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Full Length Article

InGaN nanocolumn growth self-induced by in-situ annealing and ion irradiation during growth process with molecular beam epitaxy method

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ABSTRACT

Incubation and shape transition are considered as two essential processes for nucleating of self-assembly InGaN nanocolumns (NCs) in traditional way. We propose a new approach for nuclei forming directly by in-situ annealing and ion irradiating the InGaN template during growing process. The nanoislands, considered as the nuclei of NCs, were formed by a combinational effect of thermal and ion etching (TIE), which made the gaps of the V-pits deeper and wider. On account of the decomposition of InGaN during TIE process, more nitride-rich amorphous alloys would intent to accumulate in the corroded V-pits. The amorphous alloys played a key role to promote the following growth from 2D regime into Volmer-Weber growth regime so that the NC morphology took place, rather than a compact film. As growth continued, the subsequently epitaxial InGaN alloys on the annealed NC nuclei were suffered in biaxial compressive stress for losing part of indium content from the NC nuclei during the TIE process. Strain relaxation, accompanied by thread dislocations, came up and made the lattice planes misoriented, which prevented the NCs from coalescence into a compact film at later period of growing.

1. Introduction

Annealing is a traditional technique in material processing, especially for alloys forging [1,2], which can eliminate the defects and residual stress, reduce the hardness, generate phase transition in steel, and so forth. These applications of annealing have the identical effects on III-nitrides semiconductors. In addition, many research groups, worldwide, made great efforts to investigate the micro-structural changes of GaN [3–7], InGaN [3–5,8–14] and InAlN [3,4,15] induced by break of chemical bonds in annealing process. This makes it more attractive to remove the phase separation in rich indium content alloys according to the method of annealing [14,16,17]. Besides that, for GaN related semiconductors, annealing is usually applied to activate dopants [18] and prepare ohmic contact [19].

Comparing with the huge number of works about the annealing, however, there are only a limited number of investigations about the GaN surface treatments using nitrogen ions at elevated temperature [21–25]. The most famous effect caused by ions on GaN surface was interpreted into the Bradley-Harper (BH) theory [26]: if the incident ion beam, at low glancing angle, did not react chemically with the solid, the ripple would form on surface and it can be considered in general to be results of competition between a curvature-driven roughness, introduced by ion sputtering, and smoothing induced by surface diffusion. Whereafter, the nano-sculpting technique, on this basis of BH theory, was developed to assist the growth by molecular beam epitaxy (MEB), on the aim of eliminating the dislocations [20,21,27,28].

At the same time, GaN nanocolumns (NCs) by MBE gain much attraction for their high aspect ratio about lightening [29] and photodetecting [30]. GaN NCs have advantages to be grown catalyst-free or without substrate pre-patterning. In other words, the self-assembled GaN NCs do not require any noble metal catalyst or expensive semiconductor microfabrication. Furthermore,

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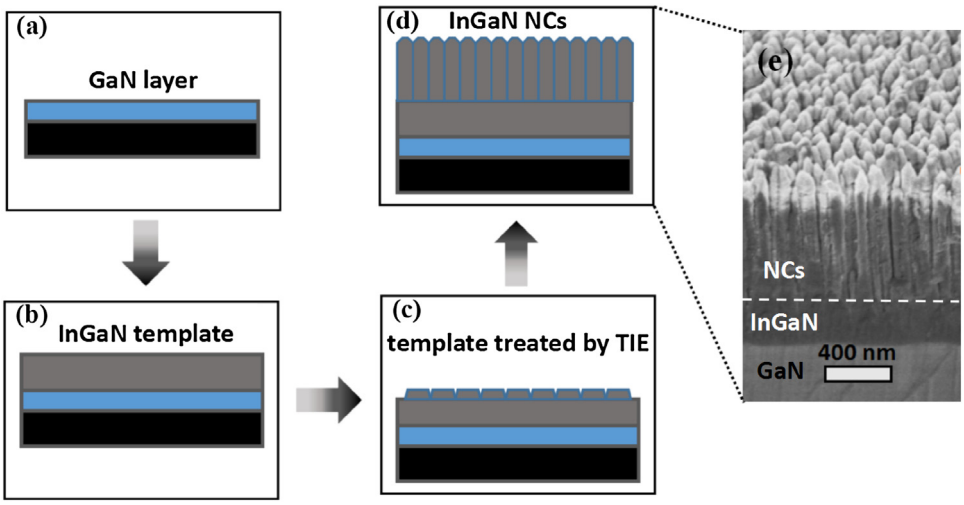

Fig. 1. (a)–(d) Schematic of the MBE growth process of InGaN NCs: (a) GaN epitaxial layer on sapphire which is drawn in color black. (b) InGaN template epitaxy on GaN layer. (c) InGaN nanostructures caused by in-situ TIE treatments on the surface of InGaN template. (d) Schematic diagrams of grown InGaN NCs. Fig. 1 (e) XSEM image of InGaN self-induced NCs with tilt view, which is schematically illustrated in Fig. 1 (d).

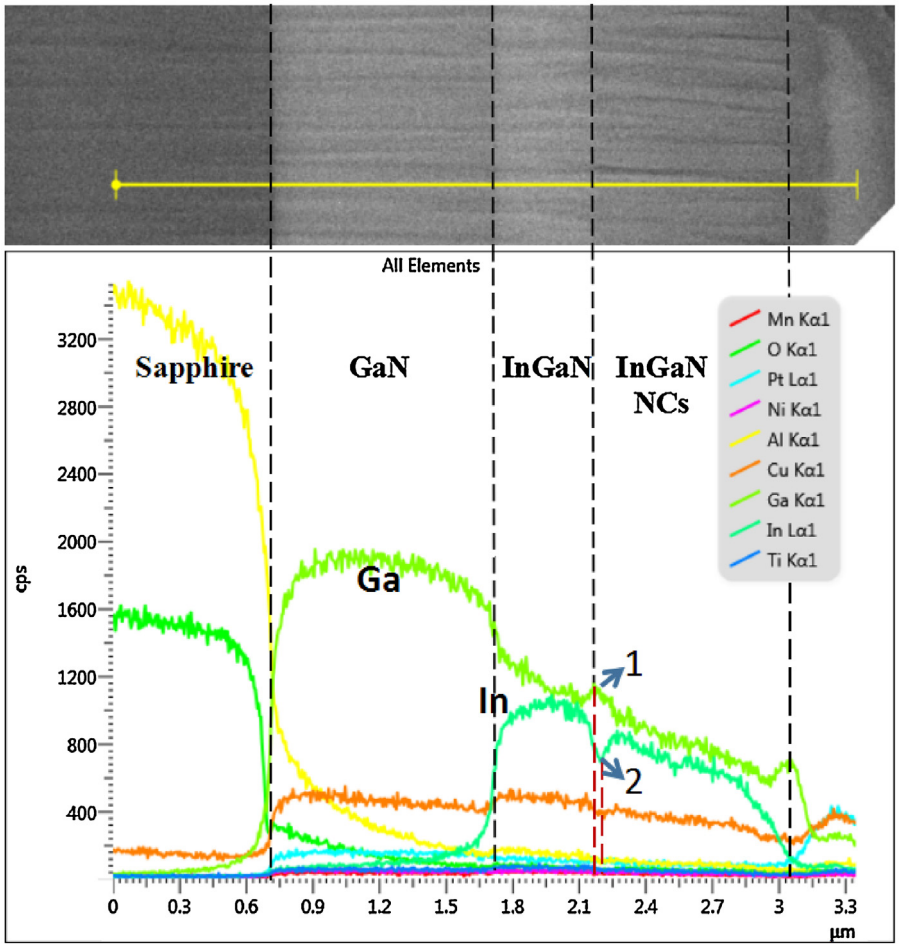

Fig. 2. EDS scanning along the growth direction of [0001]. The yellow straight line marks the scanning range in upper part of image. The lower part illustrates the change of chemical composition within the scanning range. The origins of elements O, Pt, Ni and Ti are the coating film on the surface to protect the sample from ion damage. The others are from the TEM specimen grating. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the self-assembly method is a novel growth mode by MBE and it is valuable for fundamental researches on theory and application. Although the self-assembled NCs were first achieved in 1997 [31], the formation mechanisms of GaN NCs haven't been elucidated clearly until now.

In fact, the self-induced NCs must go through three steps: Forming the NC nuclei, elongating the nuclei and ending up with the