Inhomogeneous electron distribution in InN nanocolumns

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Electronic, transport and optical properties of low-dimensional systems
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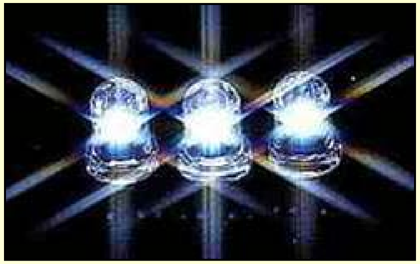
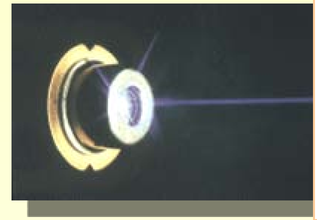
VNIVERSITAT DE VALÈNCIA I[CM]UV Institut de Ciència dels Materials

Nitride semiconductors:

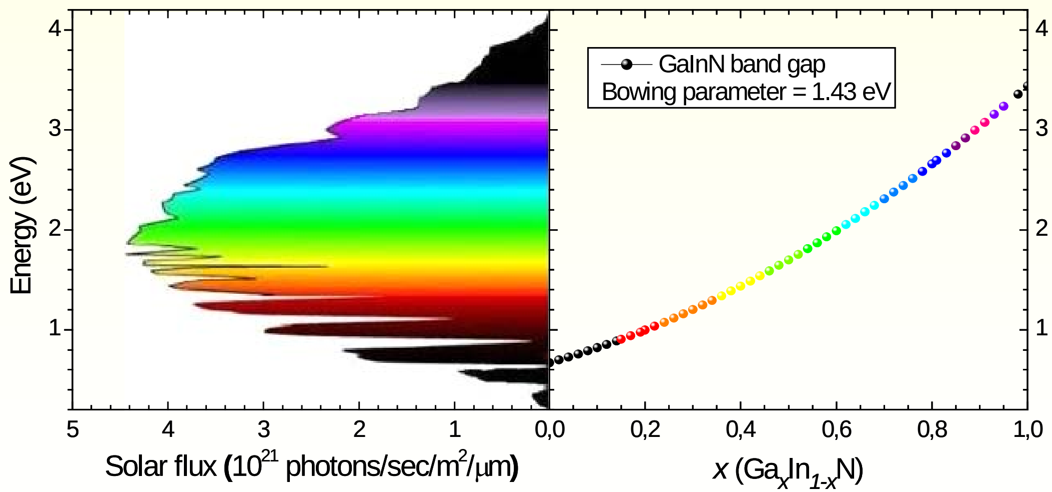
GaN, AlN, InN





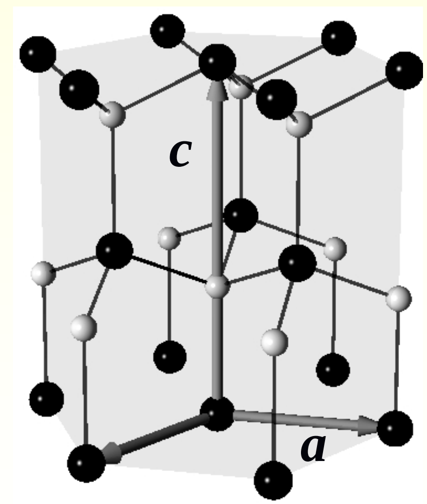
Bandgap of $Ga_{1-x}In_xN$ – Solar spectrum

High efficiency solar cells.



Wurtzite structure

Non-centrosymmetric



Polar and non-polar surfaces

Indium nitride

Low crystalline quality layers.
Bandgap (E_G): 1.9 eV

2002 →

High crystalline quality.
Reasigned E_G: 0.67 eV.

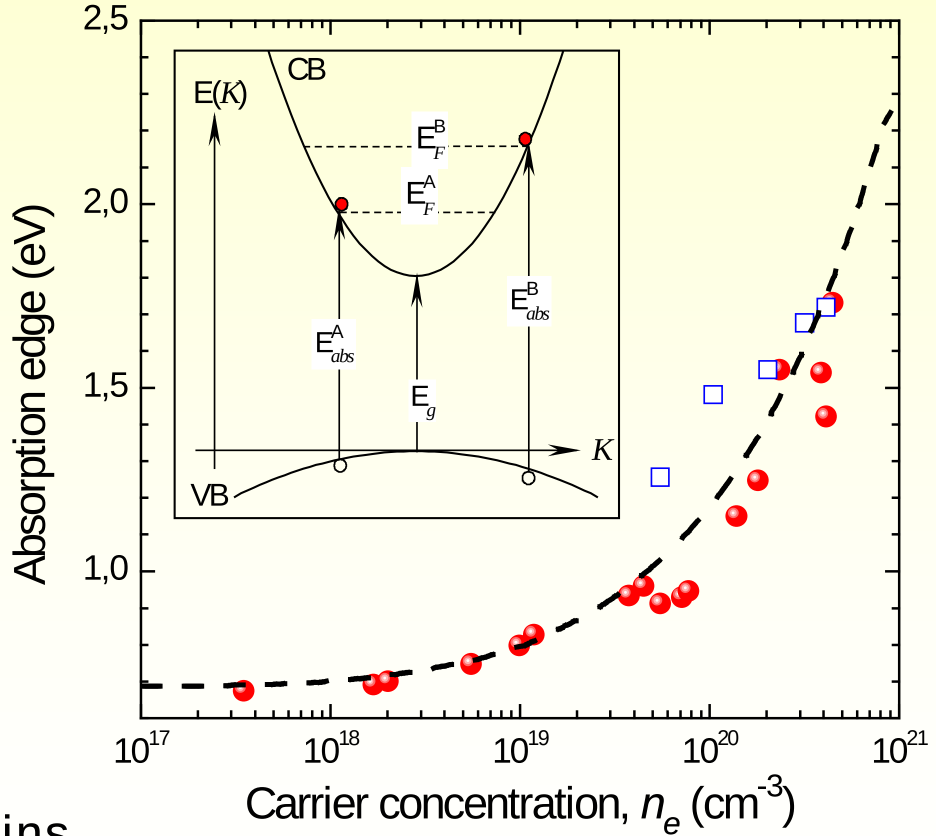
High density of electrons (donors)

↓

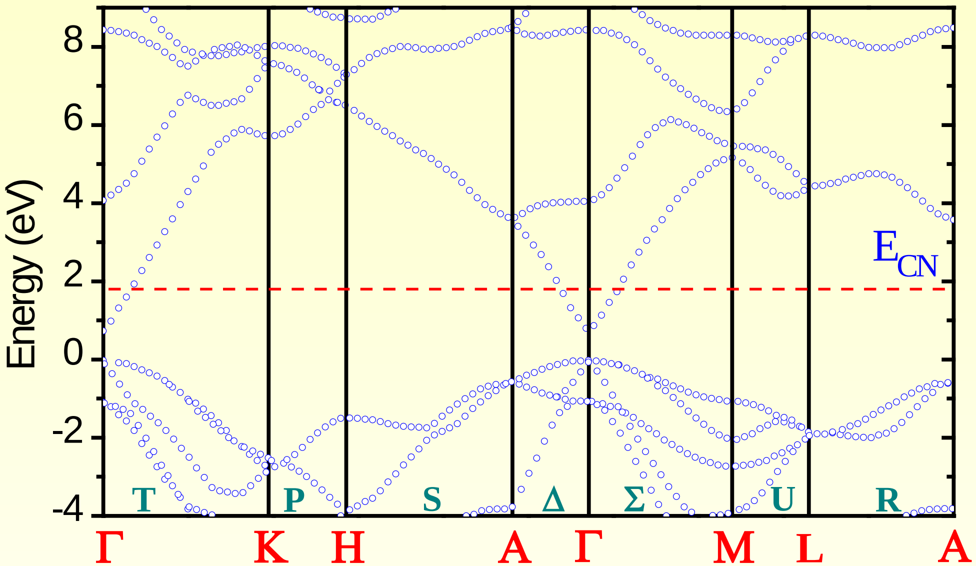
Electron effective mass very small

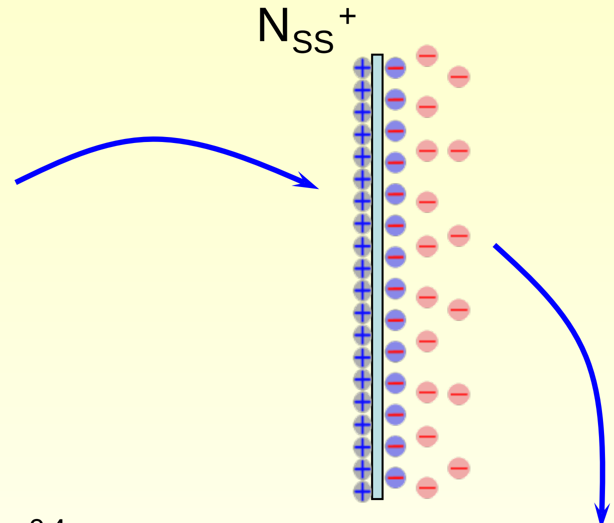
Large shift of the absorption edge (Burstein-Moss).

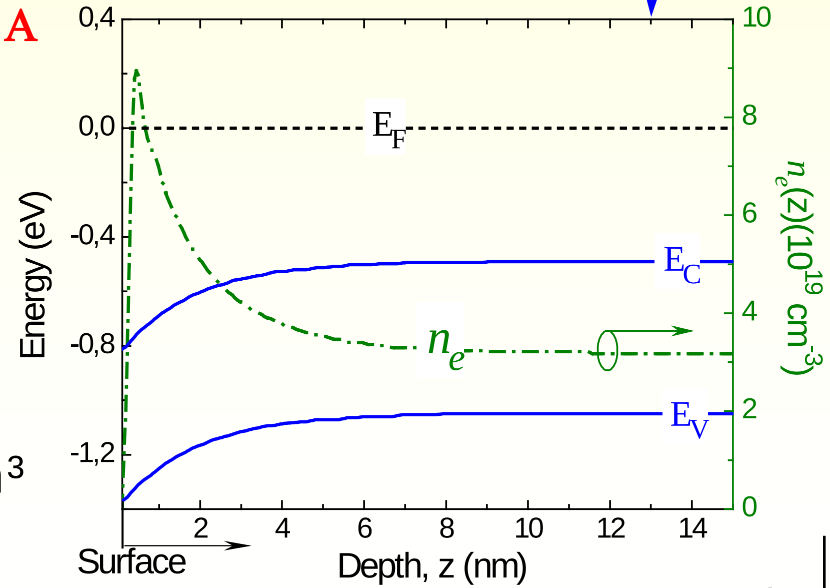
Free electron concentration remains high: $n_e > 3\text{x}10^{17}$ cm^{-3}



Surface electron accumulation layer.





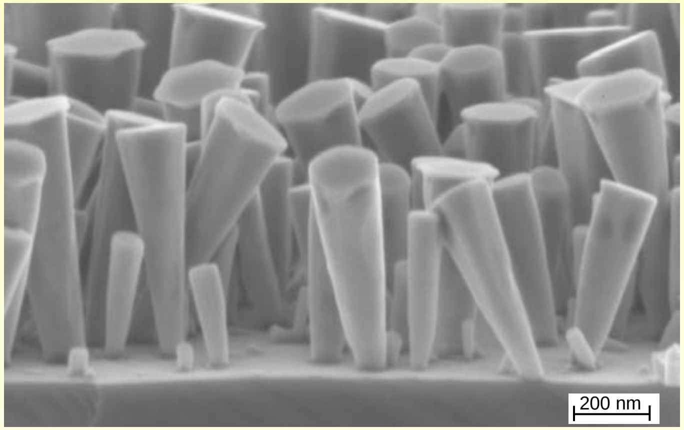


Polar surfaces: Intrinsic

Non-polar surfaces
- Intrinsic[1]
- Extrinsic[2]
- No accumulation[3]

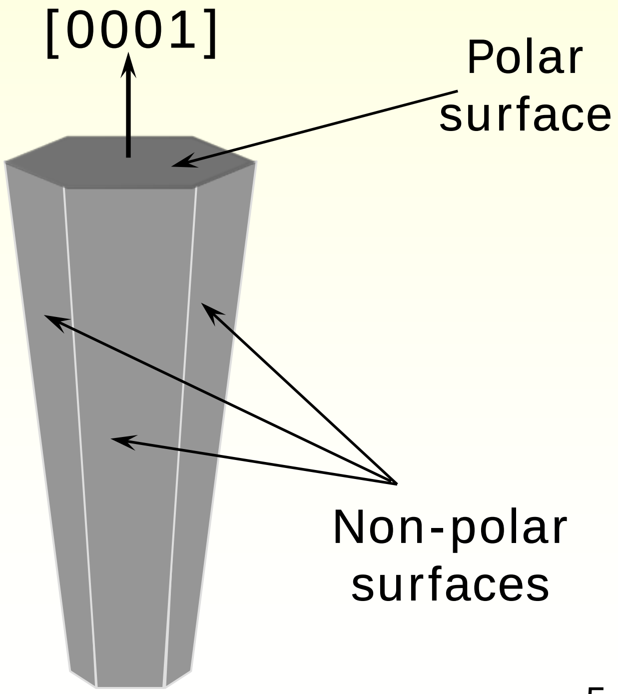
1. Appl. Phys. Lett. **91**, 092101 (2007). 2. J. Appl. Phys. **101**, 081704 (2007). 3. Phys. Rev. Lett. **101**, 106803 (2008).

Nanocolumns (NCs)



Why NCs?

- Higher surface/volume ratio.
- Lower density of dislocations.
- Increase radiative recombination.



NCs grow spontaneously along c-axis.
Most surface is non-polar.

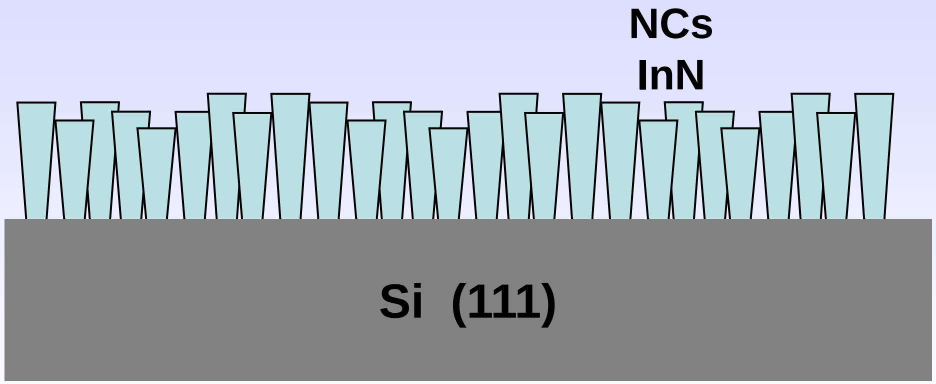
Non polar surfaces properties can be studied in more detail.

InN NCs: samples

-Growth: Plasma-assisted MBE.

-N_2-rich conditions

-Growth time: 300 m.

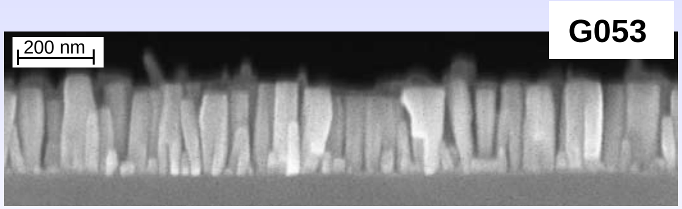


T_S, Indium beam equivalent pressure (BEP), N_2-flux: variables.

Sample	T_S (°C)	In-BEP (mbar)	N_2^{flux} (sccm)	P_{RF} (W)
G053	400	3.0×10^{-8}	2.0	500
G071	475	3.0×10^{-8}	2.0	500
G047	500	3.0×10^{-8}	2.0	500
G041	500	1.5×10^{-8}	1.5	400
G044	500	3.0×10^{-8}	1.5	450
G136	475	3.0×10^{-8}	1.5	450

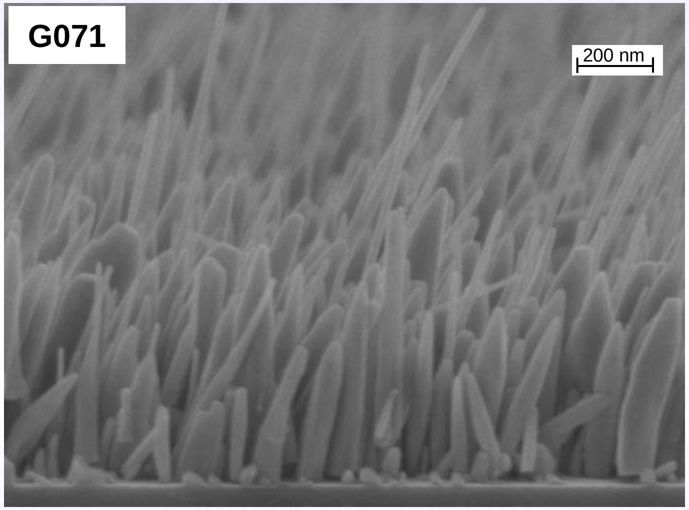
Morphology

Growth conditions strongly affect NCs morphology.

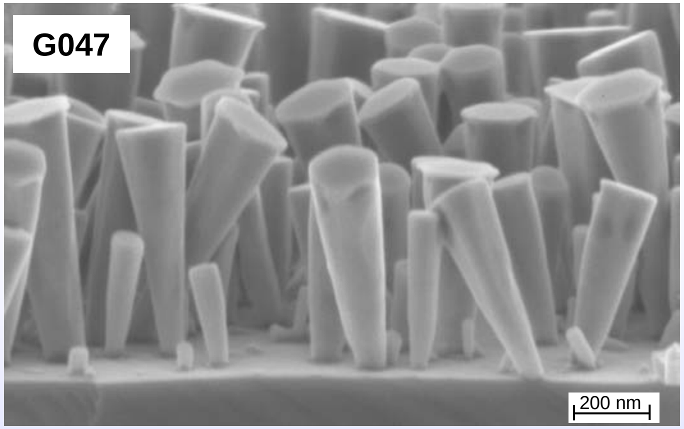


T_S=400ºC: Coalescence

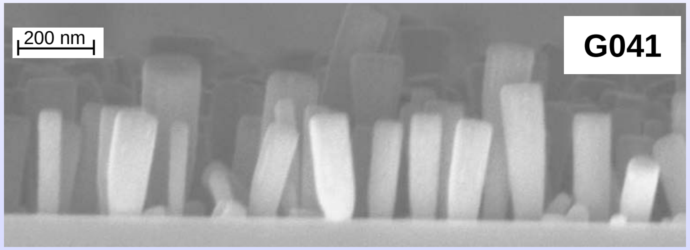
T_S=475ºC: Tapering - bimodal



T_S=500ºC: Baseball-bate shape



T_S=500ºC: Homogeneous NCs



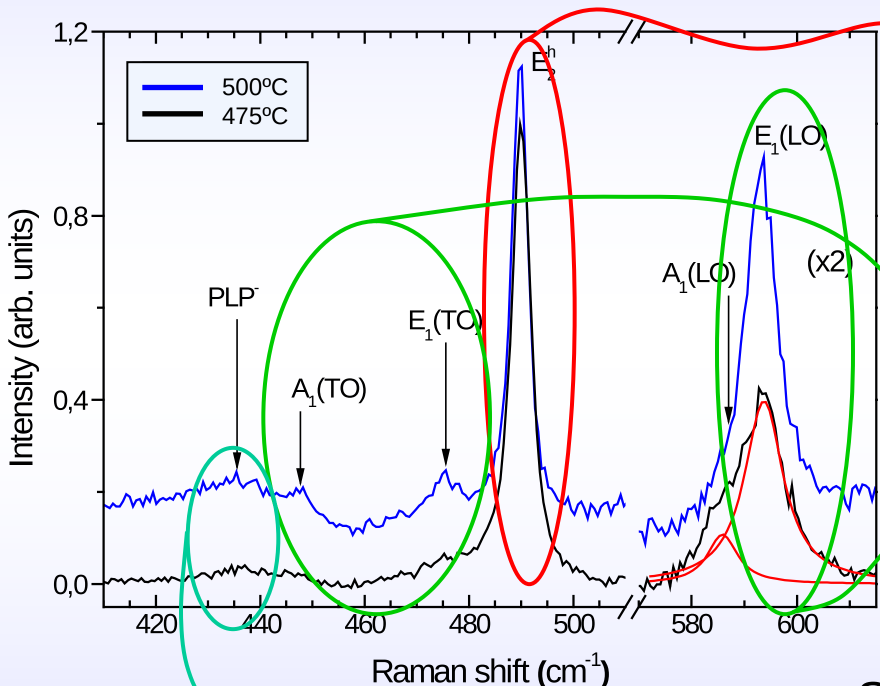
Diameters: 80-150 nm (30 nm)

Heights: 200-600 nm (1500 nm)

Raman scattering spectroscopy

Allowed modes: A_1(LO) – E_2^h

Backscattering
$Z(X, —)\text{-}Z$



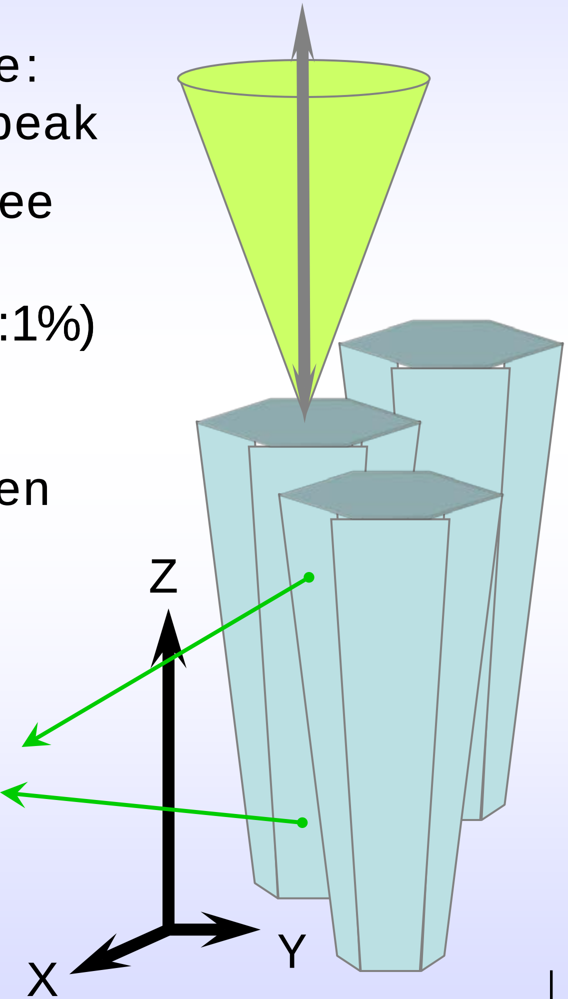
E_2^h mode: narrow peak

Strain free NCs

($^{2}{}_{xx}$ < 0:1%)

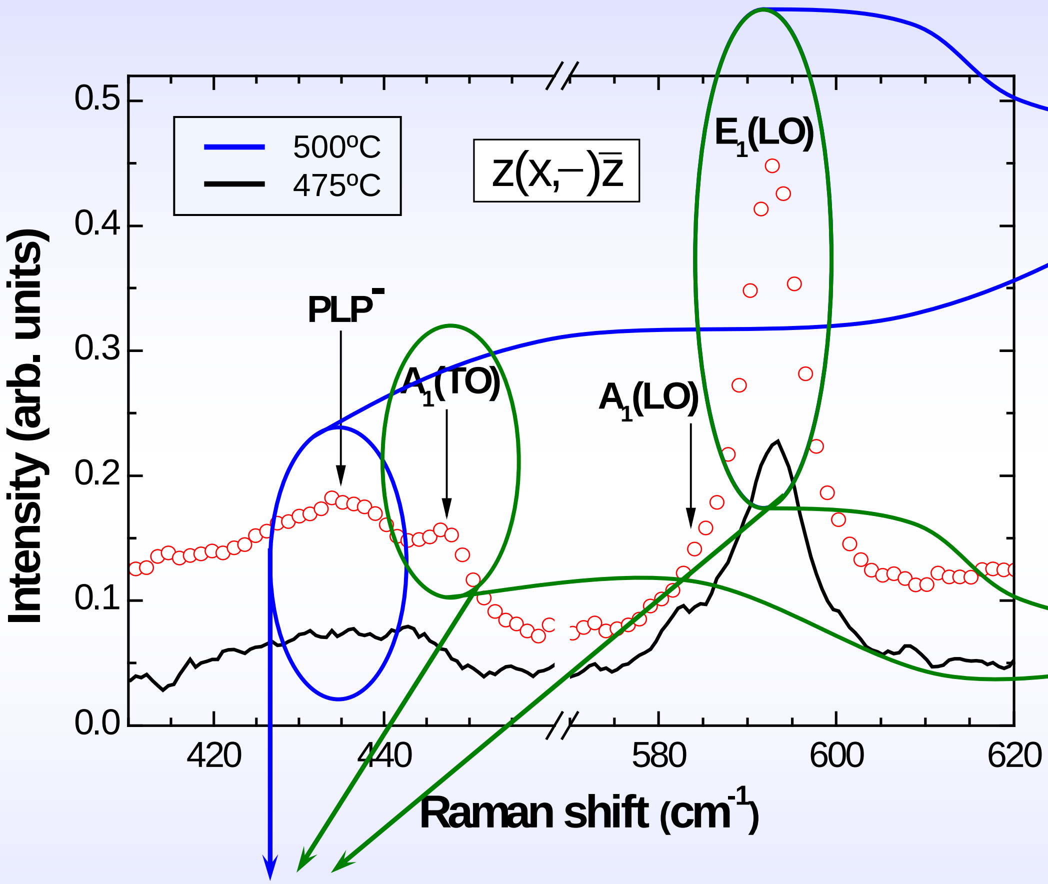
Forbidden modes

Scattering at lateral walls.



Plasmon - LO phonon coupled mode (PLP$^-$)

Raman scattering spectroscopy



Coupled - uncoupled modes coexist

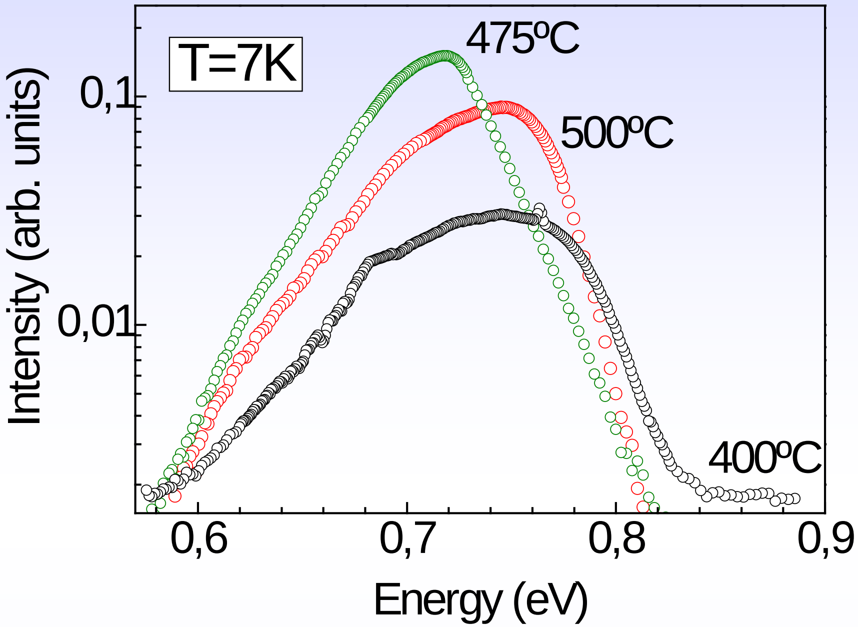
Two regions with different n_e

Forbidden modes.
Lateral walls.

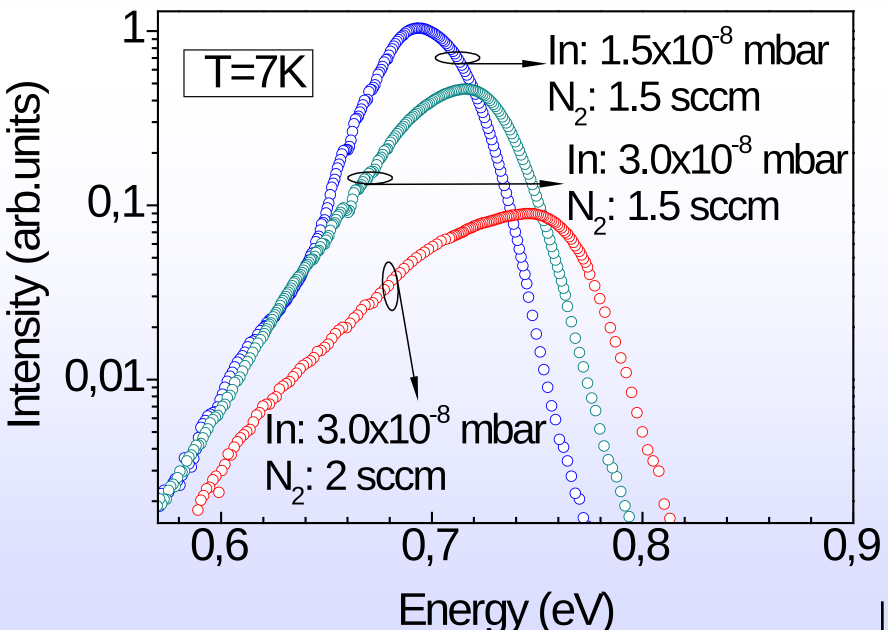
PLP- and E_1(LO) modes intensity are correlated.

Electron accumulation layer at non-polar surfaces.

Photoluminescence: growth conditions

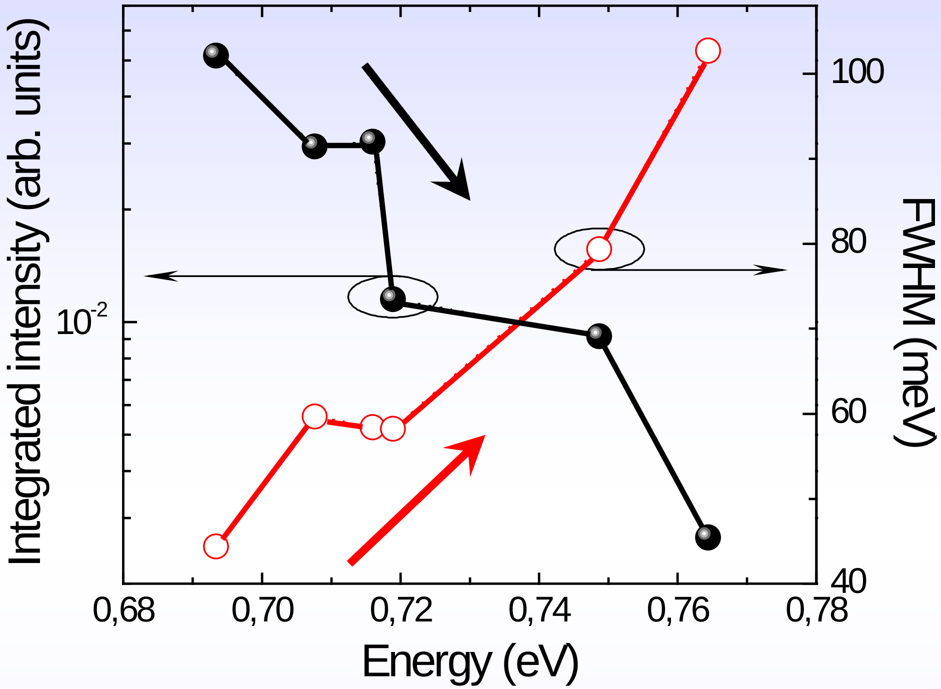


T_S effect



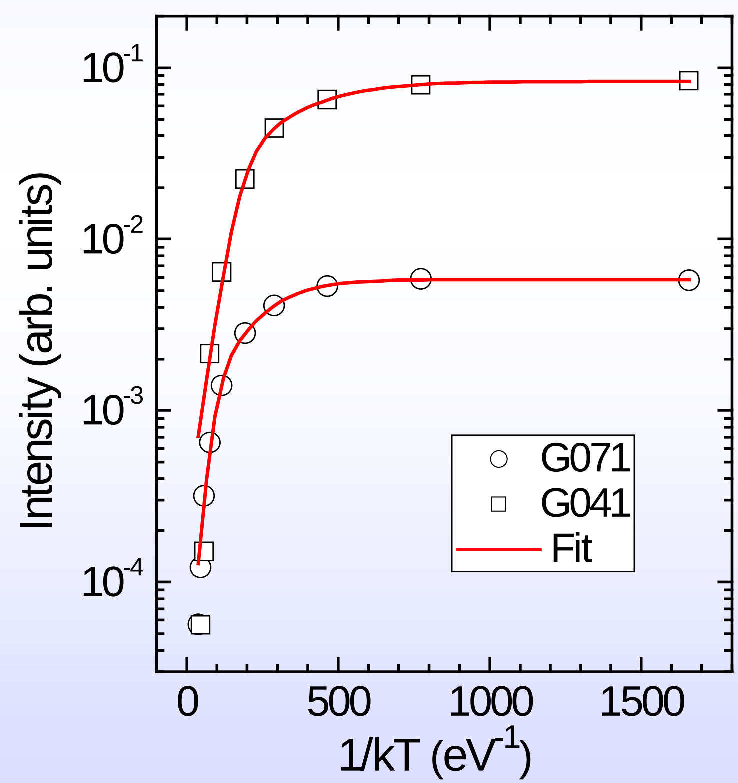
In-BEP and N_2 –flux effect

Photoluminescence



Energy, intensity and FWHM are correlated.

Temperature dependence



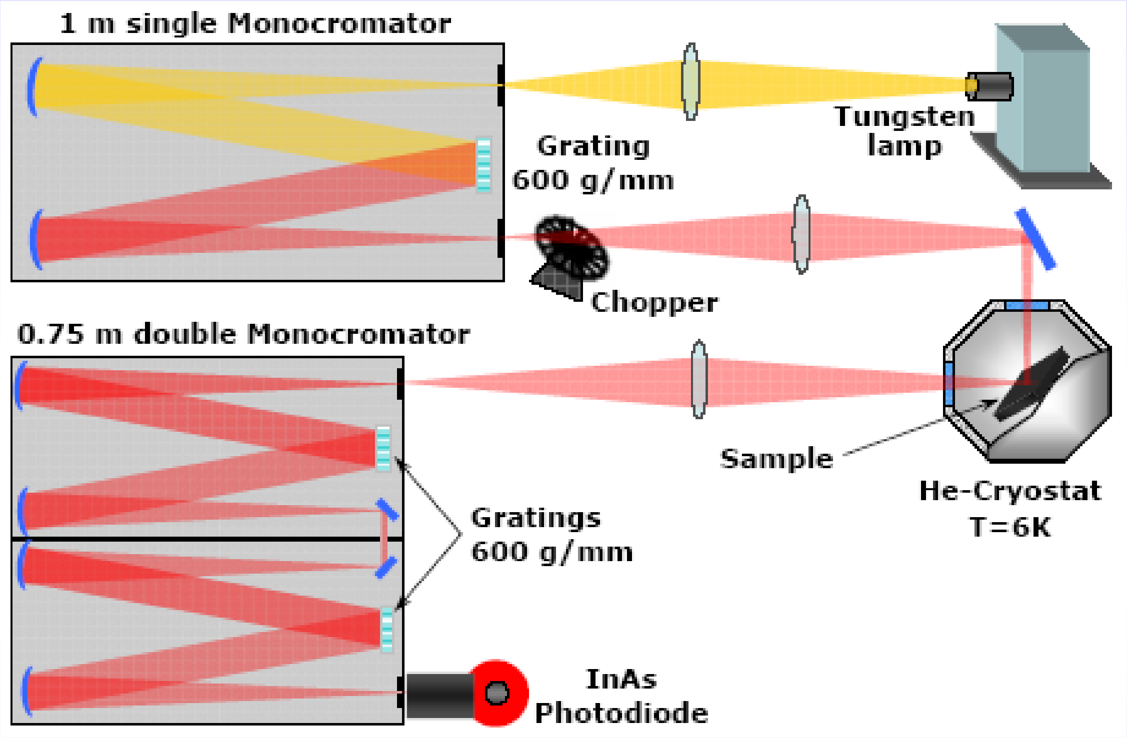
$$I(T) = \frac{I_0}{1 + A\exp(-E_1/kT) + B\exp(-E_2/kT)}$$

Two non-radiative channels.

E_1: 5-10 meV. Shallow acceptors

E_2: 40-50 meV. Deep acceptors

Photoluminescence excitation (PLE)

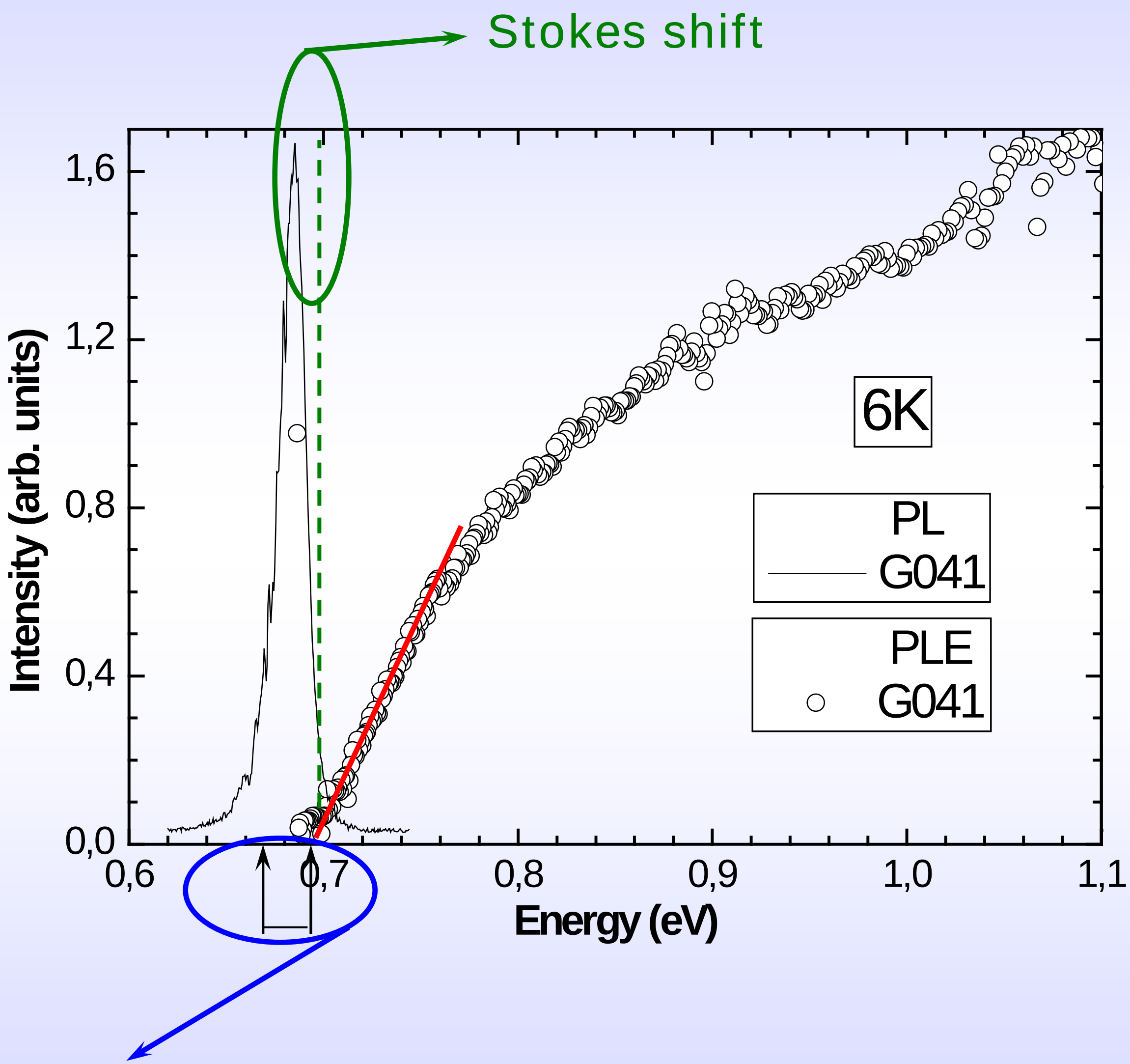


- 10K.
- Excitation: Halogen lamp + monochromator.
- Detection: N_2-cooled InAs Photodiode.
- Spectral resolution: <1.5 meV

PLE: characteristics

Line-shape similar to bulk material.

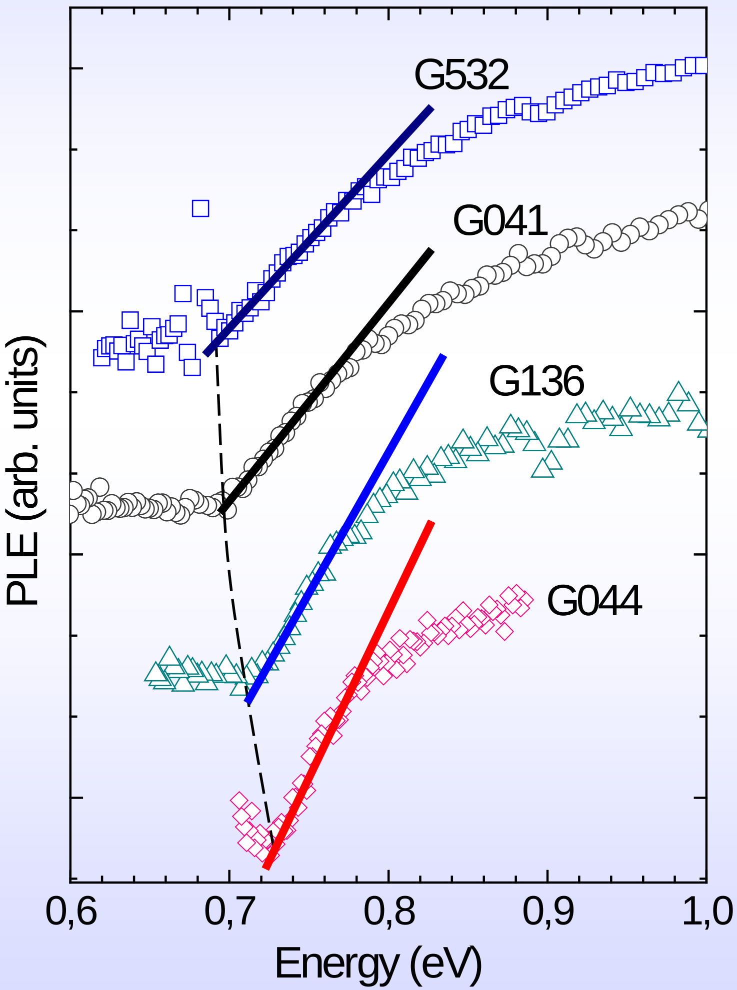
Featureless – High electron concentration



E_{abs} higher than InN bandgap

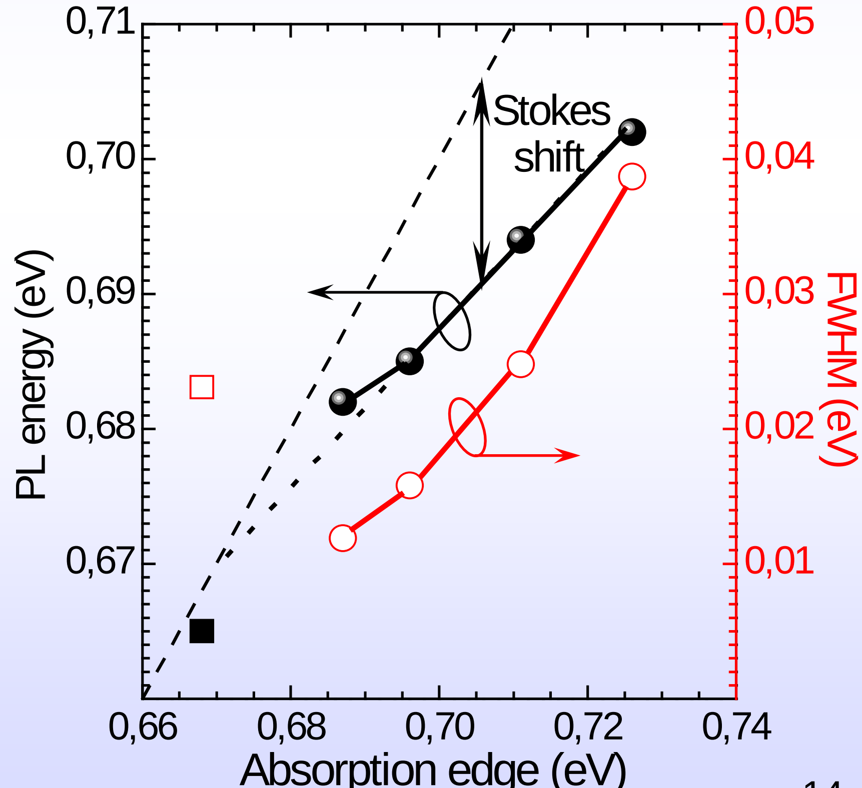
Accumulation layer: growth conditions

PLE is different for each sample.

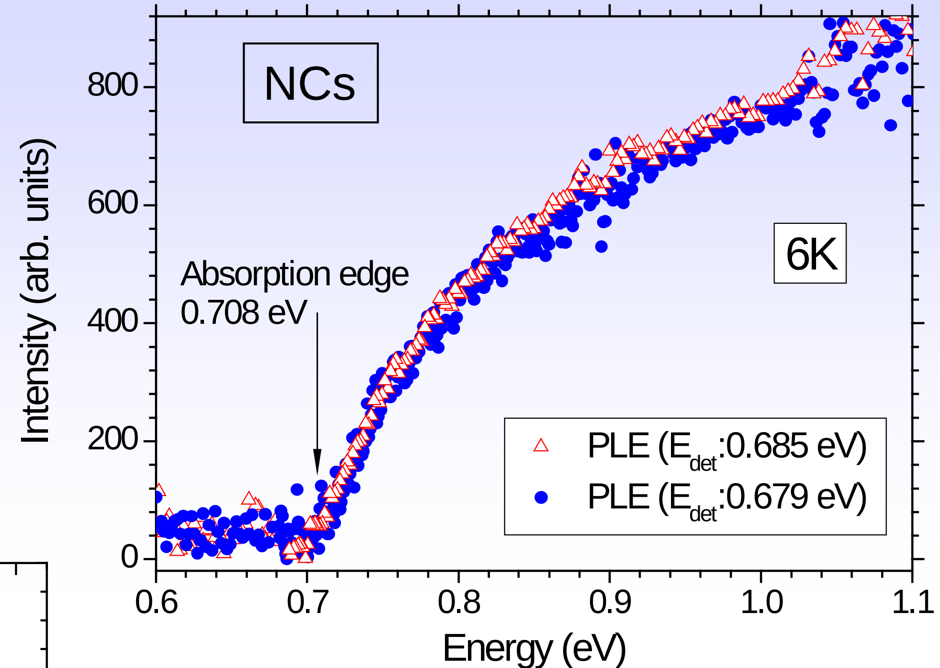


Energy and FWHM of the PL peak increase as E_{abs} increase.

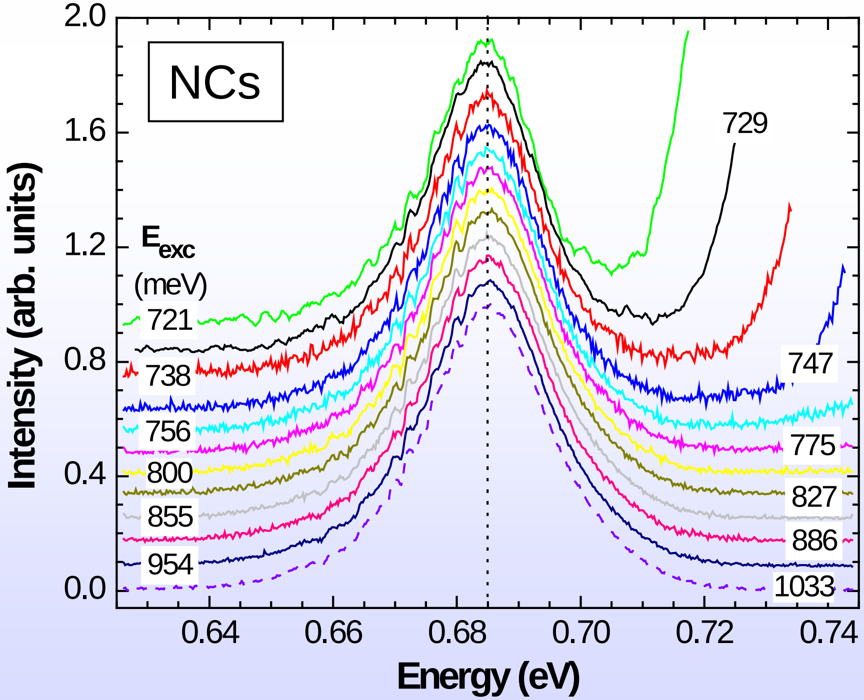
PL peak energy does not follow E_{abs} variation.



Broadening



PL does not depend on E_{exc}.



E_{abs} does not depend on E_{det}.

Homogeneous broadening

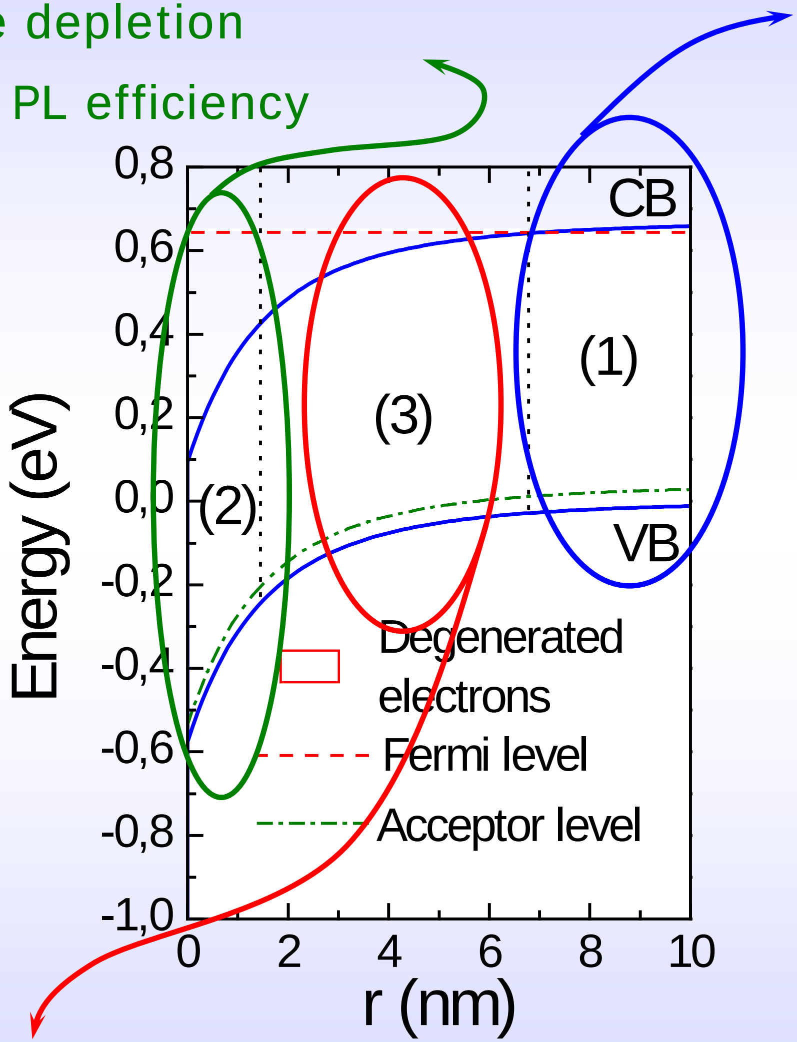
Schematic NC image

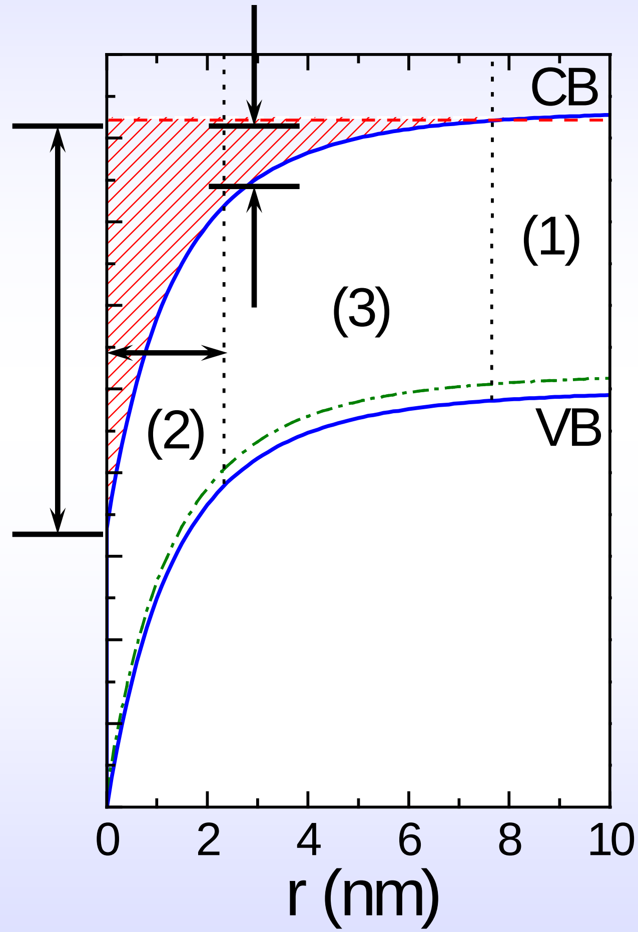
Hole depletion

Low PL efficiency

Lower e^- concentration.

Low PL efficiency.





High PL efficiency.

Different N_D and N_{SS}.

Conclusions

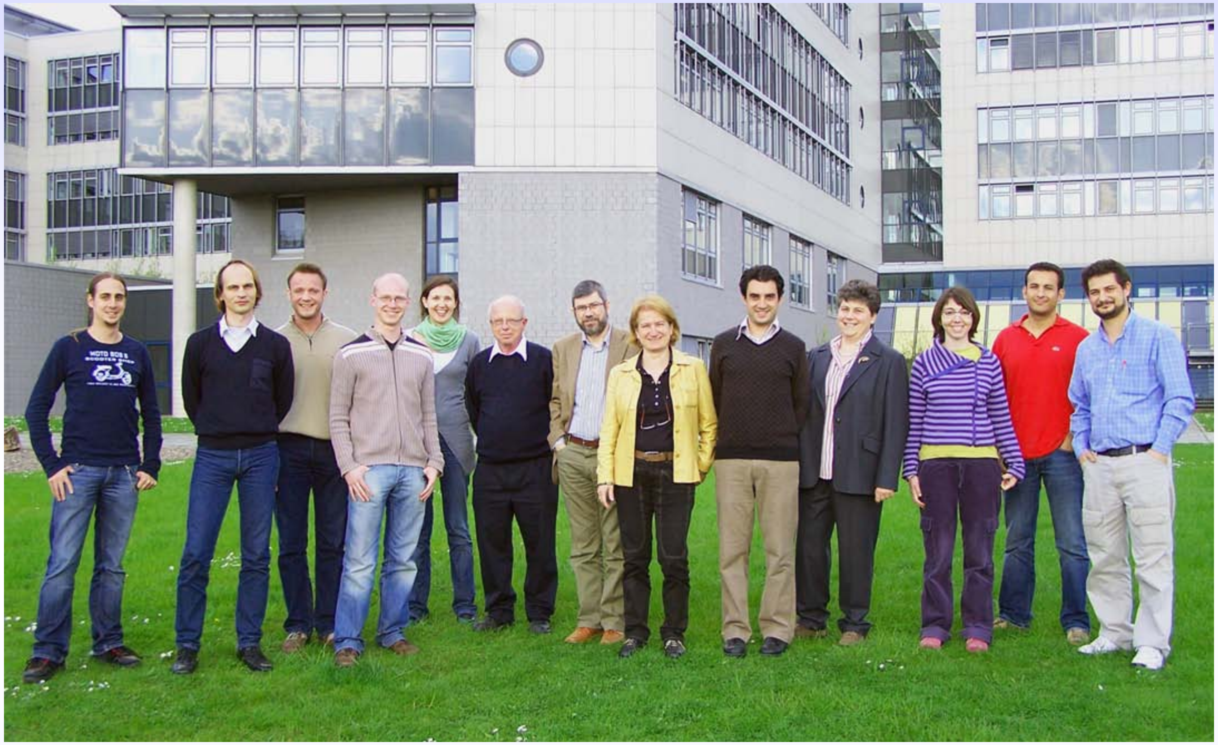
• Optical properties and morphology of the nanocolumns are strongly affected by the growth conditions.

• There is electron accumulation at the non-polar surfaces of InN.

• Photoluminescence in InN nanocolumns comes from degenerated electrons recombining with localized holes.

• Differences in the photoluminescence are attributed to different volume and surface charge for each sample. Electron accumulation at non-polar surfaces is not intrinsic.

Acknowledgements:



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