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OPTO-ELECTRONICS REVIEW **19**(1), 30–33

DOI: 10.2478/s11772-010-0055-2

Properties comparison of GaN epilayers deposited under different growth temperatures

P. WANG[1,2], H. YAN[1], B. CAO[1], W. WEI[1], Z. GAN*[1,2], and S. LIU[1,2]

[1]School of Mechanical Engineering, Huazhong University of Science and Technology, 1037 Luoyu Road, 430074 Wuhan, China

[2]Wuhan National Lab of Optoelectronics, Huazhong University of Science and Technology, 1037 Luoyu Road, 430074 Wuhan, China

Undoped GaN epilayers were grown on c-plane sapphire substrates under different growth temperatures by metalorganic chemical vapour deposition (MOCVD). The optical and structural characteristics of these grown samples were studied and compared. It was found that the crystalline quality of GaN film deposited at 1050°C was better that of other samples. Photoluminescence spectra showed that the intensities of yellow luminescence band of the samples decreased as the growth temperature increased. All above test results demonstrate that high temperature deposition can serve as a good method for high-quality GaN epilayer growth and there exists an optimal growth temperature.

Keywords: gallium nitride, metalorganic chemical vapour deposition, growth temperature.

1. Introduction

Gallium nitride (GaN) is a promising material for optoelectronic devices such as green and blue light emitting diodes (LEDs), laser diodes (LDs), UV photodetectors, high power and high temperature optoelectronic devices due to its wide direct band gaps, high breakdown fields, and excellent chemical and thermal stabilities [1]. Because of the lack of bulk GaN materials, the GaN epilayer is widely grown on other substrates such as sapphire, silicon carbide and Si, which have large mismatches with GaN in lattice constants and thermal-expansion coefficients [2–4]. This results in high-density threading dislocations, which have great effect on the performance of aforementioned devices. Many groups have made a great effort to obtain high-quality GaN crystals with a low dislocation density. A two-step growth process employing a buffer layer which generally is GaN or AlN nuclear layer in a low temperature have been adopted to reduce the threading dislocation densities and improve the quality of GaN crystals [5]. Recently, reduction in dislocation density has been achieved by employing epitaxial lateral overgrowth (ELOG) technique [6]. Above approaches have contributed to improvement in the crystalline quality of GaN films and the performance of related devices. However, many detailed process conditions during growth procedure could influence the properties of GaN epilayer. Thus, further understanding on the mechanisms of growth and the effects of different conditions is needed to obtain high quality GaN crystals.

In this paper, undoped GaN epilayers were grown on *c*-plane sapphire substrates under different growth temperatures by metalorganic chemical vapour deposition (MOCVD). The optical and structural characteristics of these GaN samples were investigated by photoluminescence (PL) and X-ray diffraction (XRD) techniques. The surface morphologies were observed using scanning electron microscopy (SEM).

2. Experiment

The GaN epitaxial films in this work were grown on *c*-plane sapphire substrates in a Thomas Swan horizontal MOCVD reactor at a low pressure of 275 torr. The substrates were first baked in flowing N_2 gas at 1050°C for 10 min. Then, the substrates experienced a nitridation process in NH_3 gas at 1050°C for 5 min. Trimethyl gallium (TMG) source was used as precursor for gallium and NH_3 for nitrogen. N_2 was used as the carrier gas. In this experiment, a two-step growth method consisting of the deposition of a buffer layer and the GaN epitaxial growth was employed. During the growth process, the TMG flow rate was 70 sccm and the NH_3 flow rate was 9000 sccm for the GaN growth. After GaN buffer layers about 2-μm thick were deposited at 1050°C, undoped GaN epilayers with a thickness of about 2 μm was grown at 700°C, 900°C, 1050°C, and 1100°C respectively. All other growth conditions kept the same during the growth processes in order to compare properties of these samples.

Room temperature PL experiments were carried out by the 325-nm line of a He-Cd laser. XRD measurements were performed with a high resolution PANalytical PW 3040/60 X'Pert Pro system to evaluate the crystalline quality of the

*e-mail: zhiyingan@yahoo.com.cn

undoped GaN films. The surface morphologies of the GaN layers were examined by a field emission scanning electron microscope.

3. Results and discussion

Figure 1 presents the SEM images of the top surface morphologies of the samples grown under different temperatures. As shown in Fig. 1(a), a number of irregular island-structures formed at a low temperature of 700°C. In Fig. 1(b), some hexagonal pits can be observed on the surface when the growth temperature is 900°C. These pits correspond to different types of threading dislocations including edge, screw, and mixed types. It can be seen that the isolated islands coalesce rapidly as the deposition temperature increases. When the growth temperature further increased to 1050°C and 1100°C, the smooth surface morphologies of the samples were obtained, as shown in Figs. 1(c) and 1(d).

The crystalline qualities of the GaN epitaxial films were measured by high resolution double crystal XRD using the GaN symmetrical (002) and asymmetrical (102) reflections. Figure 2(a) and 2(b) show the comparison of XRD ω-scans rocking curves for (002) plane and (102) plane of the samples, respectively. The values of full width at half-maximum (FWHM) for the samples grown at 700°C, 900°C, 1050°C, and 1100°C are 0.109, 0.082, 0.068, and 0.066 degree for GaN (002) plane, respectively. The FWHM values for the epilayers deposited at 700°C, 900°C, 1050°C, and 1100°C are 0.119, 0.101, 0.095, and 0.1 degree for GaN (102) plane, respectively. Rocking curves of the GaN symmetrical (002) and asymmetrical (102) reflections present the information about the mixed threading dislocation density and pure edge dislocation density, respectively [7,8]. Figure 3(a) and 3(b) illustrate the variation tendency of the FWHM values of GaN (002) plane and (102) plane for the samples dependent on different deposition temperatures, respectively. As shown in Fig. 3(a), the FWHM values of (002) plane of these samples decrease as the growth temperature increases. When the deposition temperature increased from 1050°C to 1100°C, the FWHM value of (002) is almost unchanged. It can be seen that the FWHM value of (102) plane of the film grown at 1050°C is lowest from Fig. 3(b). These XRD measurement results indicate that high temperature deposition can reduce the density of threading dislocations and improve the crystalline quality, which corresponds to the SEM examination results. These results also show that there exists an optimal growth temperature to obtain the best crystalline quality of the GaN films.

Figure 4 describes the room temperature PL spectra of the undoped GaN epitaxial layers grown at different tempe-

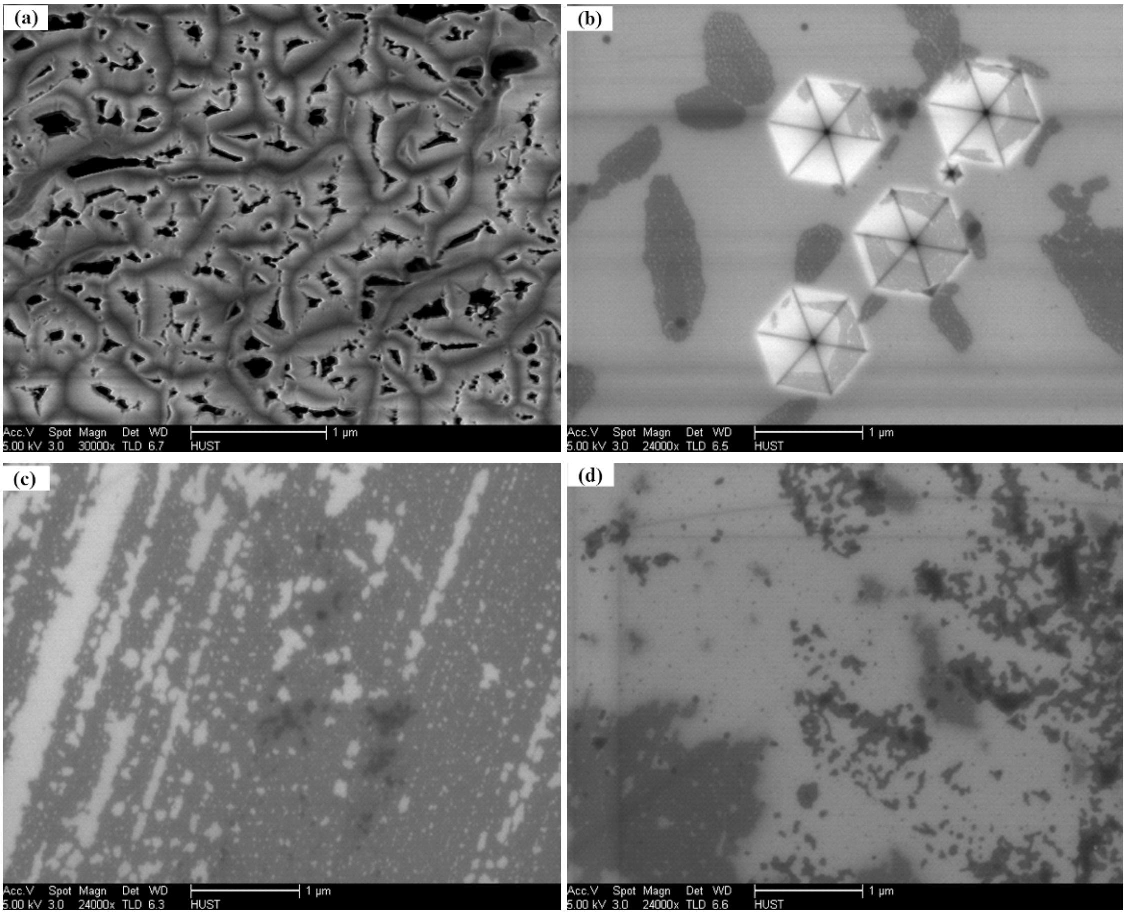

Fig. 1. SEM images of top surface morphologies of samples grown under different temperatures including: (a) 700°C, (b) 900°C, (c) 1050°C, and (d) 1100°C.

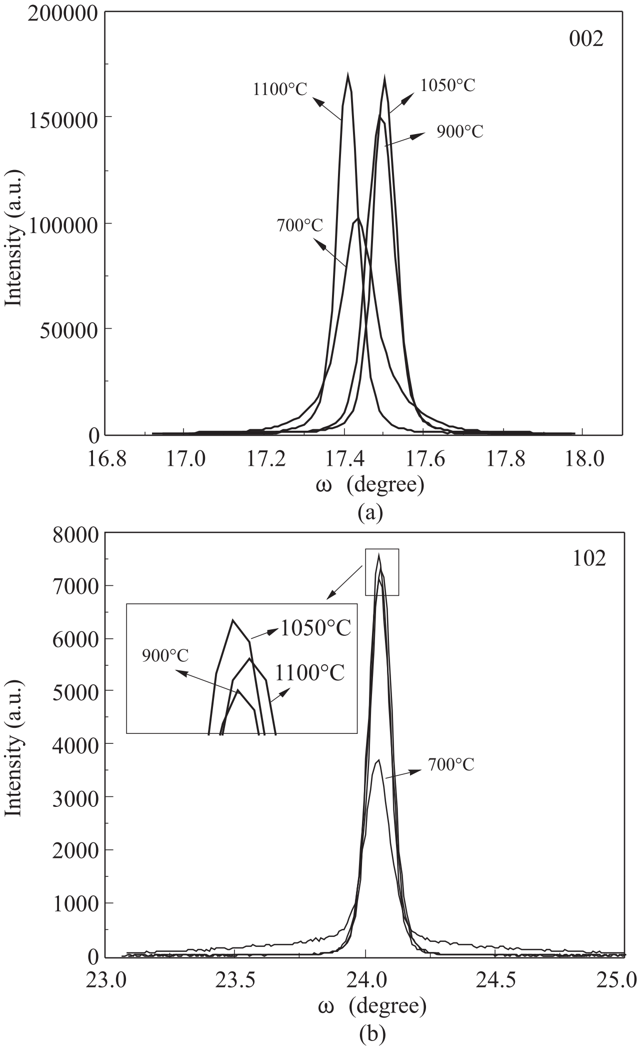

Fig. 2. XRD ω-scans rocking curves for: (a) (002) plane and (b) (102) plane of samples grown at different temperatures.

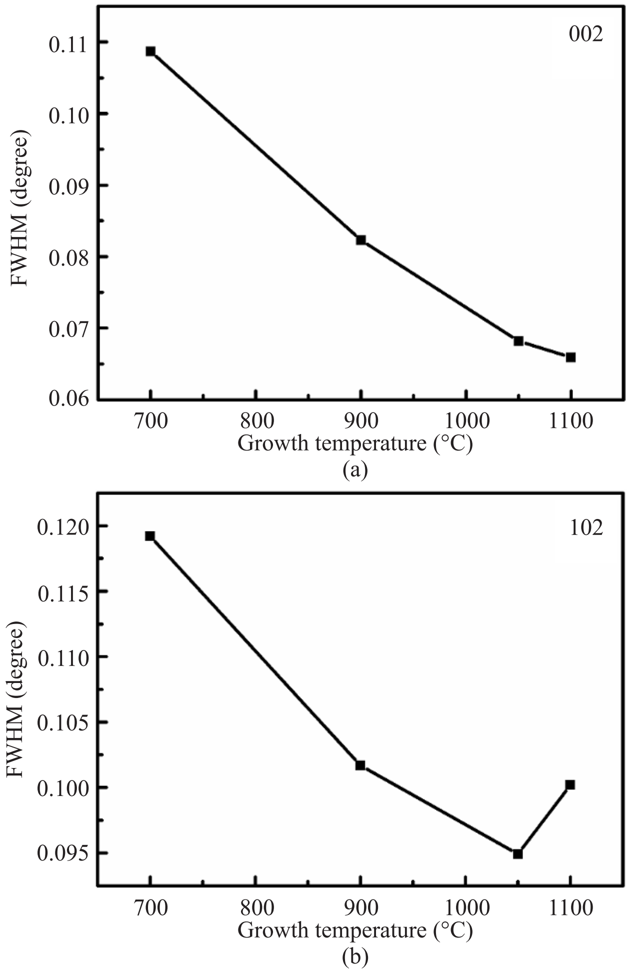

Fig. 3. Variation tendency of FWHM values of: (a) GaN (002) plane and (b) (102) plane for samples grown at different temperatures.

ratures. The spectra of all these samples exhibit a sharp near-band-edge emission peak and a broad yellow emission band. However, the intensities of the two emissions are distinct for each sample. The near-band-edge emission peaks centre at about 347 nm and the yellow luminescence bands are in the range of 470–620 nm. Previous studies presented that the yellow luminescence band was related to deep levels of defects in GaN such as native defects, impurities, and extended defects [9–12]. The undoped GaN films grown at 700°C and 900°C show much stronger yellow luminescence band than the samples grown at 1050°C and 1100°C, which can be attributed to more defects formed during low-temperature growth. The band-edge emission intensity of each sample increases slightly as the growth temperature rise up. The intensity ratios of the yellow band to the band-edge emission for the samples grown at 700°C, 900°C, 1050°C, and 1100°C are 9.39, 9.01, 3.34, and 2.9, respectively. This result means that the optical properties of sample deposited at a high temperature is better than that of sample at a low temperature.

According to the SEM images, the threading dislocations in undoped GaN epitaxial films can be reduced as the growth temperature increases. A smooth surface was obtained when the growth temperature achieved 1050°C. The XRD analysis shows that the crystalline qualities are

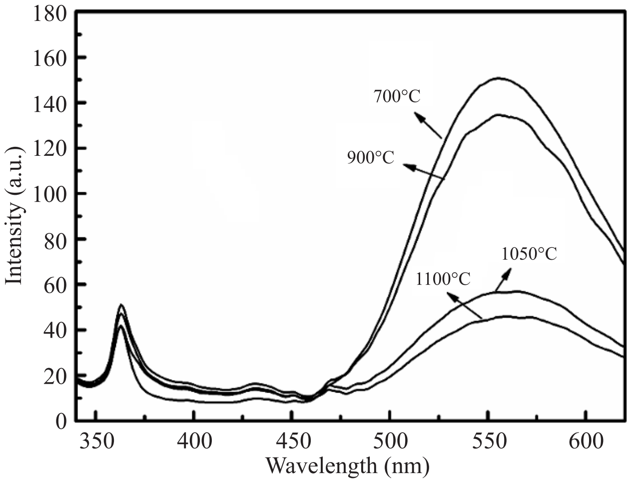

Fig. 4. Room temperature photoluminescence spectra of undoped GaN epitaxial layers grown at different temperatures.

improved by increasing the deposition temperature, which agrees with the SEM results. However, when the growth temperature increases to some extent, the crystalline qualities of GaN films deteriorate slightly, which indicates that an optimal growth temperature should be found to obtain the best crystalline quality. The PL measurement results present that the optical properties of sample deposited at a high temperature is better, which could be attributed to reduction of the defects in GaN film.

4. Conclusions

In conclusion, we studied the influence of different growth temperature on the properties of undoped GaN layers. It was found that the crystalline quality of undoped GaN film deposited at 1050°C was better that of other samples. PL spectra showed that the intensities of yellow luminescence band of the samples decreased as the growth temperature increased, which indicated high temperature growth could improve optical properties of GaN films. All the above test results demonstrate that high temperature deposition can serve as a good method for high-quality undoped GaN epilayer growth. However, an optimal growth temperature should be obtained in further detailed experiments.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (No. 50835005). The authors would like to acknowledge Huazhong University of Science & Technology Analytical and Testing Centre for the support in some test experiments.

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