論文 / 著書情報
Article / Book Information

題目(和文)	原子ステップサファイアc面基板由来のNiO系回折格子ナノ構造に関する研究
Title(English)	Study on NiO-Based Grating Nanostructure Derived from Atomically Stepped Sapphire (0001) Substrate
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（博士課程）
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論 文 要 旨

THESIS SUMMARY

専攻： Department of	物質科学創造　　専攻	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of　（　工学　）
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

NiO has multifunctional properties, and can be used for UV detectors, electrochromic devices, organic solar cells, and UV-light emitting diodes as examples. Effectively controlling the size, morphology, and structure of NiO nanomaterials is imperative for applications involving the morphology-dependent properties. Hence, the development of NiO nanostructured materials is stimulating worldwide interests. According to previous works in my laboratory, periodic straight nanogroove arrays were formed on room-temperature pulsed laser deposited NiO(111) epitaxial thin films grown on atomically stepped sapphire (0001) substrates by annealing in air. To my knowledge, there are no other self-organizing formation methods of NiO periodic straight nanostructures that have potential applications for UV plasmonics and UV photonics, but the formation mechanism was unknown. Understanding the formation mechanism could conduce to the nanogroove size control for the industrial applications. Therefore, the influence of various conditions on the NiO periodic straight nanogroove array formation derived from the atomically stepped sapphire (0001) substrate was investigated. Firstly, the nanogroove array was formed via rapid thermal annealing (RTA) to optimize the formation time and to effectively fabricate the sample. The array formation took approximately 60 s at 973 K. The nanogroove formation process time reduced to 1/100 of the previous research. Secondly, it was confirmed that adjusting the annealing temperature, the NiO film thickness, and the O_2 deposition pressure was important to form the nanogroove array. Thirdly, the influence of the sapphire substrate terrace width on the array formation was investigated. The nanogroove periodicity corresponded well with the used substrate terrace width of the 0.22-nm-high stepped sapphire (0001) substrate. It was of great interest that the two types of 180°-rotated triangular crystalline domain were alternately grown on each film terrace divided by the nanogrooves. In addition, the two types of triangle crystals were not mixed on one film terrace. The origin of the morphology was considered in a new concept layer matching epitaxy (LME) model, in which the misfit between thin film and substrate is postulated by the difference of the in-plane atomic geometry in each topmost surface layer. The LME model was substantiated by the transmission electron microscopy results, in which the NiO crystal grains were uniepitaxially grown on each terrace of the 0.22-nm-high stepped sapphire (0001) substrate to match the alternately mirror-symmetrical oxygen sublattices between the adjoined terraces, resulting in the formation of plane defects at the twin domain boundaries of the NiO thin film near the atomic steps. These twin boundaries would hamper the coalescence of the film terraces when restructuring via RTA. It was also confirmed by systematically increasing the annealing temperature that the straight nanogroove array could not be formed on the sapphire $(11\bar{2}0)$ substrate. These results led to the fabrication of 0.43-nm-high stepped sapphire (0001) substrates. NiO thin films were uniepitaxially grown on the 0.43-nm-high stepped sapphire (0001) substrates instead of biepitaxial growth, which further supported the LME model. Considering the nanogroove formation mechanism based on the LME model, it was suggested that the diffusibility of the plane defects was important to deepen the nanogrooves. Therefore, the nanogroove arrays were fabricated via RTA of $Li_xNi_{1-x}O$ ($x < 0.6$) thin films deposited on 0.22-nm-high stepped sapphire (0001) substrates. After RTA at 1373 K for 60 s, the depth of the nanogroove array was 5 times greater than it was when annealing the nondoped NiO film. Consequently, the rainbow-colored interference appeared on the entire film surface. The reflective angular profiles dependent on wavelength and incident angle of visible light corresponded well to the calculated results by the grating equation. The grating efficiency was influenced by the grating depth and grating linearity. Finally, the crucial results obtained through the study have been concluded as follows. The RTA method is a useful tool to optimize the postannealing condition of thin films, such as programming rate and annealing temperature because the heating and cooling rates are 100 times faster than a conventional furnace annealing method, leading to the fast production. Furthermore, the rapid heating and cooling rates enable to freeze the transient states in the nanogroove formation. The freezing techniques of transient states could be used in areas of crystal growth of various materials. The LME model has the potential to improve the consideration of the lattice mismatch between thin films and substrates even in other materials. There is possibility to manipulate the self-organizing formation of periodic straight nanogroove arrays derived from the 0.22-nm-high stepped sapphire (0001) substrates using other cubic thin film materials. Understanding the formation mechanism conduced to the nanogroove size control, and the nanogroove arrays were functionalized by deepening the grooves as grating nanostructures.