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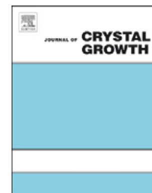

Improvement of *M*-plane GaN thin film grown on pre-annealing β-$LiGaO_2$ (100) substrate

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ABSTRACT

In this paper, we report the growth of *M*-plane GaN thin films on $LiGaO_2$ (100) substrates pre-annealed in vacuum and in air ambient. The surface of *M*-plane GaN film grown on the $LiGaO_2$ (100) substrate pre-annealed in air ambient was significantly improved. X-ray diffraction data showed that the *M*-plane GaN thin film grown on the $LiGaO_2$ (100) substrate pre-annealed in air ambient has better crystal quality than that grown on the $LiGaO_2$ (100) substrate pre-annealed in vacuum. In addition, the strain generated between GaN thin film and $LiGaO_2$ substrate was relaxed when the GaN thin film grew on the $LiGaO_2$ substrate pre-annealed in air ambient. It revealed that the thermal annealing $LiGaO_2$ substrate in air ambient can suppress the formation of lithium-rich surface effectively, and then one can grow a high quality *M*-plane GaN thin film on the $LiGaO_2$ substrate.

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1. Introduction

III-nitrides are prominent compound semiconductors because their band-gap can be tuned by changing the III-group alloy ratio. Recently, some researchers reported that the efficiency of GaN-based device is limited due to the quantum-confined Stark effect (QCSE) [1]. This effect is inevitable as long as the strained quantum wells (QWs) structure is built on the polar orientation of GaN. The strong electrostatic field tilts the band structure of AlGaN/GaN QW, resulting in the quenching of photoluminescence due to the spatial separation of electron–hole pairs. Consequently, the luminous quantum efficiency of the optoelectronic devices made of *c*-plane GaN is reduced. One of the solutions is the employment of nonpolar orientation of GaN substrate such as {11–20} (*a*-plane) and {1–100} (*M*-plane). Although using non-polar orientation GaN can avoid QCSE, the performance of non-polar nitride device is still lower than that of *c*-plane nitride device due to the poor crystal quality of the nonpolar GaN [2].

β-lithium gallate (β-$LiGaO_2$, LGO) has an orthorhombic crystal structure (a=5.402 Å, b=6.372 Å, and c=5.007 Å) and can be described as a wurtzite-like structure [3]. The *M*-plane basis of GaN wurtzite structure (a=3.189 Å and c=5.185 Å) is nearly matched to the selected lattice axis of pseudo-hexagonal $LiGaO_2$; for instance, $2a_{GaN} \approx b_{LGO}$ and $c_{GaN} \approx c_{LGO}$. In spite of a small lattice mismatch between *M*-plane GaN and LGO, a large strain in *M*-plane GaN thin film was observed by X-ray diffraction measurement [4,5] and the strain lead to the peeling of the GaN film off the LGO substrate after the growth of GaN thin film. So far, the interpretation of the peeling of GaN thin film off the LGO substrate was attributed to the anisotropic thermal expansion of GaN and LGO [4]. However, it cannot interpret completely the peeling off phenomenon. A possible reason leading to a large strain in the *M*-plane GaN thin film could arise from the lattice mismatch between GaN and LGO due to a wrong surface treatment on the basal plane of the LGO substrate. Prior to the study of the growth of *M*-plane GaN on LGO (100) substrate, we found that thermal annealing is a key factor for the epi-growth of *M*-plane GaN thin film on LGO. Without the thermal annealing process, the *M*-plane GaN cannot be grown on LGO (100) substrate epitaxially. Schuber et al. also reported the same result [4]. However, Doolittle et al. found that a second phase (i.e. Li_5GaO_4) was introduced on the LGO substrate when annealing in vacuum ambient, while pre-annealing lead to form a lithium-rich surface [6]. The lithium-rich surface of the annealed LGO substrate results in a deteriorating impact to change the lattice parameters of LGO and enhances the lattice mismatch between *M*-plane GaN and LGO.

In this paper, the growth of *M*-plane GaN on pre-annealed $LiGaO_2$ substrate by plasma-assisted molecular beam epitaxy (MBE) has been studied. The LGO substrates were annealed in vacuum and in air ambient. From the analysis of structure characterization, we not only found that the crystal quality of *M*-plane GaN was improved but also the strain between GaN and LGO was reduced using the LGO substrate pre-annealed in air ambient.

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2. Experiment

The $1 \times 1\ cm^2$ β-$LiGaO_2$ (100) square wafers were cut from the crystal ingots which were fabricated by the traditional Czochralski pulling technique. The $LiGaO_2$ substrates were polished by SiC powders to approach the desiring thickness. Al_2O_3 powder solution and colloidal silica (SiO_2) suspension were used to eliminate scratches resulting from the polishing by SiC. After the polishing, the $LiGaO_2$ substrates were soaked in phosphoric acid solution at room temperature for less than 1 min, and rinsed with acetone. Finally, the $LiGaO_2$ substrates were washed by deionized water. Detailed description for the polishing method was reported in the previous work [7]. Prior to thermal annealing, all LGO substrates were etched by H_3PO_4 solution (H_3PO_4:H_2O = 1:40). In the annealing process of LGO substrate, we set two annealing ambients, i.e. in vacuum (denoted as sample A) and in air (denoted as sample B). For annealing in air, the LGO substrate was annealed by an electric furnace at 1050 °C for 2 h. The LGO substrate was fully covered (face-to-face) by another LGO substrate in order to prevent the evaporation of Li and contamination from the furnace. For annealing in

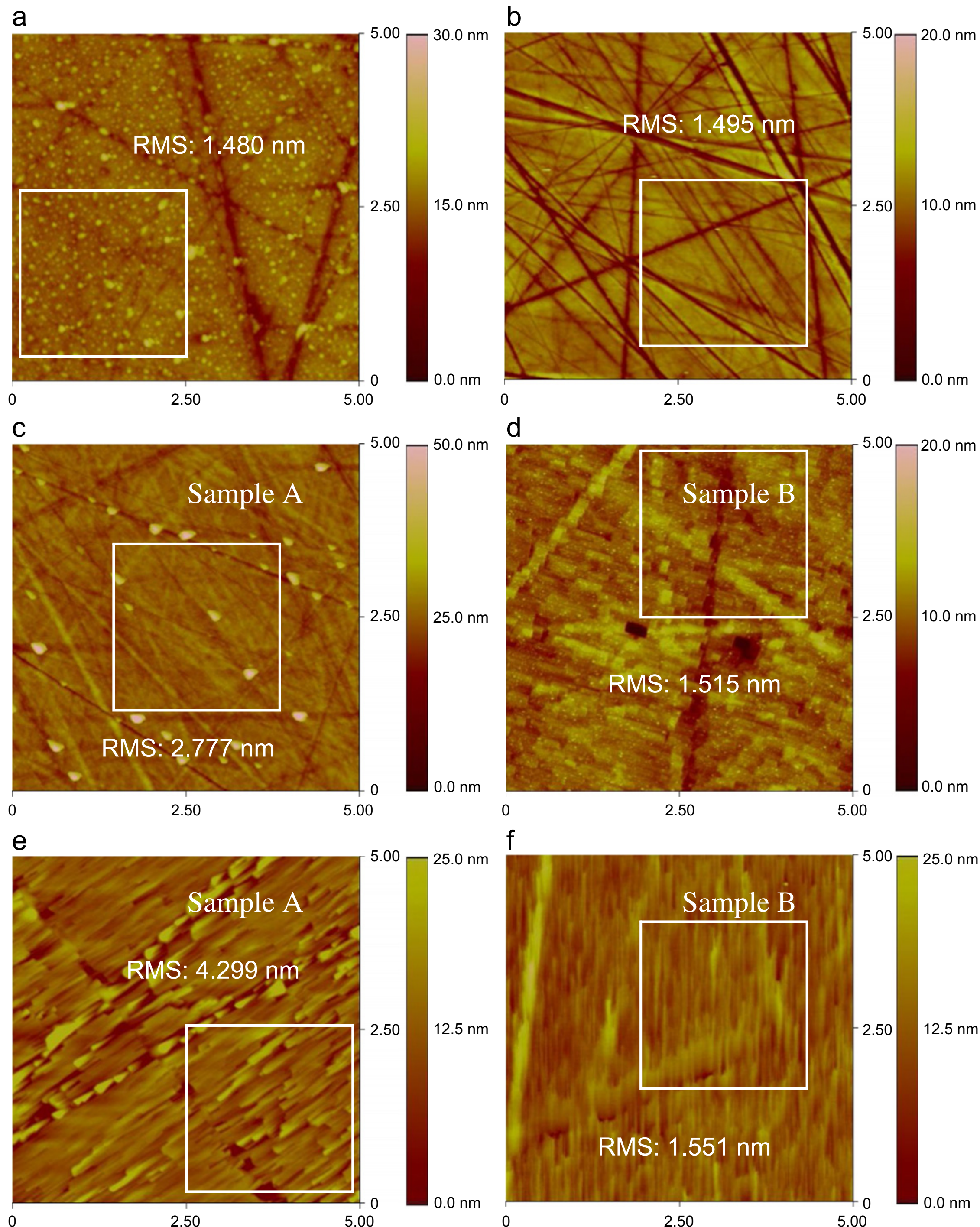

Fig. 1. AFM images of LGO substrates and growing samples surface by 5 μm × 5 μm scan: (a) as-received LGO substrate, (b) H_3PO_4 solution etched LGO substrate, (c) LGO after annealing in vacuum (sample A), (d) LGO after annealing in air (sample B), (e) as-grown GaN on sample A, and (f) as-grown GaN on sample B. Squares indicate the executed area of RMS analysis.

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