



High-quality GaN nanowires grown on Si and porous silicon by thermal evaporation

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ABSTRACT

Nanowires (NWs) of GaN thin films were prepared on as-grown Si (1 1 1) and porous silicon (PS) substrates using thermal evaporation method. The film growth produced high-quality wurtzite GaN NWs. The size, morphology, and nanostructures of the crystals were investigated through scanning electron microscopy, high-resolution X-ray diffraction and photoluminescence spectroscopy. The NWs grown on porous silicon were thinner, longer and denser compared with those on as-grown Si. The energy band gap of the NWs grown on PS was larger than that of NWs on as-grown Si. This is due to the greater quantum confinement effects of the crystalline structure of the NWs grown on PS.

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1. Introduction

The direct band gap semiconductor GaN (band gap of 3.4 eV) has great potential for use in optoelectronic devices over a wide range of wavelengths for III-nitrides, from the blue to the near ultraviolet wavelength. One-dimensional nanostructures such as NWs and nanorods have excellent electrical, optical, and mechanical properties, as well as great potential for various applications, such as probe microscopy tips and interconnections in nanoelectronics [1].

Processing techniques, especially those for crystal growth of III–V nitride nanostructures, have been successfully established. Plasma etching and reactive ion etching have been mainly used to etch III–V nitride crystals. However, the damage caused by the ion or plasma bombardment is a serious problem in these processes [2–4].

Vapor phase methods have also been used for NW production. These include physical methods such as laser-assisted catalytic growth, carbon-nanotube-confined reaction, catalytic reaction based on a vapor–liquid–solid mechanism and thermal chemical vapor deposition, and direct reaction of metal gallium with ammonia [5–10].

Wu et al. [13] synthesized GaN NWs on Si substrate by ammoniating $\text{Ga}_2\text{O}_3/\text{BN}$ films under a flowing ammonia atmosphere. Their results demonstrate that NWs are hexagonal wurtzite GaN with smooth surfaces. They also discussed the growth mechanism of crystalline GaN NW. Popa et al. [14] demonstrated

controlled nanostructuring of GaN by focused-ion-beam treatment with subsequent photoelectrochemical (PEC) etching. The proposed mask-less approach based on direct writing of surface negative charge, which shields the material against PEC etching, allows the fabrication of GaN nanowalls and NWs with lateral dimensions as small as 100 nm.

Thermal evaporation using a tube furnace and flowing Ar gas is a promising technology for the fabrication of GaN NWs and nanorods. It is inexpensive and can be easily controlled to obtain NWs of desired sizes [11,12]. The objective of the present study was to prepare high-quality single crystal wurtzite GaN NWs on PS on the polished and unpolished sides, and Si (1 1 1) substrate; using thermal evaporation technique, a novel procedure for preparing GaN semiconductors, without using ammonia gas. The porous substrates play important roles in fabricating GaN nanostructures due to the ability of the pore walls to interact with atoms and molecules together with the capacity of controllable pore space to capture or load gas molecules, and solid particles [15–18].

2. Materials and methods

The electrochemical cell was used to fabricate the porous silicon (PS) [19]. N-type Si wafer with a dimension of $1\text{ cm} \times 1\text{ cm} \times 283\text{ }\mu\text{m}$, (1 1 1) orientation, resistivity of $0.75\text{ }\Omega\text{ cm}$, and doping concentration of $1.8 \times 10^{17}\text{ cm}^{-3}$ was etched through an electrochemical process to produce the porous structure. The wafer was placed in an electrolyte solution (hydrofluoric acid (HF): ethanol, 1:4) with a current density of 60 mA/cm^2 at an etching time of 15 min for each side. Before the etching process, the Si substrate was cleaned using the Radio Corporation of America

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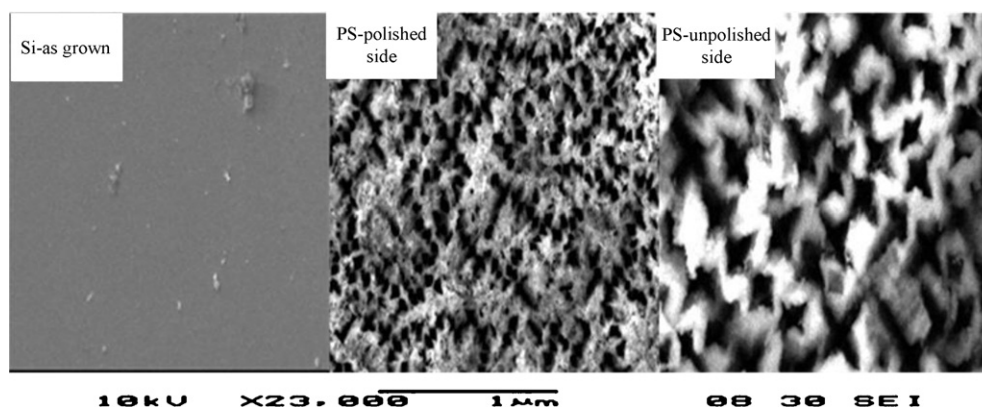


Fig. 1. SEM images of as-grown Si and PS formed on both sides of the crystalline Si wafer.

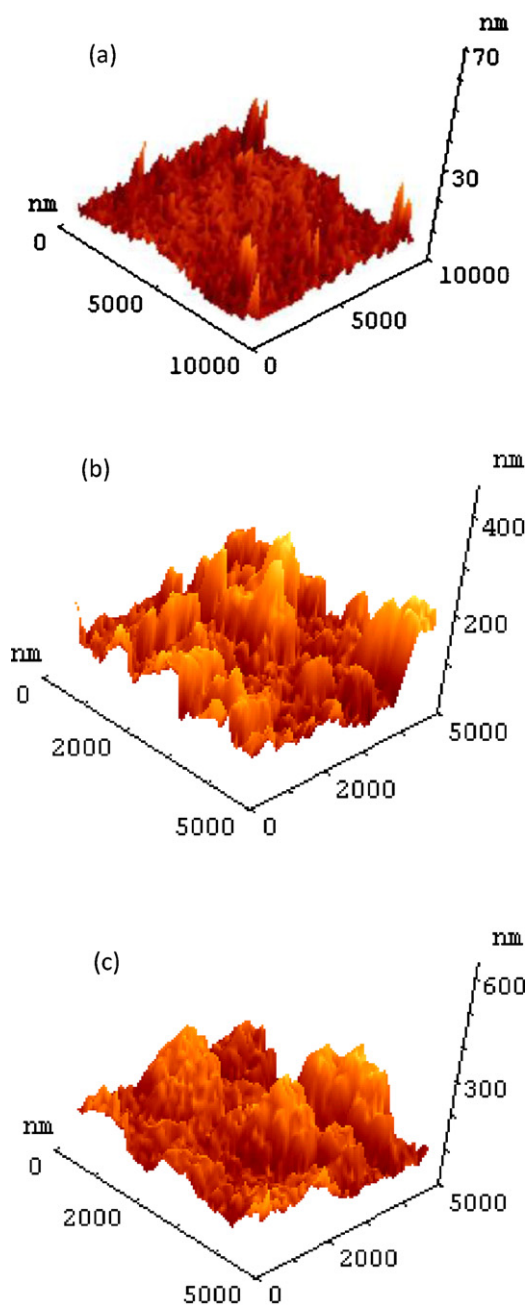


Fig. 2. AFM images of PS: (a) as-grown; (b) polished front side; (c) unpolished back side.

method (RCA) to remove the oxide layer, it was then immersed in HF acid to remove the native oxide. The electrochemical cell was made by Teflon and has a circular aperture with radius of 0.4 cm, and the silicon wafer is sealed below. The cell consists of two-electrode system with the Si wafer as the anode and platinum as the cathode. The process was carried out at room temperature. After etching, all samples were rinsed with ethanol and dried in air.

The GaN NWs were prepared by heating GaN powder of purity 99.999% at $\sim 1000^\circ\text{C}$ for 2 h under an Ar gas stream introduced at $0.5\text{ cm}^3/\text{min}$. Subsequently, they were deposited on as-grown Si and PS substrates placed inside ceramic boats by the thermal evaporation with no template or catalyst used in the synthesis. Prior to heating, the furnace was cleaned using a stream of Ar.

The surface morphology and structural properties of the nanostructures were characterized using scanning electron microscopy (SEM), atomic force microscopy (AFM) and high-resolution X-ray diffraction (HR-XRD). Photoluminescence (PL) was also performed at room temperature using He–Cd laser ($\lambda = 325\text{ nm}$).

3. Results and discussion

The SEM images in Fig. 1 illustrate the smooth surface of as-grown Si and the uniformity of the surface of the PS for the polished and unpolished sides.

The uniformity was due to the isotropic characteristic of HF/ethanol etching and the optimal conditions of the current density and etching time. The isotropic etching resulted in spherical pores. The etched surface formed on the polished side showed pores and small protrusions. Pores on the unpolished side were larger (around 110 nm) than those on the polished side (around 40 nm) due to greater etching of the initial surface with higher surface roughness than polished side. Fig. 2 demonstrates that the three dimensional topographic images of the PS etched surfaces with the pyramidal shape were distributed over the entire surface. The pyramidal shape indicated that the increase in the surface roughness is due to the effect of the etching parameters' effect on the surface characterization.

Fig. 3(a) shows the configuration of NWs formed on Si by extended high-temperature processing inside the furnace. The short and fluffy fibrous NWs with sharp tips are randomly oriented and less dense. The nanostructures formed on polished and unpolished sides of the PS are shown in Fig. 3(b) and (c), respectively. The nanostructures on both sides of the PS had corn-shaped structures. On closer inspection, the corn-shaped structure on the polished side consisted of bundles of long NWs which are dense and well-defined and preferentially oriented in one direction. The corn-shaped structure on the unpolished side had the same characters, however their NWs seem to be bundled closer together, thus creating a smoother image than those on the polished side.

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