Crystal growth of lattice-relaxed high-quality AlGaN templates and fabrication of UV-B laser diodes on these templates

Motoaki Iwaya[1]*, Ryosuke Kondo[1], Ryota Hasegawa[1], Ayumu Yabutani[1], Eri Matsubara[1], Sho Iwayama[1,2], Tetsuya Takeuchi[1], Satoshi Kamiyama[1], Hideto Miyake[2].
*lead presenter: iwaya@meijo-u.ac.jp
[1] Meijo University, Japan
[2] Mie University, Japan

Ultraviolet-B (UV-B: wavelength 280~315 nm) laser diodes are used for various applications in many fields, including high-precision processing, lithography, medicine, and biotechnology. One of the materials suitable for realizing such devices is AlGaN, a direct-transition semiconductor that provides large optical gain with interband transitions covering the entire UV-B region. The AlN molar fraction in the AlGaN active layer of the UV-B laser diodes should be 0.30-0.45, which means that there is a large lattice mismatch of ~1% with AlN and GaN where high-quality substrates and templates are present. Therefore, the realization of high-quality lattice-relaxed AlGaN is desired. In this report, we discuss the results of our investigation of the fabrication method of such high-quality lattice-relaxed AlGaN. In addition, we also introduce the characteristics of the UV-B laser diode fabricated on the AlGaN.

$Al_{0.68}Ga_{0.32}N$ crystal was grown on a sputtered AlN templates annealed at high temperature on a sapphire substrate. 1-μm period and 1-μm height AlN nanopillars were formed in a triangular lattice by etching AlN using the inductively coupled plasma etching method after forming a mask by the nanoimprint method. $Al_{0.68}Ga_{0.32}N$ crystals were grown on these AlN nanopillars by metalorganic vapor phase epitaxy, and as shown in the cross-sectional transmission electron microscopic (TEM) image in Fig. 1, AlGaN crystals were grown with voids formed at the AlN nanopillar interface. Characterization of this $Al_{0.68}Ga_{0.32}N$ by X-ray diffraction reciprocal lattice space mapping confirmed that the $Al_{0.68}Ga_{0.32}N$ was almost completely lattice relaxed. Furthermore, the dislocation density was estimated to be 3×10^8 cm^{-2}, which is a fairly high quality $Al_{0.68}Ga_{0.32}N$. The dislocation density of AlGaN fabricated on general AlN is over 10^9 cm^{-2}, indicating that the dislocation density was reduced by roughly one order of magnitude. Furthermore, a UV-B laser diode structure was stacked on this AlGaN template to fabricate a laser diode. The fabricated device was confirmed to oscillate at a wavelength of 300 nm under room temperature pulse driving. The peak optical output power was up to 150 mW, and the external differential quantum efficiency was approximately 8.6%. These results indicate that AlGaN crystals grown in this method are extremely useful for high-performance UV-B laser diodes.

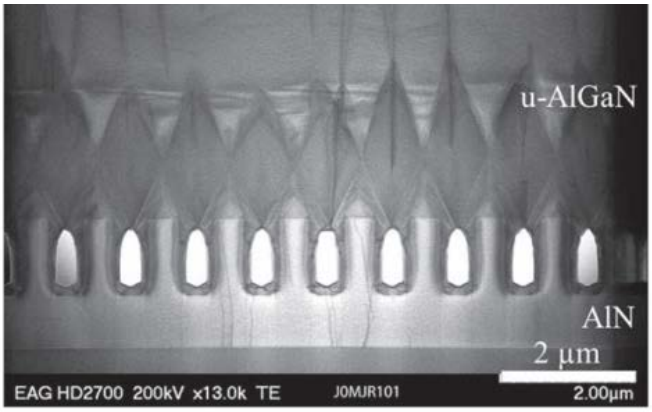

Fig. 1 Cross sectional TEM image of AlGaN on AlN nanopillars

Acknowledgments:
This study was partially supported by the MEXT Private University Research Branding Project (2016–2020), JSPS KAKENHI (22H00304), JST CREST (JPMJCR16N2), NEDO Feasibility Study Program, and JST A-step Project (JPMJTR201D).