Available online at www.sciencedirect.com

SCIENCE DIRECT®

Optical Materials 23 (2003) 147–150

OPTICAL Materials

www.elsevier.com/locate/optmat

Growth and photocurrent property of GaN/anodic alumina/Si

R.L. Jiang *, J.Z. Wang, P. Chen, Z.M. Zhao, Y.F. Mei, J.H. Wu, B. Shen, R. Zhang, S.L. Gu, X.L. Wu, Y.D. Zheng

Department of Physics, Nanjing University, Nanjing 210093, PR China

---

Abstract

Gallium nitride (GaN) epilayers were grown on Si(1 1 1) substrates using nearly polycrystalline α-Al_2O_3 as the buffer layer by low-pressure metal organic-chemical vapor deposition. The buffer was formed by anodic porous alumina annealed at high temperature. The scanning electron microscope measurement showed that the surface of GaN epilayer was smooth. Simple photoconductive detectors were fabricated with these materials. The spectral response of these detectors exhibited a relatively sharp cutoff near the wavelength of 360 nm and a peak at 340 nm with a shoulder near 360 nm. Under 5 V bias, the responsivities at 340 and 360 nm were measured to be 3.3 and 2.4 A/W respectively.

Keywords: GaN; Buffer; Anodic alumina; Photodetector

---

1. Introduction

Gallium nitride (GaN) has been considered to be one of the most promising materials for the fabrication of high-responsivity and visible–blind ultraviolet (UV) detectors due to its direct and wide-bandgap, high saturation electron drift velocity and the excellent physical and chemical properties. GaN UV photodetectors are essential for applications such as atmosphere UV radiation detecting, flame sensors, engine monitoring, and future fiber optical communications. In the recent years, the growth technology of GaN on sapphire (α-Al_2O_3) has become relatively mature. GaN films grown on Si substrates are more attractive for their low cost, large size and the possibility of integrating GaN devices with Si-based electronics techniques. However, there are still difficulties in growing high-quality GaN films on Si substrates due to the large lattice mismatch (17%), thermal mismatch (37%) and difficult nucleation between GaN and Si. So, it is quite important to select and study appropriate buffer layer materials between GaN and Si. Some materials have been used as the buffers, such as SiC, AlN, GaAs, Al_2O_3, ZnO and so forth [1–5]. AlN is a good buffer material, but it is difficult to obtain optimal growth conditions in different growth systems.

In this paper, we report that nearly polycrystalline α-Al_2O_3 was used as the buffer layers between GaN and Si substrates. The nearly polycrystalline α-Al_2O_3 was formed by anodic porous alumina annealed at high temperature. Simple photoconductive detectors were fabricated with these materials. Photocurrent properties of the detectors are described and discussed.

---

[*] Corresponding author. Tel.: +86-25-3593554 (Off.); fax: +86-25-3328130.

E-mail address: rljiang@jlonline.com (R.L. Jiang).

0925-3467/03/$ - see front matter © 2003 Elsevier Science B.V. All rights reserved.
doi:10.1016/S0925-3467(03)00050-8

2. Experimental

The aluminium film was deposited on the high resistivity (1 1 1)-oriented Si substrate using electron-beam evaporation and then anodized in a real-time controlled anodization equipment which is monitored by the anodic *I–t* curve. The controlling process has been published elsewhere [6]. Using a platinum plate as the cathode, the anodization was carried out in 15 wt.% sulfuric acid under a constant dc voltage of 5, 10 and 15 V respectively. Using different voltage can change the aperture size. Experiment proved that the best quality GaN material with anodic alumina as the buffer layer was obtained at the voltage of 10 V. After anodization, the samples were annealed in the rapid thermal process/low-pressure metal organic-chemical vapor deposition (RTP/LP-MOCVD) system [7] under nitrogen protection for 30 min at a temperature of 1000 °C. The X-ray diffraction (XRD) measurement showed that the status of anodic porous alumina were different after annealed at different temperature. When the annealing temperature was lower than 800 °C, the anodic porous alumina was amorphous; when it was increased to 1000 °C, polycrystalline peaks of α-Al_2O_3 appeared. The higher annealing temperature, the more peaks and the higher peak intensity [8] (see Fig. 1). In this experiment, samples were annealed at 1000 °C. The about 350 nm thick porous anodic alumina was obtained after it was annealed. Then GaN layers were grown on the annealed anodic alumina buffer in two steps. At first, about 30 nm thick low-temperature GaN was grown in situ at 500 °C. The temperature was then increased to 950 °C to grow the final GaN epilayers, the thickness of which is 500 nm. The annealed anodic porous alumina and thin low-temperature GaN buffer layers will relax some of the strains between Si and GaN and are helpful to restrain the Si diffusion at high temperature [9].

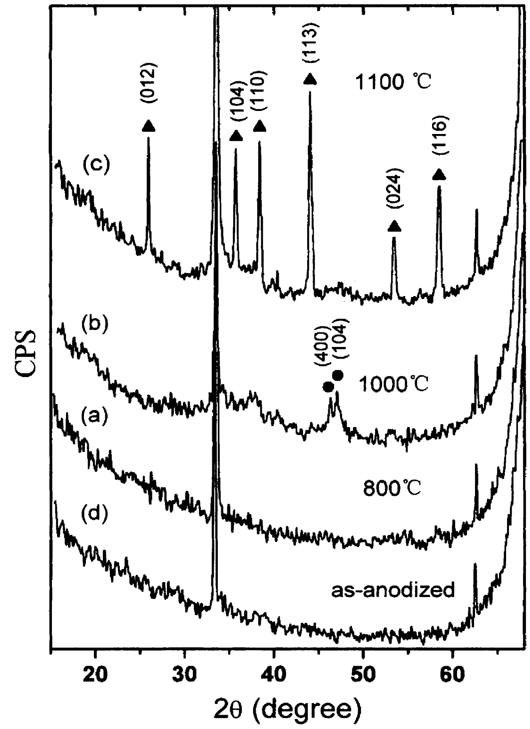

Fig. 1. XRD pattern evolution of anodic alumina on Si substrates as a function of annealing temperature. (This figure is cited from Ref. [8].)

The metal–semiconductor–metal photoconductive detectors were fabricated with the above material. The interdigitated finger electrodes of the detectors were 10 μm wide and 550 μm long with 20 μm-wide spacing. In order to get good ohmic contacts, Ti/Al/Pt/Au were selected to be the electrode metals on the n-type GaN. Their thickness were 30, 100, 40 and 200 nm respectively. The metal electrode was alloyed at the temperature of 650 °C for 10 min under nitrogen protection. The current–voltage properties between two electrodes were measured with a semiconductor parameter analyzer. It showed that they were ohmic contacts. The typical value of the dark resistance between two electrodes was about 3 kΩ.

3. Results and discussion

The above materials were measured. Fig. 2 shows the surface photos, taken by scanning electron microscope (SEM), of anodic alumina on Si before (a) and after (b) annealing. In comparison with (a) the surface of (b) is smoother and the pellets are smaller. Fig. 3 shows the surfaces of GaN on Si with annealed anodic alumina (a) and AlN (b) as their buffer layers, both of which were

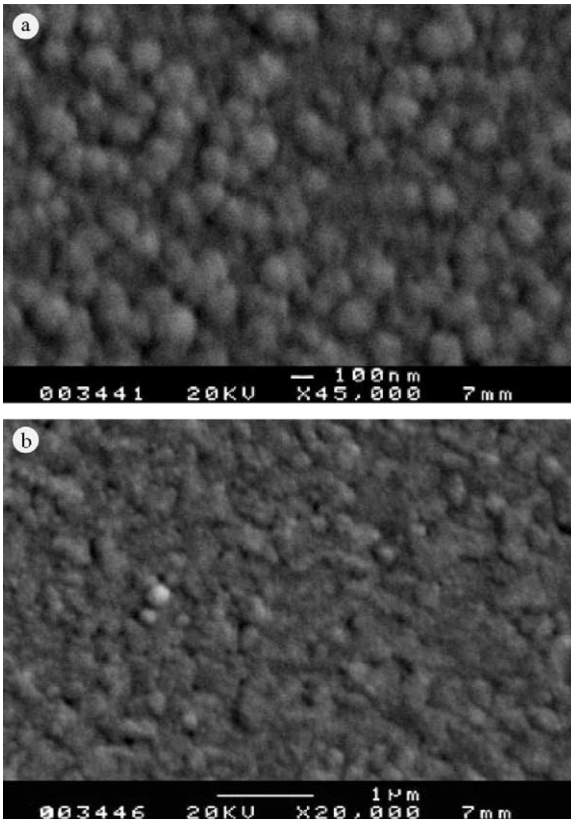

Fig. 2. SEM photographs for the surfaces of anodic alumina buffer layers on Si before (a) and after (b) annealing.

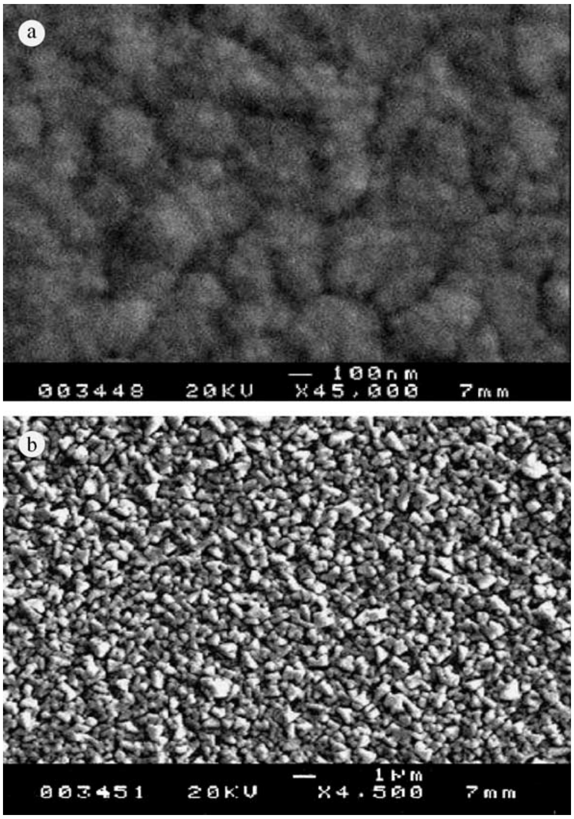

Fig. 3. SEM photographs for the surfaces of GaN grown on Si with annealed anodic alumina buffer layer (a) and AlN buffer layer (b).

grown in the same system. Evidently, the surface of (a) is much smoother than that of (b), indicating that the latter was 3-dimension growth, while the former tended to be quasi-2-dimension growth.

Fig. 4 is the XRD pattern of GaN/anodic alumina/Si. It showed that the GaN was polycrystalline. In addition to crystal (0 0 0 2), (0 0 0 4) peaks of GaN, there are also (1 0 1 0), (1 0 1 1), (1 1 2 0) peaks of polycrystalline GaN. The electrical properties of GaN films were determined by Hall measurements. The unintentionally doped GaN films were n-type. The background carrier concentration was about 3.4×10^{18} cm^{-3}, and the Hall mobility was 43 cm^2/Vs. The detailed description of the materials will be published elsewhere.

The spectral responses of the photodetectors were measured using a system including mainly a

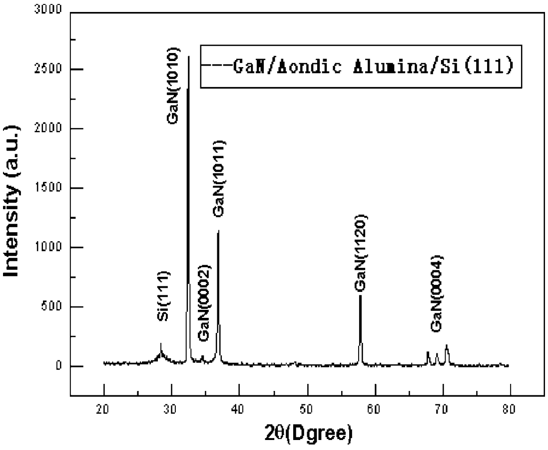

Fig. 4. XRD pattern for GaN on Si with anodic alumina as the buffer layer.

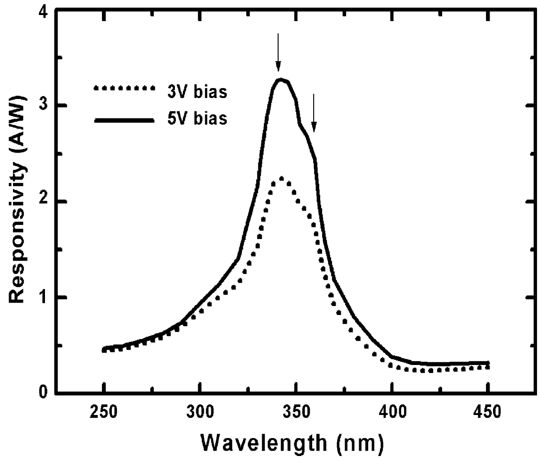

Fig. 5. Spectral response of a GaN/anodic alumina/Si detector under 3 and 5 V bias, respectively.

xenon light source, a monochromator, a lock-in amplifier and a computer controlled data sampling equipment. The samples were illuminated from the front side.

The responsivity as a function of wavelength for a GaN/nearly polycrystalline α-Al_2O_3/Si detector is shown in Fig. 5. It shows a relatively sharp cutoff near the wavelength of 360 nm and a peak at 340 nm with a shoulder near 360 nm. The responsivity increases with bias. Under 5 V bias, the responsivities at 340 and 360 nm were measured to be 3.3 and 2.4 A/W respectively. The responsivity declines between the wavelengths from 340 to 250 nm.

It is known that the maximum responsivity should be near 360 nm if only the GaN layer absorbs the light; while in Fig. 5, the maximal peak responsivity is at 340 nm but not at 360 nm. The reason may be that the insufficiently oxidized aluminum diffused into the GaN layer during the high-temperature growth and formed $Al_xGa_{1-x}N$ the bandgap of which is wider than GaN. The responsivity is weak at the short wavelength of 250–320 nm. The explanation is that the photoinduced carriers are mostly recombined by the surface and at defects that make the photoinduced carriers contribute little to the outer-circuit.

4. Conclusion

Nearly polycrystalline α-Al_2O_3 was obtained after anodic porous alumina on Si(1 1 1) substrates was annealed in high temperature. Using this material and low-temperature GaN thin layer as the buffer layers, GaN epilayers were grown on Si. The surface of GaN layer is smooth, but it is polycrystalline. Prototype photoconductive detectors were fabricated with these materials. The spectral response of these detectors exhibited a relatively sharp cutoff near the wavelength of 360 nm and a peak at 340 nm with a shoulder near 360 nm. Under 5 V bias, the responsivities at 340 and 360 nm were measured to be 3.3 and 2.4 A/W respectively. Results indicate that further investigation is needed to use annealed anodic porous alumina as the buffer layer between GaN and Si. If the annealing temperature is increased, better results may be obtained.

Acknowledgements

The authors would like to acknowledge Nanjing Electronic Devices Institute for the fabrication of aluminum film and the electrodes of photodetectors. This project was supported by Special Funds for Major State Basic Research Program of China no. G20000683, and National Natural Science Foundation of China under grant nos. 69987001, 60276031 and 60136020.

References

[1] T. Takeuchi et al., J. Cryst. Growth 115 (1991) 634.
[2] P. Kung et al., Appl. Phys. Lett. 66 (1995) 2958.
[3] Lianshan Wang et al., Appl. Phys. Lett. 72 (1998) 109.
[4] A. Strittmatter et al., Appl. Phys. Lett. 74 (1999) 1242.
[5] S.A. Nikishin et al., Appl. Phys. Lett. 75 (1999) 2073.
[6] Jian-ping Zou et al., Chin. J. Semicond. 21 (2000) 255 (in Chinese).
[7] B. Shen et al., Appl. Phys. A 68 (1999) 593.
[8] J.H. Wu et al., Appl. Phys. A 72 (2001) 735.
[9] M. Razeghi, A. Rogalski, J. Appl. Phys. 79 (1996) 7433.