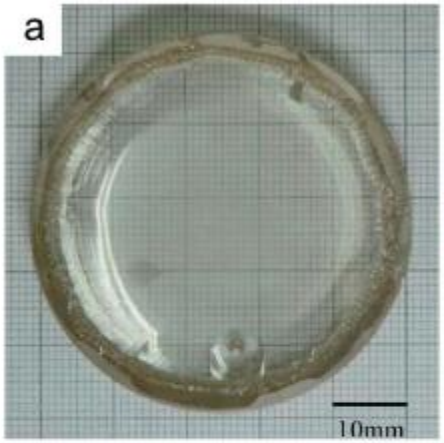
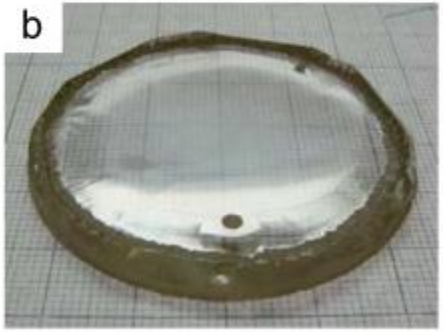
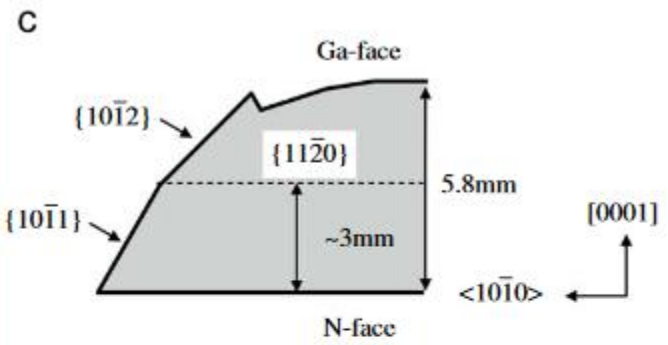
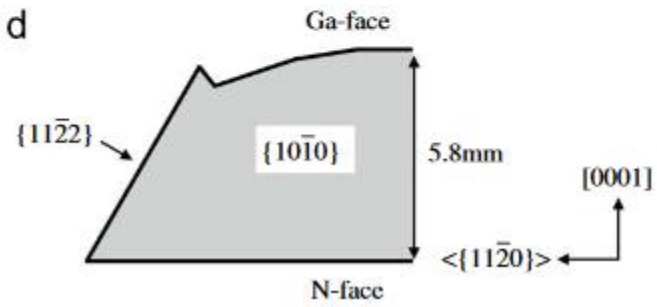
Homoepitaxial Growth by Hydride Vapor Phase Epitaxy Of Semi-Polar GaN on Ammonothermal Seeds. Influence of lateral growth on HVPE-GaN grown in the c-direction.

Motivation







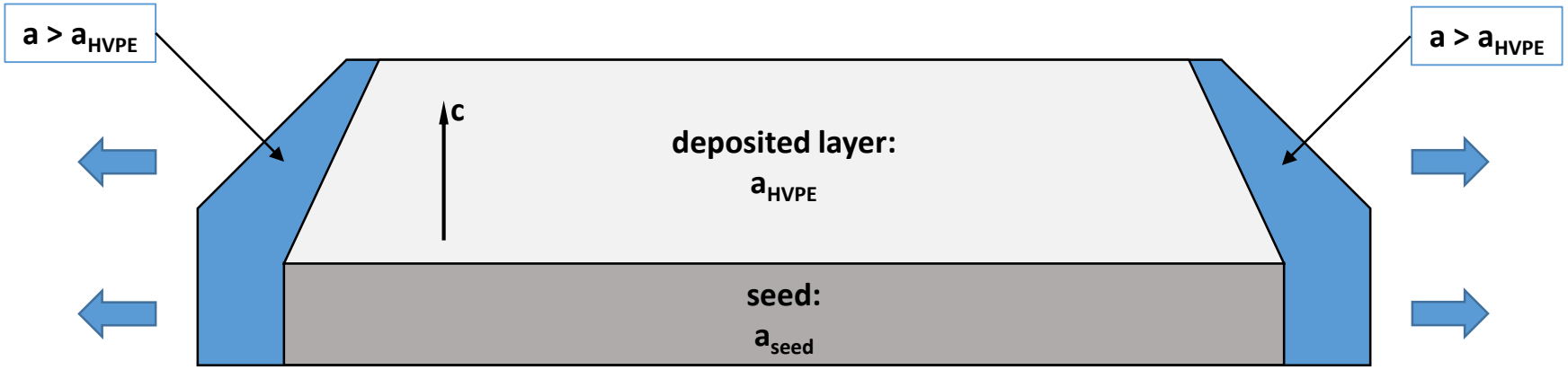


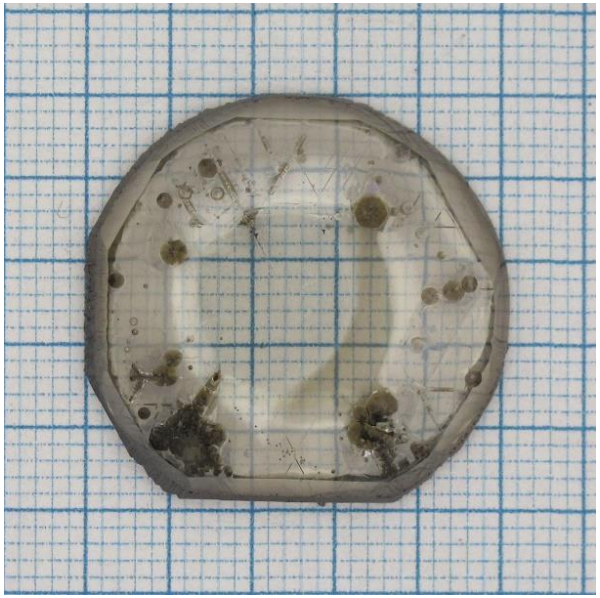
- HVPE-GaN crystals are usually grown in the $[0001]$ direction.
- Due to anisotropy of the growth semi-polar $\{10\bar{1}1\}$, $\{10\bar{1}2\}$, and $\{11\bar{2}2\}$ facets appear.

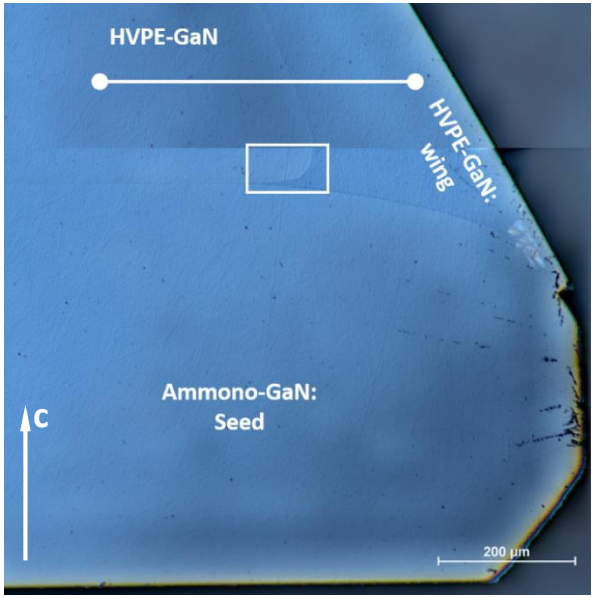
(a) Freestanding bulk GaN crystal grown by HVPE. (b) Bird-eye-view of the bulk GaN crystal. Cross-sectional schematic images of the bulk GaN crystal for (c) $(11\bar{2}0)$ and (d) $(10\bar{1}0)$ planes.

*K. Fujito, et al., Volume 311, Issue 10, 1 May 2009, Pages 3011-3014

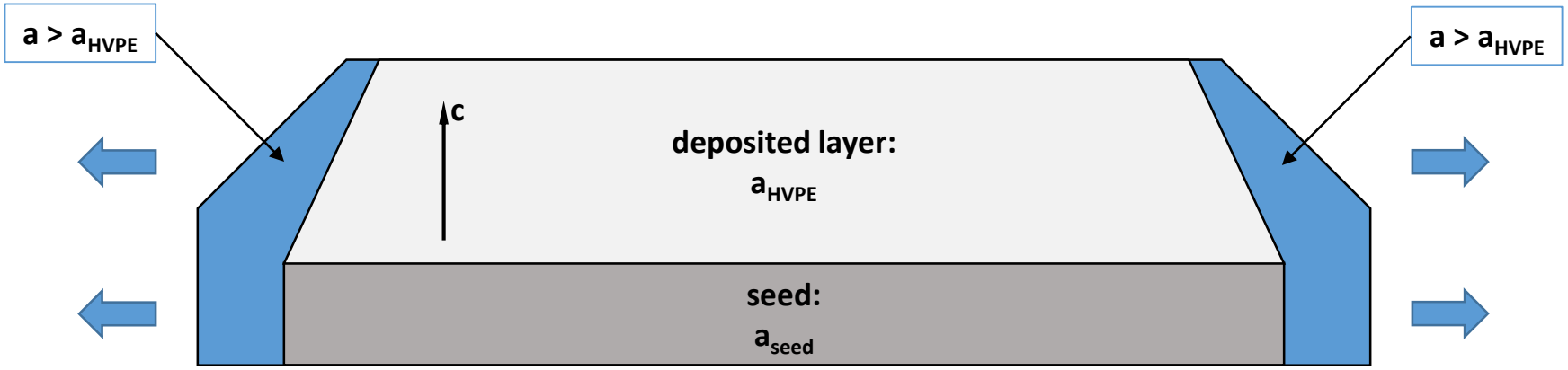
Motivation

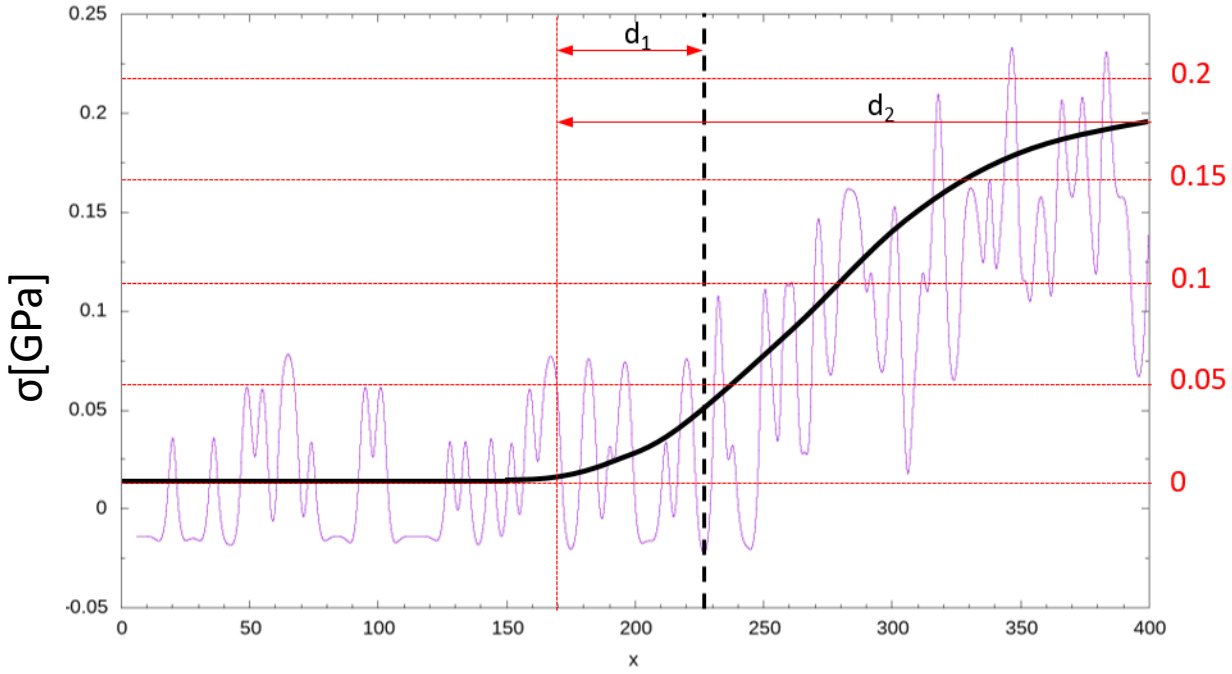

a > a_HVPE
a > a_HVPE
c
deposited layer:
a_HVPE
seed:
a_seed

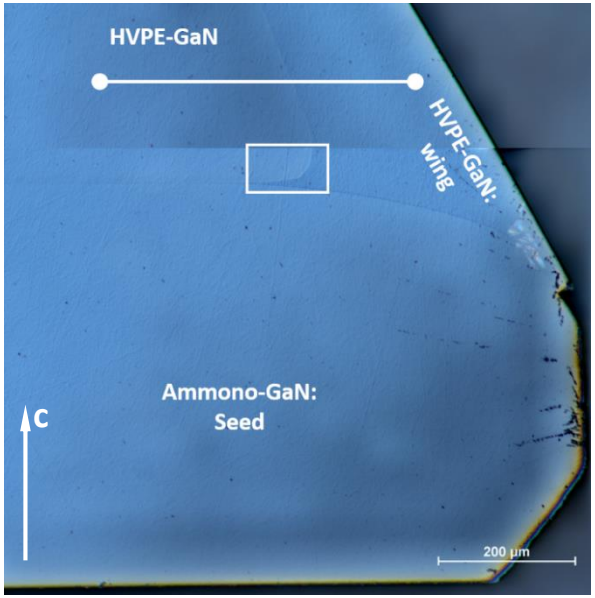



HVPE-GaN
HVPE-GaN: wing
Ammono-GaN: Seed
c
200 µm

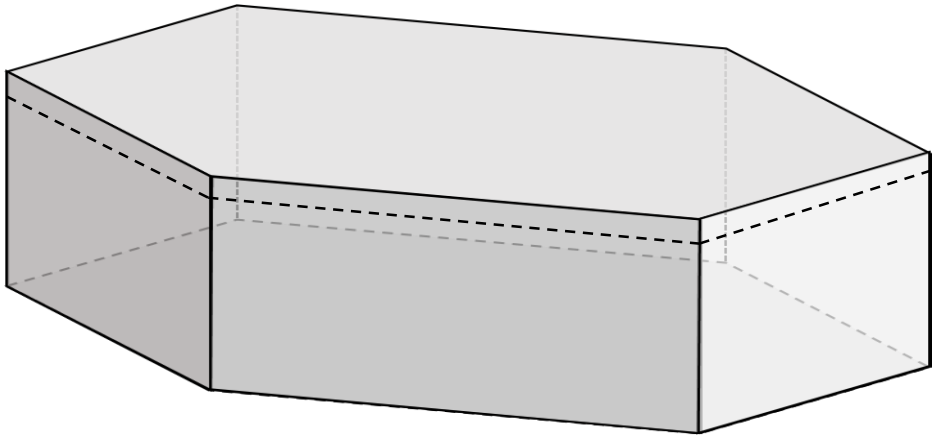
Motivation

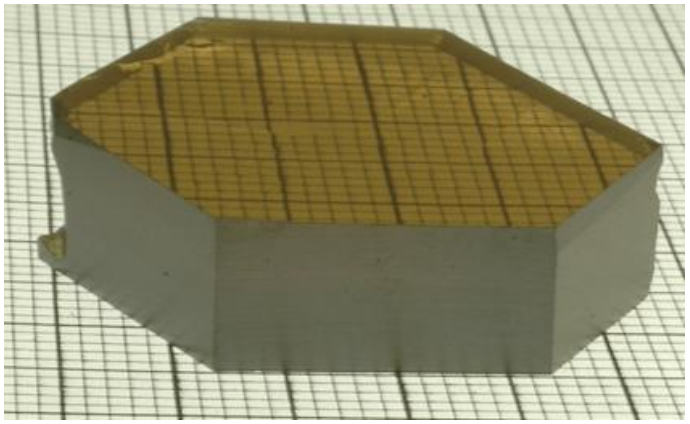

a > a_HVPE
a > a_HVPE
c
deposited layer:
a_HVPE
seed:
a_seed


σ[GPa]
x
d1
d2
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
50
100
150
200
250
300
350
400
0.2
0.15
0.1
0.05
0

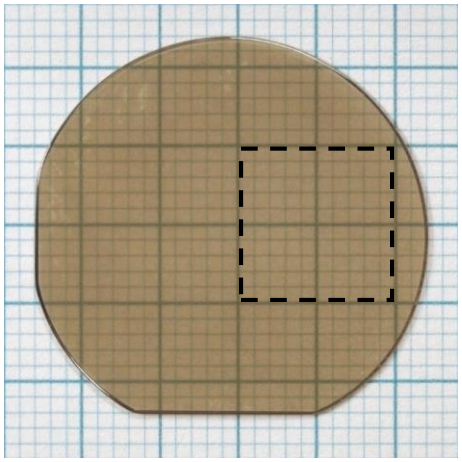

HVPE-GaN
HVPE-GaN: wing
Ammono-GaN: Seed
c
200 µm

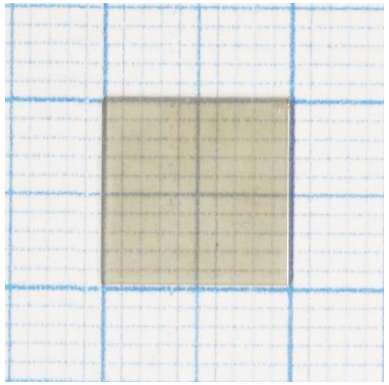
Seed preparation



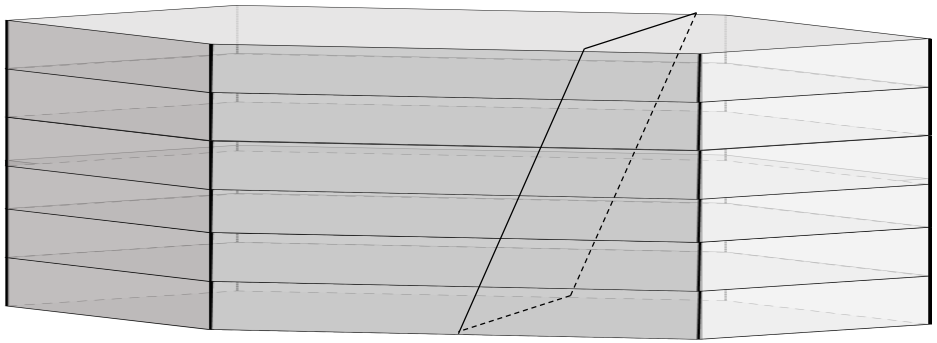


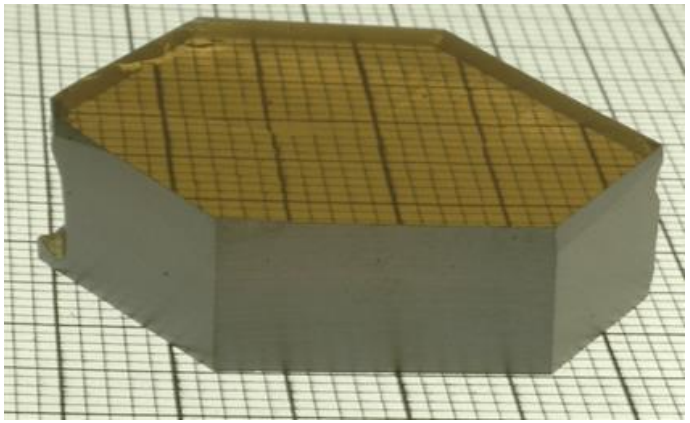
c-plane substrates:



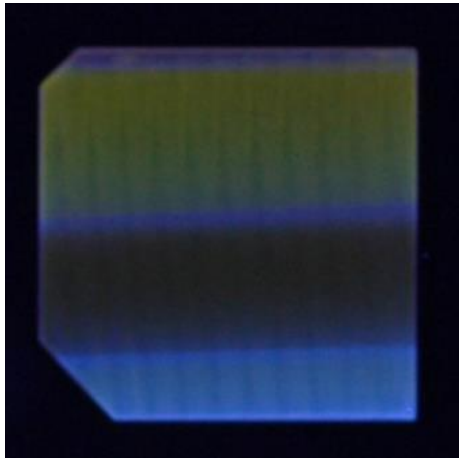


Seed preparation

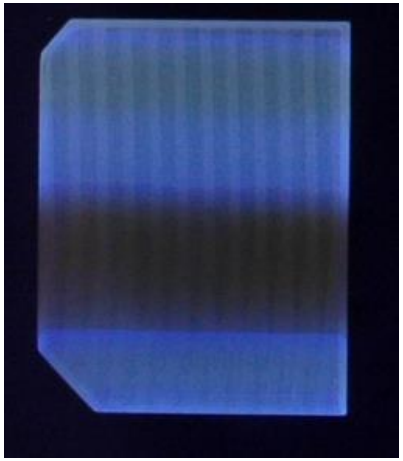




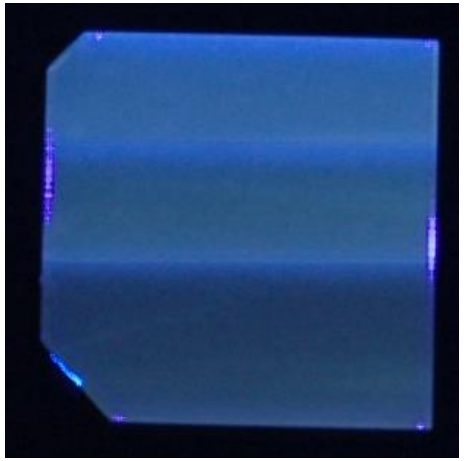
$(10\bar{1}1)$



$(10\bar{1}2)$



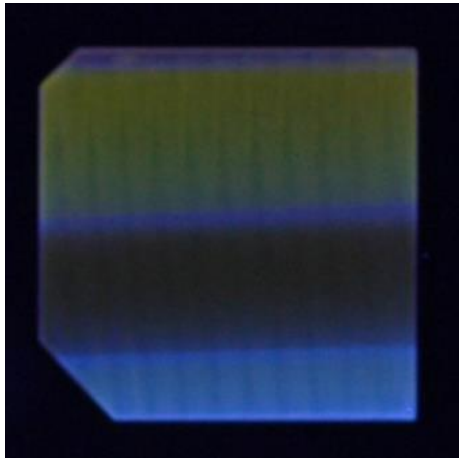
$(11\bar{2}2)$



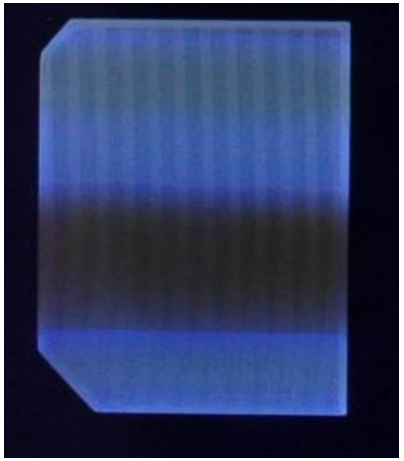
Seed preparation

	$(10\bar{1}1)$	$(10\bar{1}2)$	$(11\bar{2}2)$	(0001)
FWHM [arcsec]	59	40	33	38.52
R [m]	12	11	14	11.7

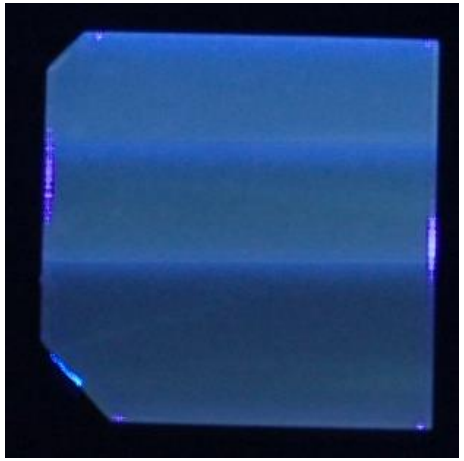
$(10\bar{1}1)$



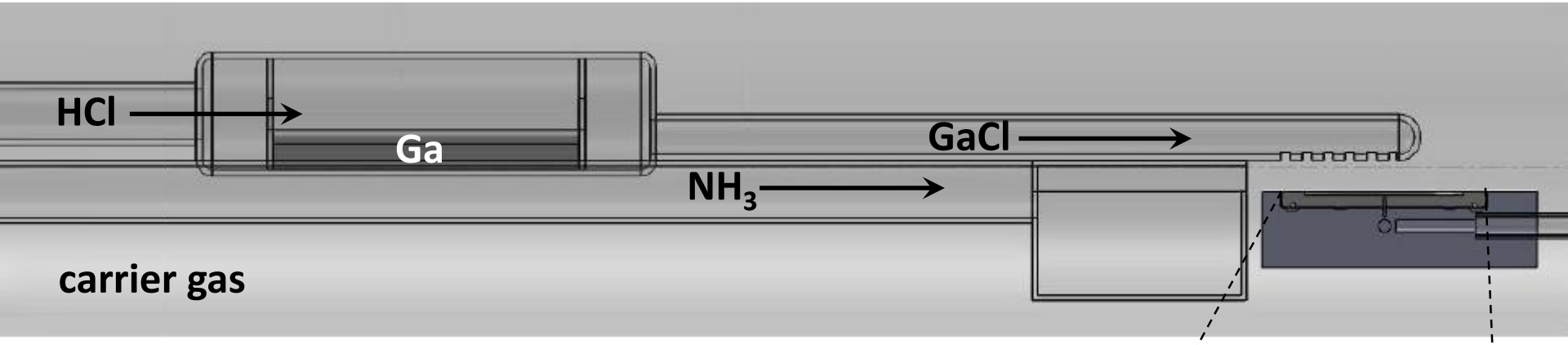
$(10\bar{1}2)$



$(11\bar{2}2)$



Experimental setup



Three substrates with various crystallographic surfaces: $(10\bar{1}1)$, $(10\bar{1}2)$, $(11\bar{2}2)$, and reference (0001) plane substrates in one run.

Growth conditions:

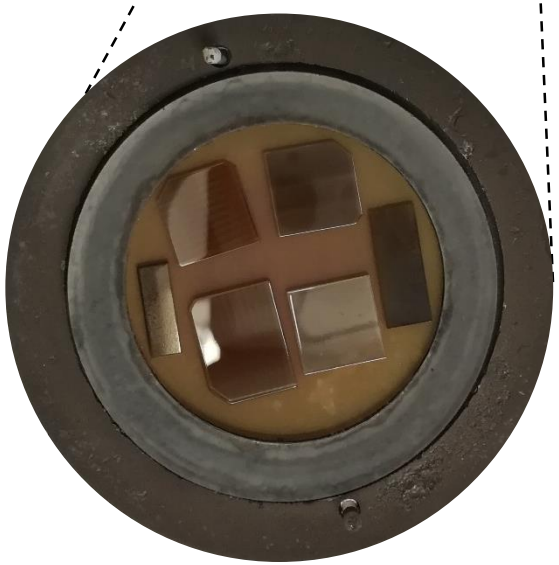
T=1045°C

p=800mbar

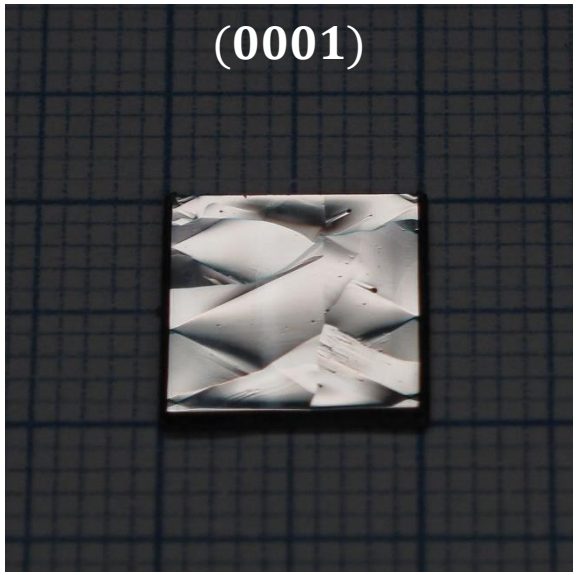
HCl flow=30ml/min

V/III ratio=20

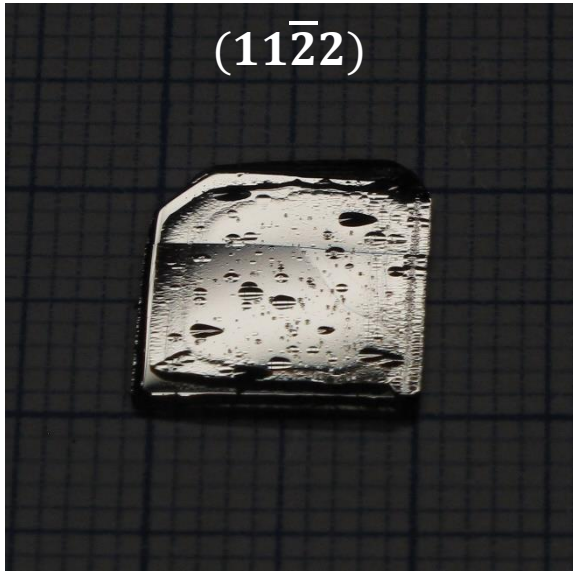
t=2h



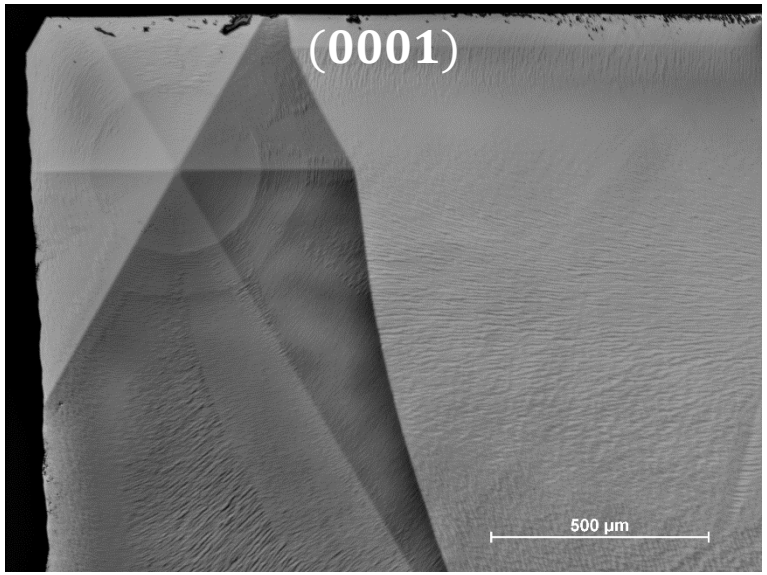
Morphology and growth rate

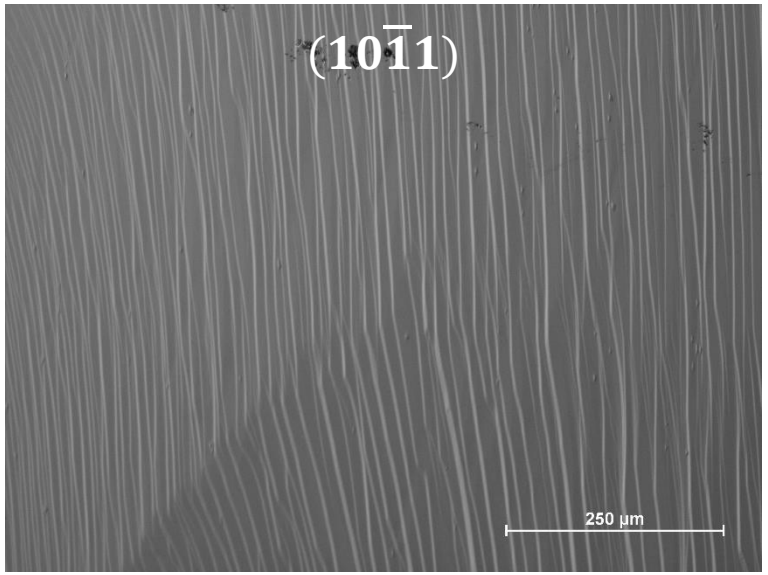


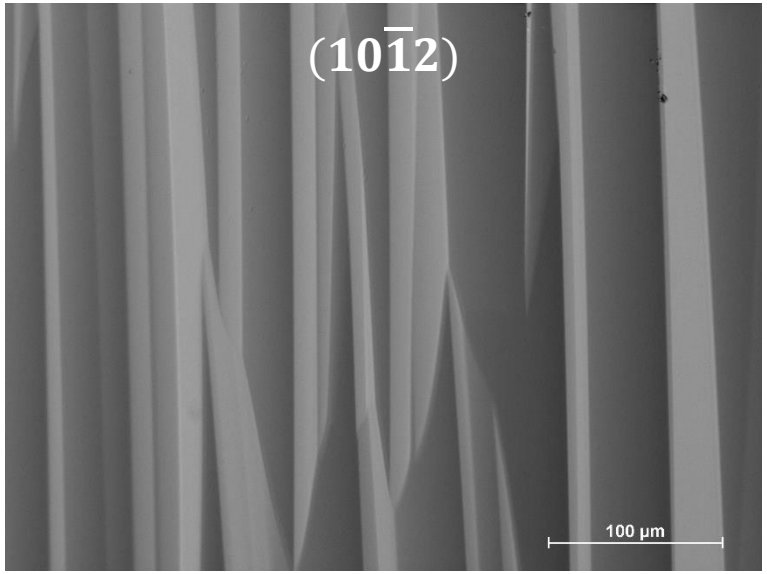
Growth rate [µm/h]			
(0001)	$(10\bar{1}1)$	$(10\bar{1}2)$	$(11\bar{2}2)$
210	138.5	245	173.5

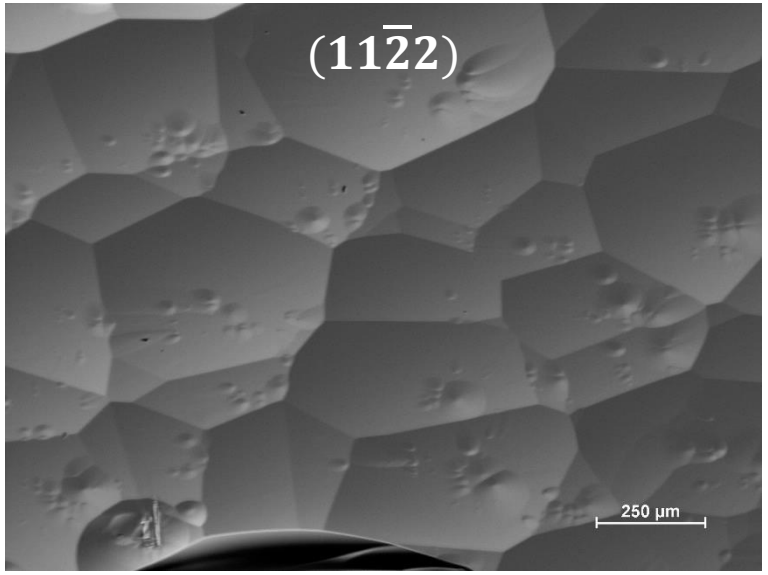


Morphology









seeds

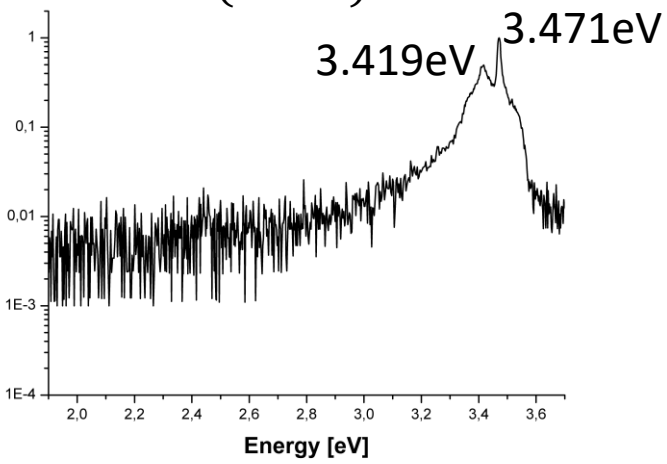
	$(10\bar{1}1)$	$(10\bar{1}2)$	$(11\bar{2}2)$	(0001)
FWHM [arcsec]	59	40	33	38.52
R [m]	12	11	14	11.7

new grown layers

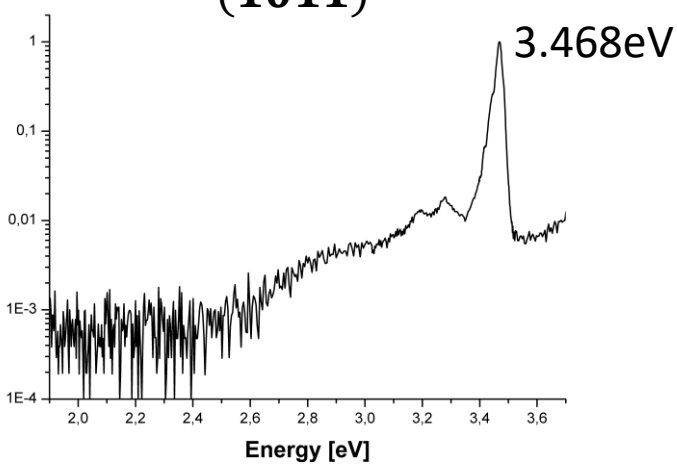
	$(10\bar{1}1)$	$(10\bar{1}2)$	$(11\bar{2}2)$	(0001)
FWHM [arcsec]	34.5	46	62.5	78
R [m]	18.5	13.5	18.5	10.2

Optical properties – PL

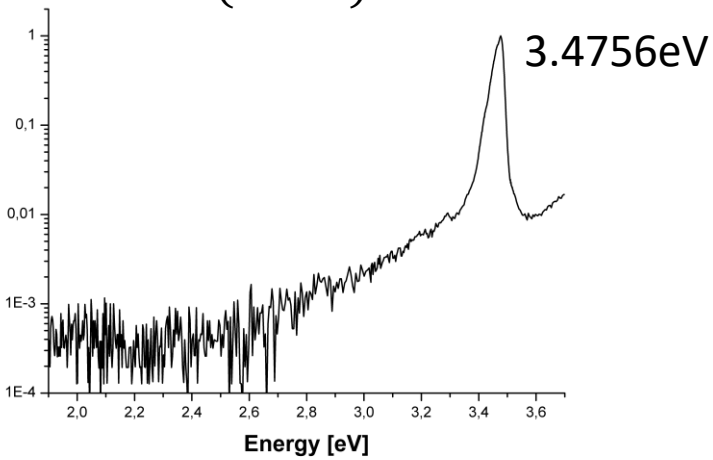
$(\mathbf{0001})$



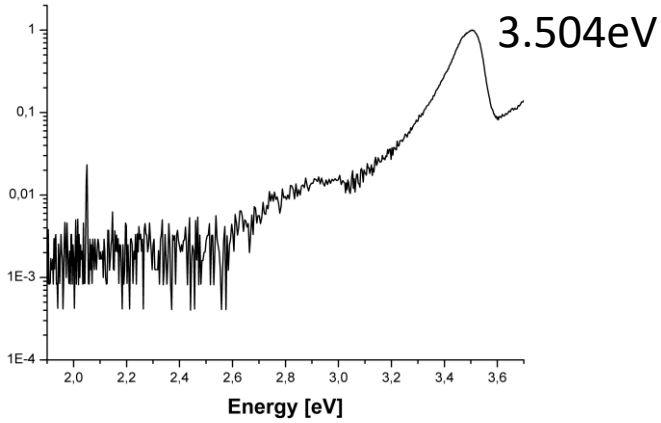
$(\mathbf{10\bar{1}1})$



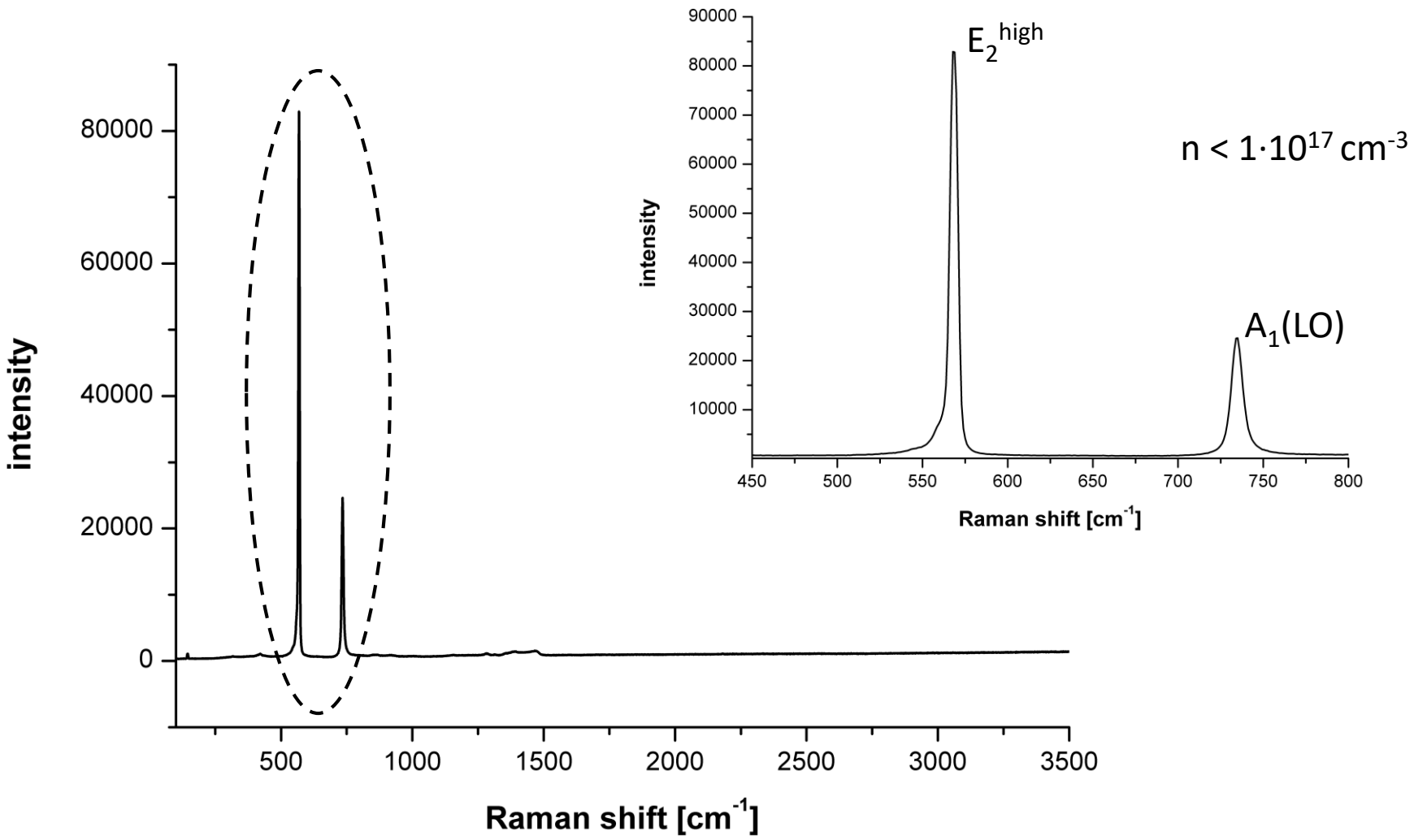
$(\mathbf{10\bar{1}2})$



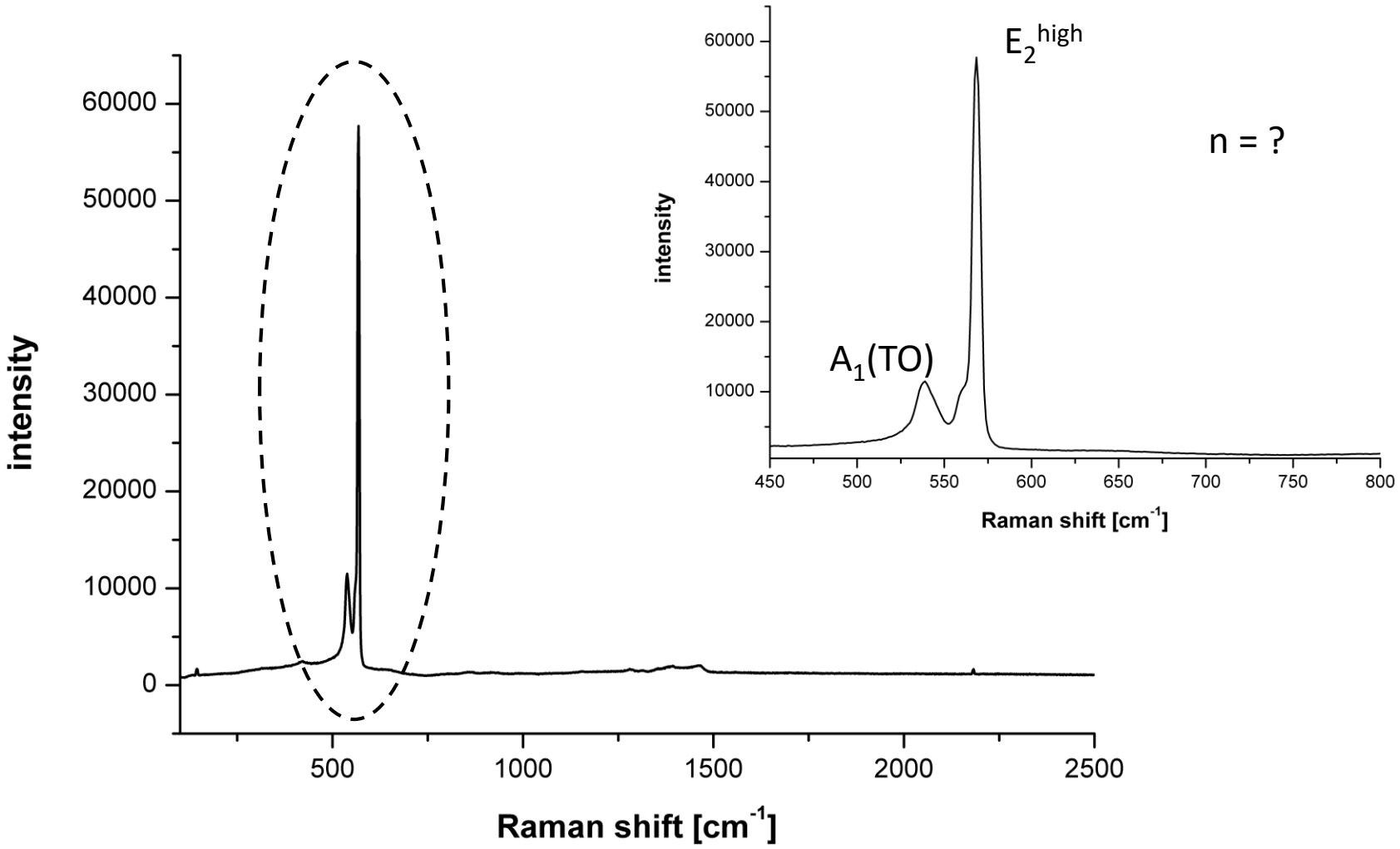
$(\mathbf{11\bar{2}2})$



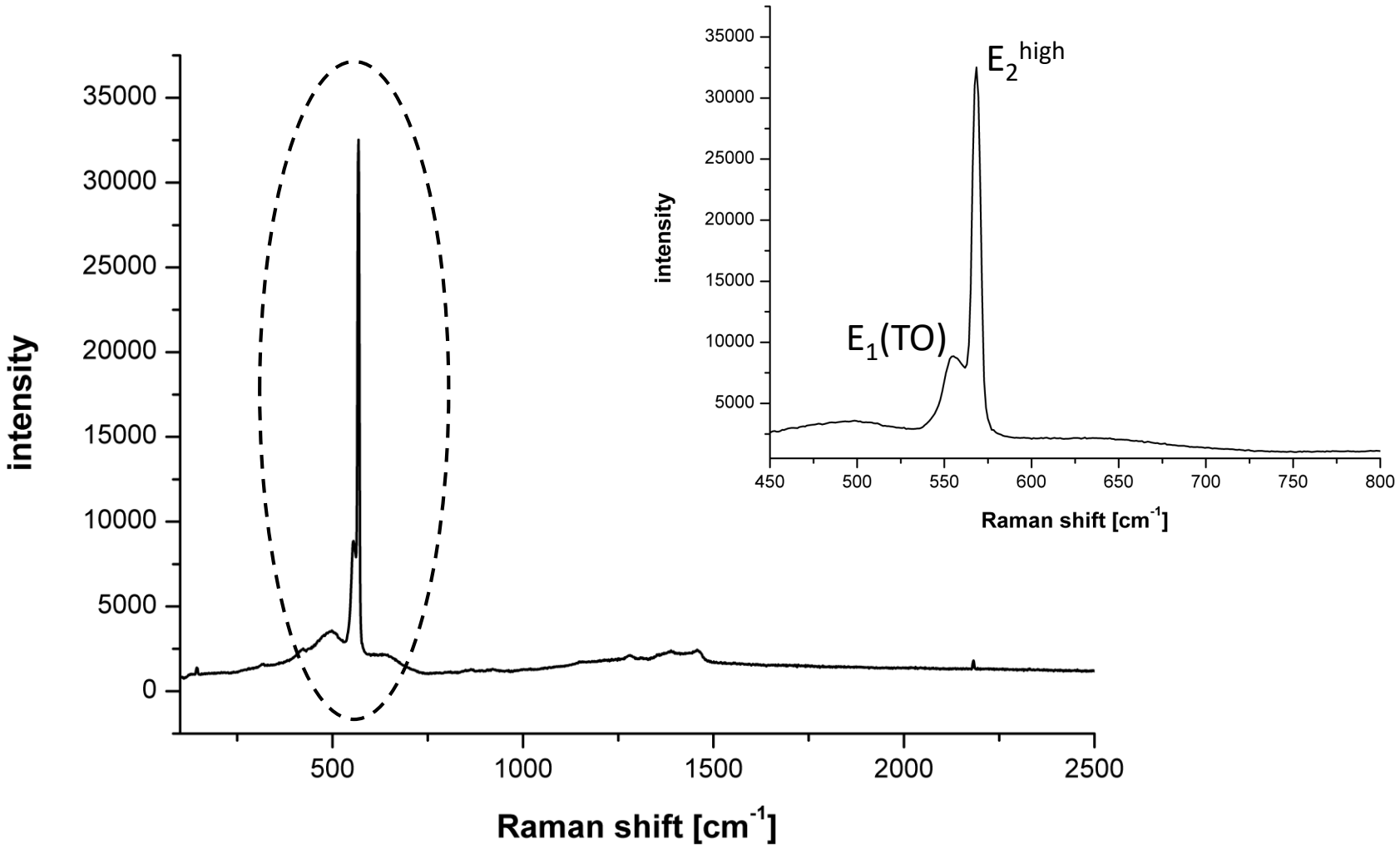
Raman spectroscopy – (0001)-plane



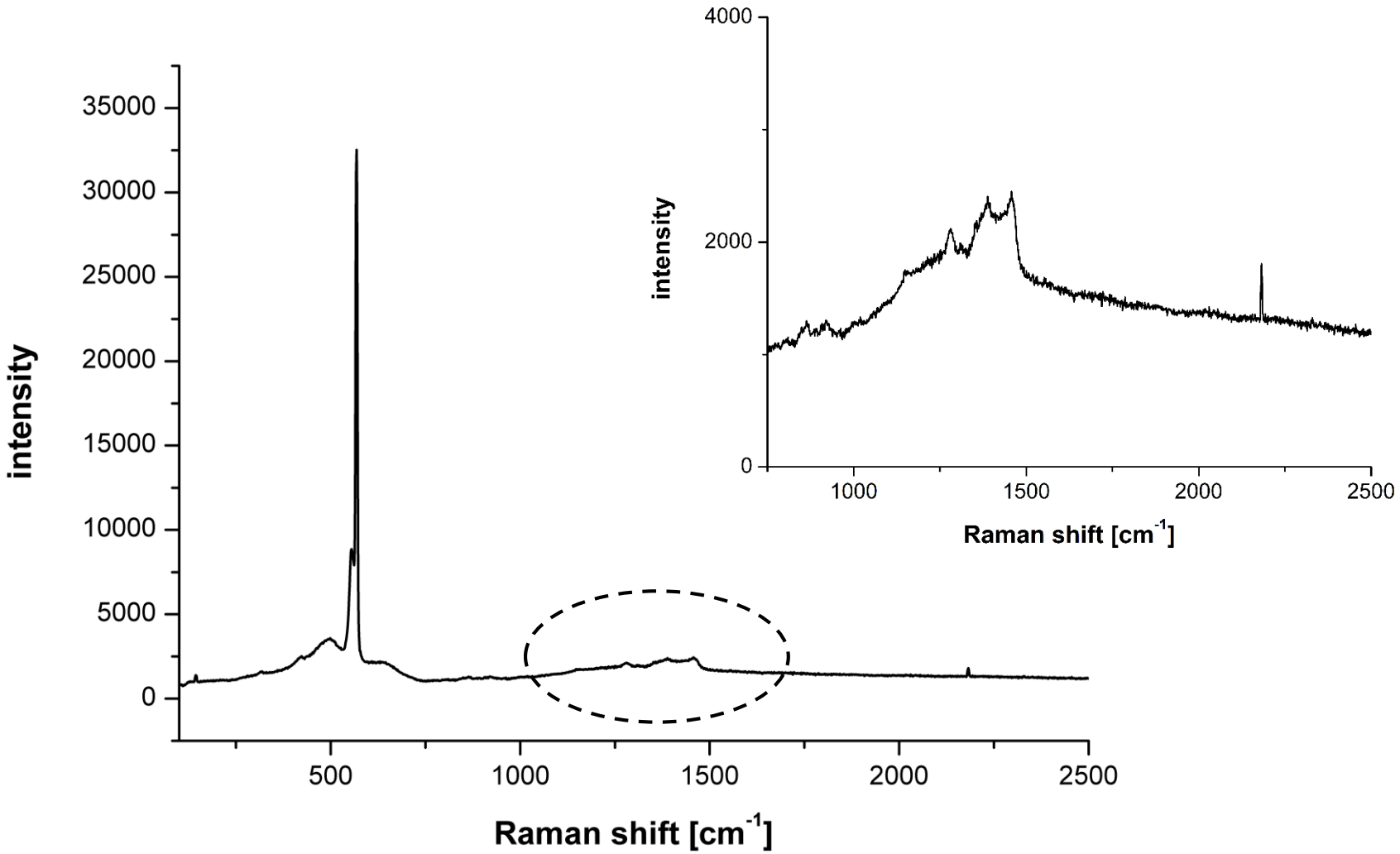
Raman spectroscopy – $(10\bar{1}1)$-plane



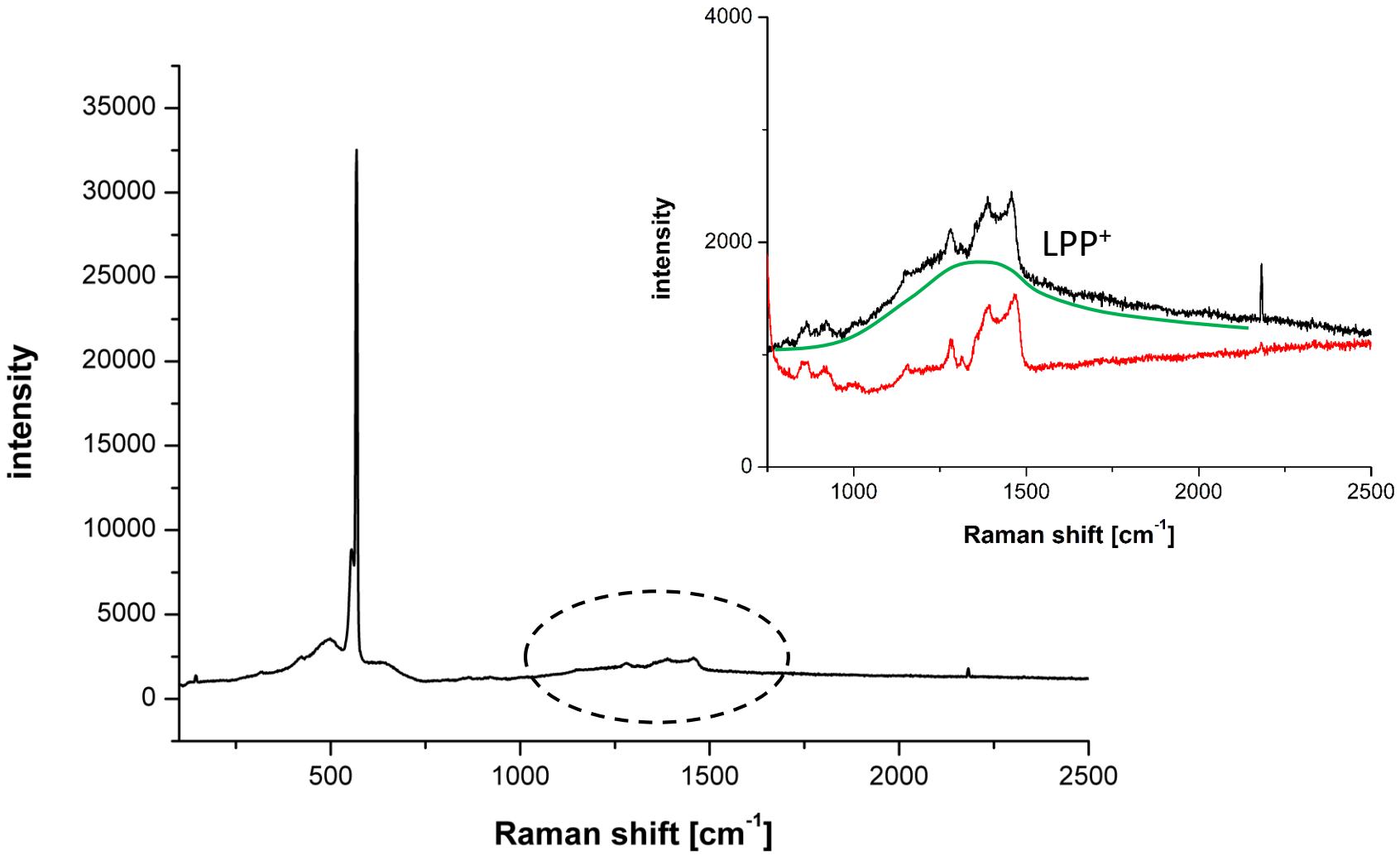
Raman spectroscopy – $(10\bar{1}2)$-plane



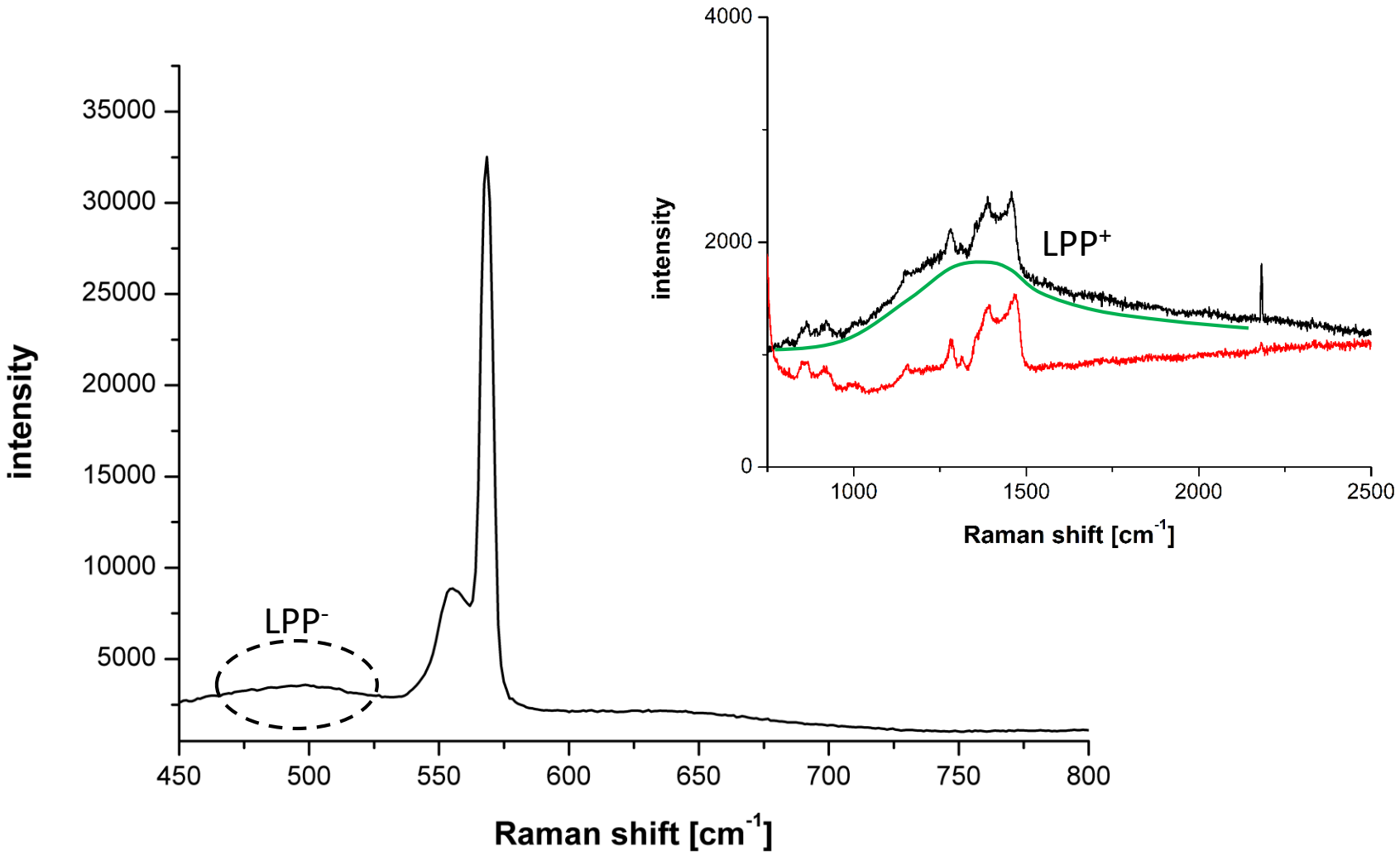
Raman spectroscopy – $(10\bar{1}2)$-plane



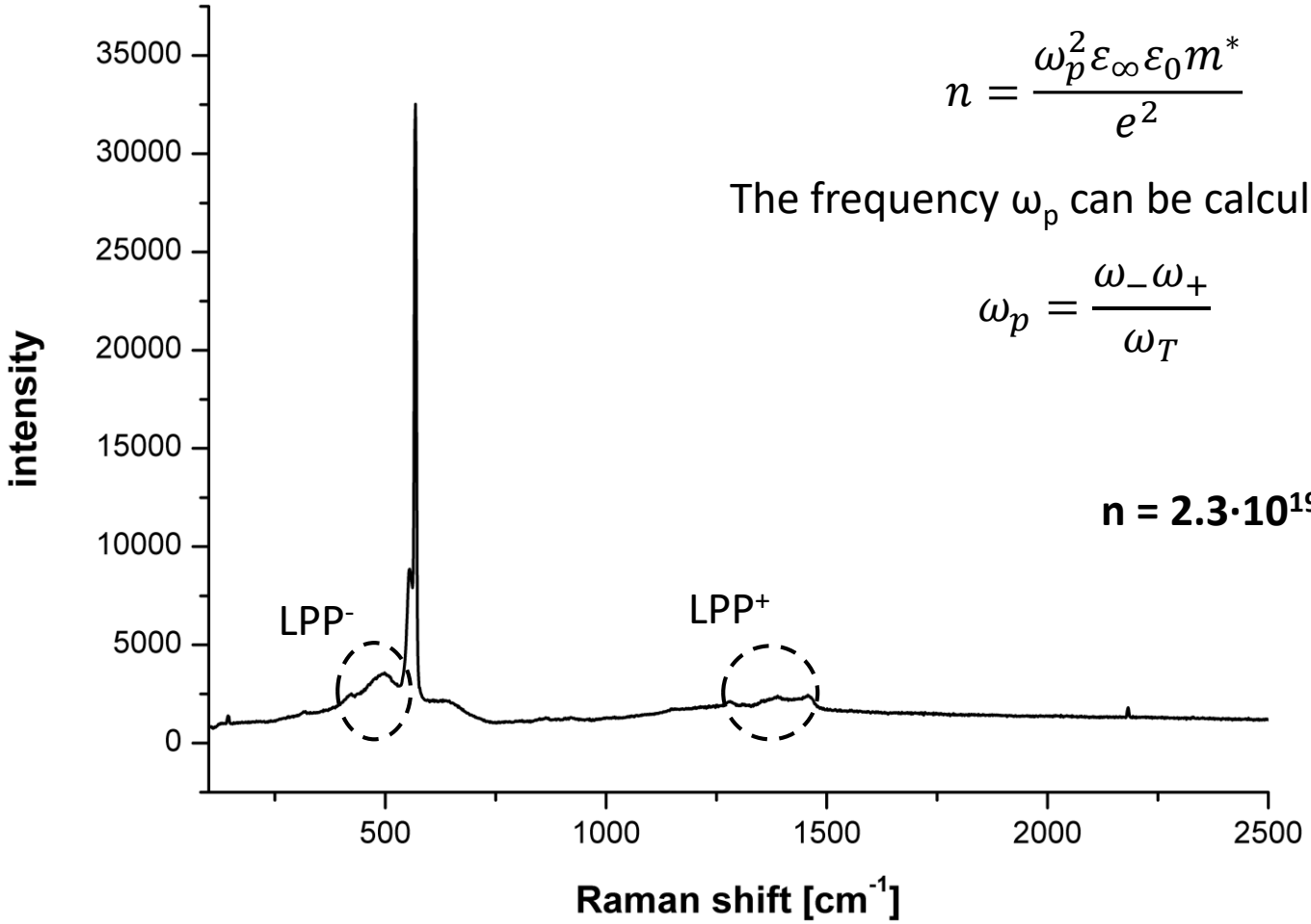
Raman spectroscopy – $(10\bar{1}2)$-plane



Raman spectroscopy – $(10\bar{1}2)$-plane



Raman spectroscopy – $(10\bar{1}2)$-plane



$$n = \frac{\omega_p^2 \varepsilon_\infty \varepsilon_0 m^*}{e^2}$$

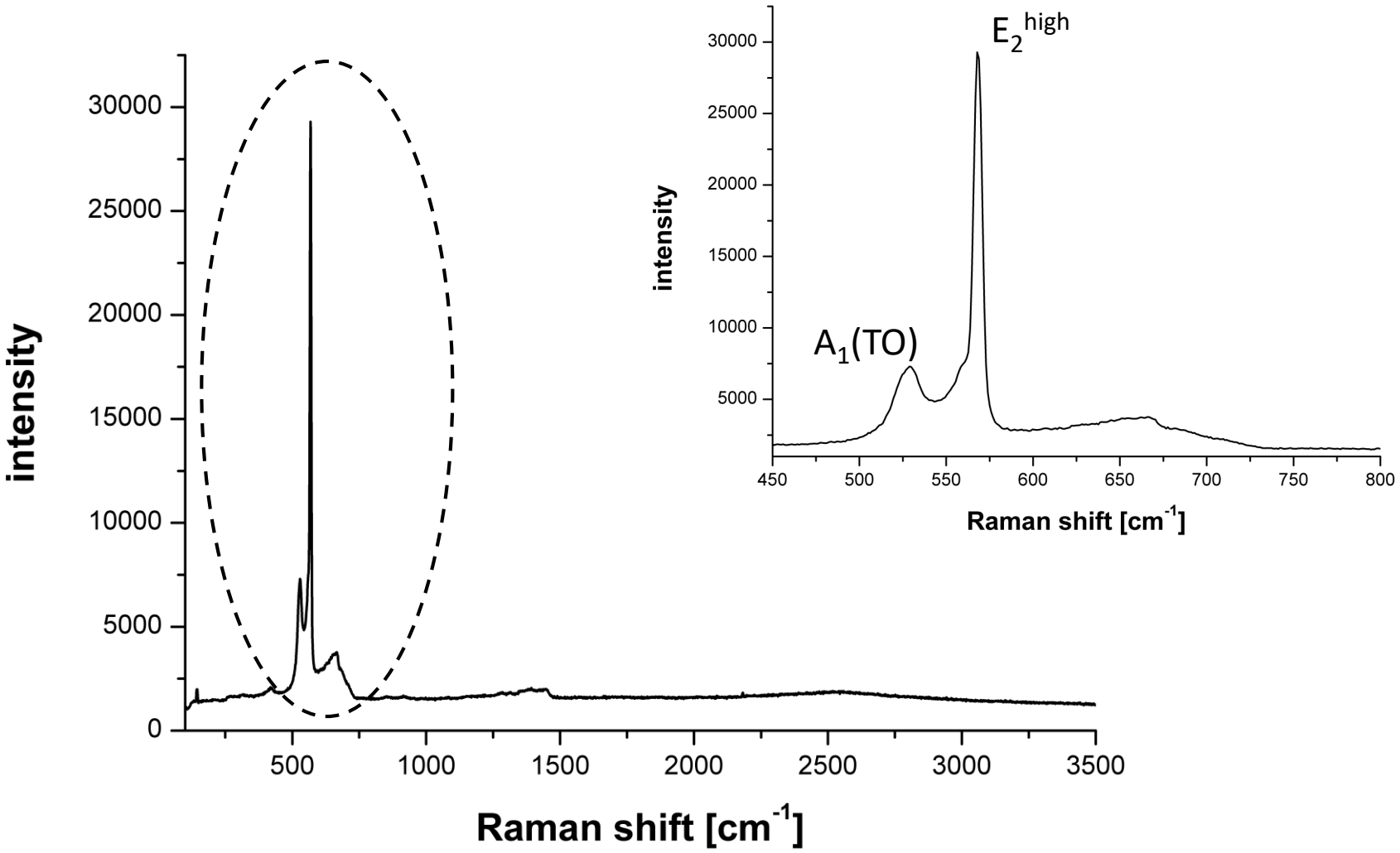
The frequency ω_p can be calculated as:

$$\omega_p = \frac{\omega_- \omega_+}{\omega_T}$$

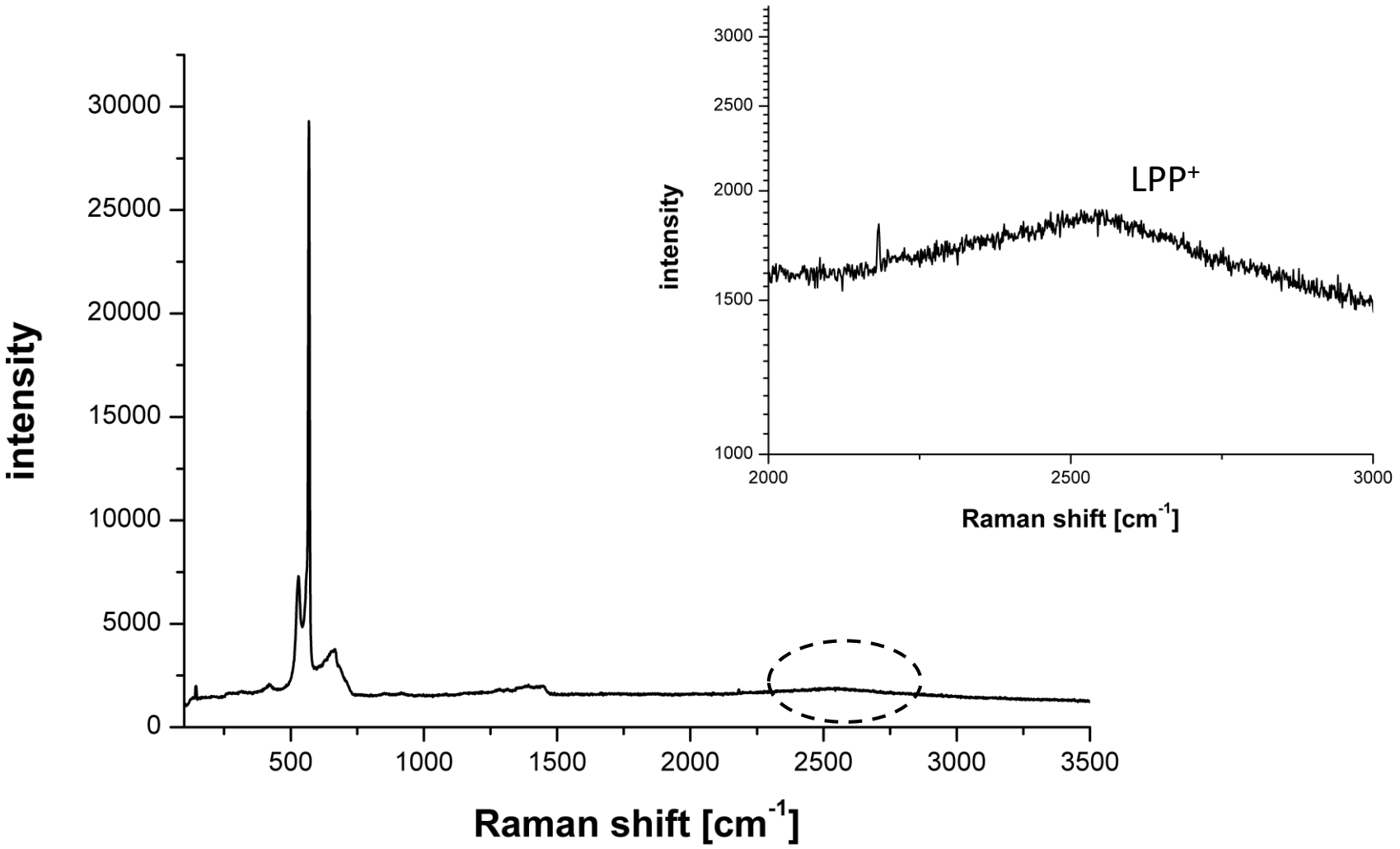
$n = 2.3 \cdot 10^{19}\ cm^{-3}$

P. Perlin, et al., Appl. Phys. Lett. **67**, 2524 (1995)

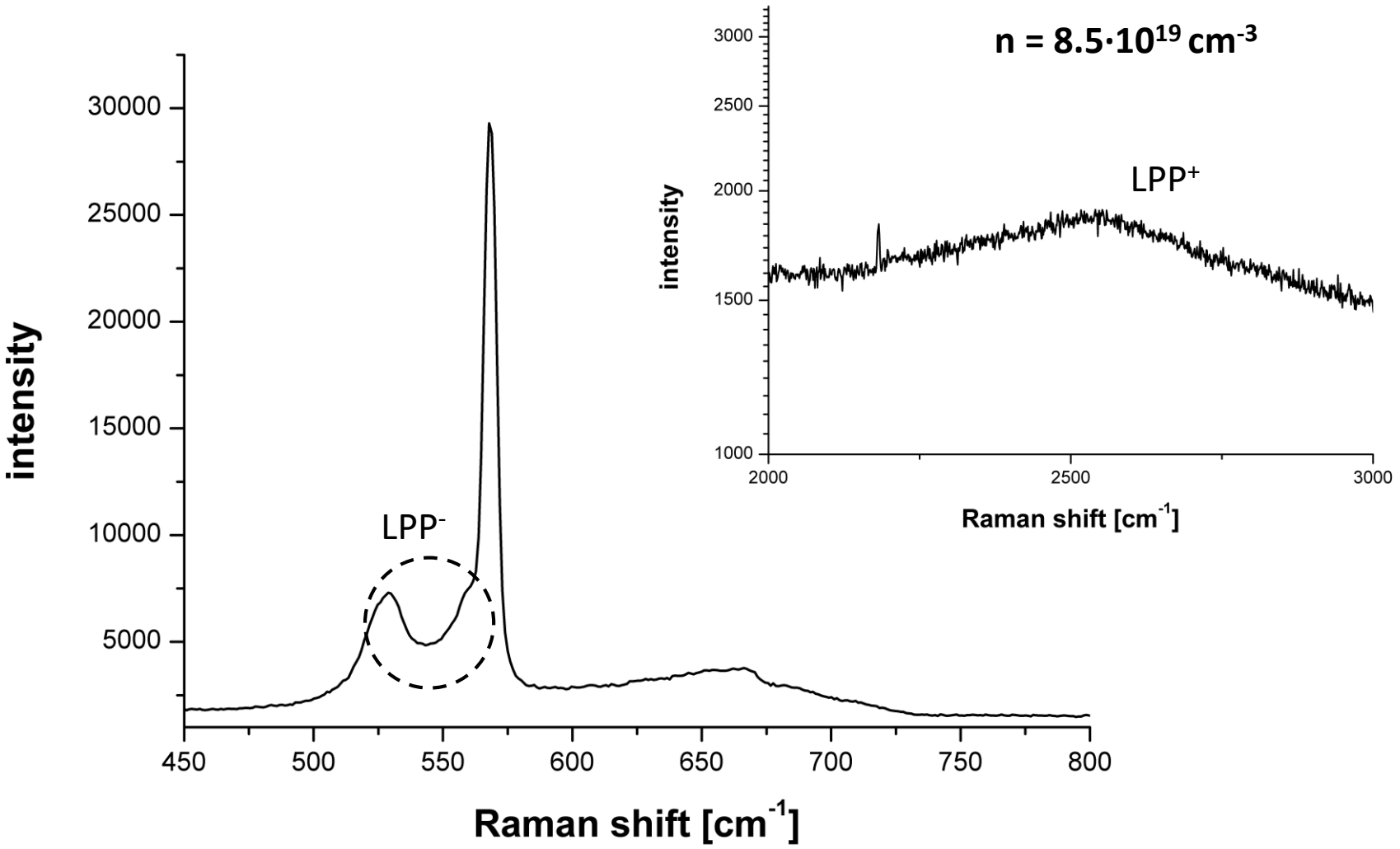
Raman spectroscopy – $(11\bar{2}2)$-plane



Raman spectroscopy – $(11\bar{2}2)$-plane

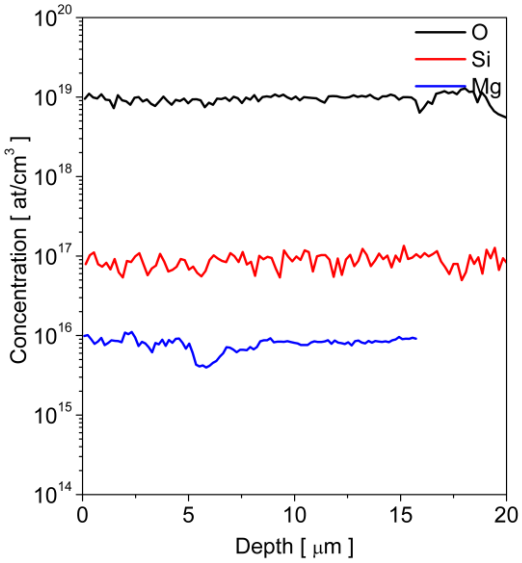


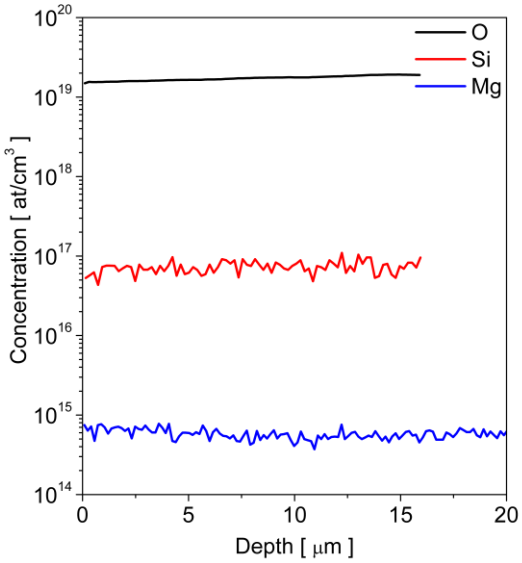
Raman spectroscopy – $(11\bar{2}2)$-plane

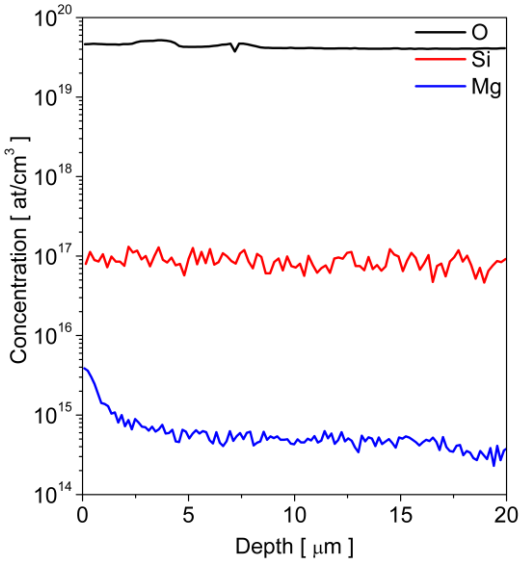


P. Perlin, et al., Appl. Phys. Lett. **67**, 2524 (1995)

$(10\bar{1}1)$	$(10\bar{1}2)$	$(11\bar{2}2)$







	$(10\bar{1}1)$	$(10\bar{1}2)$	$(11\bar{2}2)$
oxygen [cm^{-3}]	$1 \cdot 10^{19}$	$2 \cdot 10^{19}$	$6 \cdot 10^{19}$
silicon [cm^{-3}]	$1 \cdot 10^{17}$	$7 \cdot 10^{16}$	$1 \cdot 10^{17}$

Impurity vs carrier concentration

	$(10\bar{1}1)$	$(10\bar{1}2)$	$(11\bar{2}2)$	(0001)
oxygen [cm^{-3}]	$1 \cdot 10^{19}$	$2 \cdot 10^{19}$	$6 \cdot 10^{19}$	BDL
silicon [cm^{-3}]	$1 \cdot 10^{17}$	$7 \cdot 10^{16}$	$1 \cdot 10^{17}$	$1 \cdot 10^{17}$
n [cm^{-3}]	-	$2.3 \cdot 10^{19}$	$8.5 \cdot 10^{19}$	$< 1 \cdot 10^{17}$

All semipolar layers are strongly doped by oxygen. These crystals are highly conductive n-type GaN layers.

The origin of lattice mismatch between new-grown c-plane GaN crystals and laterally grown part of the crystal is high oxygen concentration in the wings.
Oxygen is the source of high free carrier concentration.

SUMMARY

- It was demonstrated that the semi-polar GaN substrates, obtained by slicing of multi-regrown ammonothermal bulk GaN, can be used as seeds for the HVPE crystallization.
- The growth rate and morphology of obtained crystals strongly depend on the crystallographic growth direction.
- The electrical as well as optical properties of the crystals grown in naturally occurring semi-polar directions are significantly different from the properties crystals grown the c-direction.
- The main source of free carrier concentration is oxygen.
- In order to reduce the effect of lateral growth on crystallization in c-direction, one should look for other growth conditions:
  - Lattice engineering.
  - Thermal field control.

Acknowledgements

This research was supported by TEAM TECH program of the Foundation for Polish Science co-financed by the European Union under the European Regional Development Fund. (POIR.04.04.00-00-5CEB/17-00)

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and ONR Global through program NICOP: N62909-17-1-2004