CONTENTS

Abstract (Chinese) ...........................................................................................................i
Abstract (English) ........................................................................................................... ii
Acknowledgment .............................................................................................................iv
Contents ............................................................................................................................ v
Table Captions ................................................................................................................viii
Figure Captions ............................................................................................................... ix

Chapter 1

Introduction ....................................................................................................................... 1
1.1 Research Background of the Group III-Nitrides ..........................................................1
1.2 Organization of this thesis ......................................................................................... 4

Chapter 2

Experimental Techniques ............................................................................................ 11
2.1 Molecular beam epitaxy (MBE) system ................................................................... 11
2.2 Material Characteristic Analysis .............................................................................. 12
2.2.1 High Resolution X-ray Diffraction (HRXRD) ...................................................... 12
2.2.2 Field emission scanning electron microscopy (FESEM) ...................................... 13
2.2.3 Photoluminescence (PL).................................................................................................................14
2.2.4 Atomic Force Microscopy (AFM)........................................................................................................14

Chapter 3

GaN Epitaxy Growth on Sapphire (0 0 0 1) Substrates.......................................................17
3.1 Introduction.........................................................................................................................................17
3.2 Growth procedure of the GaN epitaxy layer on sapphire.........................................................18
3.3 Characteristics of the GaN epitaxy layer on sapphire..........................................................19
3.4 Summary..........................................................................................................................................23

Chapter 4

GaN Epitaxial Growth on Silicon (1 1 1) Substrates...............................................................36
4.1 Introduction.......................................................................................................................................36
4.2 Growth procedure of the GaN epitaxial layer and nanorods on Si (1 1 1)..........................37
4.3 Characteristics of the GaN epitaxial layer and nanorods on Si (1 1 1).................................39
4.4 Summary.......................................................................................................................................45

Chapter 5

Conclusions..........................................................................................................................................68
Table Captions

Chapter 1

Table 1-1 Parameters of III-nitrides and some substrates

Chapter 3

Table 3-1 The growth parameters of GaN epitaxy layer with various nitridation temperatures.

Chapter 4

Table 4-1 The growth parameters of GaN on Si with AlN/α-Si₃N₄ buffer structure

Table 4-2 The growth parameters of self-assembled GaN nanorod growth
Figure Captions

Chapter 1

Fig. 1-1 Bandgap and lattice constants of III-nitrides (solid rectangles). Effective lattice constants considered as substrates for hetero-epitaxy of III-nitrides are also shown (hollow circles).

Fig. 1-2 Electron drift velocity at 300 K in GaN, SiC, Si and GaAs computed using the Monte Carlo technique.

Fig. 1-3 Schematic drawing of the crystal structure of wurtzite Ga-polarity and N-polarity GaN.

Chapter 2

Fig. 2-1 The system description of this ULVAC MBE.

Chapter 3

Fig. 3-1 SEM surface morphologies of GaN on (a) non-nitrided sapphire, (b) nitrided sapphire and (c) after 2M KOH etching for 30min.

Fig. 3-2 Symmetric (0 0 0 2) (top figure) and asymmetric (1 0 1 2) (bottom figure) rocking curve of GaN epitaxy layer on nitrided and non-nitrided sapphire.

Fig. 3-3 Real time RHEED pattern for nitridation on sapphire at 200°C, 500°C and 800°C.
along the \(<1 1 i 0>\) azimuth.

Fig. 3-4 FWHM of the x-ray rocking curve for the symmetric \((0 0 0 2)\) and asymmetric \((1 0 i 2)\) diffraction of GaN on different nitridation temperature sapphire.

Fig. 3-5 AFM image of AlN buffer layer on the (a) \(800^\circ \text{C}\) and (b) \(200^\circ \text{C}\) nitrided sapphire.

Fig. 3-6 The schematic diagram of AlN-IL inserted in GaN.

Fig. 3-7 FWHM of the x-ray rocking curve for the symmetric \((0 0 0 2)\) and asymmetric \((1 0 i 2)\) diffraction of GaN epilayer with various growth time of AlN-IL.

Fig. 3-8 SEM surface morphology of the GaN with various growth time of AlN-IL.

Fig. 3-9 PL spectra (linear scale) of the GaN with various growth time of AlN-IL. The inset is the PL spectra (log scale) of the GaN with various growth time of AlN-IL, which normalize to neutral-donor-bound exciton \((D^0X)\) peak.

Fig. 3-10 Symmetric \((0 0 0 2)\) (top figure) and asymmetric \((1 0 i 2)\) (bottom figure) rocking curve of GaN epityax layer on \(1.0^\circ\)-off cut and no-off cut sapphire.

Fig. 3-11 FWHM of the x-ray rocking curve for asymmetric \((1 0 i 2)\) diffraction as function of c-axis lattice constant of GaN.

Chapter 4

Fig. 4-1 schematically depicts the growth procedure of GaN epilayer on Si \((1 1 1)\) by using simultaneous AlN/\(\alpha\)-Si\(_3\)N\(_4\) buffer structure.
Fig. 4-2 Schematic diagrams of the overgrown GaN on self-assembled GaN nanorods

Fig. 4-3 The RHEED pattern of (a) the Si (1 1 1) 7x7 surface, (b) to (d) 15s, 30s, 45s Al pre-seeding layer deposition, (e) AlN w/o Al pre-seeding layer after 600s growth, (f) AlN with 45s Al pre-seeding layer after 600s growth and (g) the streaky (1×1) GaN RHEED pattern (45s Al pre-seeding layer).

Fig. 4-4 FWHM of the x-ray rocking curve for the symmetric (0002) diffraction of GaN epilayer layer with various deposition time of Al pre-seeding layer.

Fig. 4-5 XRD in the θ-2θ scan mode obtained from a GaN with α-Si₃N₄/AlN buffer structure on Si (1 1 1) substrate (45s Al pre-seeding layer).

Fig. 4-6 SEM surface image of the GaN epitaxial layer on Si (1 1 1) with AlN/α-Si₃N₄ structure (45s Al pre-seeding layer), (a) plane view and (b) cross-section view.

Fig. 4-7 Symmetric (0 0 0 2) and asymmetric (1 0 1 2) diffraction x-ray rocking curve of GaN epitaxial layer on Si (1 1 1) with AlN-IL (45s Al pre-seeding layer).

Fig. 4-8 PL of the GaN epitaxial layer on Si (1 1 1) with AlN-IL (45s Al pre-seeding layer) measured at 13K.

Fig. 4-9 SEM images of the self-assembled GaN nanorod grown on Si (1 1 1). Plan view and cross-section view of (a) Sub. Temp.=750 °C (b) Sub. Temp.=800 °C (c) Sub. Temp.=850 °C (d) Sub. Temp.=900 °C.

Fig. 4-10 The RHEED pattern along the <1-100> azimuth (Top pattern) and <2-1-10>
azimuth (Bottom pattern) during the GaN nanorod growth of

(a) Sub. Temp.=750 °C  (b) Sub. Temp.=800 °C  (c) Sub. Temp.=850 °C

(d) Sub. Temp.=900 °C

Fig. 4-11 Dependence of the GaN nanorod density and diameter on the growth temperature.

Fig. 4-12 The height of GaN nanorods as function of the growth temperature.

Fig. 4-13 SEM images of the self-assembled GaN nanorod grown on Si (1 1 1). Plan view and
cross-section view of the BEP of (a) Ga=2.8×10^{-8}torr  (b) Ga=7.1×10^{-8}torr

(c) Ga=2.0×10^{-7}torr  (d) Ga=3.6×10^{-7}torr.

Fig. 4-14 XRD in the $\theta$ -2 $\theta$ scan mode of self-assembled nanorods in growth
temperature=850°C.

Fig. 4-15 PL spectra of the GaN nanorods with different (a) V/III ratio and (b) growth
temperature.

Fig. 4-16 The RHEED pattern along the <1-100> azimuth (Top pattern) and <2-1-10>
azimuth (Bottom pattern) of (a) GaN nanorods, and (b) overgrown GaN.

Fig. 4-17 SEM images of (a) MBE-overgrown and (b) MOCVD-overgrown GaN on
self-assembled nanorods. After 2M KOH etch of (c) MBE-overgrown and
(d) MOCVD-overgrown GaN.

Fig. 4-18 XRD in the $\theta$ -2 $\theta$ scan mode of (a) MBE-overgrown and
(b) MOCVD-overgrown GaN on the nanorods.
Fig. 4-19 PL spectra (linear scale) of the (a) MBE-overgrown and (b) MOCVD-overgrown GaN on self-assembled GaN nanorods. The insets are the PL spectra (log scale) of the overgrown GaN.