# 論文 / 著書情報
# Article / Book Information

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| 題目(和文) | 室温でのレーザープロセスを用いたワイドバンドギャップM2O3(M=Al, Ga)薄膜のエピタキシャル成長に関する研究 |
| Title(English) | Study on Epitaxial Growth of Wide-Band-Gap M2O3 (M=Al, Ga) Thin Films by Room-Temperature Laser Processing |
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# 論 文 要 旨

THESIS SUMMARY


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| 専攻：<br>Department of | 物質科学創造 専攻 | 申請学位（専攻分野）：<br>Academic Degree Requested | 博士<br>Doctor of （ 工学 ） |
| 学生氏名：<br>Student's Name | 塩尻 大士 | 指導教員（主）：<br>Academic Advisor(main) | 吉本 護 教授 |
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）


In this study, room-temperature (RT) fabrication methods of wide band gap oxide epitaxial thin films using laser processing and the epitaxy mechanisms were investigated. In particular, RT fabrication of $\beta$-$Ga_2O_3$ and $\alpha$-$Al_2O_3$ thin films on sapphire substrates was examined. The purpose of this study was to provide the RT fabrication method of the ultra-smooth wide-bandgap oxide epitaxial thin films applicable in a wide range. In addition, providing of the new knowledge of the low-temperature (LT) fabrication process of epitaxial thin films was the aim of this study. This thesis consists of seven chapters including general introduction and general conclusions.

In general introduction (Chapter 1), the background and purpose of this thesis are described. The importance and variety of wide band gap and oxide materials in future device applications were mentioned. The advantages of laser processing and RT epitaxy were also described.

In Chapter 2, the fundamental thin film fabrication and analysis techniques are introduced. RT epitaxial growth of wide-bandgap oxide thin films is explained in the subsequent chapters.

In Chapter 3, effects of buffer layer on epitaxial growth temperature of $\beta$-$Ga_2O_3$ thin films was studied using PLD process. As a results, LT epitaxial growth of $\beta$-$Ga_2O_3$ $(\bar{2}01)$ thin films were achieved on the NiO (111)-buffered $\alpha$-$Al_2O_3$ (0001) substrates at 300ºC. The LT epitaxial $\beta$-$Ga_2O_3$ thin films exhibited a high flat surface compared with the high temperature grown thin films directly grown on the $\alpha$-$Al_2O_3$ (0001) substrates. The transmittance and optical band gap value of the LT epitaxial $\beta$-$Ga_2O_3$ thin films grown at 300–400ºC were similar to that of $\beta$-$Ga_2O_3$ thin films directly deposited on the substrates at 600–700ºC. However, RT epitaxy of $\beta$-$Ga_2O_3$ thin films was not achieved by this conventional PLD process.

In Chapter 4, a method for RT fabrication of the $\beta$-$Ga_2O_3$ crystal thin films by KrF excimer laser annealing (ELA) of amorphous $Ga_2O_3$ thin films was studied. As a results, the amorphous $Ga_2O_3$ thin films were uniaxial oriented grown on the $\alpha$-$Al_2O_3$ (0001) substrates by ELA using KrF laser irradiation at the fluence of 100–250 mJ/$cm^2$ in air at RT. The laser annealed films had slightly roughened and cracked surfaces compared with the as-grown films. The optical energy gap estimated from the transmittance values of the amorphous $Ga_2O_3$ film before ELA was 4.4 eV; this increased to

4.7–4.9 eV for the laser irradiated films. However, RT epitaxy of $\beta$-$Ga_2O_3$ thin films was not achieved using this ELA process.

In Chapter 5, the epitaxial crystallization of $\beta$-$Ga_2O_3$ thin films on NiO-buffered $\alpha$-$Al_2O_3$ substrates was achieved by combining RT-PLD and subsequent RT-ELA. As a results, epitaxial $\beta$-$Ga_2O_3$ $(\bar{2}01)$ films were fabricated through excimer-laser annealing crystallization of the amorphous $Ga_2O_3$ thin film deposited onto epitaxial NiO (111)-buffered $\alpha$-$Al_2O_3$ (0001) substrates. The laser-annealed epitaxial $\beta$-$Ga_2O_3$ thin film had ultra-flat surface with the root mean square roughness of 0.19 nm. The transmittance value of the laser-annealed epitaxial $\beta$-$Ga_2O_3$ thin films (~70 nm) were >90% in the region from 300 to 800 nm. The optical energy gap of the $\beta$-$Ga_2O_3$ thin films was estimated to be 4.9 eV. In the CL spectra of the epitaxial $\beta$-$Ga_2O_3$ thin films, broad UV–green emission was observed. Notably, the optical and luminescence properties of the laser-annealed epitaxial $\beta$-$Ga_2O_3$ thin films were similar to those of single-crystalline $\beta$-$Ga_2O_3$.

In Chapter 6, the RT-PLD homoepitaxial growth of $\alpha$-$Al_2O_3$ thin films by atomically controlling components of substrate surface morphology such as atomic step density was investigated. As a results, homoepitaxial $\alpha$-$Al_2O_3$ thin films were obtained at RT on densely stepped $\alpha$-$Al_2O_3$ $(01\bar{1}2)$ substrates with 0.35-nm-high atomic steps and approximately 20-nm wide terraces. The obtained film surface was atomically stepped similar to the $\alpha$-$Al_2O_3$ substrate before deposition. In contrast, amorphous $Al_2O_3$ thin films were obtained on the stepped $\alpha$-$Al_2O_3$ $(01\bar{1}2)$ substrates with a wider terrace width of approximately 100 nm. The epitaxial $\alpha$-$Al_2O_3$ thin film had ultra-flat surface with the root mean square roughness of 0.10 nm. These results suggest a correlation between the RT homoepitaxial growth behavior of $Al_2O_3$ thin films and atomic step density of the $\alpha$-$Al_2O_3$ substrates.

Through these chapters, RT epitaxy method of $\beta$-$Ga_2O_3$ and $\alpha$-$Al_2O_3$ thin films with ultra-smooth surface was developed. As a consequence, in this thesis, the buffer layer enhanced ELA epitaxy process and the PLD method using densely stepped substrate was found to enable the RT epitaxy of wide bandgap oxide thin films. RT fabrication methods in this study are expected to be applicable in a wide range for the development of the crystal engineering of wide band gap oxide thin films. It was also revealed that the atomically stepped structure of substrate would be an extremely important factor of epitaxy as well as the growth temperature, precursor energy, lattice mismatch, surface atom, and others. Therefore, these epitaxy process are expected to open the door for the fabrication of next-generation electronic devices in the near future.