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GaN nanocolumns formed by inductively coupled plasmas etching

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Abstract

GaN nanocolumns were formed by inductively coupled plasma (ICP) etching. It was found that tops of these nanocolumns were hexagonal with the *c*-axis perpendicular to substrate surface. It was also found that density of the GaN nanocolumns depends strongly on etching parameters which suggests that the formation of these GaN nanocolumns was not related to the dislocation density in the original GaN epitaxial layers. Furthermore, it was found that we can reduce the dimension and increase the density of the GaN nanocolumns by decreasing the bias power during ICP etching.

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1. Introduction

GaN is an interesting material with high electron velocity, large breakdown electric field, good mobility, high thermal conductivity and thermal stability. These properties have made GaN a promising material that can be used for various optical and high-speed electronic devices [1–3]. In the past three decades, tremendous efforts have been devoted to the physics, chemistry and synthesis of GaN-related materials. Progress in GaN-based devices has also been achieved at an astonishing speed in recent years. For example, GaN-based light emitting diodes (LEDs), laser diodes (LDs), heterostructure field-effect transistors (HFETs) and ultraviolet (UV) photodetectors

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have all been demonstrated [4–9]. However, these developments were all achieved from planar-type GaN epitaxial layers. In contrast, much less effort was devoted to other morphological forms, such as nanocolumns. One-dimensional structures with nanometer-sized diameters have great potential for field emission display and other applications. They also play an important role in testing and in understanding the fundamental concepts of dimensionality and size in materials.

Recently, various synthetic techniques such as confined chemical reactions [10–17], vapor–liquid–solid (VLS) [18–21] method, and solution–liquid–solid (SLS) method [22,23] have been proposed for the preparation of GaN nanocolumns. However, it is necessary to use either templates or catalysts in all these methods. In other words, GaN nanocolumns cannot be achieved by just a few simple steps using these methods. On the other hand, it has also been reported that GaN nanocolumns can be prepared by catalyst-free approaches, such as vapor solid growth (VS), direct reaction [24,25], oxide- and chloride-assisted methods [26,27], sublimation method [28,29] and hydrid vapor phase epitaxy (HVPE) [30]. However, these methods are the so-called ''bottom-up'' techniques that one needs to build stepwise from atoms or molecules to clusters, and then to nanocolumns.

It is also possible to prepare nanocolumns using the ''top-down'' technique by removing the constituent elements from the original materials. The ''top-down'' technique is straightforward and much easier for the fabrication of vertical well-aligned nanocolumns. For example, one can use optical lithography to prepare nanocolumns with 100 nm diameter [31–33] or use nanolithography to prepare nanocolumns with 30 nm diameter [34]. Very recently, Yoshida et al. reported the fabrication of GaN nanocolumns by simple reactive ion etching (RIE) [35] without the lithography process. They placed GaN samples on top of a quartz (SiO_2) plate and claimed that Cl^+ ions will sputter the quartz plate to form ionized SiO_2 particles on GaN surface. These SiO_2 particles then served as a nanomask during etching. GaN nanocolumns were then formed due to the high etch selectivity between SiO_2 and GaN. On the other hand, Yu et al. reported the fabrication of GaN nanocolumns by inductively coupled plasma (ICP) etching [36]. With a high dislocation density of 10^8–$10^9\,cm^{-2}$ for typical GaN epitaxial layers, they claimed that ICP etching process will easily dissociate these areas and leave behind the rigid crystalline GaN regions. As a result, one can form GaN nanocolumns without the lithography process. In this paper, we report the formation of dimensionally controllable GaN nanocolumns by ICP etching.

2. Experiments

Samples used in this study were all grown on (0 0 0 1) sapphire substrates by metalorganic chemical vapor deposition (MOCVD) [37–39]. Details of the growth can be found elsewhere [40,41]. The structure of the samples consists of a 30-nm-thick GaN nucleation layer grown at 520 °C and a 3-μm-thick undoped GaN layer grown at 1050 °C. After the growth, the samples were ultrasonically cleaned in acetone, methanol and de-ionized water for 10 min in each. These samples were subsequently placed in the center of a quartz plate. We then loaded the quartz plate on the cathode electrode of our ICP system for etching. The etching gas used was a mixture of Ar, Cl_2 and BCl_3. During etching, we kept the ICP power, chamber pressure, BCl_3 flow rate, total gas flow rate and etching time at 200 W, 10 mTorr, 5 sccm, 35 sccm and 3 min, respectively. Two groups of samples were prepared. A HITACHI S-4100 high-resolution scanning electron microscope (HRSEM) was then used to characterize the surface morphologies and diameter distributions of the ICP etched samples. Finally, an atomic force microscope (AFM) was used to characterize structural properties of the ICP etched samples and to determine the density of GaN nanocolumns.

3. Results and discussion

We first prepared samples with bias power of 100 W (i.e. group A). Figs. 1(a)–(c) show top-view