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科研費
KAKENHI

科学研究費助成事業　　研究成果報告書

令和　元 年　６ 月　６ 日現在

機関番号：１１１０１
研究種目：基盤研究(A)（一般）
研究期間：2014～2017
課題番号：２６２４６０１５

研究課題名（和文）層状BNを用いたGaN系デバイスの機械的転写

研究課題名（英文）Mechanical transfer of GaN-based devices using layered BN

研究代表者
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交付決定額（研究期間全体）：（直接経費）　29,500,000円

研究成果の概要（和文）：我々は、プラズマ支援分子線エピタキシーにより(0001)サファイア基板上の3nmの膜厚の六方晶窒化ホウ素(h-BN)上に成長した100nmの膜厚のAlNバッファ層上に単結晶GaN薄膜を成長した。このh-BN/AlNバッファ層上に成長したGaN薄膜のX線回折は、h-BN層上のAlN層がGaN薄膜の結晶性を著しく向上させることを明らかにした。GaN薄膜のストリークな反射高速電子回折パターンは、平坦な表面を有する単結晶(0001) GaN薄膜がこのh-BN/AlNバッファ層上に成長したことを示した。MBEは、h-BNバッファ層上に高品質GaN薄膜を成長する手法として有望である。

研究成果の学術的意義や社会的意義
六方晶窒化ホウ素(h-BN)バッファ層上にGaN系デバイス構造を成長し、h-BNを剥離層としてそのGaN系デバイス構造を機械的に転写することが可能であるが、h-BNとGaNヘテロ成長のミクロスコピックな成長機構はほとんど解明されていない。本研究は、分子線エピタキシー法により、平坦で原子レベルで膜厚制御されたh-BNバッファ層を実現し、そのh-BN上にAlNバッファ層を導入することにより、単結晶(0001)GaN薄膜が成長することを見出した。これらの知見は、そのヘテロ成長機構を解明することに貢献し、高品質な機械的転写可能なGaN系デバイス構造の実現につながり極めて重要である。

研究成果の概要（英文）：We grew single-crystal GaN films on 100-nm-thick AlN buffer layers that were grown on 3-nm-thick hexagonal boron nitride (h-BN) buffer layers on (0001) sapphire substrates with plasma-assisted molecular beam epitaxy (MBE). X-ray diffraction for the GaN film revealed that the AlN layer on the h-BN layer enabled the crystalline quality of GaN film on it to be greatly improved. Streaky reflection high energy electron diffraction pattern for the GaN film indicated that the single crystal (0001) GaN thin film with a flat surface was grown on the AlN/h-BN buffer layer. MBE has a promising as the growth technology for high-quality GaN thin films grown on the h-BN buffer layers.

研究分野：工学

キーワード：半導体　結晶成長　半導体物性

' A≠7D≠7 ≠ X≠7 A1≠7 3B

≠2%6abû

(1) GaN (ĉ7)

/KZ¥Z8¶ GaN (ĉ4§ SiC ö

Si ... (MOVPE) ...

órSc... GaN

(ĉ4B6...

2bm2@LIZ8@bm2 cb...[Û@

0[b8CXDe8I wKZ8bSub/...[0N

rSÛ... ¥8M/...Z8S

(2) ...(ĉ4bE(ò (h-BN)...B

6... 2007 ″

AZM Ni (111) ... h-BN ... 2008 ″

A^YZwM§ V_ h-BN -...bMG0b

KSb)0 2012 ... h-BN 2x-...V_ GaN (ĉ4

B6...6G0E h-BN d7KZb GaN (ĉ4§

...

( ) m2 m2 ...

...

9...

Cc 2012 ″ h-BN @ GaN (ĉ S4 b...d7KZMG\

...bKS ( ) ...

(1) ()z... (MBE) 2 ... h-BN 2x-...B6×

#[_ MOVPE 2... h-BN -...B6...AZ8K^

... MOVPE 2... h-BN -...B6...Nq[6...

[... h-BN bN... ...bwLD...

[6...8I@ MBE 2cNq[6...

...8G... h-BN -...bN...bwLD@ MOVPE B6...ZB6×

... (RHEED) B6...b0@

...wM MBE 2... h-BN 2x-...B6...wLN

...DM

(2) MBE 2... h-BN V GaN -...B6...b0´

... h-BN V GaN -...bB6...c GaN -...pb3...Z3?

...S8J pMK...B6...co}0[6

MBE 2...Z... h-BN V_ GaN -...B6...B6...0M

... h-BN 2x-...bwL@ h-BN 2x-...Vb GaN -...b)...8D´

M

(3) MBE 2... h-BN V GaN -...b 9...Aì

MOVPE 2...Z... h-BN V B6...KS GaN -...b)...[6~

) GaN -...MG...T7[6WSbSu... h-BN V _ AlN

µ ... h-BN/AlN ´ ...M_ GaN ")-...KS MBE 2 ...

..._ h-BN 2x-...B6...b h-BN V_ AlN ´ ...6K ...

h-BN/AlN ...M_ GaN -...B6...MG... GaN -...b9...AK3...&

...

...2...

h-BN GaN AlN -...c... MBE ...)g8... (0001) ..._

B6KS B KZ[/ B ...[/ B b/...c 2000 ¥[6Su7...n%

... B ...KS Ga Al bNqb)...(...)z -h$Y

KZ... ¥...@/ B b/...c 2000 ¥[6Su...

6...T7[6...Su7...n...S E(òKZ E(ò Û

...ZN...bE(...KS BN bB6... MBE /...

bwL0...[..._ h-BN B6× X)zoU...

8 h-BN wL0ûK... h-BN b/8...6...§~ (AFM)

...Z0ûK h-BN bû...i (... ...e¥ (FTIR)

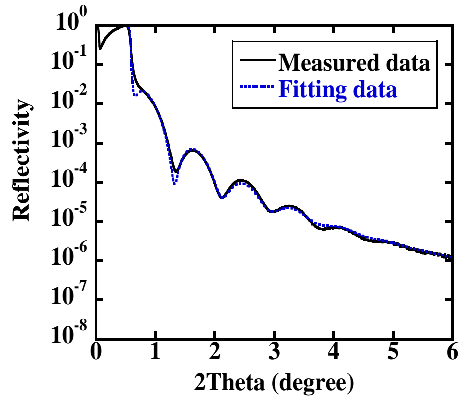
GaN AlN
b Ga Al Nq Ga Al Nq
h-BN Vb GaN AFM GaN Rigaku b
X Smart Lab

(1) MBE h-BN 2x
W 1 (0001) 950 BN X
5 Gb X MBE BN

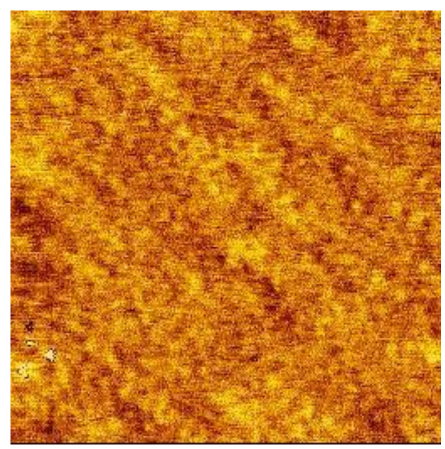
X
BN
X
BN
2.3 3.98 g/cm^3
X 1
X
BN
11 nm Gb BN
BN
BN 2θ/ω X
BN 11 nm BN 4

BN
BN BN X
2 Gb X 1
BN 3 nm MBE 2
11 nm BN
MOVPE 2 BN

MBE DISu BN
BN
W 2 11 nm BN 5 5 μm^2 AFM AFM
BN root mean square (RMS)
c 0.08 nm MBE BN 1
X 5 MBE
3 nm b AFM RMS
0.16 nm AFM RMS 1 nm
BN MBE 3
nm 11 nm BN 3
11 nm b BN 300 nm

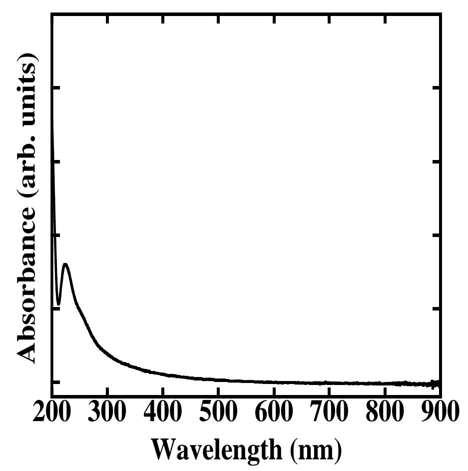


W 1 BN
X



0.6 nm

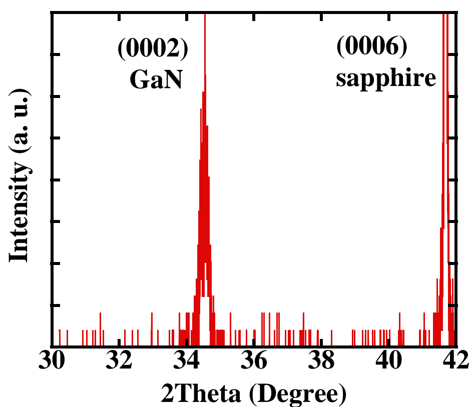
W 2 BN
AFM (5 5 μm²)



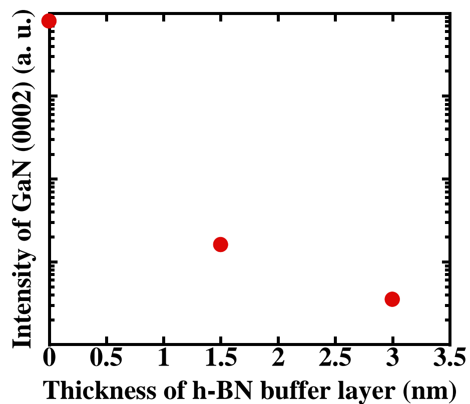
W 3 BN

h-BN
/b Ð 5.9-5.955 eV [6G KZ8WZ 300
nm Wb6E ÐQ c h-BN bå Ð 3
8Z6x 225 nm Ð{ IGb c h-BN bÉ.
P4D KCc}2s D 6Z8
BN -φ b Û ÿOMSu MBE B6KS wL 11 nm b BN -φ
b FTIR ÝKS Ð BN -φc 1375 cm^{-1}\ 1330cm^{-1}_ 2 Xb Ð
KSGb 1375 cm^{-1} b c sp^{2}) B-N b in-plane stretching [6
§I8 sp^{2}) B-N-B b out-of-plane bending b 800 cm^{-1}Ü
3b O{MG AWSO{IS 1330 cm^{-1} b c
BN b B-N)2sIN _ MBE B6KS BN -φc
(1 1)b Ð RHEED KSGb (1 1)b RHEED aoUIØ
E8@ MBE / Z Ni(111)ØB6KS h-BN -φb RHEED a
(1 1) 6WS Gb FTIR Ý RHEED MBE (0001)
§_ h-BN 2x-φB6KSG KZ8
Vb§_ MBE B6KS BN -çwb X)zoU E AFM(i
Ý FTIR Ý RHEED a 3 nm ? 11 nm bwLwM^ sp^{2})w
M h-BN 2x-φ B6KSG KZ8

(2) MBE 2§ h-BN V GaN -φB6 6 b0´
(1)[03 S MBE 2 (0001)§ X2x-φb h-BN ´
6K SbSu_ Ð h-BN µ_ GaN -φB6KS GaN
-φB6 P[KSöØ 800¥6~ h-BN 6 öØ
c 1000¥6 GaN -φbwLc 300 nm [6~ h-BN b wLc 1.5 nm \ 3 nm
[6 rS3bSu_ (0001)§öØ 1000¥Eì h-BN µ
K 300 nm bwLb GaN -φB6K h-BN VB6KS GaN -φ\ 3KS
(0001)§_ h-BN B6KS GaN -φc RHEED 0 \ X)z
G¡? (0001)') GaN -φ [6WS W 4 _ wL 1.5 nm b h-BN µ_ MBE
B6KS GaN -φb 2θ/ω X)zG M§ h-BN µ MOVPE _
B6KS GaN -φb X)zG GaN(0002) G GaN -φ[6
WS 4 M 1.5 nm bwLb h-BN µB6KS GaN -φb X)zG
ç GaN(0002)Gbs K MBE B6x GaN -φc h-BN µ_ c 3H4 ZB6x
KZ8G S MOVPE B6 öØ (1000¥)\ MBE B6 öØ (800¥)b@
Gb GaN -φb) 48 I 0SK @ 1.5 nm wLb h-BN
VB6KS GaN -φb GaN(0002)G¡ _ h-BN K B6KS
GaN -φb GaN(0002)G¡ Z--KCöKS 3 nm wLb h-BN µ_
B6KS GaN -φb X)zG GaN(0002)Gbs K GaN -φc 3 nm bwLb
h-BN µ c 3H4 ZB6 Z8G SK Ð GaN(0002)G
¡Ø 1.5 nm wL h-BN VB6KS GaN -φbG¡ Z I öKS
W 5 c§ h-BN µB6KS GaN -φb GaN(0002)X)zG¡Ø
h-BN µwLk b§_ h-BN B6KS
GaN -φb X)zG¡Ø (h-BN wL@ 0 PKZ8) KZ h-BN µ
LbQ GaN -φb X)zG¡Ø-KCöKZ8 1.5 nm \ 3 nm b h-BN



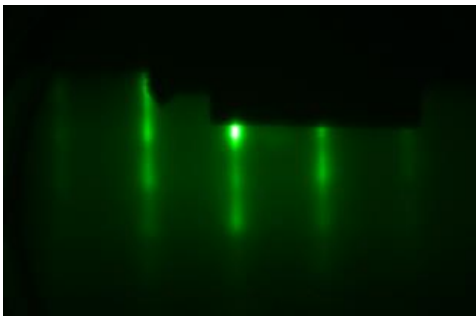
W 4 §wL 1.5 nm b
h-BN -φV GaN -φb 2θ/ω X)zG¡



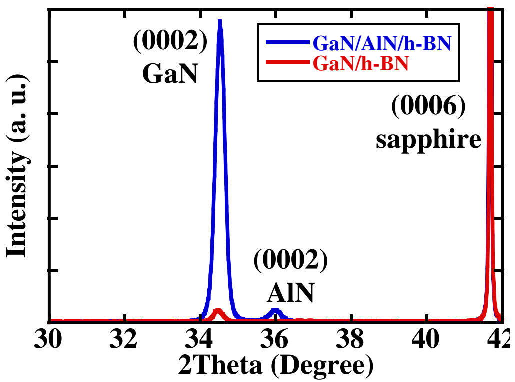
W 5 BN -φV GaN -φb (0002)X)zG
¡Ø b h-BN wLk

GaN -φb AFM @U圓圓圓KS M§
ʊ_ h-BN 圓圓B6kS GaN -φb AFM 圓8Ô
圓KSG圓)Ý h-BN µ bwLΩΩG圓Z GaN -ç
wb)ö ì K/8圓Y8圓圓
圓G\ 圓KZ8 MOVPE B6圓Z) GaN -φ@ h-BN 圓B6k
S AlN vKCc AlGaN V圓6kZ8Gὶ圓Z> MBE B6圓Zv]_
h-BN 圓_ AlN 圓6k圓 h-BN/AlN 圓_ GaN -φB6×
MG圓Z GaN -φb/8圓圓Ι E

(3) MBE 2圓 h-BN V GaN -φb92Ai
(2)[03圓S圓 MBE 2圓 h-BN 圓B6kS GaN -ç
wb)ö h-BN 圓Lb圓--KCM GaN -φb)圓M
Su MBE 圓 h-BN µ Vb GaN B6圓Z h-BN µ
V_ AlN 圓Gb h-BN/AlN 圓_ GaN -φB6kS
MBE 圓 (0001)圓L 3 nm b h-BN 圓 h-BN VwL 100 nm b
AlN 圓Ø 1000圓B6k圓Ø 800圓wL 350 nm b GaN -φ
B6kS E(圓 350 W [6~ h-BN \ GaN -φB6kE(ὺ5c 1.6 sccm
(standard cubic centimeter per minute)[6~ AlN 圓6kE(ὺ5c 0.4 sccm
[6 rSLB6圓 (0001)圓 h-BN(wL 3 nm)V_ AlN µ
K[wL 350 nm b GaN -φB6kS W 6 c h-BN/AlN 圓B6kS GaN -φ
b B6×E RHEED 圓6 (1 1)b圓(l
h-BN/AlN 圓 GaN -φ圓6kSG圓KZ8 K圓
圓cC圓KZ> 8börT(
[c8M h-BN 圓B6kS GaN -φb RHEED 圓Ü
圓l圓S GbG圓 h-BN/AlN b圓 GaN -φ
圓圓6kSG圓KZ> GaN -φb)圓8„
圓-KC圓KSG圓KZ8
W 7 c h-BN/AlN \ h-BN 圓B6kS GaN -φb 2θ/ω X)zG¡6 h-BN
圓B6kS GaN -φ圓 (0006)sapphire G圓
W 4]_ GaN(0002)bG圓_ c 3H4圓S GaN -φ圓6×
KZ8G圓KZ8 h-BN/AlN 圓B6kS GaN -φc圓
þ (0006)sapphire G圓 GaN(0002) AlN(0002)bG圓(lSG?
} GaN AlN sapphire b圓c [0001]GaN//[0001]AlN// [0001]sapphire
b6l[6G圓S h-BN b w Lc 3 nm 圓Z-圓Su X)圓E
0{圓 W 7 8Z 圓 GaN(0002)ˇ]Ø h-BN V _ AlN µ
K圓B6kS GaN -φ b GaN(0002)î l圓Z--KC圓Z8G
c h-BN 圓 b AlN 圓@ GaN -çwb)圓C圓lOG\
圓KZ8 Gb圓 W 6 b RHEED ˆ 圓 W 7 b X)zGþ)Ý h-BN/AlN ´
圓B6kS GaN -φc圓圓6圓G圓 W
S



W 6 h-BN/AlN 圓B6k
S GaN -çwb RHEED 圓



W 7 h-BN/AlN \ h-BN圓_
B6kS GaN -φb X)zG¡

圓※
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