Growth and characterization of crack-free AlGaN on AlN interlayer

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Abstract

The AlGaN samples have been grown on AlN interlayer (IL) by metalorganic vapor phase epitaxy (MOVPE). The effects of AlN IL on improvement of crystalline quality of AlGaN and Al incorporation efficiency were investigated. The samples were characterized by X-ray diffraction (XRD) using synchrotron radiation and MeV He ion Rutherford backscattering spectrometry (RBS). AlN IL shows a role of suppressing edge dislocation defect but bring an increase in the density of screw dislocation. the AlN IL also resulted in a change in the state of stress in AlGaN from tension to compression. Crack-free AlGaN films were grown successfully by inserting two AlN IL.

1 Introduction

AlGaN is key material for the fabrication of optoelectronic devices in the deep ultraviolet (DUV) and ultraviolet (UV) region such as UV LED and UV photodetector. AlGaN/GaN heterojunction field effect transistors (HFETs) are also attracting great interest due to their promising performance for high-voltage, high power, and high temperature microwave applications. However, the growth of thick crack-free AlGaN with high Al-composition is difficult due to the large lattice-mismatch between GaN and AlN. GaN epitaxial layer has typically been used as underlying layer to grow AlGaN; In this case, crack may be generated by the relaxation of tensile strain. AlN (or AlGaN) IL have been used to relieve stress between the GaN underlayer and the AlGaN layer on top, and crack-free AlGaN were grown successfully [1-6]. It has been suggested a relation between In incorporation efficiency and defect structure on the growing epilayer surface [7].

In this paper, we report the growth and characterization of AlGaN on low temperature (LT) AlN IL. Furthermore, the effects of AlN IL on improvement of crystalline quality of AlGaN and Al incorporation efficiency were investigated.

2 Experimental

The AlGaN samples were grown by MOVPE. The structure of the AlGaN samples grown on AlN IL is shown in Fig. 1.The thickness of AlN IL is 15nm and the growth temperature of AlN IL is 600 ^{o}C. All samples were un-doped. The samples were investigated by X-ray diffraction using synchrotron radiation and MeV He ion Rutherford backscattering spectrometry (RBS). For RBS/channeling measurements, a collimated 1.57Mev He+ beam was used. XRD measurements were performed on these samples by a Huber five-circle diffractometer at beam line 4W1C of Beijing Synchrotron Radiation Facility (BSRF). The X-ray wavelength was set at 1.537 Å. The spot size of the incident beam is limited by a slit system to 0.3×1.2mm2. The detector system, consisting of a scintillation counter and a 0.1 mm wide receiving slit, was located 35 cm away from the sample.

3 Results and discussions

In order to clarify the dependence of crystalline quality and Al incorporation efficiency on Al fraction x, the accurate determination of Al fraction x is essential. When the Al fraction x in AlGaN is estimated by XRD using Vegard's law**,** if the strain in AlGaN layer is not negligible, the estimated fraction x will be inaccurate [3]. But the RBS measurement is reliable and accurate method for directly determining the composition of alloy with strain. In this study, RBS measurement was used to determine the Al fraction x in AlGaN samples. Fig. 2 shows the RBS spectra of AlGaN sample with two AlN IL. The simulation of the spectrum reveals that the sample has a composition of $Al_{0.5}Ga_{0.5}N$ and thickness of 320nm for the top AlGaN layer, and a composition of $Al_{0.4}Ga_{0.6}N$ and thickness of 280nm for the underlying AlGaN layer (see Fig. 1b). The yield χ_{min} for different AlGaN samples was also evaluated from RBS spectra, it will be discussed later.

To evaluate the quality of the AlGaN films grown on AlN IL, a complete description of the mosaic structure requires both the out-of-plane and the in-plane misorientations to be fully specified [8]. Fig. 3 shows the full width at half maximum (FWHM) of ?ω-scans around (104) AlGaN and (002) AlGaN diffraction peaks for the samples with and without AlN IL as a function of Al fraction x. For the (002) reflections, comparing with the sample without AlN IL, the AlGaN grown on AlN IL exhibit an increase in FWHM of the rocking curves, For GaN epilayers, the (002) FWHM values can be taken as a figure of merit for the tilt and consequently for the density of screw threading dislocations(TDs)[9]. Therefore, in our results, the insertion of AlN IL leads to an increase in density of screw TDs. This result is opposite to that of Kashima et al, they have reported that the LT AlN IL acts as a filter against threading dislocations which have screw component [10], However, For the (104) reflections which responds to the edge type TDs, in contrast with the sample without AlN IL, an evident reduction in FWHM of the rocking curve for the samples with AlN interlayer can be observed. The result indicates that the AlN IL can reduce the threading dislocations which have edge component. On the other hand, The increase in FWHM of ω-scan around AlGaN(104) plane with increasing Al fraction x was observed, Lafford et al have reported similar results, they attribute the increase in FWHM to an increase in the threading edge dislocation density associated with the smaller diffracting element boundaries [4].

To elucidate the stress state of AlGaN layers grown on AlN IL, the relationship between the lattice constants of c and a of AlGaN was investigated using θ–2θ?scans on the (002) and (104) reflections as shown in Fig.4. The lattice constants of AlGaN according to Vegard,s law are depicted as a dot line using those of stress-free AlN and GaN. With a certain stress, for example, in compressive stress makes appoint move to the upper left from the line and vice versa [11]. It is found that the AlGaN layers are not only relaxed but also compressively stressed by the thin AlN IL while the stress in AlGaN grown directly on GaN is tensile. The result exhibits that the use of interlayer offers tunability in the in-plane lattice parameters

[6]. The compressive stress is important for the growth of the thick AlGaN with high Al-fraction x. after inserting AlN IL, the crack reduced significantly, but still observed from the AlGaN grown on one AlN IL. In order to eliminate the crack, AlGaN layers on two AlN IL as shown in Fig.1b were grown. Morphology observation reveals that the AlGaN layer using two AlN IL is crack free. Comparing with AlGaN grown with one layer AlN IL, it is found that the AlGaN with two AlN Layer shows higher Al incorporation efficiency, under same flow rate of TMAl, the Al fraction x in AlGaN with two AlN IL (Fig. 1b) was significantly greater, by at least a factor of 1.6, than that of the AlGaN layer with one AlN IL. The improvement in incorporation may be due to the change in stress state during the growth of AlGaN on different AlN IL. The Al incorporation efficiency may also be related with the defect structure on the growing surface as reported for In incorporation in InGaN [7].

The yield χ_{min} evaluated from the RBS measurement is also a figure of merit for the crystalline perfection. Fig. 5 shows the χ_{min} as a function of Al fraction x. The χ_{min} increase with increasing Al fraction x, indicating that the crystalline quality of AlGaN on one AlN IL becomes poor with increasing Al fraction x, this is consistent with the result of XRD as shown in fig. 3. Through inserting two AlN IL, the AlGaN films with χ_{min} of 2.0% were obtained and the film is crack-free, indicating the crystalline quality is quite high. The results show that the insertion of two AlN IL is an effective method to grow high quality and crack-free thick AlGaN with high Al fraction x.

4 Conclusions

AlN IL was used to grow AlGaN layers by MOVPE; the effects of AlN interlayer on the improvement of crystalline quality of AlGaN and Al incorporation efficiency in

AlGaN were investigated. AlN IL shows a role of suppressing edge dislocation defect but bring an increase in density of screw dislocation. Crack-free AlGaN films were obtained by inserting two AlN IL. The AlGaN layers are not only relaxed but also compressively stressed by the thin AlN IL.

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Figure captions:

Fig .1 Structure of AlGaN sample: (a) with one AlN interlayer and (b) with two AlN interlayer.

Fig.2 Random ( ), aligned (★), and simulated (solid line) RBS spectra of AlGaN sample with two AlN interlayer.

Fig. 3 FWHM of ?ω-scans around (a): (104), and (b): (002) AlGaN diffraction peak for the samples with and without AlN IL as a function of Al fraction x.

Fig. 4 Relationship between lattice parameter C and a for AlGaN samples grown with and without AlN interlayer

Fig. 5 Yield χ_{min} evaluated from RBS measurement as a function of Al fraction x.

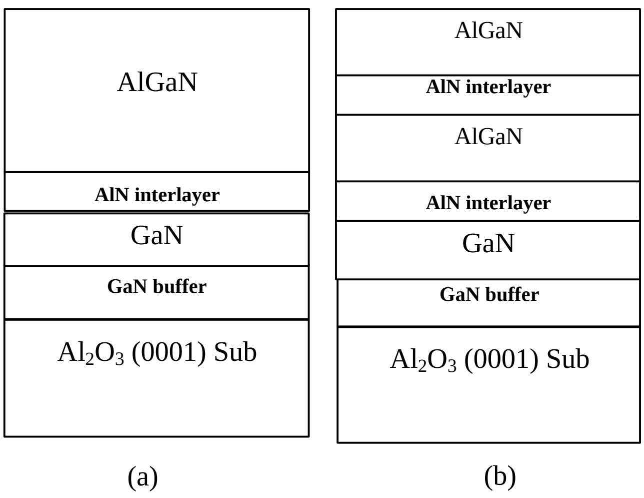
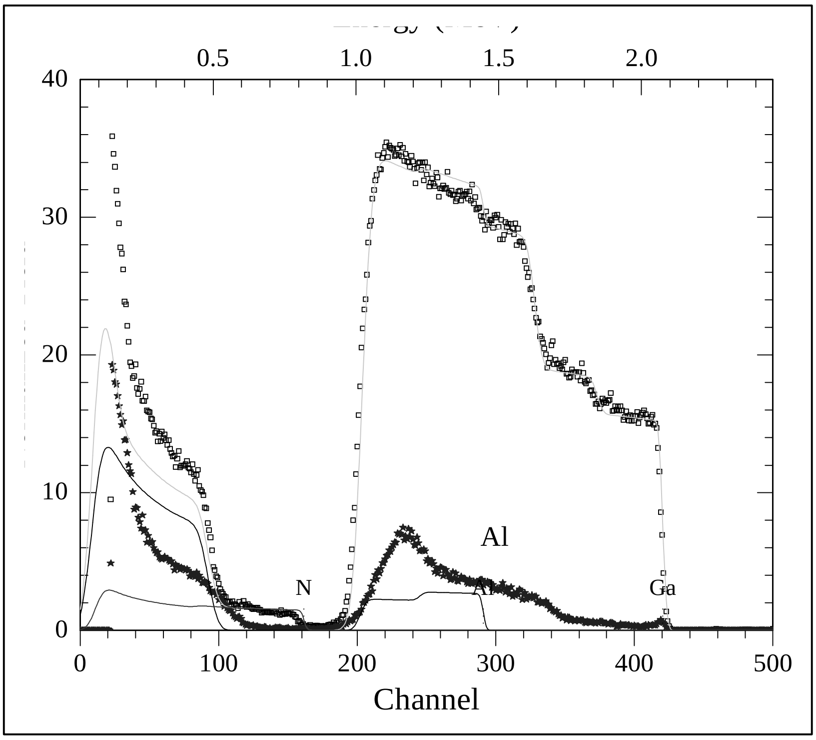


Fig. 1 of Zhixin Qin



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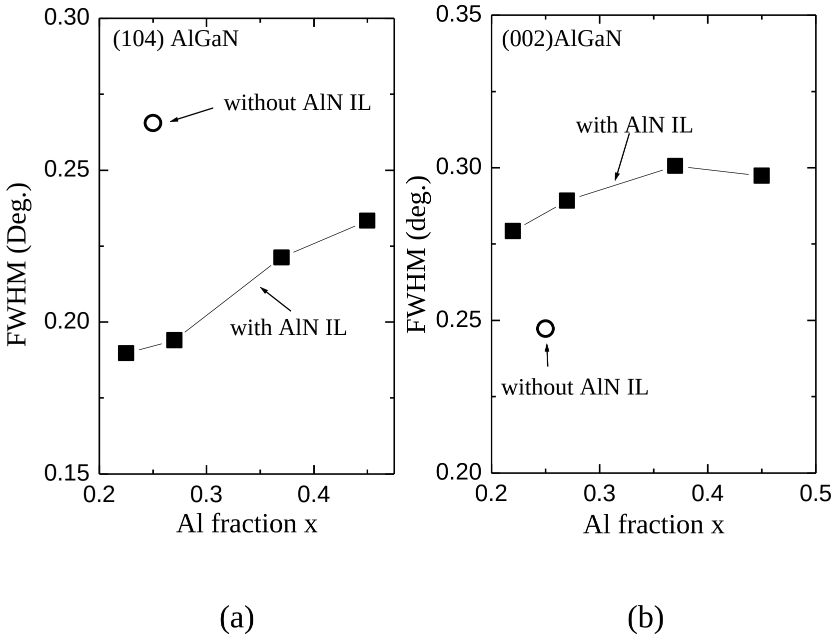

Fig. 3 of Zhixin Qin

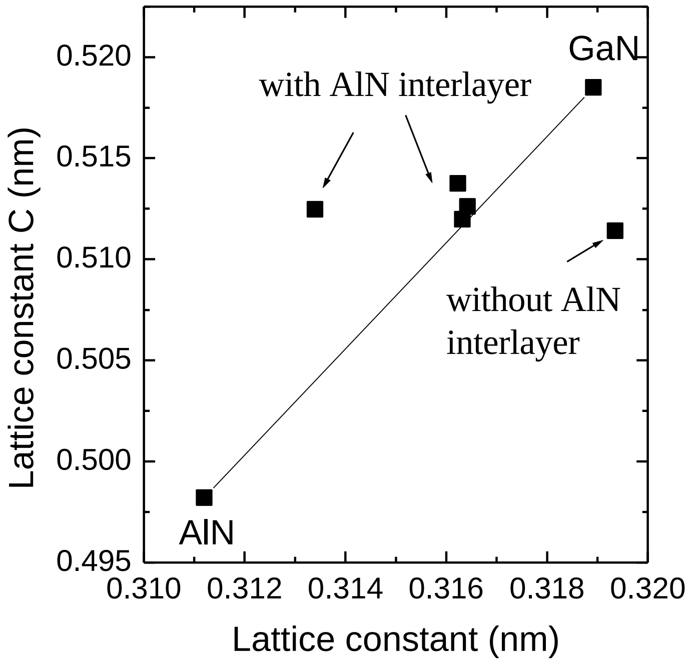

Fig. 4 of Zhixin Qin

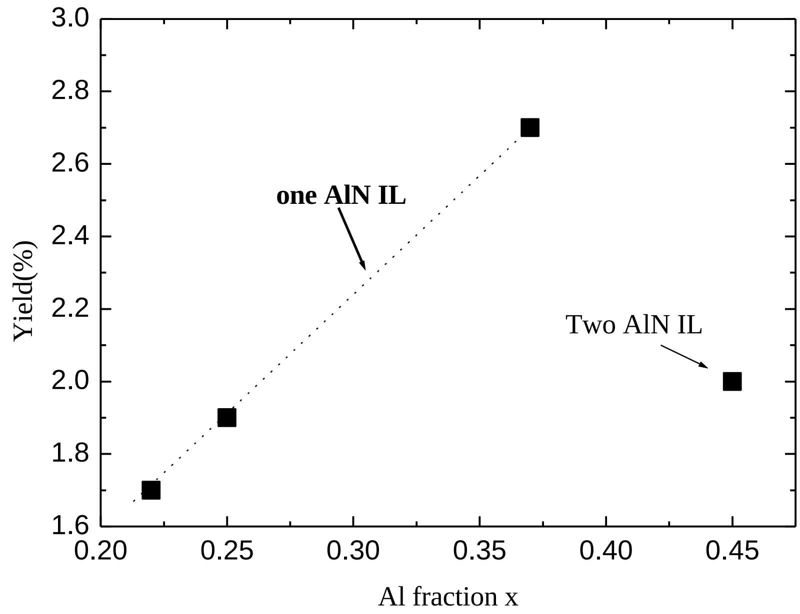

Fig. 5 of Zhixin Qin