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Growth of $GaN/Al_xGa_{1-x}N$ ($x = 0.65$) Superlattices on Si(111) Substrates Using RF-MBE

Armando S Somintac[1]*, Tomo Kikuchi[1], Michiya Odawara[2], Takashi Udagawa[2], Motoi Wada[1], Tadashi Ohachi[1]
(*1. Department of Electric Engineering, Doshisha University, 1-3 Miyakodani, Tatara, Kyotanabe, Kyoto 610-0321, Japan; 2. Electronic Materials Division, Electronics Section, Showa Denko K. K., 1505 Shimokagemori, Chichibu, Saitama 369-1871, Japan*)

Abstract: Superlattices with varying GaN well widths (2, 3, 6, 9 nm) and fixed AlGaN barrier (8 nm) with high Al-content ($x = 0.65$) were grown. Streaky RHEED patterns indicated 2D growth mode for the superlattices. XRD measurements showed multiple satellite peaks corresponding to uniform periodicity of the GaN/AlGaN pairs. The AlGaN barrier XRD peak also shifted with increasing well widths, while the GaN XRD peak was nominally unchanged. Room temperature photoluminescence experiments revealed peak emissions at energies lower than the bulk GaN energy gap. The large red shift with respect to the bulk gap is attributed to significant Stark effect for wide multiple quantum wells.

Key words: molecular beam epitaxy; superlattices; GaN; AlGaN; built-in electric field; stark effect
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Gallium nitride, aluminum nitride and their alloys have enjoyed considerable research attention in these recent years due to their potential applications to optoelectronics and high power and high temperature electronics. There have been much interest in the growth of GaN/AlGaN superlattices because of the wide range of intersubband transitions (ISBT) resulting from various well widths and barrier compositions[1, 2].

In this work, Si (111) substrates were used because they are quite appealing for the development of hybrid devices which hopes to integrate the present silicon technology with the upcoming III-nitride devices. Although large lattice mismatch exists between these two materials, there have been encouraging results when an AlN buffer layer on Si(111) was used for the GaN growth[3,4]. Several wurtzitic superlattices consisting of 40 pairs of GaN and AlGaN with varying well-widths were grown on AlGaN/AlN buffer layers. The superlattices were characterized by RHEED, standard X-ray diffraction and room temperature photoluminescence.

1 Experimental

A VG80H MBE system equipped with an IRFS-501 (Arios, Inc.) rf N * source was used to grow the GaN/AlGaN superlattices. The Si (111) substrates was etched for 1 min in 5% HF solution and rinsed in DI water. The substrate was degassed in UHV at 800 ℃ until a (7 × 7) RHEED reconstruction was observed. The AlN buffer of around 20 nm was grown after simultaneous opening of the shutters of Al cell at 1225 ℃ and the N * rf-source with 440 W. This was followed by the growth of the AlGaN buffer for 8 min to a thickness of about 115 nm. The superlattices consist of 40 pairs of AlGaN (8 nm) and GaN (2, 3, 6, 9 nm) thicknesses. The samples were capped with 30 nm GaN. The schematic diagram of the samples is given in Fig. 1(a).

2 Results and Discussion

During the degassing of the Si(111) substrate at 800 ℃, the (7 × 7) reconstruction pattern was observed. This RHEED pattern was considered to be favorable for the growth of 2D growth of AlN. This was confirmed by the RHEED taken during the growth of AlN which was semi-streaky. At the start of the AlN growth, the RHEED pattern started with diffused spotty pattern but it immediately transformed into semi-streaky pattern indicating 2D nucleation. The RHEED

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Biography: Armando S Somintac (1972 -), Male, Doctor
Corresponding author (E-mail: somintac@eml.doshisha.ac.jp)

pattern improved and intensified during the deposition of AlGaN. This clearly suggests a good quality underlayer for the superlattices. The streaky pattern would then persist during the growth of the alternating GaN and AlGaN layers. The last RHEED taken was that of the GaN cap layer consisting of very sharp streaks. This is a good sign that the underlying superlattice indeed is of good crystal quality. The RHEED sequence is shown in Fig. 1(b).

Superlattices of various well widths were grown on AlGaN / AlN buffer layers on Si (1 1 1) substrates. For reference, a bulk sample containing only the AlGaN/AlN buffer and GaN cap layers was also grown. The XRD data taken from the superlattices and the bulk sample is shown on Fig. 2. The Al mole-fraction used for all samples was approximated to be about $x = 0.66$ from Vegard's law using the data from the bulk sample.

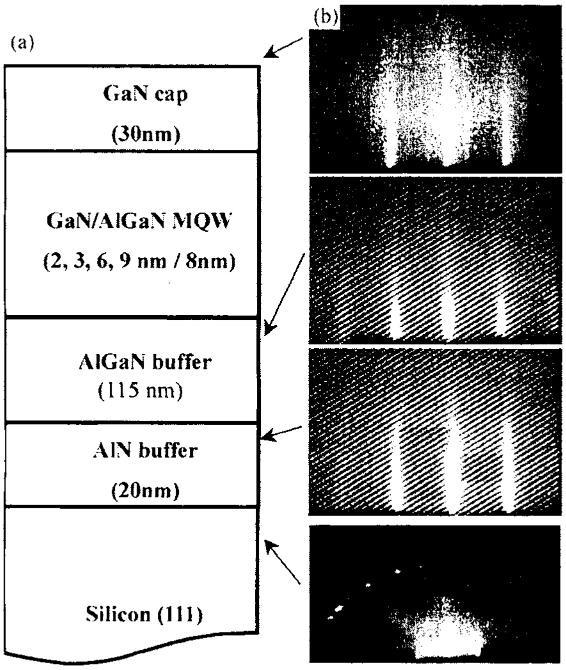

Fig. 1 Schematic diagram of superlattices (a); RHEED sequence (bottom to top): (7 × 7) reconstruction of Si (111), from the AlN and AlGaN buffer layers and the topmost RHEED came from the GaN cap (b)

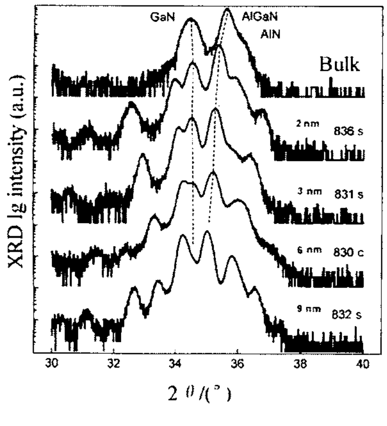

Fig. 2 Standard XRD measurements from the superlattices with varying GaN well width. For clarity the log-plots were shifted vertically. Samples were labeled 835S (no superlattice), 836S(2 nm), 831S(3 nm), 830C(6 nm) and 832S(9 nm)

As shown in Fig. 2, the satellite peaks observed for the superlattices indicates good uniformity in the periodicity of the GaN and AlGaN pairs. It should also be noted that the GaN XRD peaks for the superlattices remain nominally the same as the bulk sample without superlattice. The AlGaN peaks of the superlattices shift away from the bulk sample as the well width increases. This suggests that the thickness of the AlGaN buffer might not have been sufficient to relieve the stress transferred from the Si(111) and AlN interface. Further studies on the effect of the AlGaN buffer thickness will be carried out to elucidate this observation.

The room temperature PL spectra for the superlattices used for this work are given in Fig. 3. The PL peaks are all found to be lower than the bulk energy gap of GaN at 3.42 eV. Further, the band offset ratio for these superlattices were found to be 66:33 which is in agreement with those found by Hang et al[5]. Generally, quantum well PL peak emissions appear above the bulk energy gap and shifts towards lower energy with increasing well widths. However, for the GaN/AlGaN quantum wells, the emission peak can go lower than bulk gap particularly for c-plane MQWs[6]. This large red-shift was attributed to the Stark effect caused by high electric fields found in strained superlattices. The high Al mole fraction, $x = 0.65$ used for these superlattices, could generate high electric fields, following from the observation made by Grandjean et al[7].

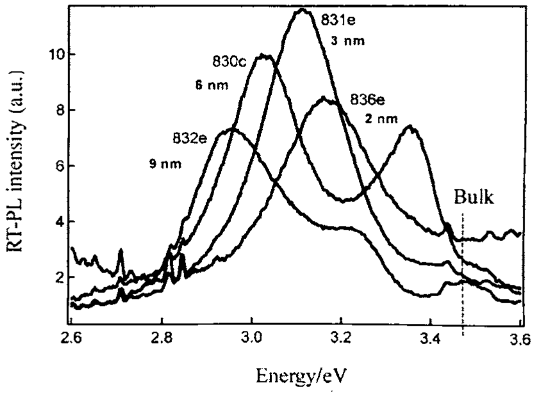

Fig. 3 Room temperature PL of superlattices with peak emissions lower than the bulk GaN energy gap (This is consistent for wide MQWs with high Al content. High Al-mole fraction generates strong electric fields causing significant Stark effect)

The slight shifting of the AlGaN XRD peaks with increasing GaN widths, as shown in Fig. 2, is a manifestation of the strain found in the superlattices. Granjean et al also showed that the GaN/AlGaN ($x < 0.3$) well width smaller than 30A is required to obtain PL emission higher than the bulk energy gap. This limit could not be ascertained at the moment due to the inherent difficulty of growing high quality thin GaN quantum wells with relatively barriers composed of large Al-mole fractions ($x = 0.65$) on Si(111) substrates. The nature of the secondary peaks found in the wider quantum well samples 832(6 nm) and 830(9 nm) remain undetermined and warrant further study.

3 Conclusion

GaN/AlGaN superlattices with high Al-content ($x = 0.65$) were successfully grown. The superlattices have the same AlGaN barrier thickness but different GaN well widths. The RHEED patterns were streaky which indicated 2D growth. Standard XRD measurements revealed multiple satellite peaks corresponding to uniform GaN/AlGaN periods. Room temperature photoluminescence peaks were all lower than the bulk GaN energy gap. Such large red shift with respect to the bulk gap is attributed to significant Stark effect for wide multiple quantum wells.

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