张荣，谢自力，韩平，修向前，刘斌，
孔洁莹，刘成祥，郑有

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Group	1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period																			
1	1 H																		2 He
2	3 Li	4 Be												5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg												13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca		21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr		39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Uun	111 Uuu	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
*Lanthanoids			*	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb		
**Actinoids			**	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No		

Si Ge

GaAs InP

LED LD

SiC

LED LD

1 (1.9-6.2 eV)

GaN (3.4 eV)
InN (1.9 eV,0.7eV)
AlN (6.2 eV)
InGaN (1.9 - 3.4 eV)
AlGaN (3.4 - 6.2 eV)

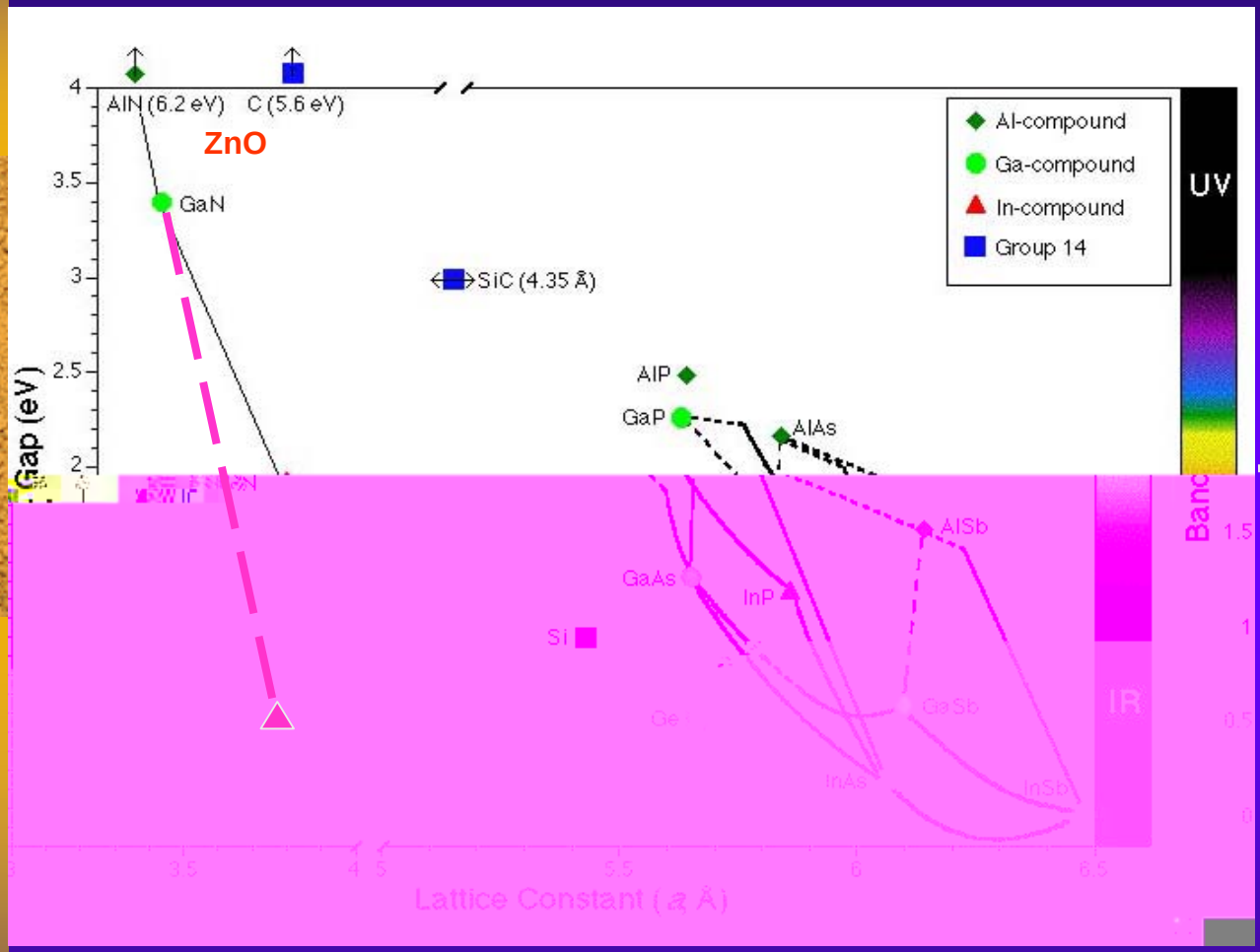
2 ZnO (2.8 - 4.0 eV)

ZnO, ZnMgO, ZnCdO

3)

SiC (2.4-3.1 eV)

(5.5 eV)


AlN (6.2 eV)
C (5.6 eV)
ZnO
GaN
SiC (4.35 Å)
Al-compound
Ga-compound
In-compound
Group 14
UV
AlP
GaP
AlAs
AlSb
GaAs
InP
Si
Ge
GaSb
InAs
InSb
IR
Band Gap (eV)
Lattice Constant (a, Å)

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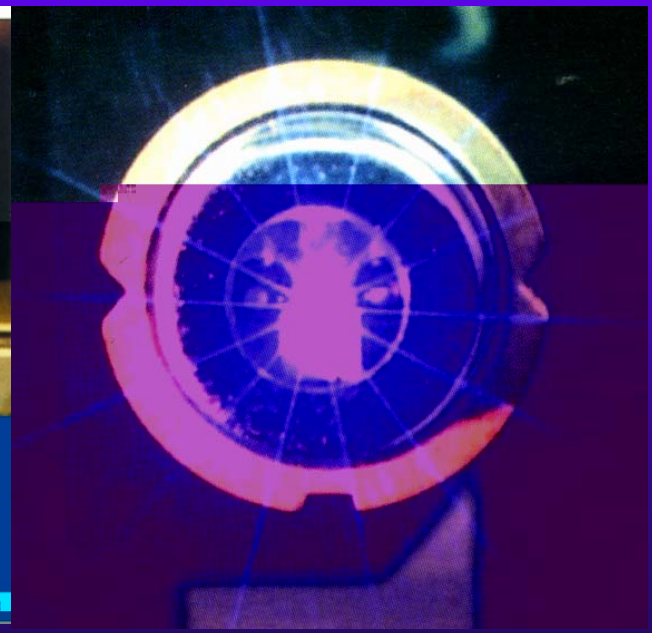
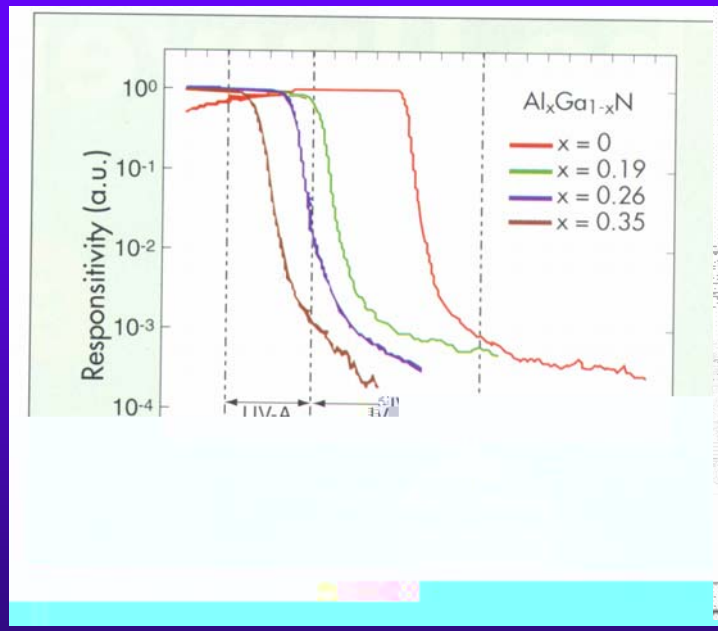
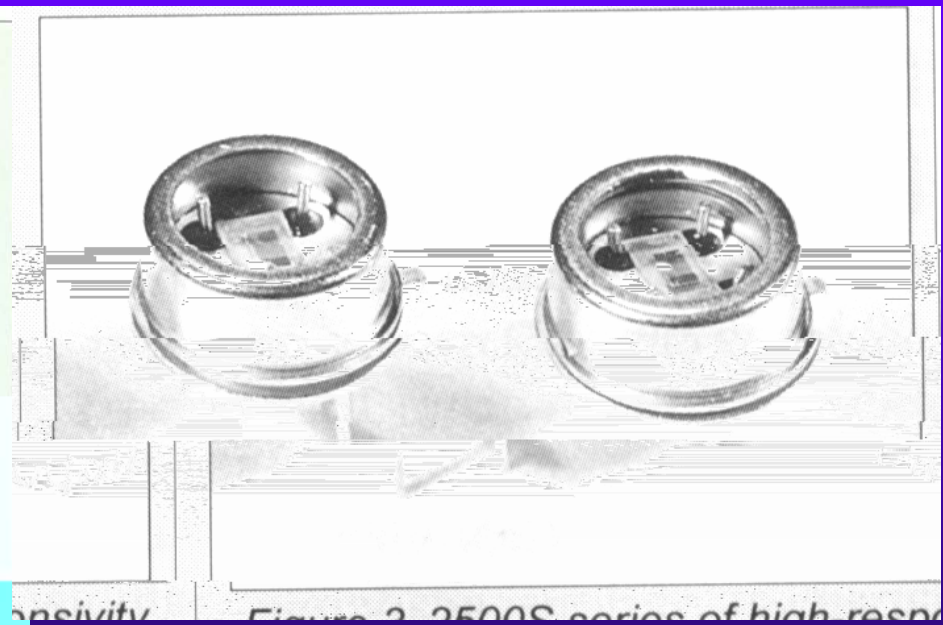
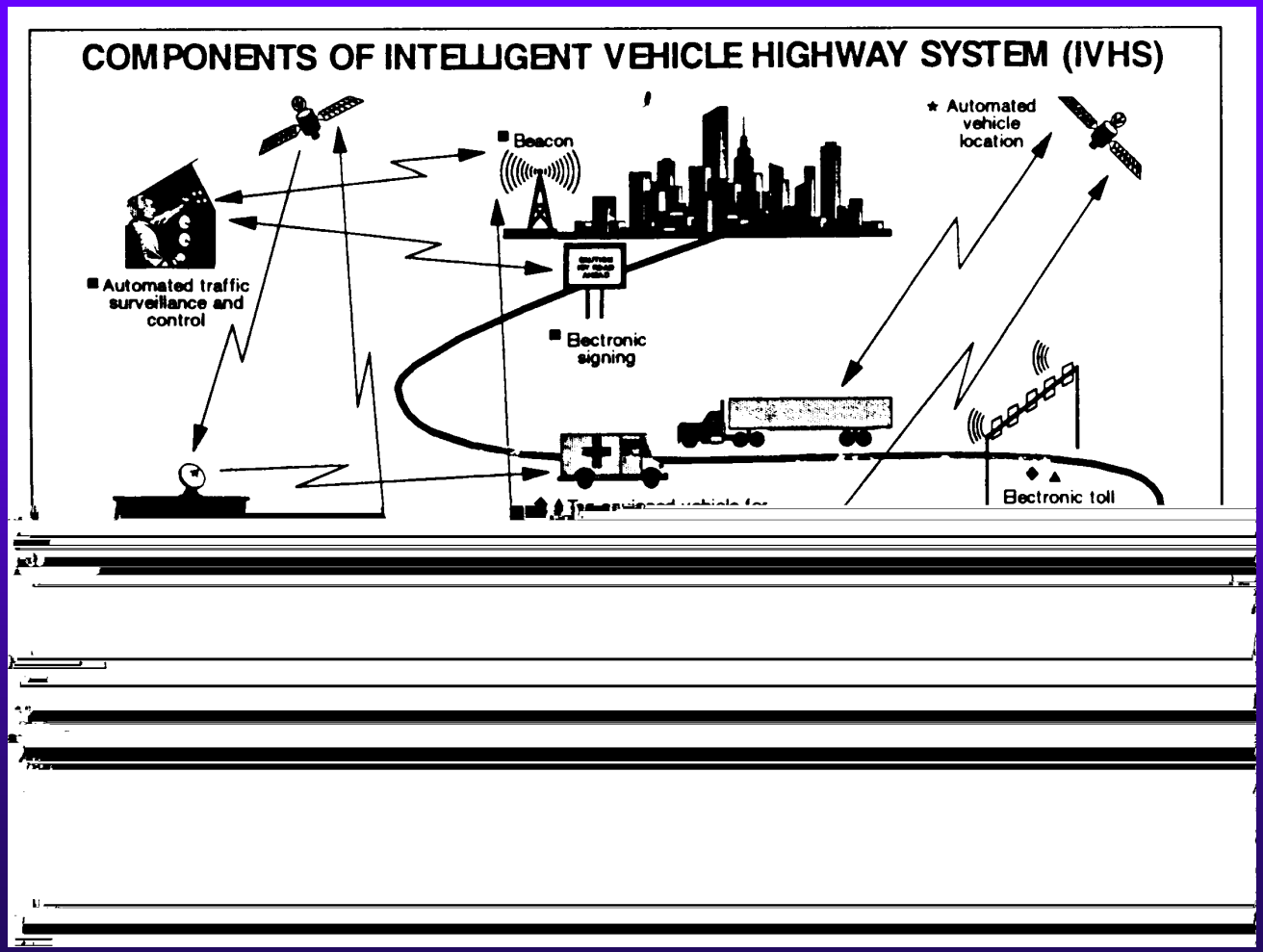
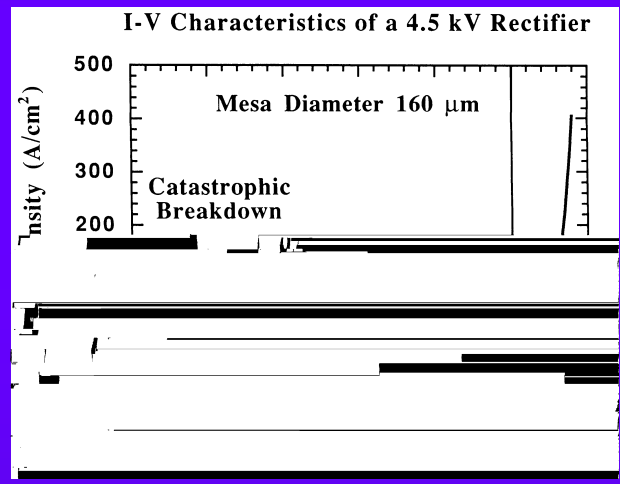
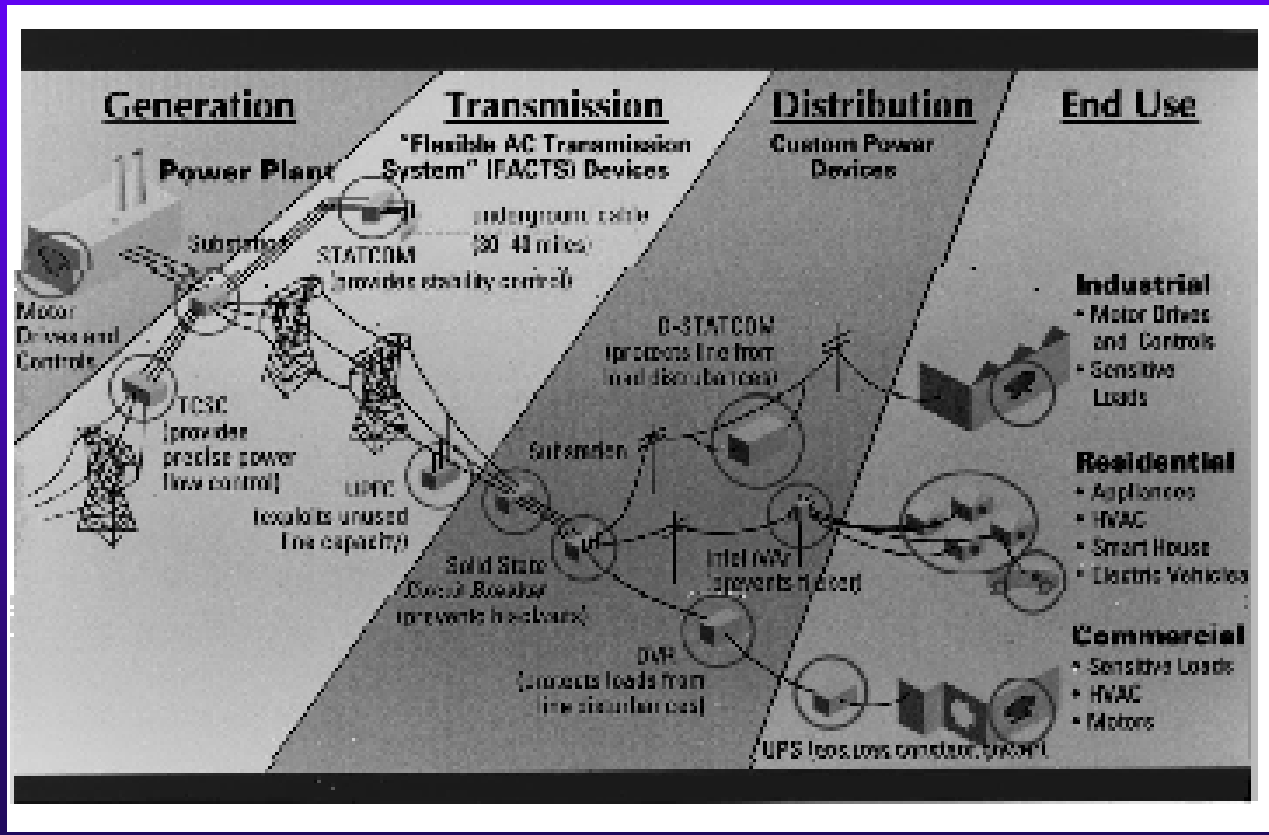


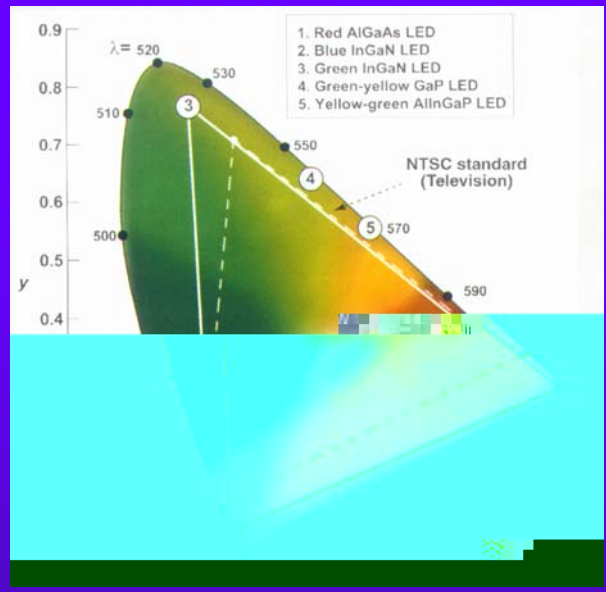

Responsivity (a.u.)
10^0
10^-1
10^-2
10^-3
10^-4
Al_xGa_1-xN
x = 0
x = 0.19
x = 0.26
x = 0.35



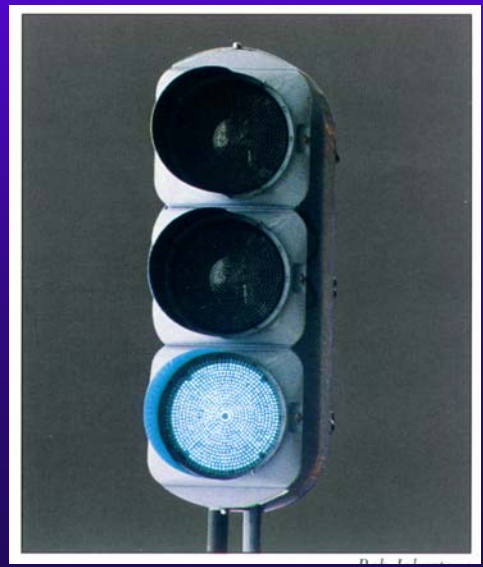

COMPONENTS OF INTELLIGENT VEHICLE HIGHWAY SYSTEM (IVHS)
Beacon
Automated vehicle location
Automated traffic surveillance and control
Electronic signing
Electronic toll

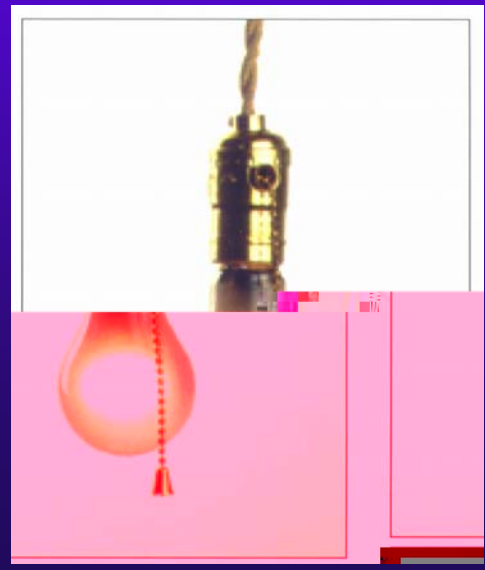

I-V Characteristics of a 4.5 kV Rectifier
500
400
300
200
Mesa Diameter 160 μm
Catastrophic
Breakdown


Generation
Transmission
Distribution
End Use
Power Plant
"Flexible AC Transmission System" (FACTS) Devices
Custom Power Devices
Substation
STATCOM
Motor Drives and Controls
TCSC
Substation
Industrial
• Motor Drives and Controls
• Sensitive Loads
Residential
• Appliances
• HVAC
• Smart House
• Electric Vehicles
Commercial
• Sensitive Loads
• HVAC
• Motors


1. Red AlGaAs LED
2. Blue InGaN LED
3. Green InGaN LED
4. Green-yellow GaP LED
5. Yellow-green AlInGaP LED
NTSC standard
(Television)
λ= 520
530
510
550
500
570
590
0.9
0.8
0.7
0.6
0.5
0.4
y


三千里藥品
SUPER LISA
SHIBUYA
每日





Crystal structure scheme

32 classes

All crystalline materials are electrostrictive (strain proportional to the square of the field)

11 classes

Center of symmetry

21 classes

No center of symmetry

1 class

Nonpiezoelectric

20 classes

Piezoelectric (strain proportional to applied field)

10 classes

Nonpyroelectric

10 classes

Pyroelectric (spontaneous polarization)

nonferroelectric

Ferroelectric (direction of Ps can be switched)

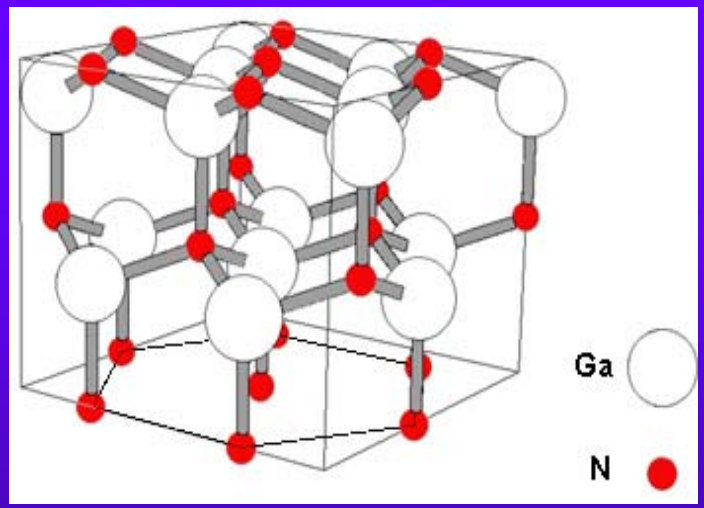
Quartz

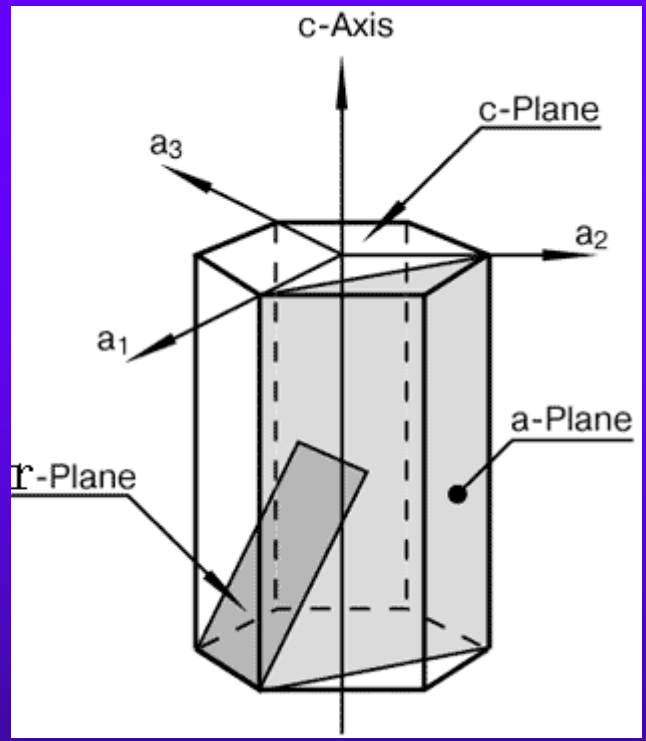
ZnO, AlN, GaN

PZT, PTO

C面GaN有源层，非中心对称结构，存在极化效应

解决办法：M面和a面GaN中无极化





c	*plane*		*a*	*plane*	
r	*plane*		*m*	*plane*	
n	*plane*		*s*	*plane*	

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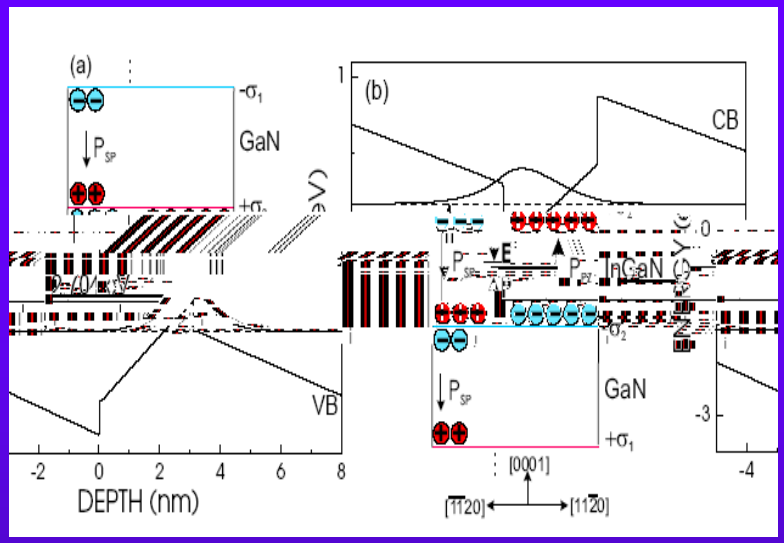
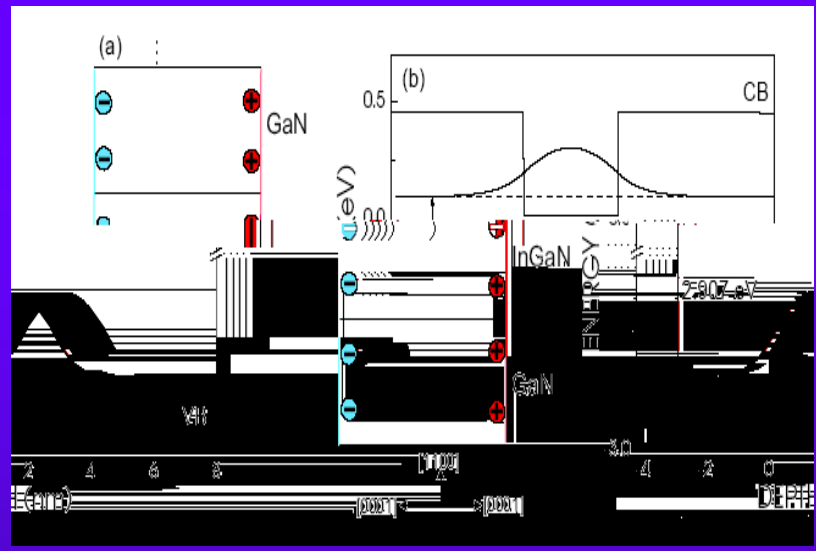
LED

у /M GaN/InGaN :





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GaN(1100) :ж

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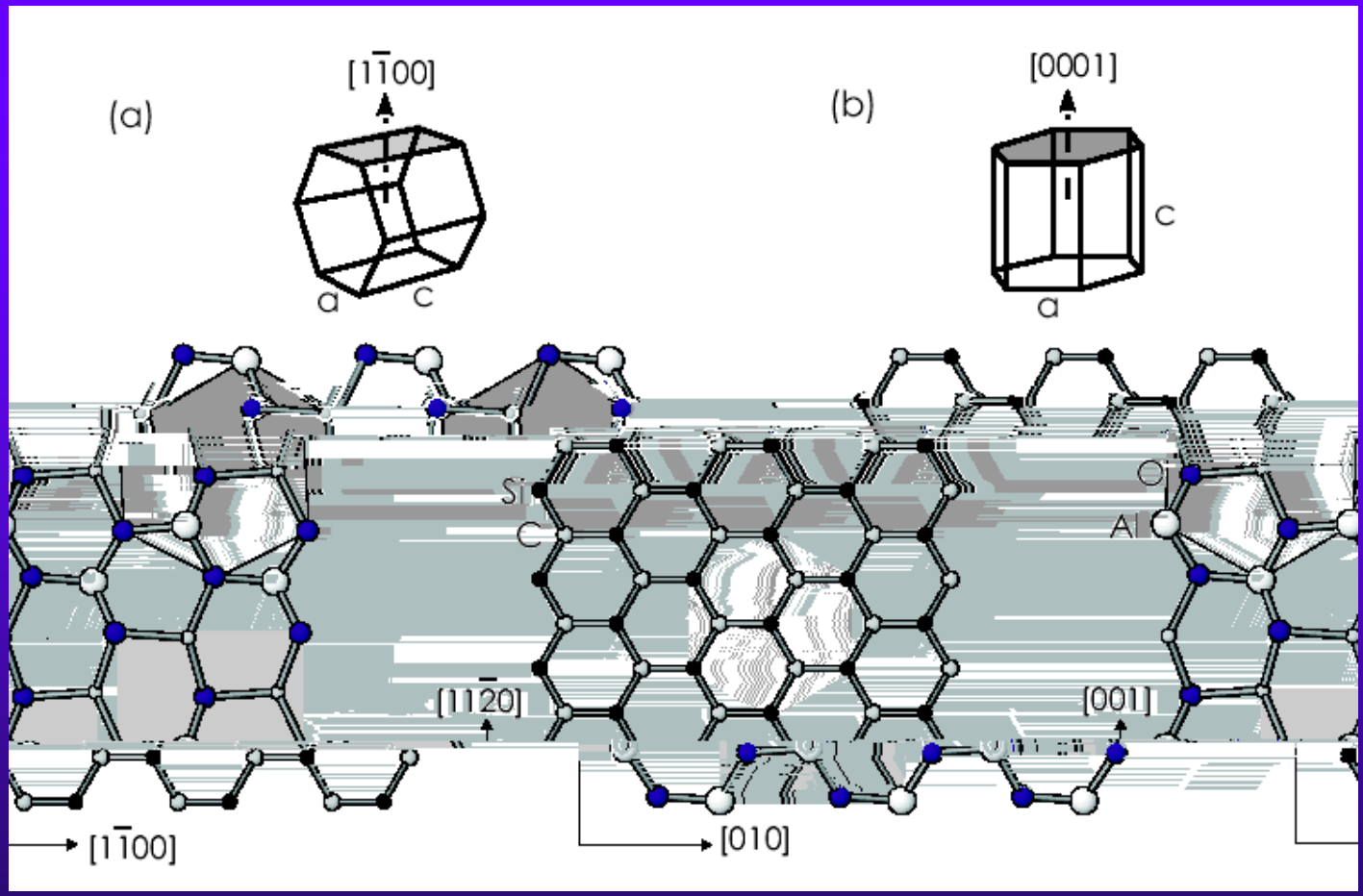
– ¥ ʌ

Li

O


(a)
[1$\bar{1}$00]
a
c
(b)
[0001]
c
a
Si
O
Al
[11$\bar{2}$0]
[001]
[1$\bar{1}$00]
[010]


DANGER
DANGER

Nonpolar m-plane GaN on $LiAlO_2$

2 InGaN/GaN heterostructures on $LiAlO_2$

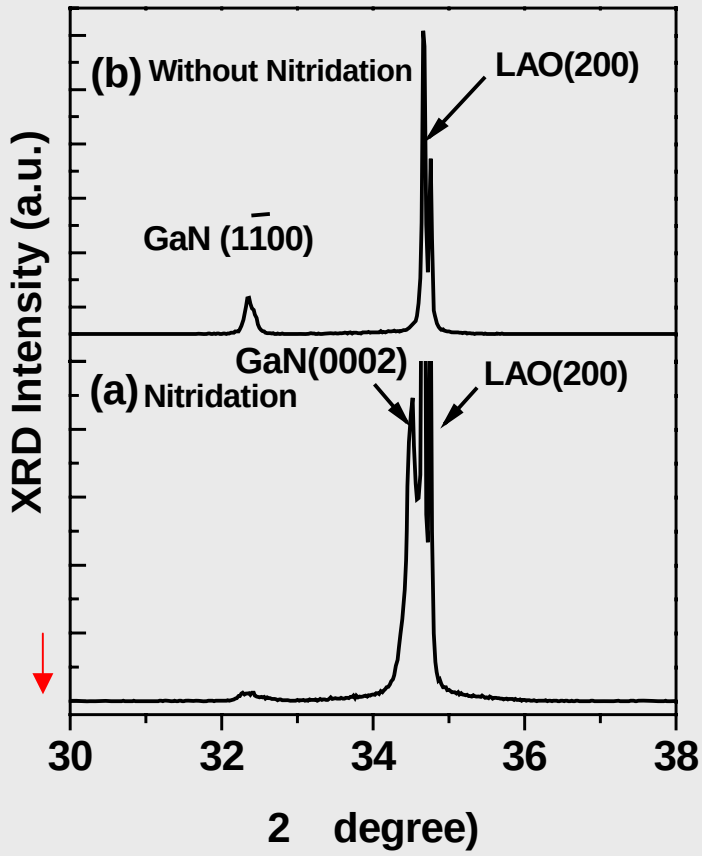
3 InGaN/GaN multiple quantum wells LEDs on $LiAlO_2$

Nonpolar m-plane GaN on LiAlO2ˆ 100˜ substrates

The effect of growth condition on the phase purity of GaN epilayer

- Nitridation of LAO substrate
- Buffer growth temperature

The effect of the Nitridation of LAO substrate on the Phase Purity of GaN Epilayer



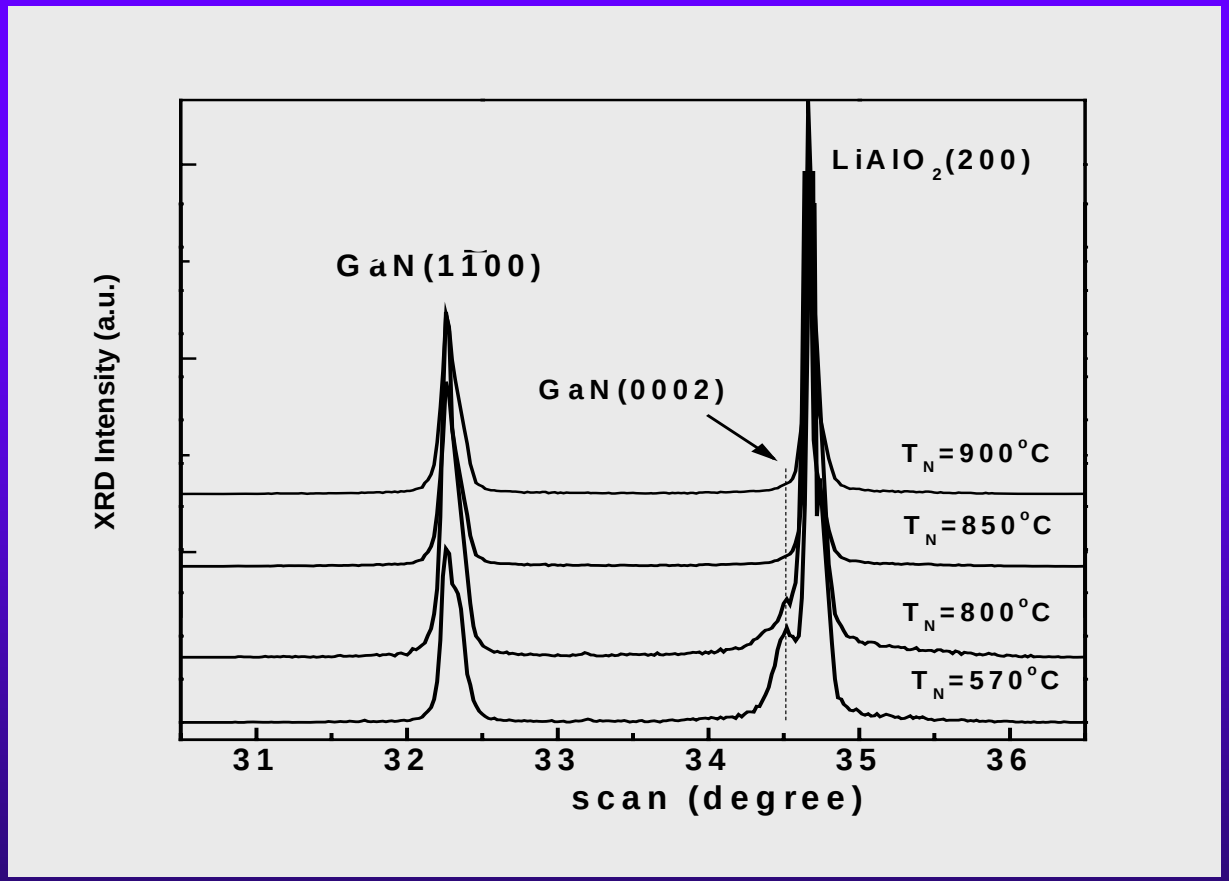
Growth condition:

Â

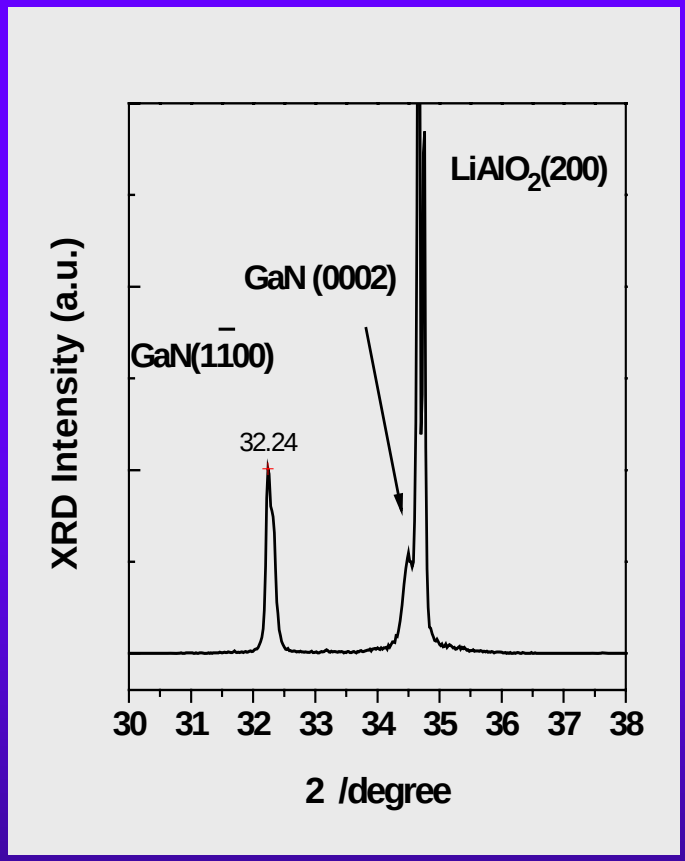
The X-ray diffraction patterns of samples with and without nitridation of the LAO substrate.

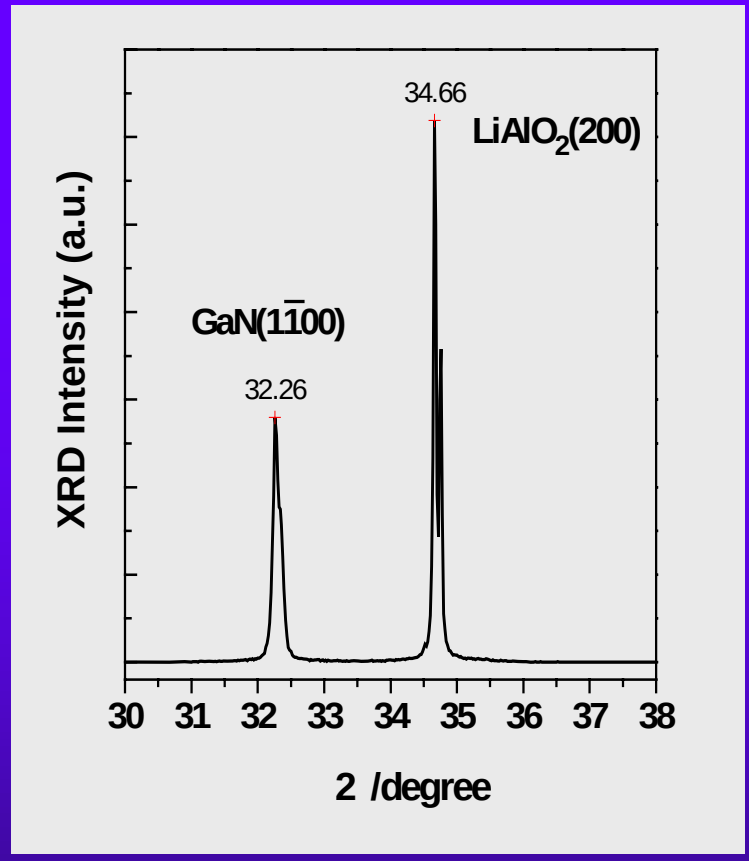
p_T

The Effect of Buffer Growth Temperature on The Phase Purity of GaN Epilayer



The X-ray diffraction patterns of samples grown at different buffer growth temperature.

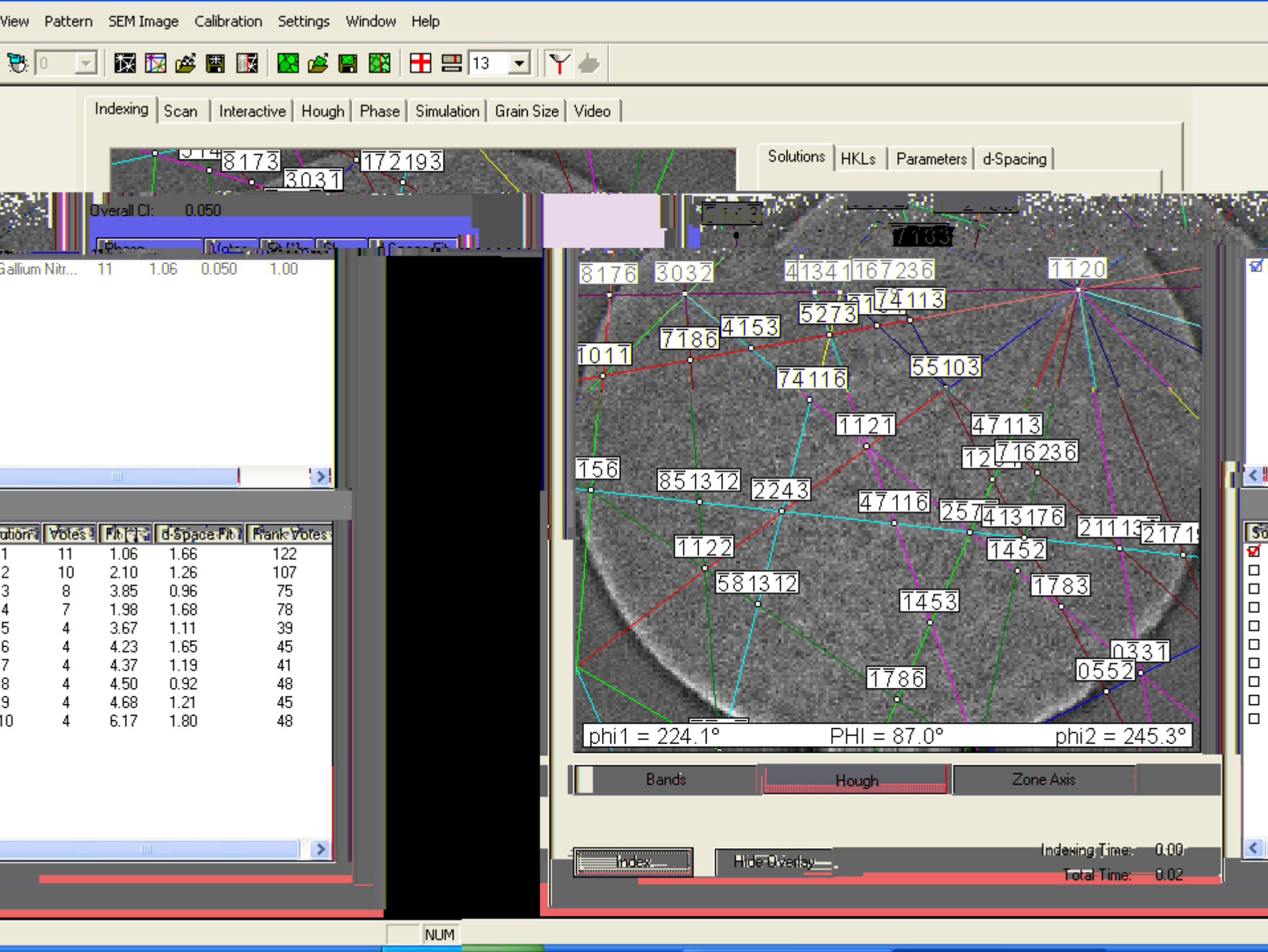


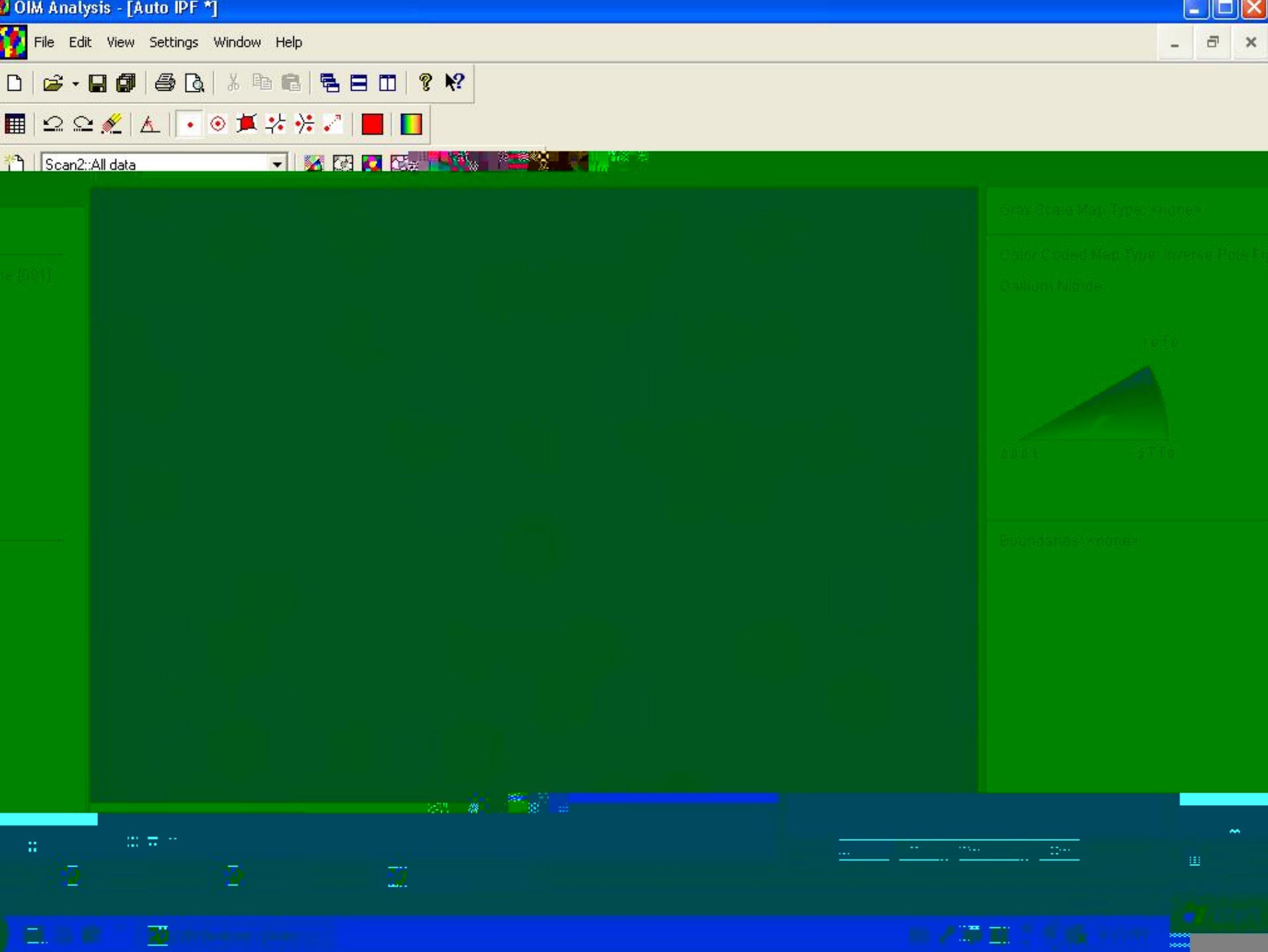


T_B=570^{0}C, T_G =1050^{o}C, t=2400s

T_B=850^{0}C, T_G =1050^{o}C, t=2400s

Results indicates that we obtain pure M-plane GaN film on LAO (100) with nucleation at 850 oC


View Pattern SEM Image Calibration Settings Window Help
Indexing Scan Interactive Hough Phase Simulation Grain Size Video
Solutions HKLs Parameters d-Spacing
Overall CI: 0.050
Gallium Nitr... 11 1.06 0.050 1.00
Votes Fit d-Space Fit Rank Votes
1 11 1.06 1.66 122
2 10 2.10 1.26 107
3 8 3.85 0.96 75
4 7 1.98 1.68 78
5 4 3.67 1.11 39
6 4 4.23 1.65 45
7 4 4.37 1.19 41
8 4 4.50 0.92 48
9 4 4.68 1.21 45
10 4 6.17 1.80 48
phi1 = 224.1° PHI = 87.0° phi2 = 245.3°
Bands Hough Zone Axis
Index Hide Overlay
Indexing Time: 0.00
Total Time: 0.02
NUM


OIM Analysis - [Auto IPF *]
File Edit View Settings Window Help
Scan2::All data

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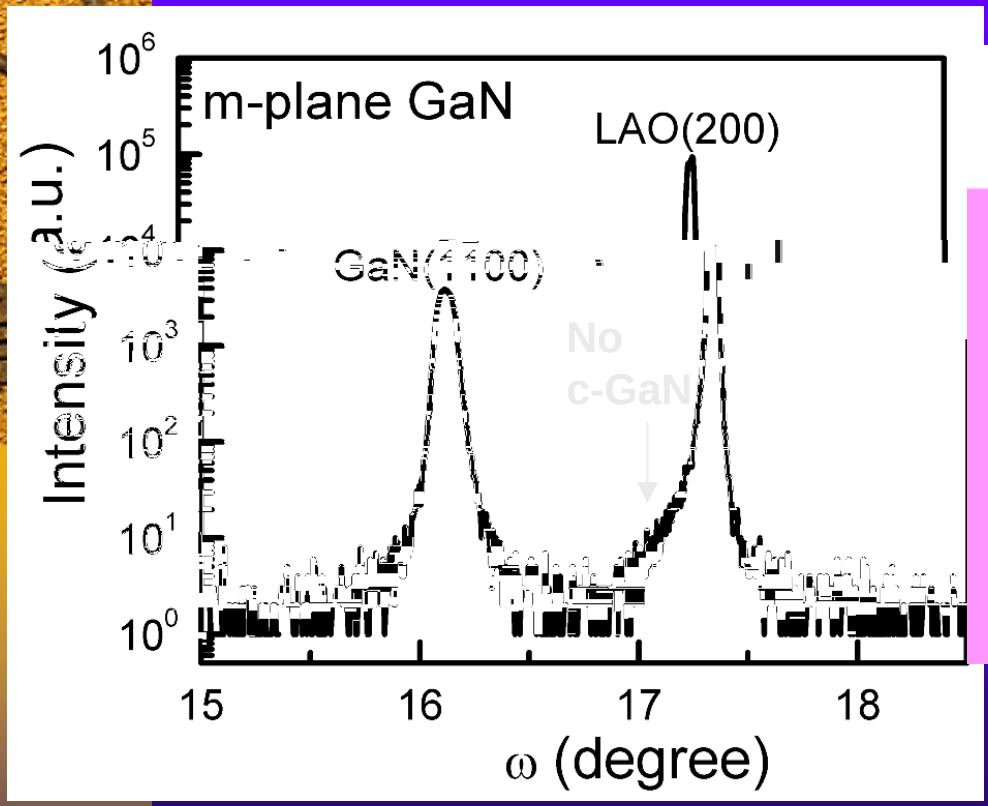
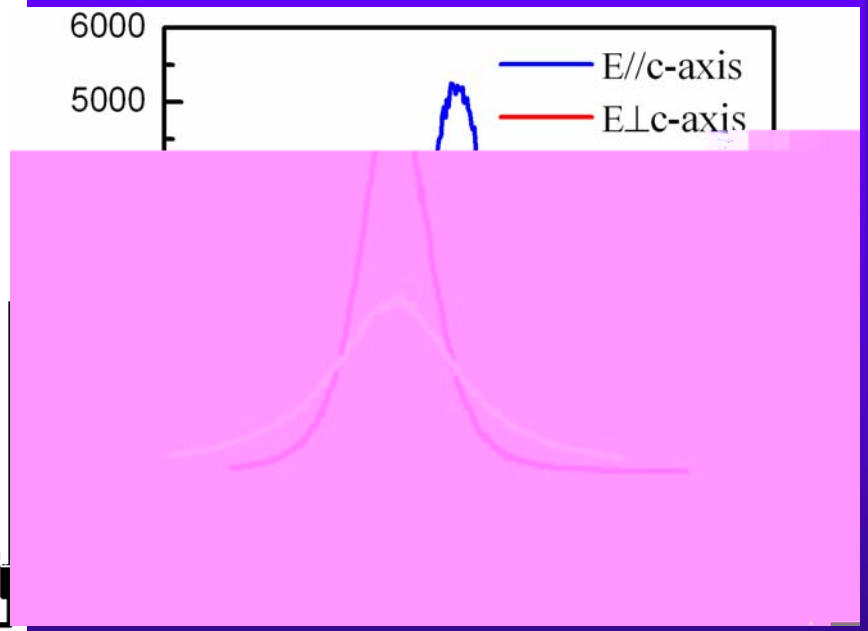

m-plane GaN
LAO(200)
GaN(1100)
No
c-GaN
Intensily (a.u.)
10^6
10^5
10^3
10^2
10^1
10^0
15
16
17
18
ω (degree)


6000
5000
E//c-axis
E⊥c-axis

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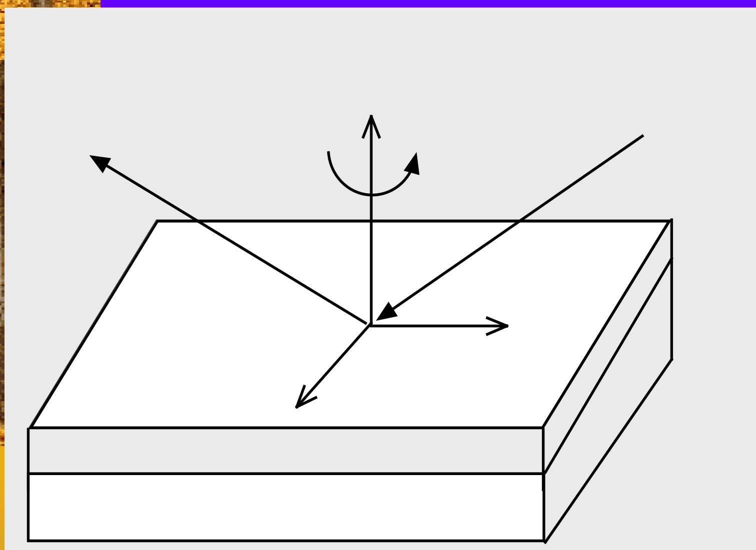
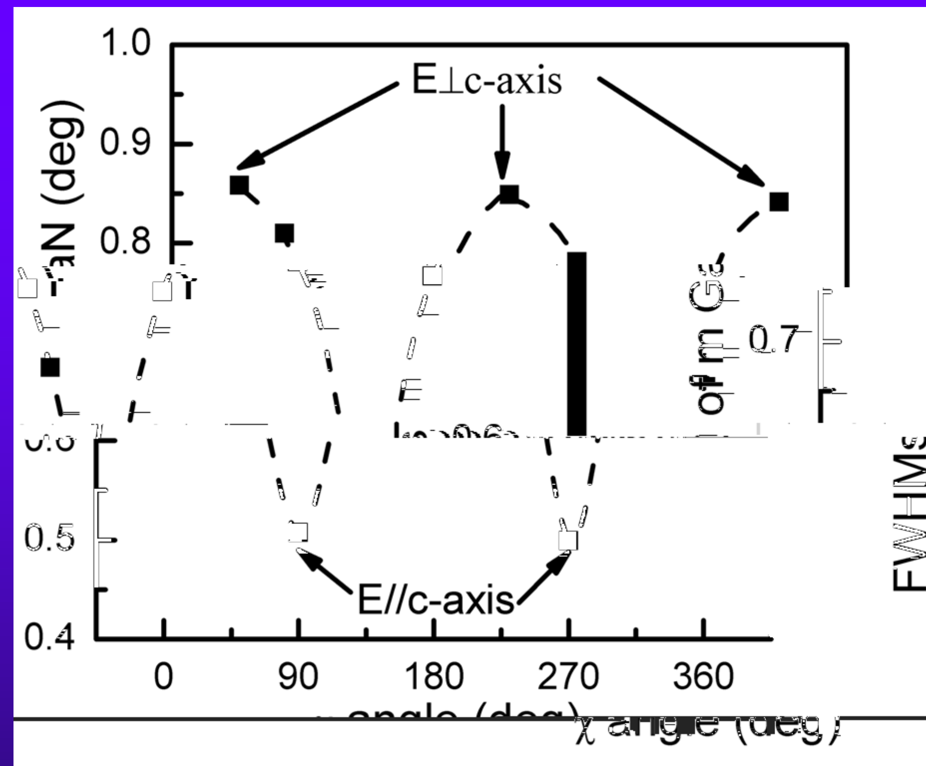
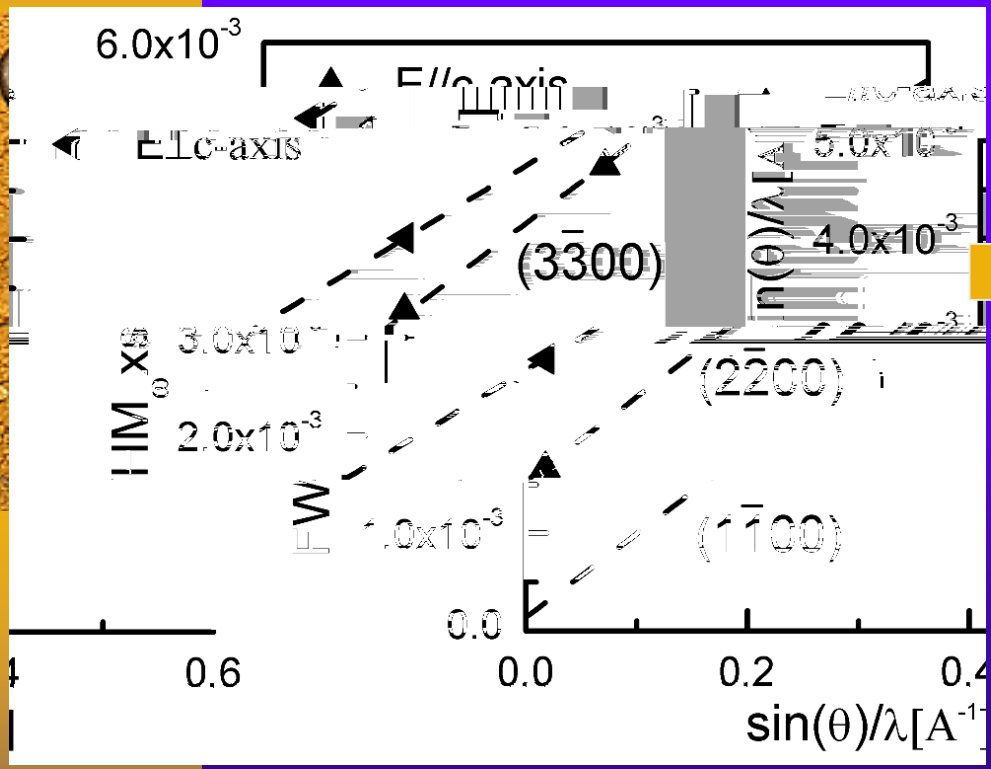



1.0
0.9
0.8
0.7
0.5
0.4
E⊥c-axis
E//c-axis
0
90
180
270
360
FWHMs
χ angle (deg)



ÿ W-H ق ت ч э л

tilt ∩ lateral correlation length

а У Â

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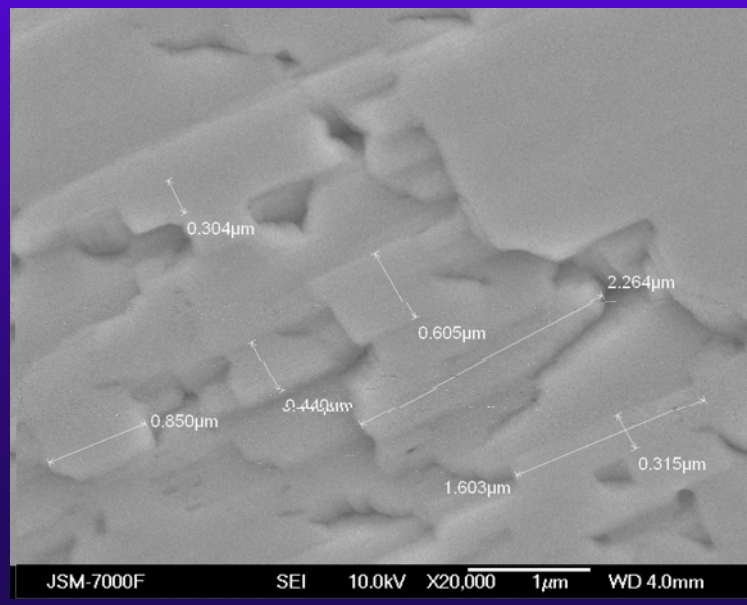

SEM

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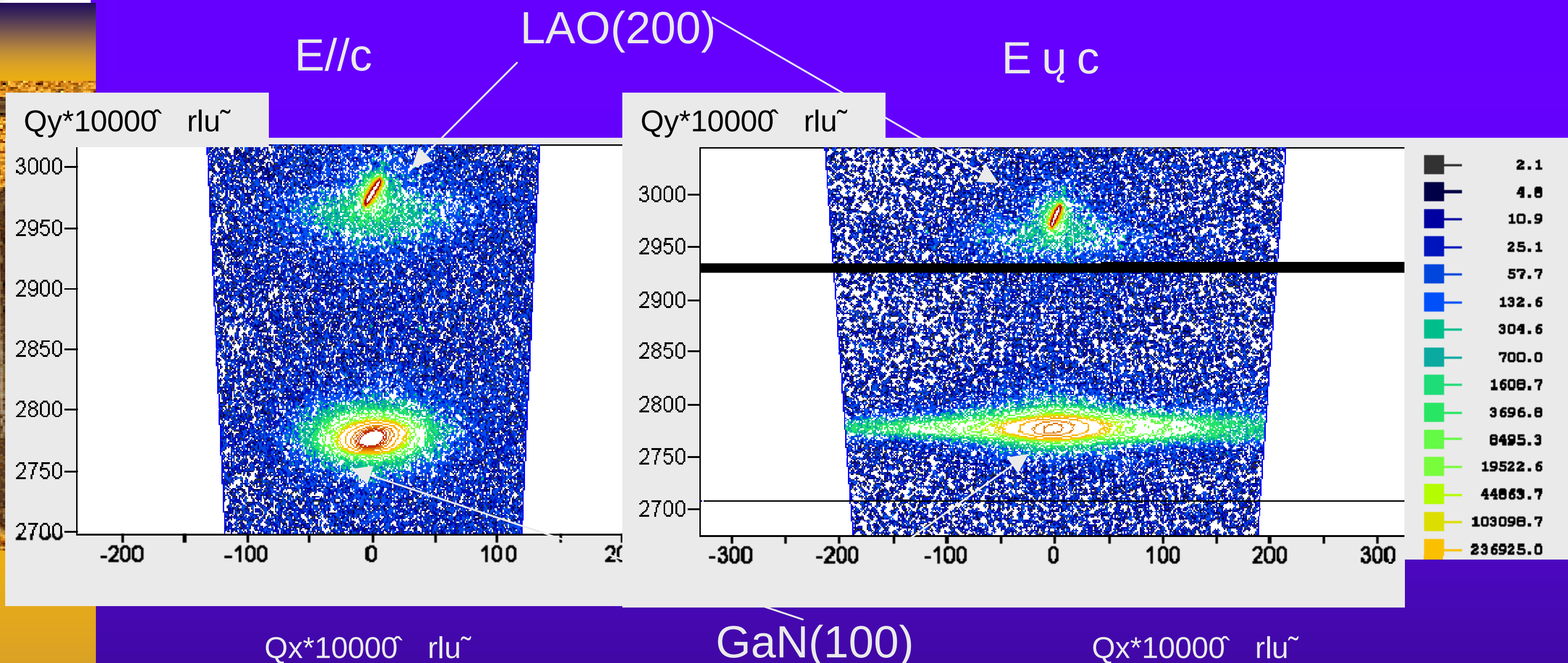
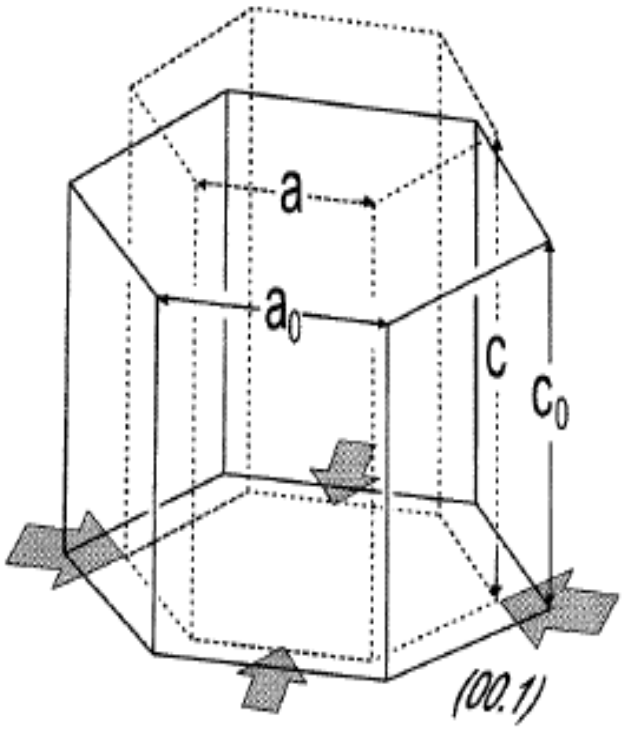


Э في ˘ m-GaN(1100) جم ˘ è X
عج E б c صي a У ˘ ɷ ﾑ
ﾑ Â GaN ᾳ a ῄ c ﾑ Э tilt ῄ lateral
correlation length ⁞ ˘ ἒ ḣ Williamson-Hall
plot ↟ Â



c-GaN

$$\epsilon_{\parallel}=\epsilon_{xx}=\epsilon_{yy}$$

$$\epsilon_{\perp}=\epsilon_{zz}$$

$$\begin{pmatrix}\sigma_{\parallel}\\ \sigma_{\perp}\end{pmatrix}=\begin{pmatrix}C_{11}+C_{12} & C_{13}\\ 2C_{13} & C_{33}\end{pmatrix}\begin{pmatrix}\epsilon_{\parallel}\\ \epsilon_{\perp}\end{pmatrix}$$

$\sigma_{\perp}$

$$\frac{\epsilon_{\perp}}{\epsilon_{\parallel}}=-2\frac{C_{13}}{C_{33}}$$

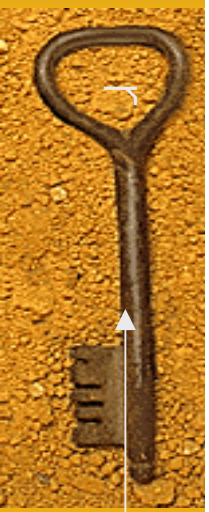
C-sap or SiC GaN

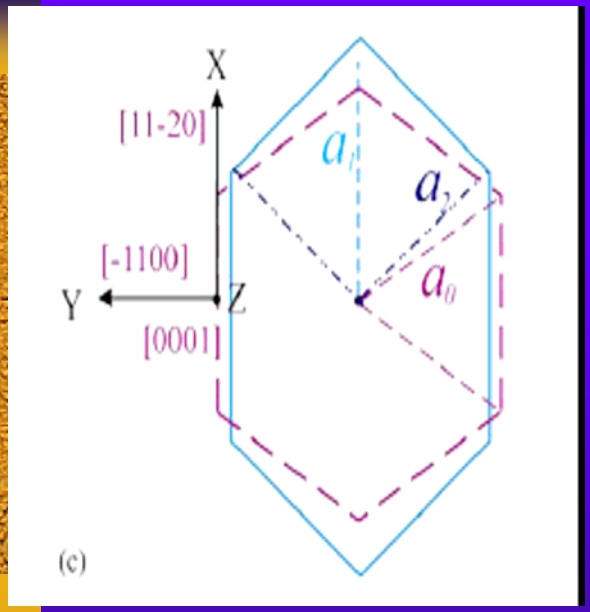
c-GaN X

(0002)

ε_{zz}

ε_{xx}





m-GaN Ώ ң ل ٨˘

a	*a*

ل '

xx	*yy*

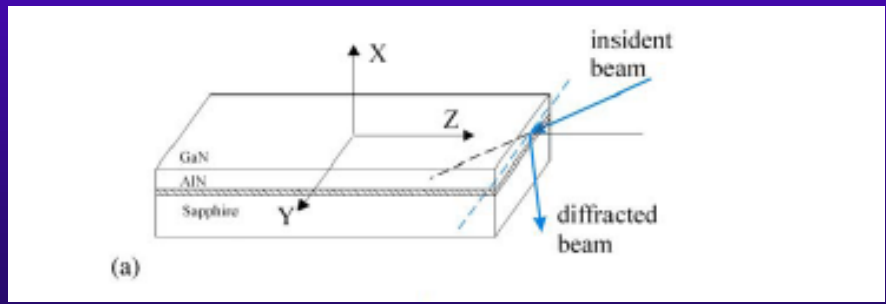
F

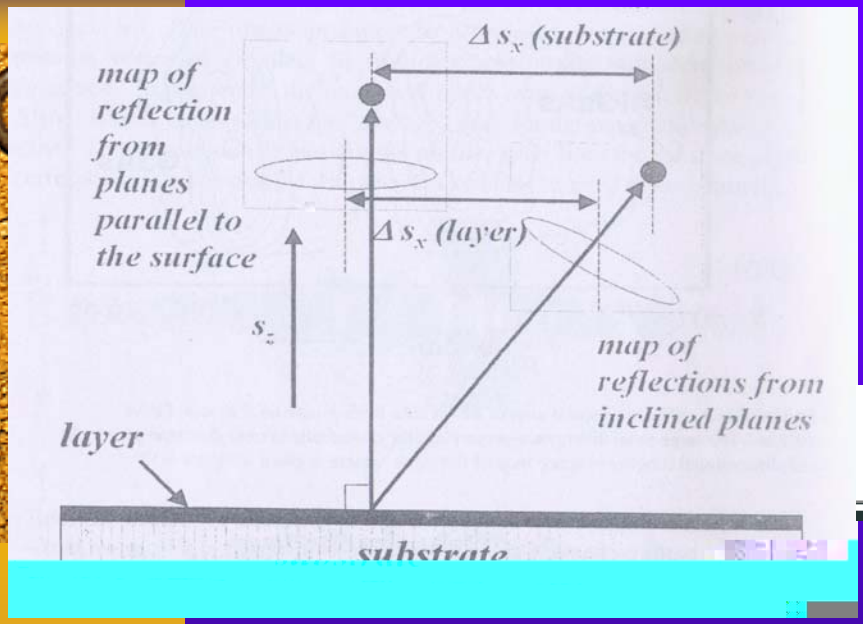
Ώ ˘ ل ' ˆ

$$\varepsilon_{yy} = -\frac{C_{12}}{C_{11}}\varepsilon_{xx} - \frac{C_{13}}{C_{11}}\varepsilon_{zz}$$

X GaN(100)˘ ˆ ε_{yy}˘
ת a ¢ ε_{xx} ת ε_{zz}

GaN ٧˘ ט edge-
geometry ק ٧ Â

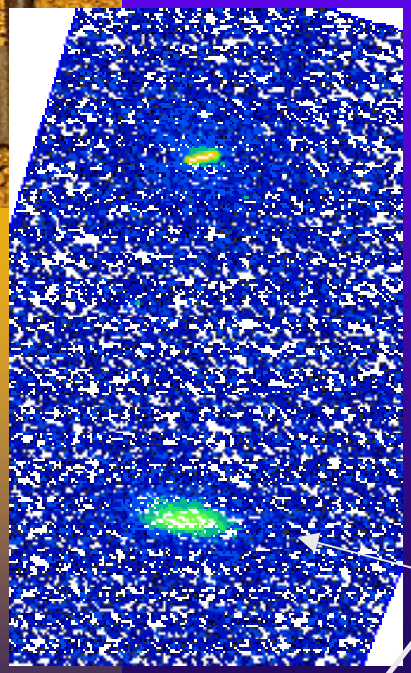


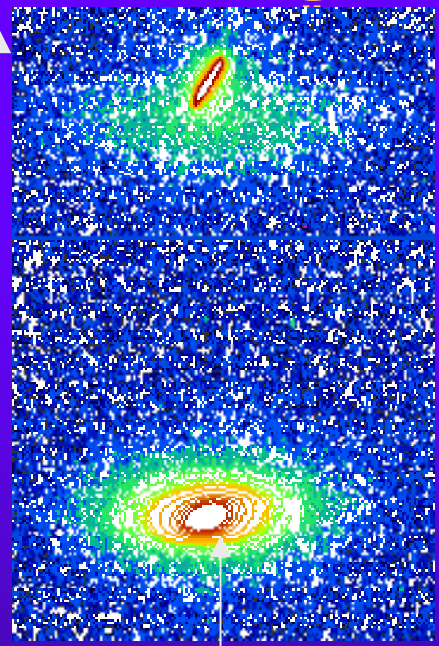


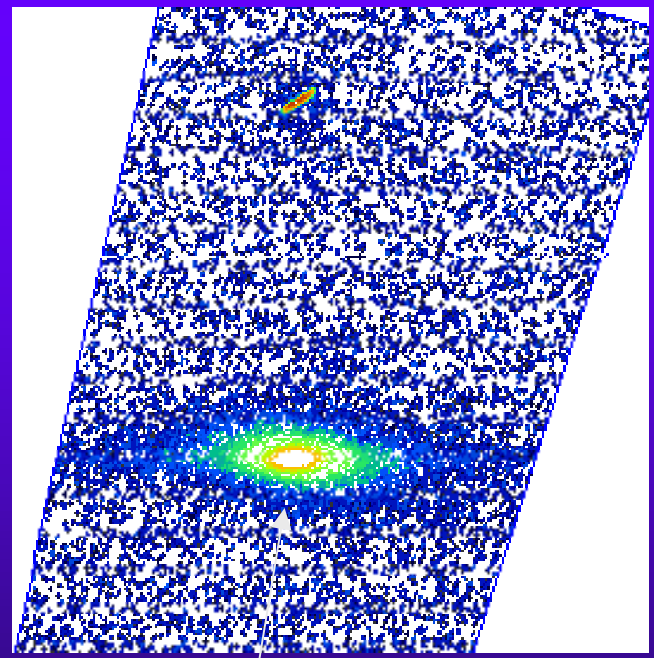
$$d_z = \frac{1}{s_z} = \frac{\lambda}{\{\sin\omega_{0\,0\,0\,2} + \sin(2\omega'_{0\,0\,0\,2} - \omega_{0\,0\,0\,2})\}}$$

$$d_x = \frac{1}{s_x} = \frac{\lambda}{\{\cos\omega_{0\,1\,\bar{1}\,5} - \cos(2\omega'_{0\,1\,\bar{1}\,5} - \omega_{0\,1\,\bar{1}\,5})\} - \{\cos\omega_{0\,0\,0\,2} - \cos(2\omega'_{0\,0\,0\,2} - \omega_{0\,0\,0\,2})\}}$$

$$strain_{xx} \quad \frac{d_x \quad d_{x\ relax}}{d_{x\ relax}}$$







Y

Z

X

GaN 100

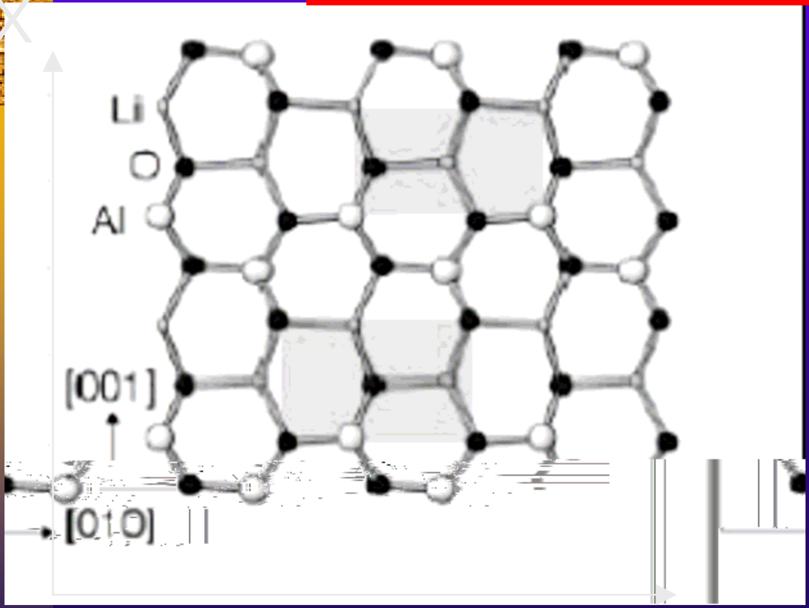
GaN 201

GaN 210

ˇ ᛙ

f_x=0.3%
f_z=1.7%

		GaN	LAO	
		α ˏ 3.17	α ˏ 10.21	69 ←
ˆ	$10^{-6}/K^{-1}$˜	à $_X$= 5.59	à $_X$= 16.86	67 ←



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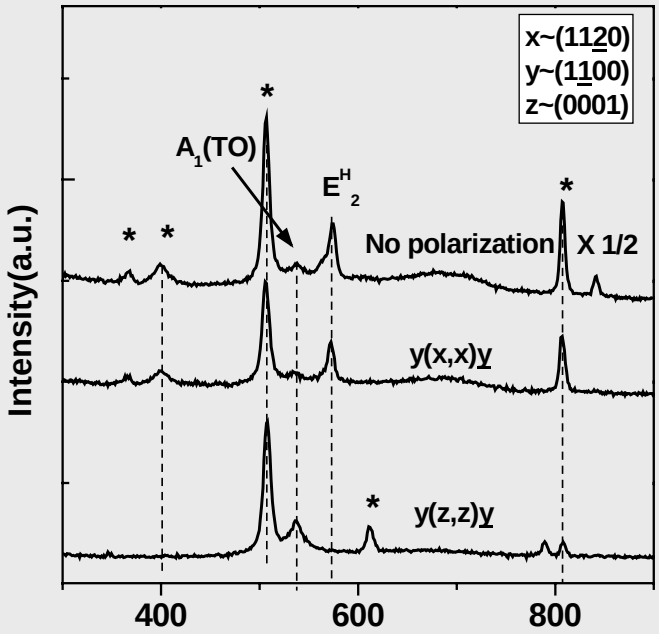
⁞ a Â

Polarized Raman spectra of m-GaN



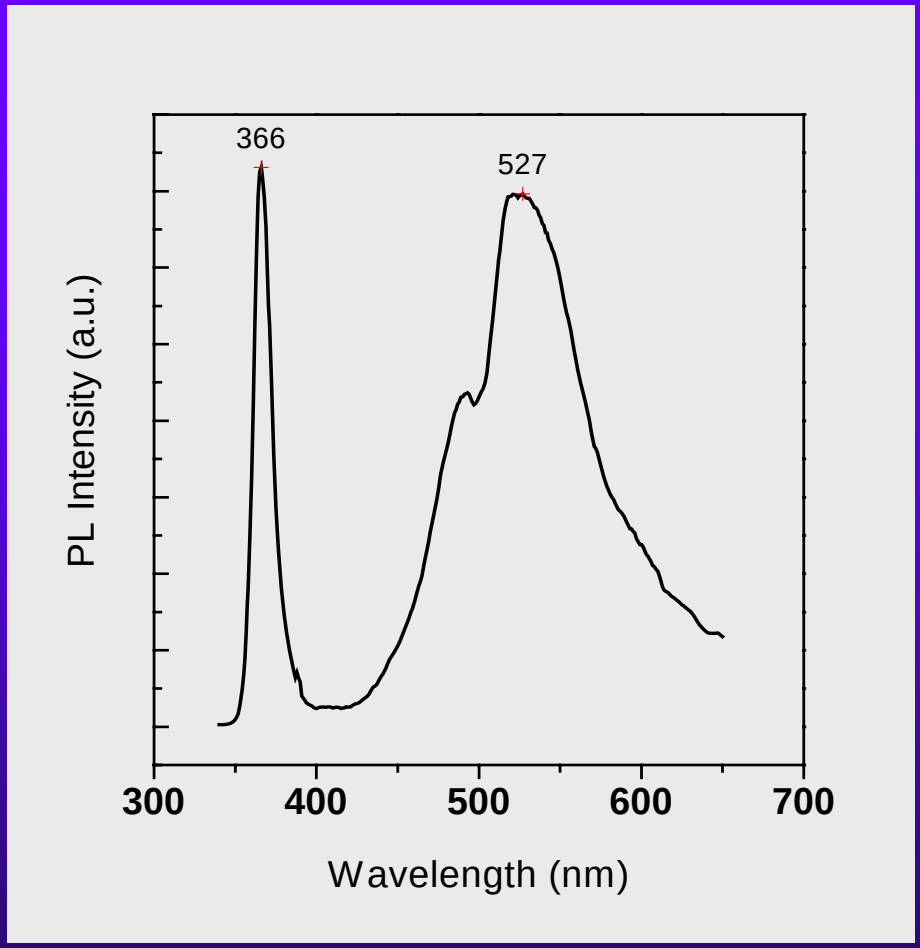
(peaks with * come from LAOsubstrate)

E_2(high) is not observable, confirming that the GaN film is a good single crystal

E_2(high) locates at 574cm^{-1} blue-shifted 5cm^{-1} indicating that compressive strain existing in the GaN film

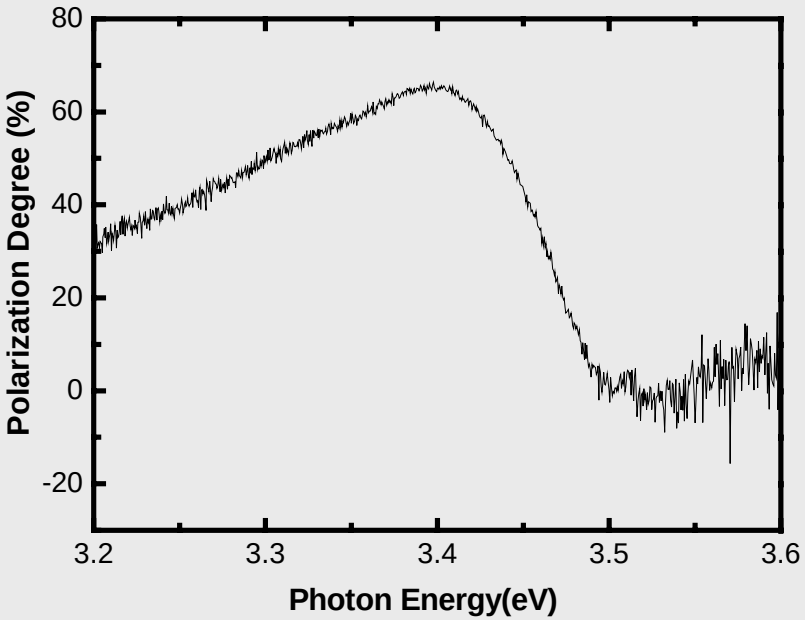
Polarized Raman spectra confirm the in-plane anisotropy of the GaN film

PL spectra of M-planeGaN



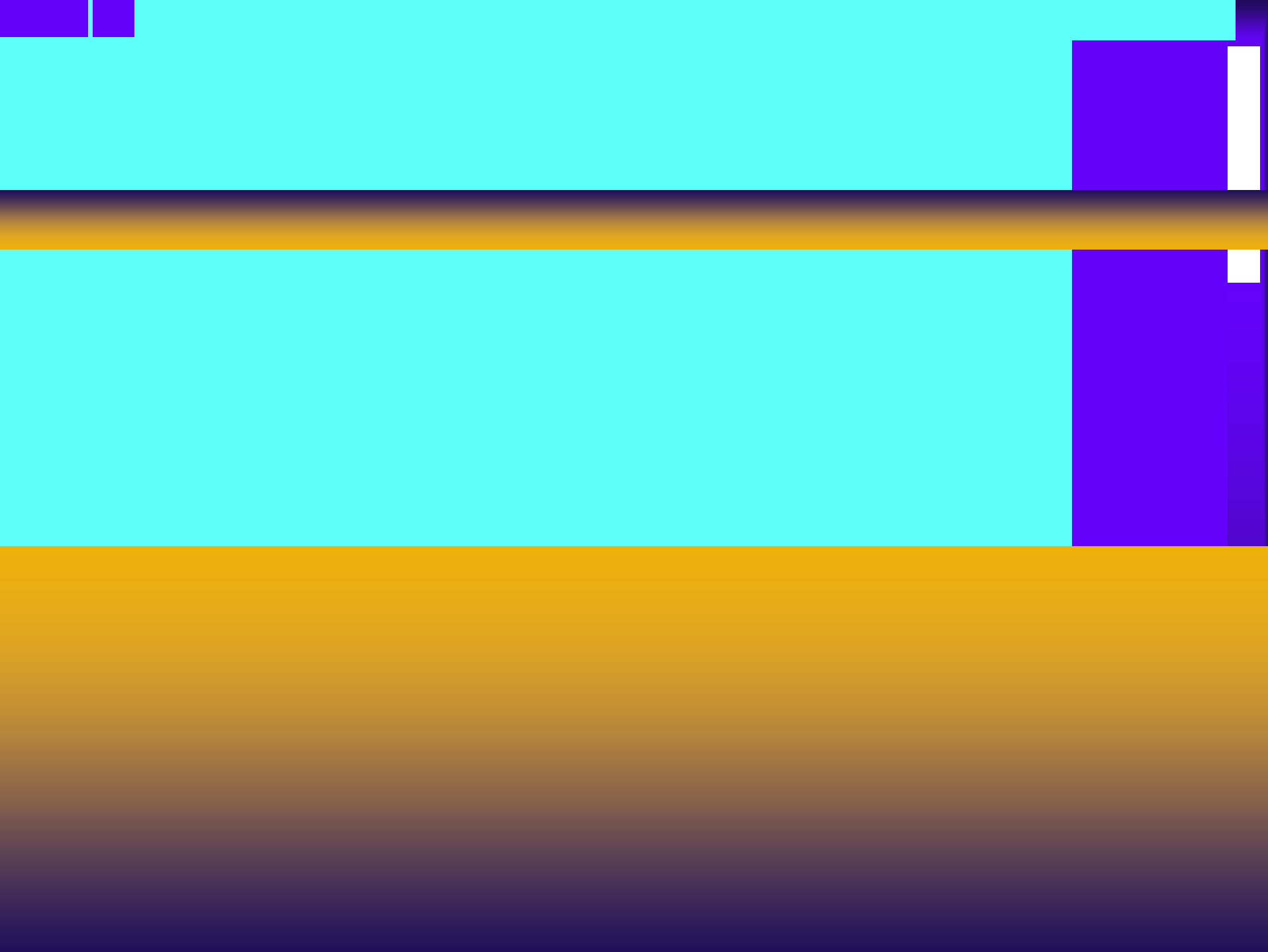
366nm: near band edge emission (NBE)

527nm: yellow band emission

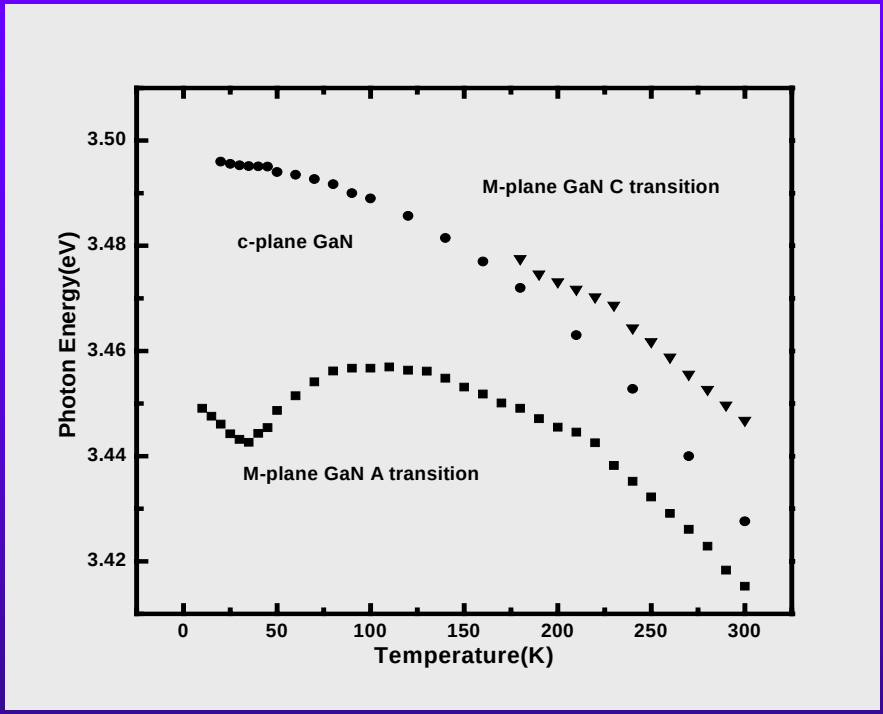


$$\frac{E \quad c \qquad E \quad c}{E \quad c \qquad E \quad c}$$

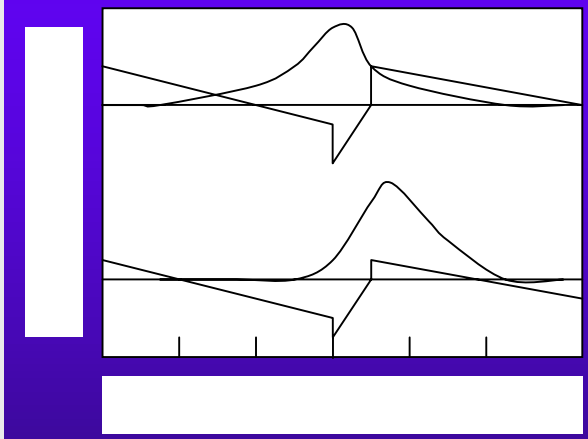
E ∥ x



√ PL


3.50
3.48
3.46
3.44
3.42
Photon Energy(eV)
0
50
100
150
200
250
300
Temperature(K)
M-plane GaN C transition
c-plane GaN
M-plane GaN A transition

S :

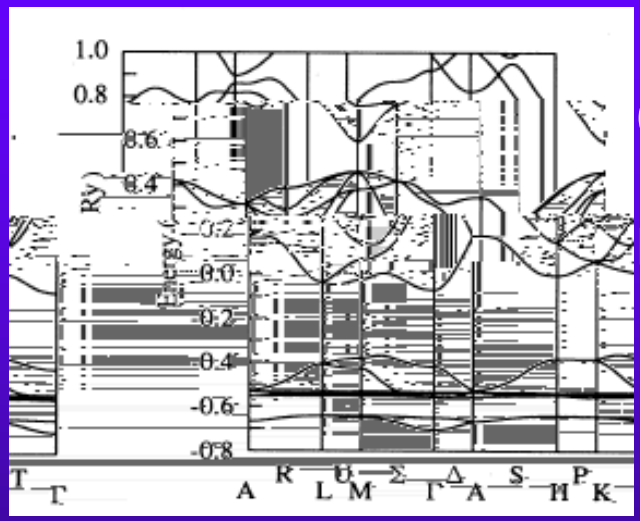


9meV

Γ Ͻ ΗOGaN

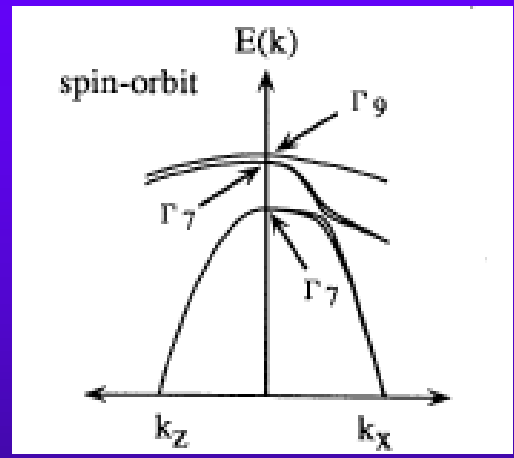
|x ¤ iy>

|z>



Ga N s

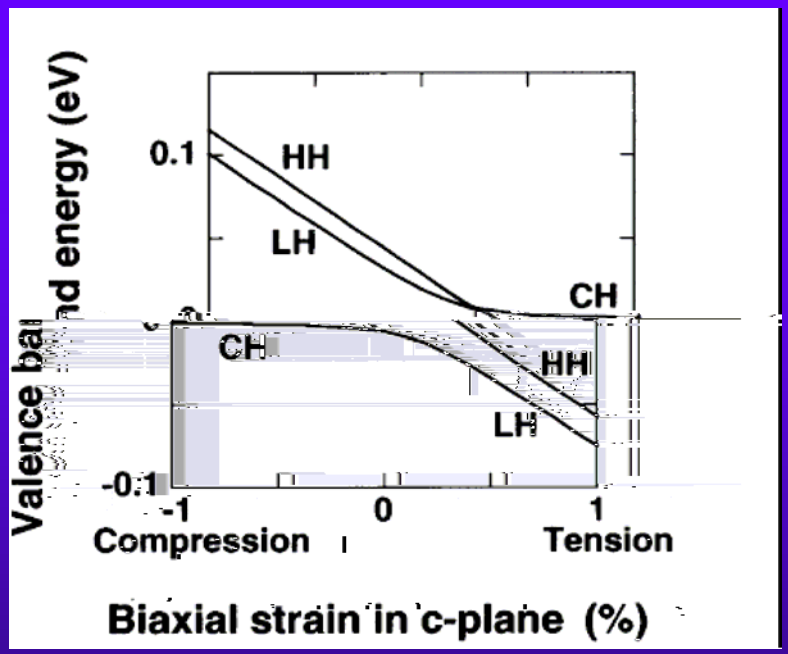
N 2p



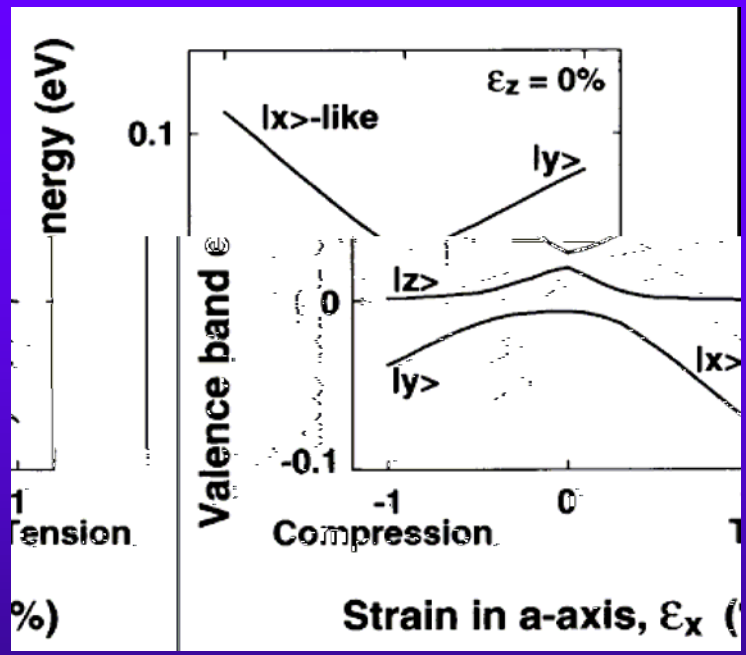
GaN

M. Suzuki et. al, Phys. Rev. B., 52(11): 8132 (1995)

F ɔ HO



C



C

K. Domen, et al. Appl. Phys. Lett. 70(8), 24 (1997).

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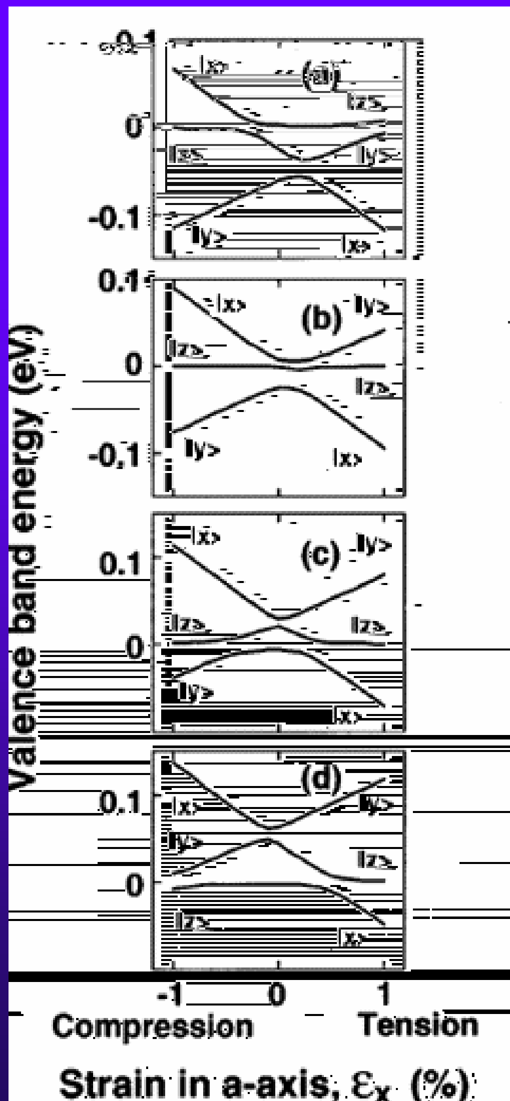
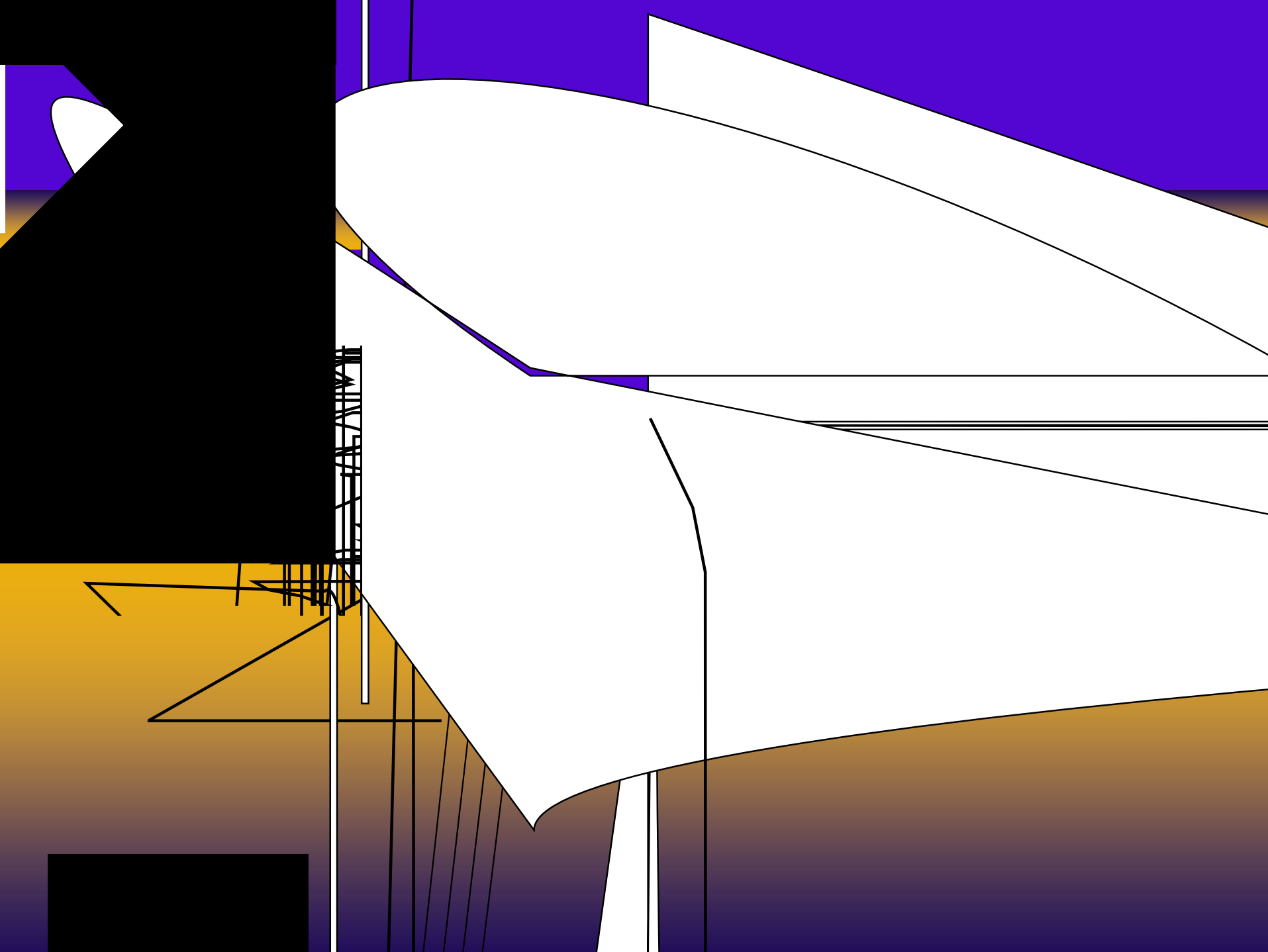

Valence band energy (eV)
(a)
(b)
(c)
(d)
|x>
|y>
|z>
0.1
0
-0.1
-1
1
Compression
Tension
Strain in a-axis, ε_x (%)

ε

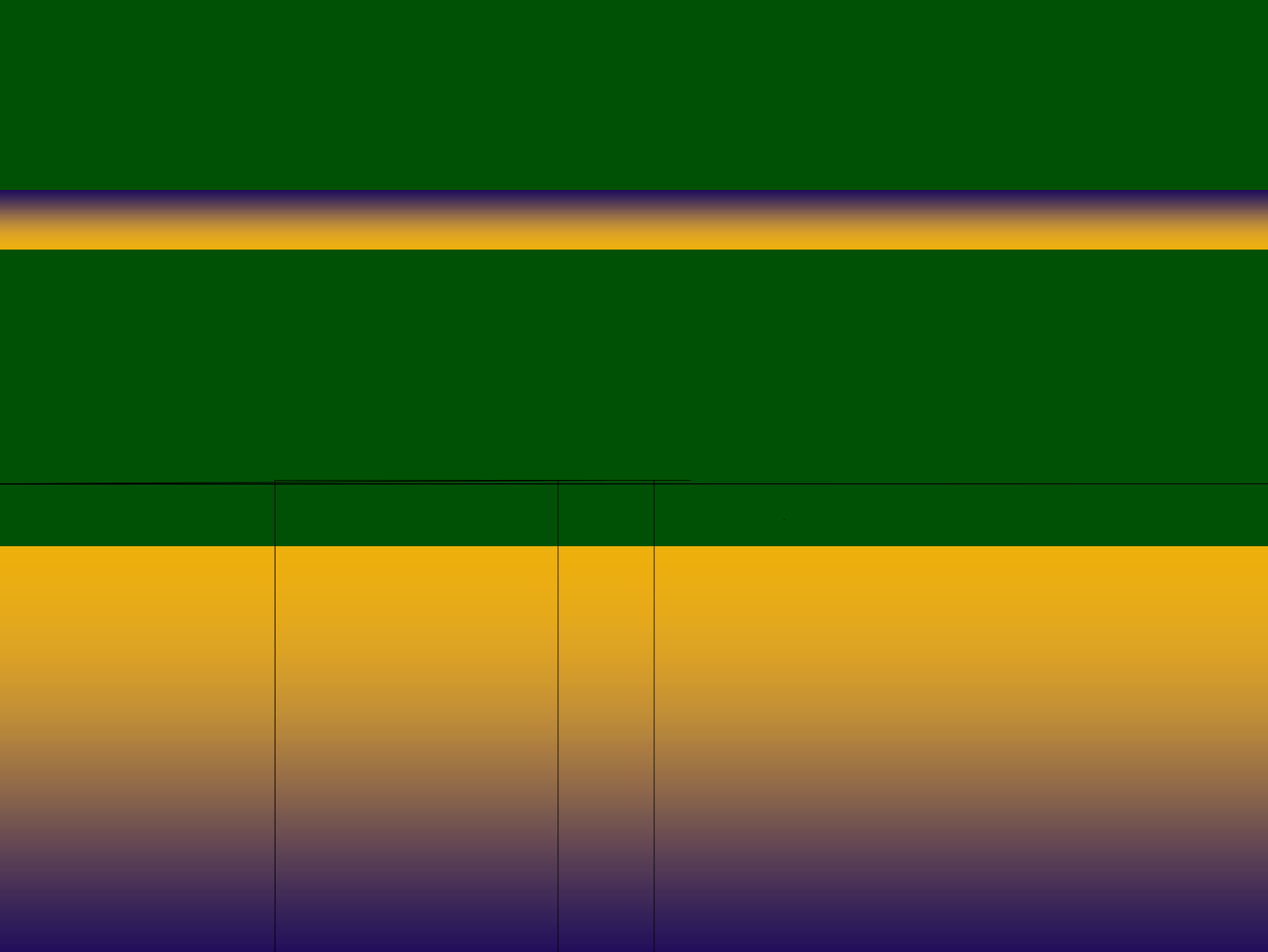
ε

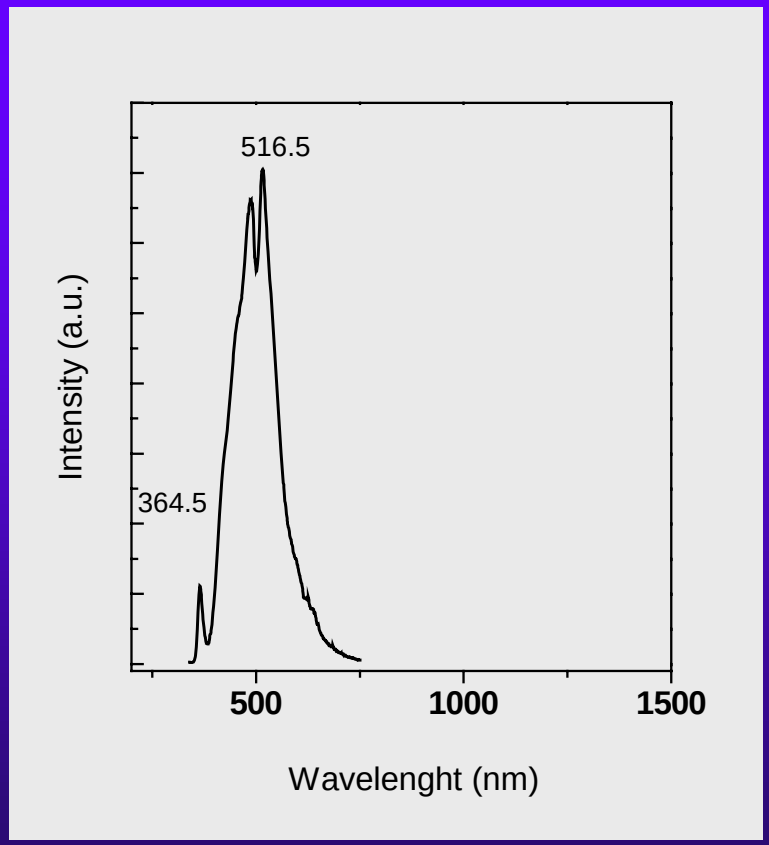
ε

ε



nonpolar m-plane InGaN/GaN heterostructures

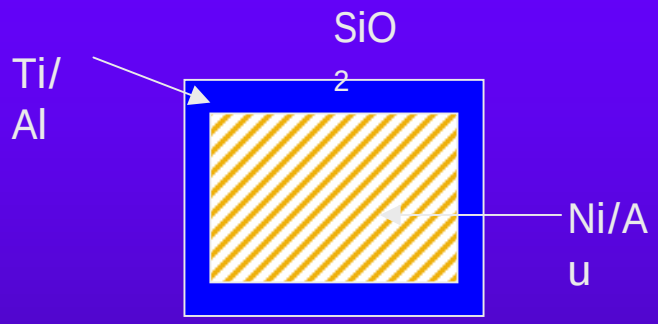


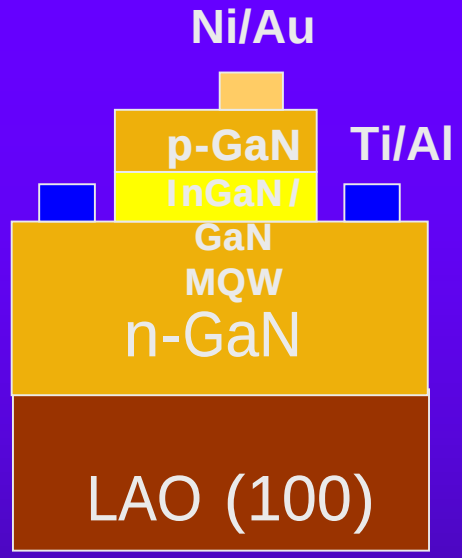


Period:5 ($In_{0.3}Ga_{0.7}N$/GaN) Quantum Wells

m-plane InGaN/ GaN MQWs LED

Schematic digram of InGaN/GaN MQWs LED



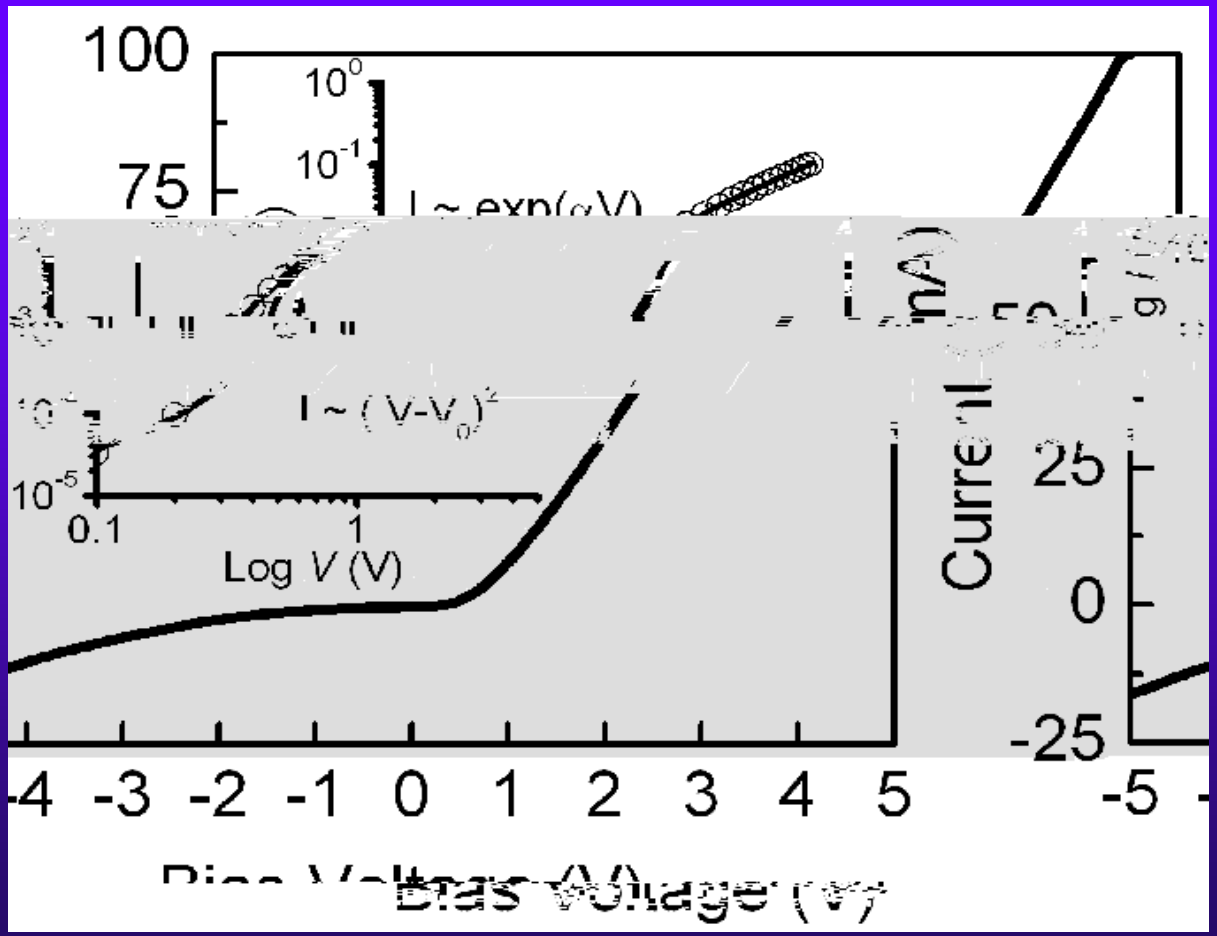


Chip size
80um ¦ 80um à
200um ¦ 200um
400um ¦ 400um à
800um ¦ 800um

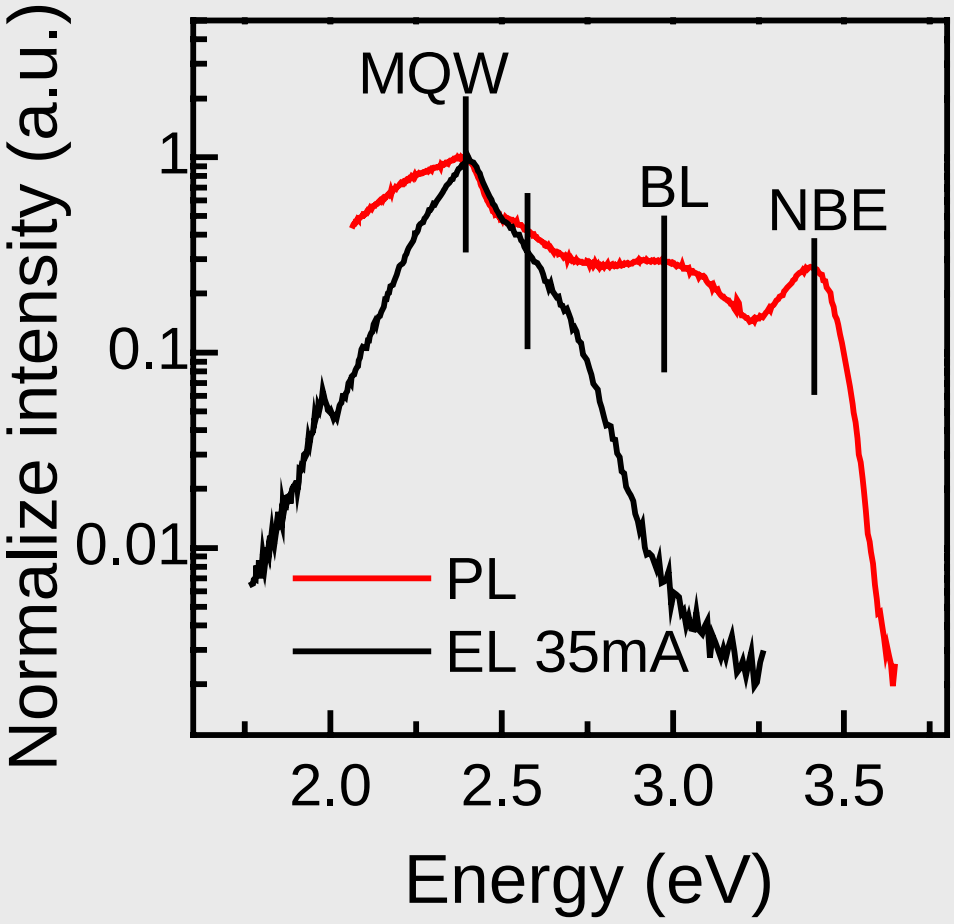
N-GaN‟ 1.2um
InGaN/GaN MQW P=5
P-GaN‟ 200nm
N type contact, Ti/Al

P type contact ,Ti/Au

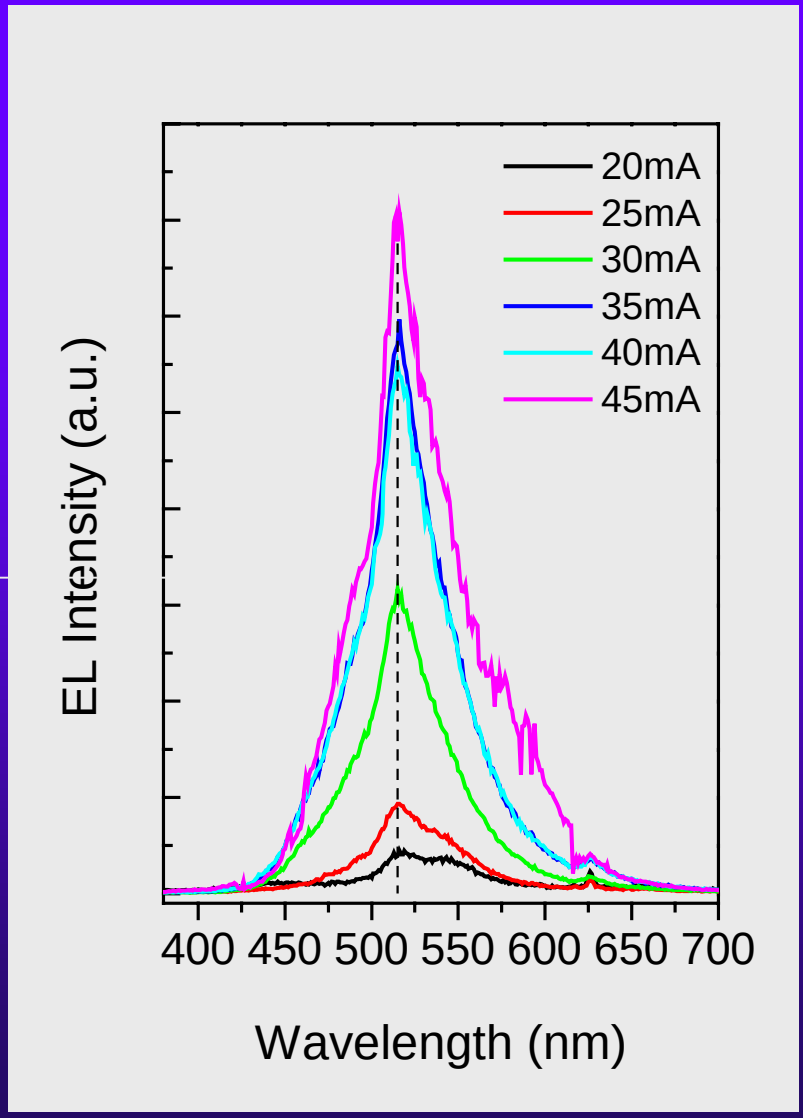
I-V curve of non-polar InGaN/GaN LED at RT



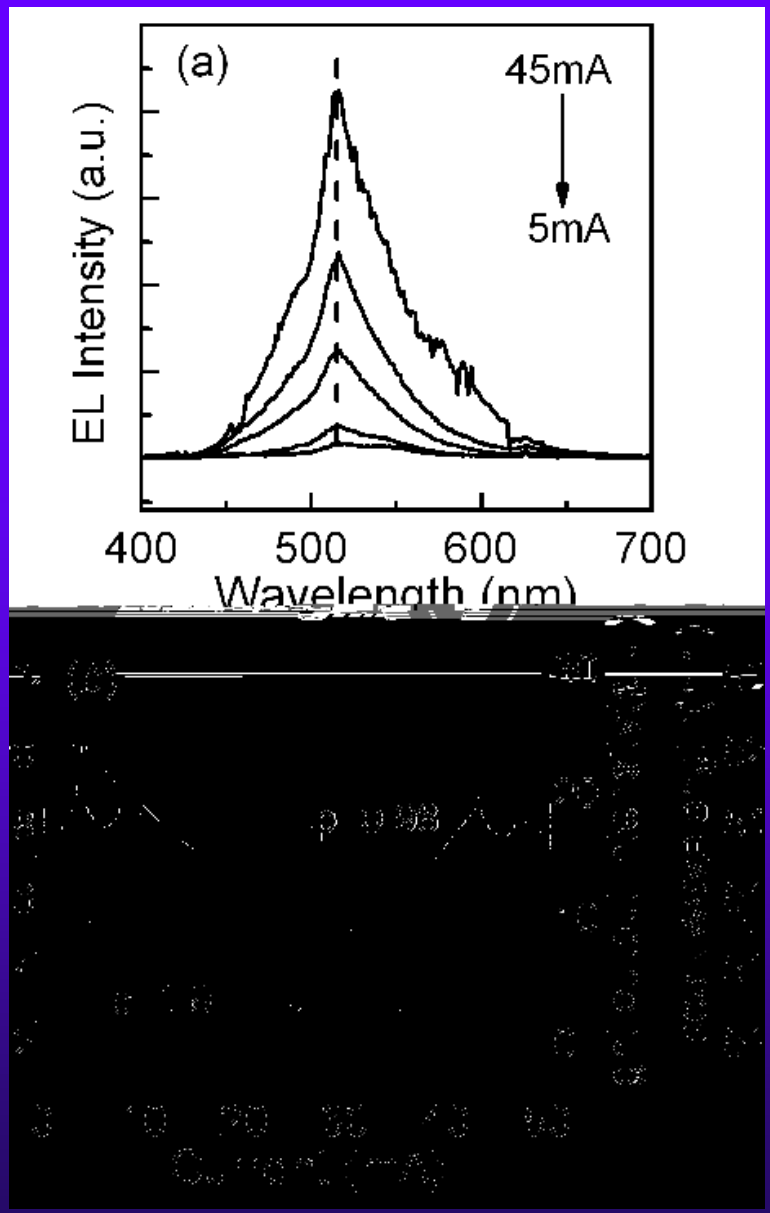
Comparison of EL spectrum to PL spectrum



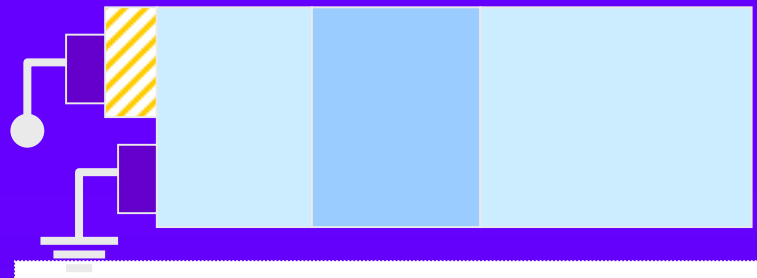
EL spectra of m-plane InGaN/GaN LED

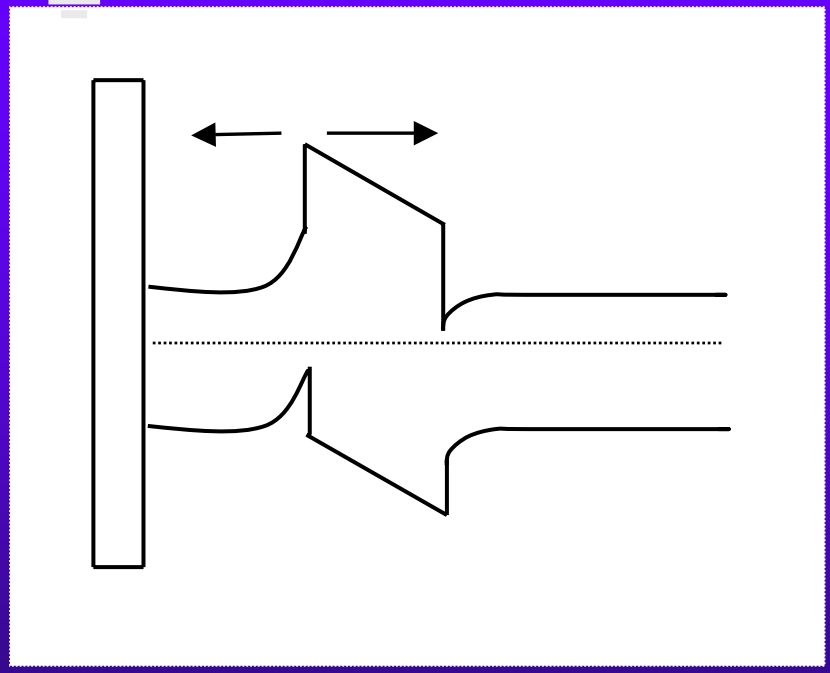


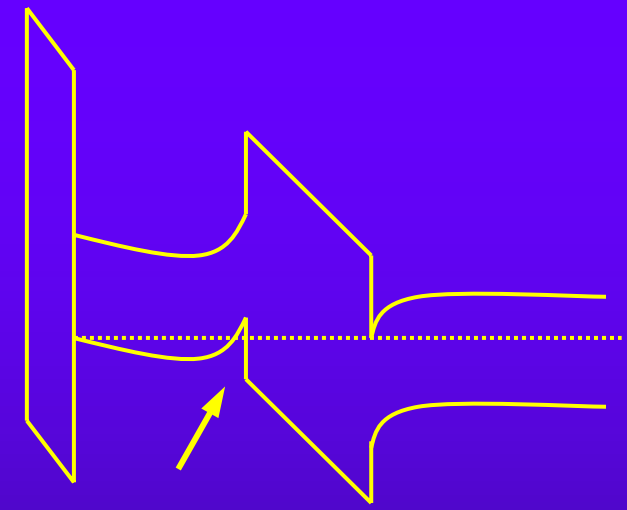
absence of polarization induced electric fields in the m-plane quantum wells



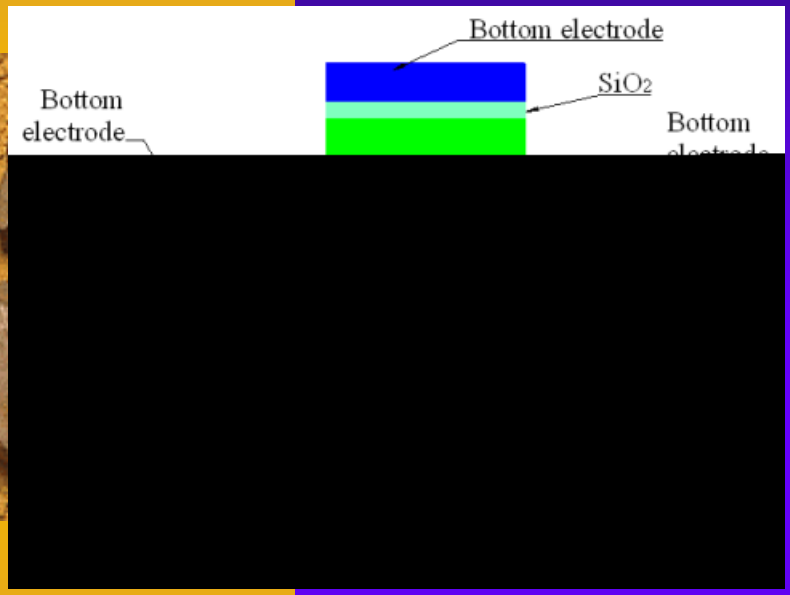
$$L \quad cI^{p}$$

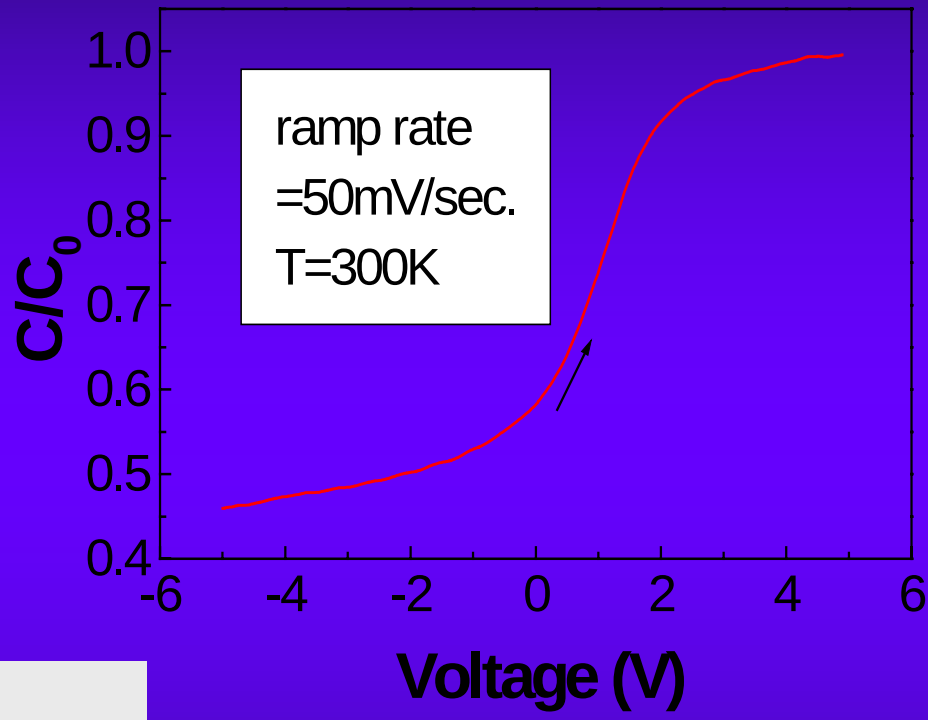






- -GaN M-F-S





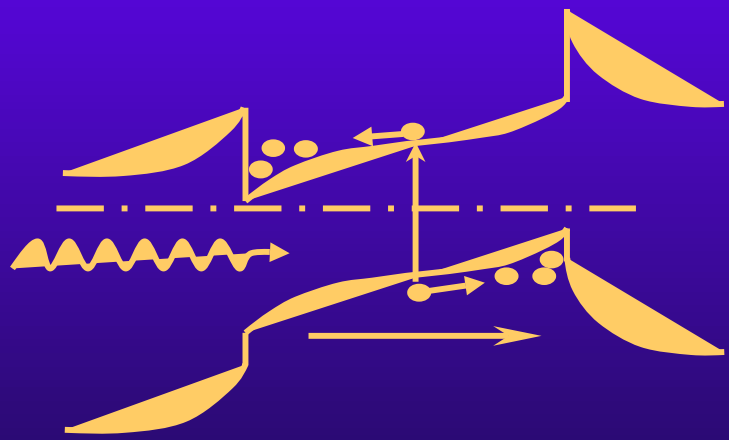
PZT: MIS

GaN

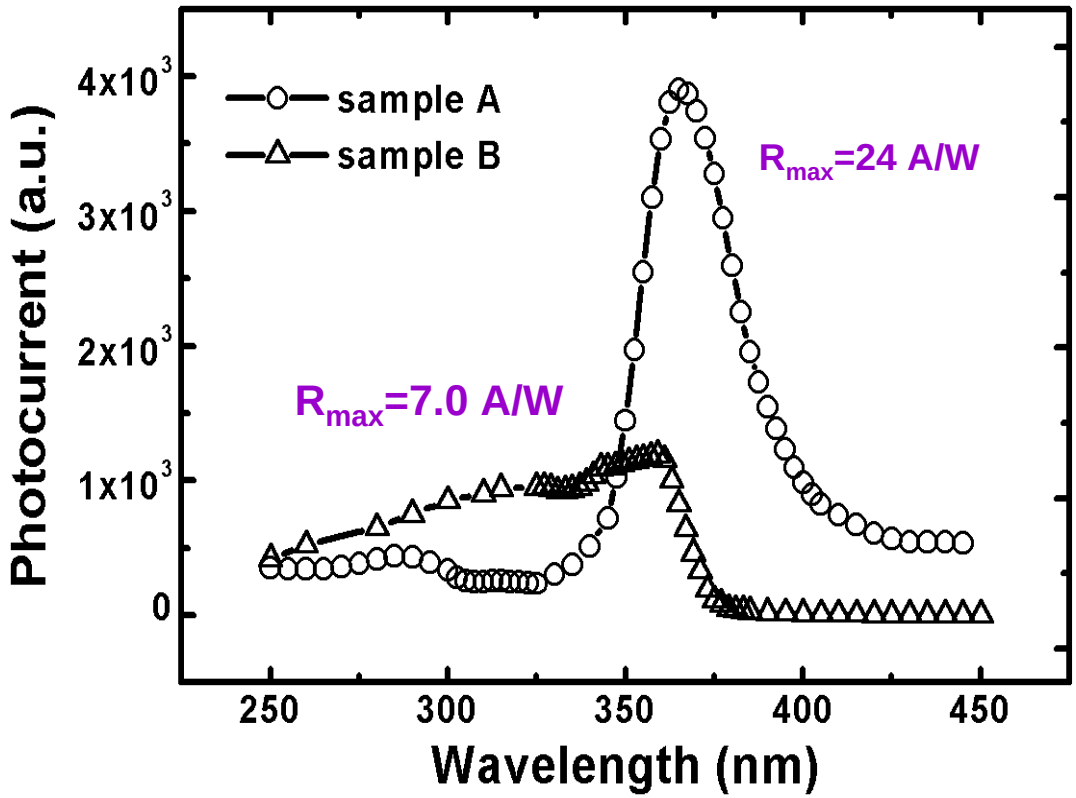
SiO_2 MIS 80V

PZT MFS -5V

AlGaN/GaN/AlGaN



monolayer	multilayer
	$Al_{0.2}Ga_{0.8}N$ (15nm)
GaN	GaN (60)
	$Al_{0.2}Ga_{0.8}N$ (15)
	GaN (500)
AlN buffer (150)	AlN buffer (150)
Si (111) substrate	Si(111) substrate


sample A
sample B
R_{max}=24 A/W
R_{max}=7.0 A/W
Photocurrent (a.u.)
4x10^3
3x10^3
2x10^3
1x10^3
0
250
300
350
400
450
Wavelength (nm)

$Al_{0.22}Ga_{0.78}N/GaN/Al_{0.22}Ga_{0.78}N$ ㄱ ㅅ

AlGaN/GaN

ㄱ ㅅ

ㄱ ㅅ

2DEG

-

ㅈ ㅏ

ㅅ

AlGaN/GaN/AlGaN

AlN/GaN

ㅅ :

ㅏ :

GaN ㅅ

10 à 12″ (3V ㅣ ㄱ)

4300A/W

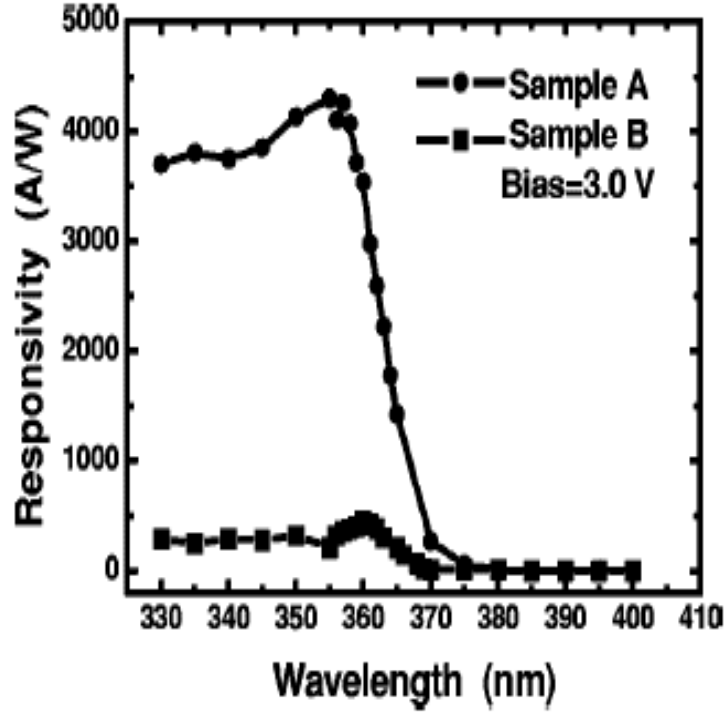


FIG. 3. Spectral response of the $Al_{0.22}Ga_{0.78}N/GaN/Al_{0.22}Ga_{0.78}N$ heterostructure photodetector (sample A) and the GaN monolayer structure photodetector (sample B) under 3.0 V bias.

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$LiAlO_2$ˆ 100˜ Э m GaN

Ո InGaN/GaN MOCVD

˘ m GaN Ո

InGaN/GaN

m GaN б ˘

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LED˘ ﾚ

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