/ZB/WZ crystal phase nano hetero-structures as discussed in ref. 4. We concluded that the combination of the quantum wells of WZ/ZB/WZ structures worked as an optical gain and the microdisk configuration worked as a WGM family resonator resulted in the unusual lasing action at approximately 390 nm.

3. Conclusions

We revealed the origin of unusual optical gain with the GaN microdisks showing lasing action at approximately 390 nm wavelength. With the TEM measurement, the existence of the WZ/ZB/WZ nano crystal phase hetero-structures were confirmed in the microdisk, and the structures forming type-II quantum wells worked as the origin of the optical gain of unusual wavelength lasing action at approximately 390 nm at room temperature. We conclude that this is the first demonstration of lasing action obtained from the ZB GaN in crystal phase nano hetero-structures with an optical microcavity at room temperature. The demonstration promotes and shows the potential to realize novel bandgap engineering with single material systems for optical devices.

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