phys. stat. sol. (c) **1**, No. 10, 2445–2449 (2004) / **DOI** 10.1002/pssc.200404981

High quality AlGaN growth by changing growth pressure and insertion of AlN/GaN superlattice interlayer

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Received 13 February 2004, accepted 8 July 2004
Published online 16 August 2004

PACS 61.10.Nz, 68.37.Hk, 68.37.Lp, 68.37.Ps, 68.55.Jk, 81.15.Gh

We have investigated the optical and structural properties of thick AlGaN layer grown using strain-relief AlN/GaN superlattice buffer on SiC/Si(111) substrate by low pressure metal organic chemical vapor deposition. A set of five period AlN/GaN superlattice interlayers was one of the most efficient methods for the strain relief by reducing biaxial tensile strain between GaN and AlGaN layer. A set of five period AlN/GaN superlattice interlayer and a thick AlGaN layer were grown by changing the growth pressure from 80 mbar to 100 mbar. The quality of AlGaN layer strongly depends on the pressure of growth of the AlN/GaN superlattice interlayer and AlGaN layer. The optimized pressure for the AlN/GaN superlattice interlayer and thick AlGaN layer was 80 mbar and 100 mbar, respectively. Crystal quality and morphology of AlGaN films improved and crack density reduced by using two-step growth method, remarkably.

1 Introduction Wide band gap group of Ш-nitrides have been recognized as important materials for the optoelectronic devices, such as blue and ultraviolet (UV) light emitting diodes (LEDs), laser diodes (LDs), and high temperature/high frequency transistors [1, 2]. Currently intense researches are under way for developing deep UV optoelectronic devices for the application in solid-state white light, super high-density storage. Because of their direct band gap from 3.4 to 6.2 eV, high Al mole fraction AlGaN layers are one of the most promising material for such devices. However, due to the biaxial tensile strain, crack network invariably generates when the thickness of the AlGaN layer on Si substrate or GaN exceeds the critical value [3]. Therefore the production of crack-free thick AlGaN ternary layer has been challenging issue due to the large lattice-mismatch (2.16%) between GaN and AlN. A considerable effort has been made to overcome the cracking problem by using AlGaN/GaN superlattice [4], and by exploiting thin InGaN stress relief layer beneath AlGaN layer [3]. Recently, Amano et al. [5] reported on the growth of crack-free thick AlGaN film by inserting a low-temperature (500 °C) grown thin AlN interlayer between GaN and AlGaN layer. Han et al. reported on control of cracking of AlGaN using a low-temperature AlGaN interlayer [6, 7]. Also, thin high temperature (HT)-AlN also significantly reduces the tensile stress in the AlGaN layer and is useful to grow crack-free high quality AlGaN films [8]. Also, the growth of AlGaN/GaN on Si substrate is particular interested. These methods can take advantage of the well-established Si technologies. Moreover, the availability of large and high quality Si substrate, as well as its low cost, make it an attractive alternative for the growth of Ш-nitride layers. In previous work we got the high quality GaN film on Si with AlN buffer using SiC intermediate layer because the SiC intermediate layer acts on reduce the lattice mismatch and reduces thermal expansion coefficient between GaN film and Si substrate [9].

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In this work, we investigated the growth of thick AlGaN layer on GaN using strain-relief AlN/GaN superlattice (SLs) interlayer on SiC/Si(111) substrate by LP-MOCVD. We found that optimum conditions for the growth of AlGaN/GaN layers strongly depended on the changing of the growth pressure of AlN/GaN SLs interlayer and thick AlGaN layers. A set of five period AlN/GaN SLs and AlGaN layer grown at 80 mbar and 100 mbar respectively improved the crystal and optical quality.

2 Experimental procedure Before growth of AlGaN on GaN, the GaN film were grown with high temperature AlN buffer and five period AlN/GaN SLs buffer on Si(111) substrate using 3C-SiC intermediate layer. Si(111) substrate were thermally cleaned at 1100 °C for 5 min in H_2 ambient. Then the 3C-SiC intermediate layer was grown at 1250 °C and 50 torr by chemical vapor deposition (CVD) using tetramethylsilane (TMS). SiC/Si substrate was cleaned again in organic solvents and etched using BOE and boling HCl for 2 min, respectively and then flushed with deionized water. GaN films were grown at 1170 °C by LP-MOCVD using TMGa, TMAl, and NH_3 as Ga, Al, and N precusors, respectively. Before the growth of 20nm thick AlN buffer layer, the substrate was thermally treated at 1170 °C for 10 min in H_2 ambient. Then Al is directly deposited on the SiC/Si(111) substrate before introducing NH_3 into the reactor. The Al pre-seeding for 20 sec prevents the formation of Si–N bonding at the surface of SiC [9]. The thin AlN buffer layer was grown for 5 min with TMAl flow rate of 33 µmol/min and NH_3 flow rate of 1400 sccm at 100 mbar, respectively. After then five period AlN(2 nm)/GaN(5nm) SLs layer were grown for 15 sec and 30 sec, respectively. GaN epilayer on the AlN/GaN SLs buffer layer was grown for 1 hour with TMGa flow rate of 90 µmol/min and NH_3 flow rate of 2800 sccm at 1170 °C and 100 mbar. AlGaN was deposited for 30 min on GaN epilayer using strain-relief AlN/GaN SLs interlayer with TMAl flow rate of 20 µmol/min, TMGa flow rate of 90 µmol/min and NH_3 flow rate of 3500 sccm at 1170 °C. The growth time of AlN/GaN SLs interlayer was 15 sec, 30 sec, respectively and the period of AlN/GaN superlattice was five period. The pressure of thick AlGaN film and AlN/GaN SLs interlalyer was varied from 80 mbar to 100 mbar.

The surface morphology of AlGaN films was studied using scanning electron microscopy (SEM) and an atomic force microscope (AFM). The Al solid composition and crystal quality of AlGaN flims were measured by X-ray diffraction (XRD) and photoluminescence (PL) measurements. The thickness of AlGaN layers on GaN film was observed using the field effect scanning electron microscopy (FESEM).

Using the transmission electron microscopy (TEM), we know reduction of dislocations of AlGaN layer by preventing the dislocation of GaN epilayer.

3 Results and discussion As seen from Table 1, thick AlGaN layers were grown by changing pressure of AlN/GaN SLs interlayer and thick AlGaN flims. Sample A has no AlN/GaN SLs interlayer between GaN and AlGaN layer, and sample B, C, D have a set of five period AlN/GaN SLs interlayer grown at different reactor pressure.

Table 1 Growth pressures for thick AlGaN layers and AlN/GaN SLs of samples.

	A	B	C	D
Growth pressure of AlN/GaN SLs interlayer between AlGaN and GaN	No	80mbar	100mbar	80mbar
Growth pressure of AlGaN layers	80mbar	80mbar	100mbar	100mbar
solid composition of Al	12%	13%	10%	10%

Figure 1 shows SEM images of AlGaN layers on GaN on the SiC/Si(111) substrate, where the thickness of AlGaN layers is about 0.8 µm. Sample A which has no AlN/GaN SLs interlayer is many network of cracks and voids in the thick AlGaN layer. These cracks were usually observed when the thickness of the AlGaN layer exeeds 0.1µm. Cracks are caused by excessive biaxial tensile stress by activating slip system around the crack tips when the AlGaN layer is over the critical thickness. We consider that the reduction of tensile stress can overcome the cracking problem through the insertion of strain-relief SLs interlayers between AlGaN and GaN. In the sample B,C,D with the insertion of the AlN/GaN SLs interlayer between AlGaN and GaN layer, the tensile strain is alleviated [Figs. 1 (b),(c),(d)].

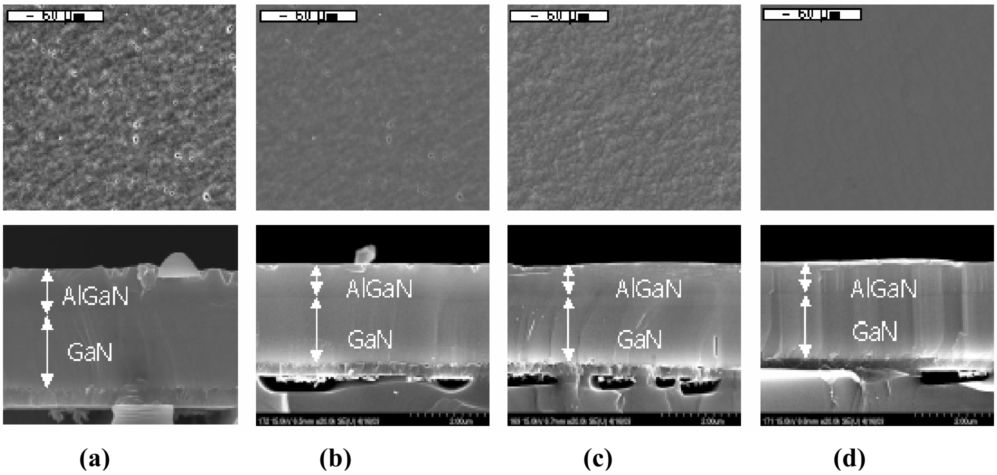

Fig. 1 SEM images of AlGaN layers grown on GaN at the conditions given in Table 1. (a) Sample A, (b) sample B, (c) sample C, (d) sample D.

As shown in Fig. 2, surface morphologies of AlGaN films were revealed by AFM investigations. The values of the root mean square (rms) of surface roughness are (a) 10.712 nm, (b) 2.716 nm, (c) 4.206 nm, and (d) 2.196 nm, respectively. As inserting of AlN/GaN SLs interlayer between AlGaN and GaN, surface morpology seems to be improved [Fig.2 (b), (c), (d)] corresponding to the SEM images. From these result , AlN/GaN SLs interlayer between AlGaN and GaN layers significally reduced cracks and voids in AlGaN layers through the tensile strain alleviation.

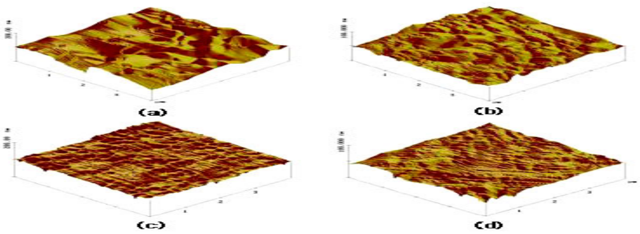

Fig. 2 AFM images of AlGaN layers grown on GaN at the conditions shown in Table 1. (a) Sample A, (b) sample B, (c) sample C, (d) sample D.

Generally, crystal quality and surface morphology strongly depend on reactor pressure. In case of single step growth, when AlN/GaN SLs and AlGaN layer were grown at same low pressure around 80 mbar, surface morphology was improved but crystal quality was deteriorated [Fig. 2 (b), Fig. 3(b)]. As increasing in reactor pressure to 100 mbar, crystal quality was improved but surface became rougher [Fig. 2(c), Fig. 3(c)]. In previous work, we studied growth of GaN layer by two-step growth [10]. In this work, we tried also to grow AlGaN layer by two-step method where AlN/GaN SLs interlayer and AlGaN layers have different reactor pressure to promote both crystal quality and surface morphology. Pressure of AlN/GaN SLs interlayer and AlGaN layer was varied from 80 mbar to 100 mbar. From the result, growth pressure of SLs interlayer was optimized at 80 mbar and thick AlGaN layer at 100 mbar [Figs. 1, 2, 3 (d)]. Crystal quality and morphology of AlGaN epi-layer improved and crack density reduced by using two-step growth method, remarkably. It is considered that the surface diffusion at low pressure and lateral growth at initial state dominate on the surface morphology of AlGaN epi-layer. The lateral growth of the first AlN/GaN SLs interlayers enhances surface morphology and reduces the strain in AlGaN layer. As increase in pressure of first AlN/GaN SLs interlayers to 100 mbar, surface morphology is rougher and crack density is increased as shown in Fig. 1(c), Fig. 2(c). In this case, the higher vertical growth rate compared with the lateral growth rate makes discontinuous islands which are caused by many terraces and steps. It results in rough surface and high crack density in AlGaN layer. Then the growth of discontinuous island is fast, and second AlGaN layer is not fully coalesced. The root mean square (RMS) roughness of surfaces is reduced from 4.206 nm [Fig. 2(c)] to 2.196 nm [Fig. 2(d)] as decreasing pressure of first AlN/GaN SLs interlayer. Sample D has a good surface morphology in AlGaN layer by lateral growth of first AlN/GaN SLs interlayer.

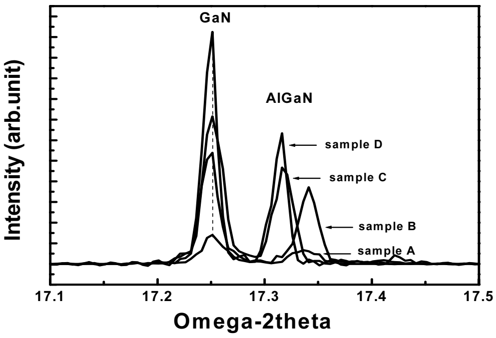

Fig. 3 HRXRD (2θ–ω) spectra of AlGaN layers grown on GaN at the conditions given in Table 1. (a) Sample A, (b) sample B, (c) sample C, (d) sample D.

Figure 3 shows (0002) 2θ–ω XRD results. These results show that AlGaN layers were well grown on GaN epi-layer. The Al-solid compositions of these samples were estimated from X-ray diffraction (XRD) and the photoluminescence (PL) results [Table 1]. The FWHMs of AlGaN(0002) planes are (a) 188.04 arcsec, (b) 162.98 arcsec, (c) 149.37 arcsec, (d) 142.46 arcsec, respectively. Sample A has poor crystal quality due to tensile stress between AlGaN and GaN. Because AlGaN layer was grown without AlN/GaN SLs interlayer. In this sample the network of cracks and voids exists in AlGaN layer [Fig. 1 (a)]. The other side, sample D has good quality of AlGaN layer because AlN/GaN SLs interlayer and AlGaN layer were grown by two-step method of changing the reactor pressure.

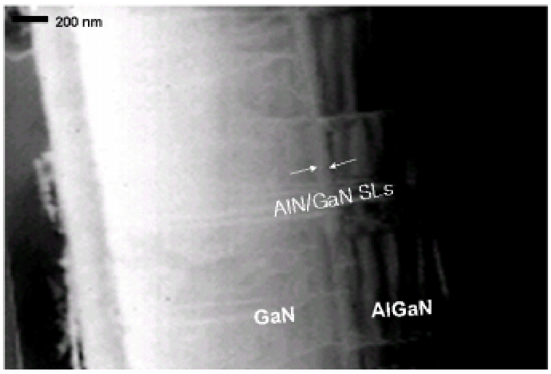

Fig. 4 TEM image of AlGaN layers grown on GaN under sample D condition.

Figure 4 shows the transmission electron microscopy (TEM) image of AlGaN flim grown on the GaN epi-layer with five period AlN/GaN SLs interlayer at same condition for sample D. As shown in Fig. 4, we obtained reduction of dislocation from GaN epi-layer using AlN/GaN SLs interlayer between GaN and AlGaN layer.

4 Conclusions We have successfully grown thick AlGaN layer on GaN using strain-relief AlN/GaN superlattice interlayer on SiC/Si (111) substrate by LP-MOCVD. We have investigated the properties AlGaN layers by changing the growth pressure of AlN/GaN SLs interlayer and thick AlGaN layers.

AlGaN layer with AlN/GaN SLs interlayer is much better than AlGaN layer without AlN/GaN SLs interlayer in structural properties and crystal quality. Especially, surface morphology and crystal quality was improved by two-step growth. The pressure of AlN/GaN SLs interlayer was optimised at 80 mbar and thick AlGaN at 100 mbar. Then, we obtained the FWHM of XRD rocking curves of a AlGaN(0002) plane was 142.46 arcsec, and the RMS value of surface roughness was 2.196 nm. We show also improved surface morpology and low dislocation density of AlGaN layer through the images of SEM and TEM, respectively.

Acknowledgements This work has been supported by the project of special basic research of the KOSEF (R01 – 1999 – 00034).

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