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Characterization of GaN epitaxial layers on SiC substrates with $Al_xGa_{1-x}N$ buffer layers

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Abstract

High quality GaN epitaxial layers were obtained with $Al_xGa_{1-x}N$ buffer layers on 6H–SiC substrates. The low-pressure metalorganic chemical vapor deposition (LP-MOCVD) method was used. The 500 Å thick buffer layers of $Al_xGa_{1-x}N$ ($0 \leq x \leq 1$) were deposited on SiC substrates at 1025°C. The FWHM of GaN (0004) X-ray curves are 2–3 arcmin, which vary with the Al content in $Al_xGa_{1-x}N$ buffer layers. An optimum Al content is found to be 0.18. The best GaN epitaxial film has the mobility and carrier concentration about 564 $cm^2\ V^{-1}\ s^{-1}$ and $1.6 \times 10^{17}\ cm^{-3}$ at 300 K. The splitting diffraction angle between GaN and $Al_xGa_{1-x}N$ were also analyzed from X-ray diffraction curves. © 1997 Elsevier Science S.A.

Keywords: GaN; Epitaxial layers; $Al_xGa_{1-x}N$ buffer layers; 6H–SiC substrates

1. Introduction

Gallium nitride is a wide bandgap semiconductor and has attracted considerable interest because of its applications in blue, green and ultraviolet LED (light-emitting diodes) detectors and diode lasers. GaN materials are also explored to be used in high temperature electronic devices. Although a lattice-matched substrate is difficult to obtain, C-face (0001) sapphire has been successfully used as a substrate to grow GaN film by MOCVD [1,2]. Because of the large difference in lattice constants (lattice mismatch about 13.8) and thermal expansion coefficients between the sapphire substrate and GaN film, the performance of GaN-based devices depends critically on the initial grown layer that affects the growth of the misfit dislocations and polarity-related defects. Hence, substrates with smaller mismatches would be desirable.

6H-silicon carbide (SiC) has a lattice constant closer to that of GaN, with a mismatch of about 3.4%. LEDs emitting at 348 nm from an AlGaN pn-junction on the α(6H)–SiC substrates have been reported [3]. Nevertheless, to grow high-quality and mirror like surface GaN epitaxial layer still needs the buffer layers, such as AlGaN [4] or AlN [5,6]. The enhanced surface mobility of the adatoms and the reduced mismatch in lattice constant between AlN and 6H–SiC ($\Delta a/a_0 \approx 1\%$) at high temperatures are the reasons that AlN buffer layer is often used in growing GaN epitaxial layers on SiC substrates. However, the role of buffer layers on the thermal stress between GaN and SiC substrates have not been discussed in detail. In this paper, we report on the characterization of GaN films which were grown on 500 Å thick $Al_xGa_{1-x}N$ ($0 < x < 1$) buffer layers. The influence of Al content in AlGaN buffer layers on the subsequently GaN properties, such as crystalline quality, optical and electronic properties are characterized.

2. Experiments

The AlGaN/GaN films were grown by LP-MOCVD on 6H–SiC substrates. The wafers were cut along the base plane orientation. We chose the (0001) silicon face, for which each Si atom has a single dangling bond at the surface, because C dangling bonds will occur only at the step sites. Sasakis results [7] indicated that GaN epitaxial layers on $(0001)_{Si}$ and $(0001)_C$ SiC are terminated with nitrogen and gallium, respectively. This polarity difference will influence the GaN surface mor-

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phology and the photoluminescence characteristics. The $(0001)_{Si}$ SiC substrates were degreased in sequential ultrasonic baths of acetone for 30 min, then rinsed in deionized water and cleaned by RCA cleaning procedure [8]. Heavy metals were removed using a heated (80°C) H_2SO_4:HNO_3 solution. Next, a surface oxide was grown in a HCl:H_2O_2:H_2O (5:3:3) solution [9] at 60°C to passivate the Si dangling bonds, in a manner similar to that for Si substrates [10] [11]. This grown silicon dioxide was then stripped with a diluted (10:1) H_2O:HF solution. After the final HF dip, the SiC substrates were blown dry with N_2 prior to the growth. During the growth, the SiC substrates were placed on a graphite susceptor in a horizontal-type reactor with a RF heater. Triethylgallium (TEGa), trimethylaluminum (TMA) and ammonia (NH_3) were used as the Ga, Al and N sources, correspondingly. The V/III ratio, N/(Ga + Al) mole ratio, was kept constant at ~ 10000 in this growth system. The carrier gas is hydrogen (H_2) and the growth pressure was kept at 76 torr. Before growing GaN films, the SiC substrates were treated by thermal baking at 1100°C to minimize the surface contamination.

In order to find an optimum buffer layer to grow better GaN epitaxial layers on SiC substrates, the buffer layers prior to the GaN epitaxial layers were prepared. Varying the x(mole fraction of $Al_xGa_{1-x}N$ layers) from 0 to 1, the electric and crystalline properties of GaN epitaxial layer were studied to analyze its influence on these thin $Al_xGa_{1-x}N$ layers. Using DC-XRD (double-crystal X-ray diffraction) measurement to analyze the crystalline properties, the GaN (0004), $Al_xGa_{1-x}N$ (0004) and 6H–SiC $(000\underline{12})$ peaks were displayed as X-ray diffraction curve. The electric and luminescence properties of GaN epitaxial layers with $Al_xGa_{1-x}N$ layers are also measured by Hall effect measurement and Photoluminescence (PL).

3. Results and discussion

There are eight 1.3 μm thick undoped GaN epitaxial samples grown on 6H–SiC substrate with different Al mole fraction undoped-$Al_xGa_{1-x}N$ buffer layers. The growth temperature of $Al_xGa_{1-x}N$ buffer layers and GaN epitaxial layers are fixed at 1025°C. The thickness of $Al_xGa_{1-x}N$ buffer layers are fixed at 500 Å, which is an optimum thickness found for this study. The Al mole fraction of $Al_xGa_{1-x}N$ are varied form 0 to 1. The influence of $Al_xGa_{1-x}N$ buffer layers on the GaN epitaxial growth is analyzed by Hall effect measurement. The carrier mobility and concentration of GaN epitaxial layers varied with the Al mole fraction of $Al_xGa_{1-x}N$ buffer layers, shown in Fig. 1. The carrier mobility is about 500 cm^2 V s at 300 K for GaN layers using $Al_xGa_{1-x}N$ buffer layers with x value between 0.07 and 0.7 (x valve is Al mole fraction of $Al_xGa_{1-x}N$). The Al contents were determined by the X-ray and PL measurements. The highest mobility and lowest concentration are about 564 cm^2 V^{-1} s^{-1} and 1.6×10^{17} cm^{-3}. for a GaN epitaxial layer using an $Al_{0.18}Ga_{0.82}N$ buffer layer.

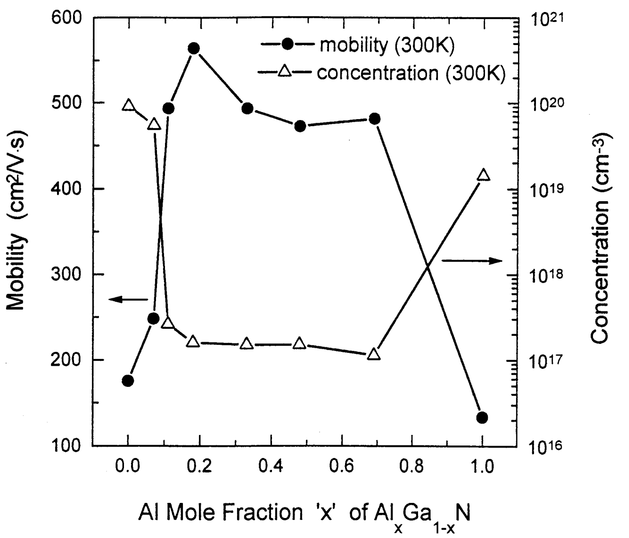

Fig. 1. The GaN Hall mobility measured at 300 K as a function of the Al mole fraction x of 500 Å-thick $Al_xGa_{1-x}N$ buffer layers from GaN to AlN.

The crystalline quality of GaN epitaxial layers were measured by DC-XRC. The FWHM of GaN (0004) diffraction curves are shown in Fig. 2, with different Al content in $Al_xGa_{1-x}N$ buffer layers. The FWHM of

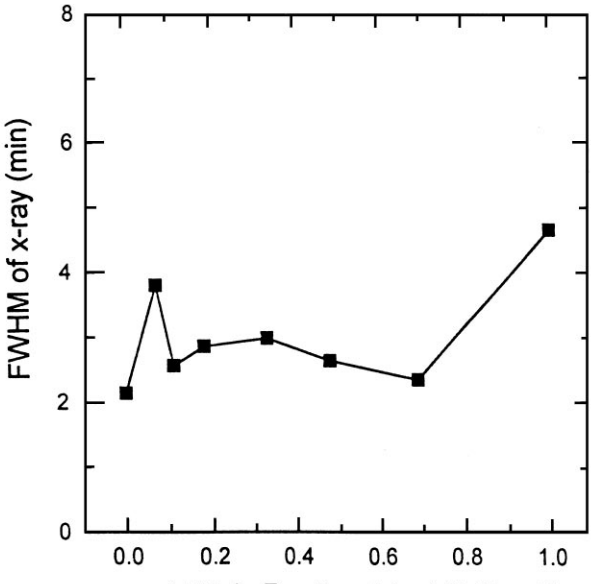

Fig. 2. The FWHM of the XRD for GaN (0004) diffraction curves as a function of the Al mole fraction x of 500 Å-thick $Al_xGa_{1-x}N$ buffer layers from GaN to AlN.

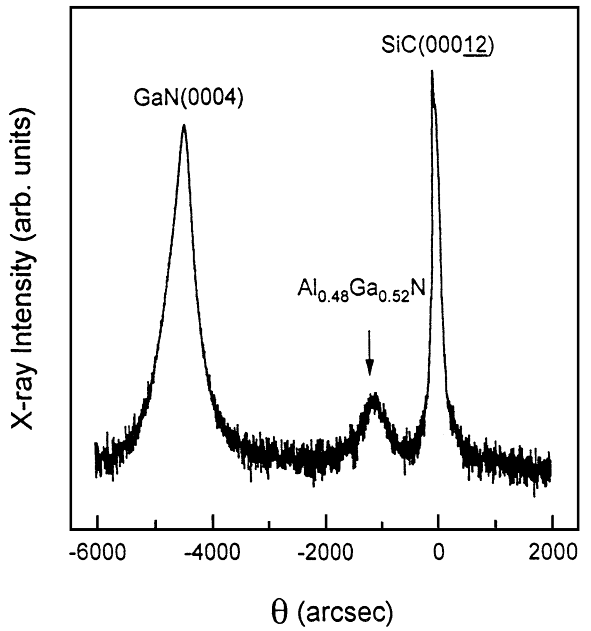

Fig. 3. Double-Crystal X-ray curve of $GaN/Al_{0.48}Ga_{0.52}N/SiC$ structure deposited on $(0001)_{Si}$ SiC. There are (0004) GaN peak, (0004) $Al_{0.48}Ga_{0.52}N$ peak and (00012) SiC peak in this figure.

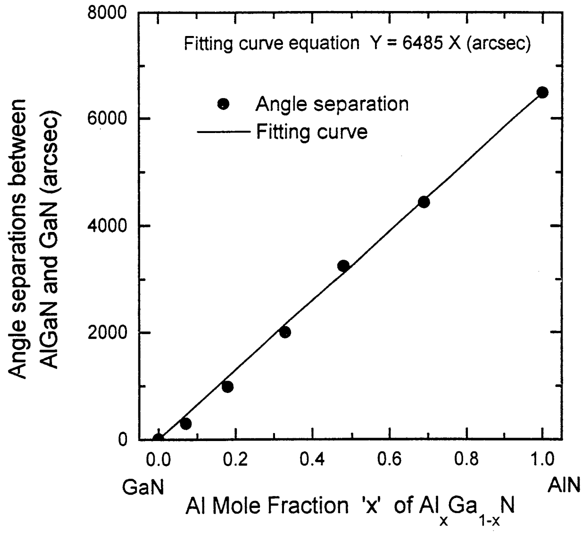

Fig. 4. AlGaN angle separation from GaN (arcsec) as a function of the Al mole fraction x of 500 Å-thick $Al_xGa_{1-x}N$ buffer layers from GaN to AlN.

GaN (0004) X-ray curves are 2–3 arcmin. There are three X-ray diffraction peaks, each of them is identified as GaN (0004), $Al_{0.48}Ga_{0.52}N$ (0004) and SiC (000$\underline{12}$)and shown in Fig. 3. The 500 Å-thick $Al_{0.48}Ga_{0.52}N$ buffer layer was observed clearly between GaN and SiC diffraction peaks. The AlGaN (0004) peak separation from GaN(0004) was measured to determine the mismatch between epitaxial films and substrate. The separation angle was measured for all eight samples with different Al content $Al_xGa_{1-x}N$ buffer layer. The angle separation versus Al mole Fraction of $Al_xGa_{1-x}N$ is shown in Fig. 4. The curve is an approximation to a linear relationship. The fitting curve equation is $Y = 6485X$ (arcsec) in which the Y parameter is AlGaN angle separation from GaN (unit: arcsec) and the X stands for Al mole fraction of AlGaN. The luminescence properties of GaN epitaxial layers were measured by PL using 325 nm He–Cd Laser at 300 and 20 K. The PL curves contained the 357 nm-bandedge emission peaks at 300 and 20 K are shown in Fig. 5. The 550 nm-yellow emission peak diminished as the sample being cooled. This $Al_{0.7}Ga_{0.3}N$ is an insulator film and it is useful in GaN-based device. The PL-FWHM of GaN epitaxial layers with different Al contents of $Al_xGa_{1-x}N$ are about 27 meV and shown in Fig. 6.

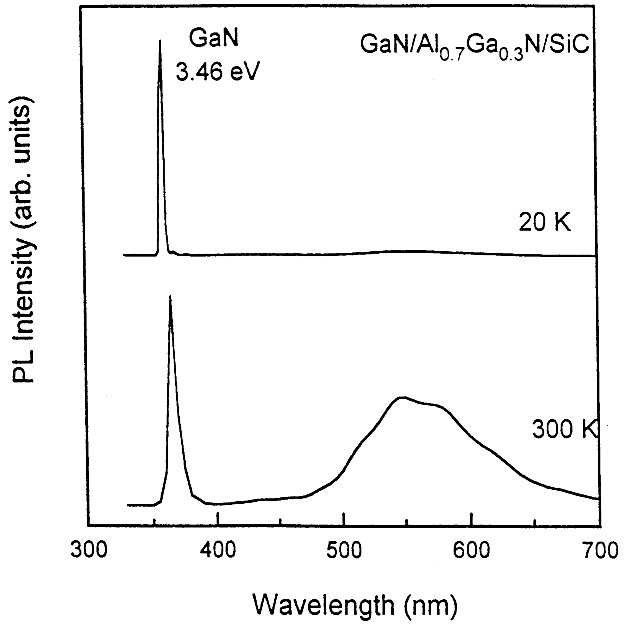

Fig. 5. The 20 K photoluminescence spectrums of the $GaN/Al_{0.7}Ga_{0.3}N/SiC$ structures measured with a He–Cd laser excitation ($\lambda = 325$ nm 8 mW).

4. Conclusions

In summary, GaN epitaxial layers with AlGaN as the buffer layer were deposited on 6H–SiC substrates. Using different Al composition in $Al_xGa_{1-x}N$ thin film as the buffer layers, the GaN properties were analyzed by DCX-ray, Hall effect and PL measurement. These 500 Å AlGaN buffer layers significantly improve the GaN crystalline quality by reducing the mismatch between GaN and SiC substrates. Also, these buffer layers were deposited on SiC substrates at 1025°C, which are intended to relax the thermal stress between GaN epitaxial layers and SiC substrate. The FWHM of GaN

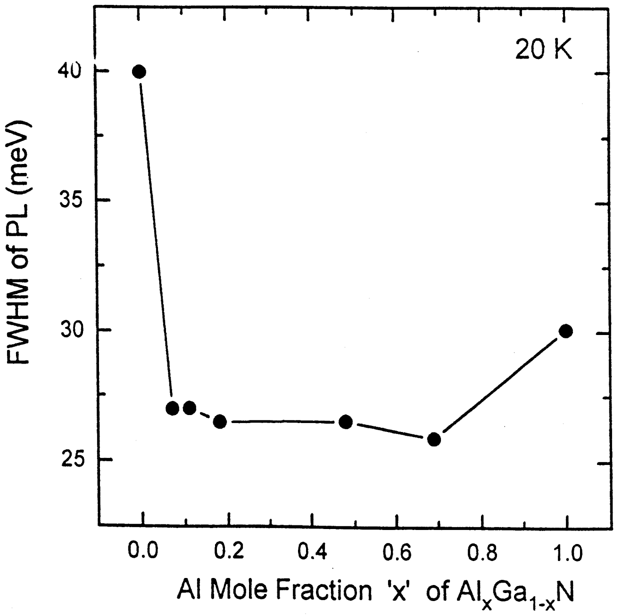

Fig. 6. The FWHM of the PL spectrums for GaN (0004) epitaxial layers as a function of the Al mole fraction x of 500 Å-thick $Al_xGa_{1-x}N$ buffer layers from GaN to AlN.

(0004) X-ray curves are about 3 arcmin using $Al_xGa_{1-x}N$ buffer layers, except the sample with AlN buffer layer. In order to have good GaN crystalline property on SiC substrate, AlN buffer layer must deposited above 1100°C [5]. With buffer layer of $Al_{0.18}Ga_{0.82}N$, we obtain the best GaN epitaxial quality in this study. The mobility and carrier concentration are 564 cm^2 V^{-1} s^{-1} and 1.6×10^{17} cm^{-3} at 300 K, respectively. The $Al_xGa_{1-x}N$ ($x > 0.4$) layers had electric insulator property and can be used as MESFET device.

Acknowledgements

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