Characterization of thin film InGaN/GaN QWs formed by removing a substrate with UV laser irradiation for blue VCSELs

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1. Introduction

GaN-based semiconductor lasers have been attracting much commercial attention and their performances have been dramatically improved [1]. GaN-based vertical cavity surface emitting lasers (VCSELs) are expected to be a key device for use in high-density optical storages, laser printers, full color displays, and illuminations due their potentials of dense two-dimensional arrays and circular beam profile [2]. A few research groups have demonstrated optical pumping of GaN VCSELs, however, room temperature (RT) continuous wave (CW) oscillation has not been achieved yet [3][4][5]. For further improvements of lasing characteristics, the fabrication process of a micro-cavity should be developed as well as the good crystal quality of GaInN

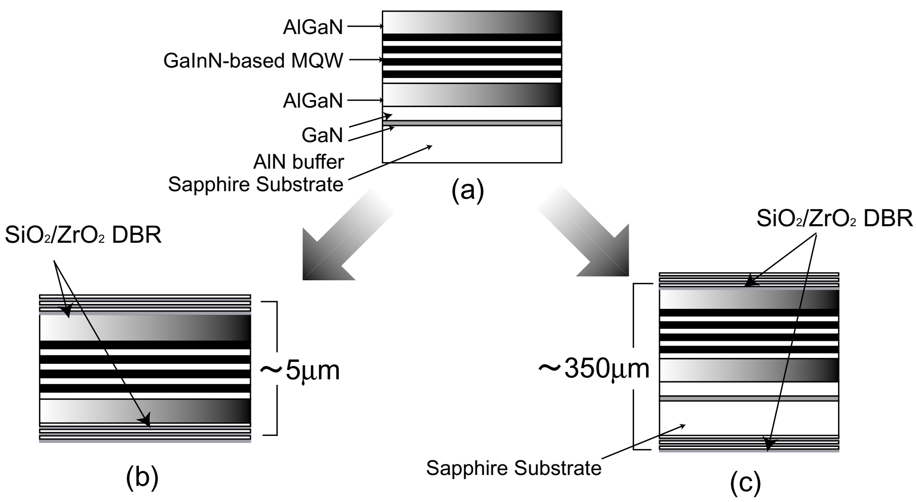

Fig.1 Schematic structure of (a) a wafer before fabricating a cavity structure, a vertical cavity structure (b) without sapphire substrate and (c) with substrate.

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QWs.

We have used a dielectric DBR (SiO_2/ZrO_2) for fabricating a GaN-based vertical cavity structure. Dielectric DBRs may have advantages in comparison with semiconductor DBRs because of their high reflectivity with small number of pairs. The schematics of two-types vertical cavity structure with and without a substrate are shown in Fig.1. The cavity without a substrate shown in Fig.1b is much shorter (approximately 70 times shorter) than that with a substrate shown in Fig.1c, since the thickness of the sapphire substrate (350μm) is dominant in the cavity length. A micro-cavity is effective to reduce diffraction loss, resulting in improvements of lasing performances of blue VCSELs. We have fabricated the GaN-based micro-cavity structure shown in Fig.1b with removing a sapphire substrate from epitaxial layers.

In this report, we have attempted to form thin film InGaN/GaN QWs separated from a sapphire substrate for fabricating a micro-cavity structure and characterized the optical property of separated QWs by photo luminescent (PL) measurements.

2. Growth of GaN-based QWs

GaN-based heterostructure has been grown by metal organic vapor phase epitaxy (MOVPE) on a (0001) sapphire substrate at atmospheric pressure. Following the growth of AlN buffer layer, 5 mm thick GaN layer has been grown. The QWs consist of the 10 pair InGaN/GaN layers emitting at λ=406 nm. The total thickness of grown layers containing the InGaN/GaN QWs is 6μm.

3. Substrates separation process by irradiating UV light

Removing substrates by etching and polishing is difficult, since the sapphire substrate is quite stable chemically and physically. We have focused on the laser-induced thermal decomposition of GaN crystal and used this process to separate a sapphire substrate [6].

Utilizing the solder as glue, the epitaxial surface is adhered to a glass substrate to support a thin film structure. THG-YAG laser (355 nm) is irradiated to the sample from the backside of the sapphire substrate and is absorbed in an intermediate GaN layer between QWs and a sapphire substrate as shown in Fig.2. Laser irradiation generates intense local heating and then the intermediate GaN crystal decomposes into Ga and N_2 thermally. The focused spot size is 1mm in diameter and the laser power density is as large as 300 mJ/cm^2 for generating sufficient heat. Laser scanning was carried out to decompose the large area of a GaN layer due to its small spot size. The uniform

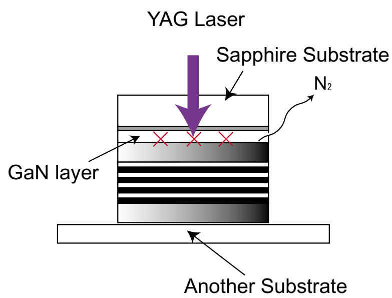

Fig.2 Schematic of GaN thermal decomposition.

scanning resulted in removing the sapphire substrate. In this experiment, the focused spot was moved manually by a micropositioner. We have a plan to introduce the computer-controlled micropositioner to avoide the non-uniformity of the manual movement. By removing Ga at the QWs/sapphire interface by HCl etching, standing-alone crystal layers separated from the sapphire substrate could be obtained.

4. Characterization and Discussion

We have succeeded in removing a sapphire substrate through the process mentioned above. After removing the substrate, we have analyzed the surface roughness of the epitaxial layer side by AFM and the observed image(10μm×10μm) is shown in Fig.3.

The result of cross-sectional profile shows that the surface roughness is ranging from 100 to 700 nm. Since the emission wavelength of GaN-based semiconductor laser is 400 nm, this roughness could largely deteriorate cavity. Smoothing the surface of the intermediate GaN layer after removing substrates could be essential for realizing RT CW oscillation of blue VCSELs.

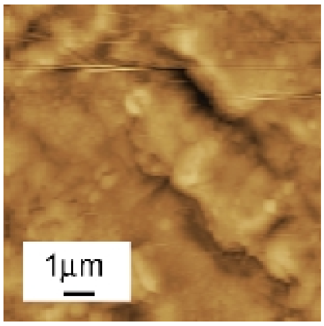

Fig.3 Surface structure of intermediate GaN layer after removing the substrate observed by AFM

The RT PL spectrum of QWs after removing the sapphire substrate is shown in Fig.4. The emission wavelength is 406 nm and narrow FWHM (18 nm) is observed, which is comparable to the value before separating the substrate (17 nm). After removing the sapphire substrate, the PL intensity is reduced to approximately one-third. The surface roughness would scatter the pumping light and the emission from QWs, which could reduce the PL intensity. These results show that the substrate removing process has hardly deteriorated the optical property of QWs and is applicable to fabricate the microcavity structure of GaN-based VCSELs.

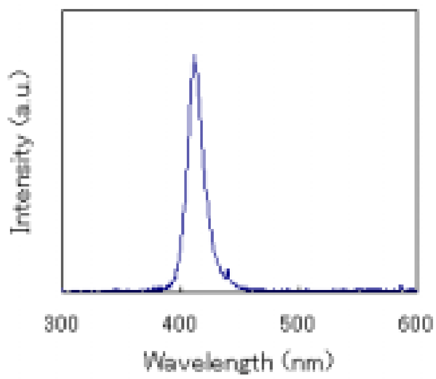

Fig.4 PL spectrum of standing QWs after removing the substrate

5. Conclusion

We have characterized the thin InGaN/GaN QWs fabricated by removing a sapphire substrate with UV light irradiation for making a micro-cavity structure. The PL properties of standing-alone QWs show no noticeable degradation of QWs in the removing process. We pointed out the importance of the flatness of removed interface. The substrate separation technique becomes quite important high quality cavity structures and could lead to room temperature CW operation of optical pumping GaN-based VCSELs.

Acknowledgement

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