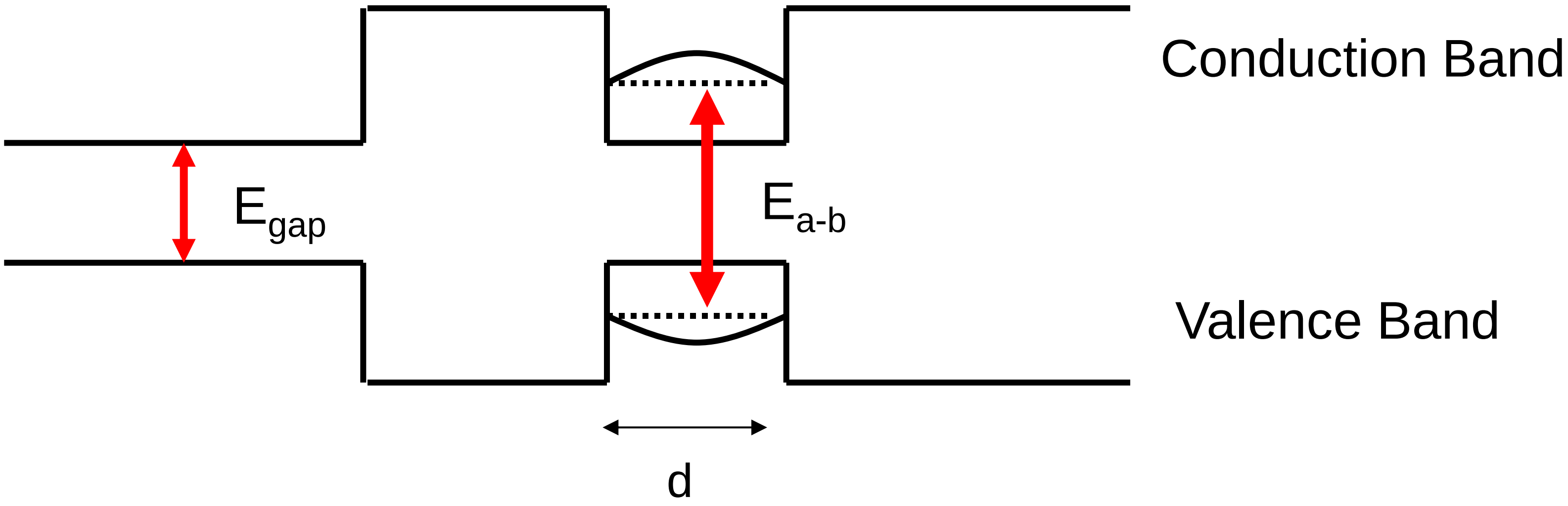
STEM Cathodoluminescence of Individual GaN/AlN Quantum Disks within a single Nanowire

Luiz Fernando Zagonel[1], Mathieu Kociak[1*], Stefano Mazzucco[1], Odile Stéphan[1], Marcel Tencé[1], Katia March[1], Romain Bernard[1], Benoit Laslier[1], Maria Tchernycheva[2], Lorenzo Rigutti[2], Francois Julien[2], R. Songmuang[3]

1- Laboratoire de Physique des Solides, CNRS/UMR8502, Université Paris-Sud, Orsay, 91405, France
2- Institut d'Electronique Fondamentale, CNRS/UMR 8622, Université Paris-Sud, Orsay, 91405, France
3- CEA-CNRS group "Nanophysique et Semiconducteurs", Institut Nel, Grenoble, France

Introduction

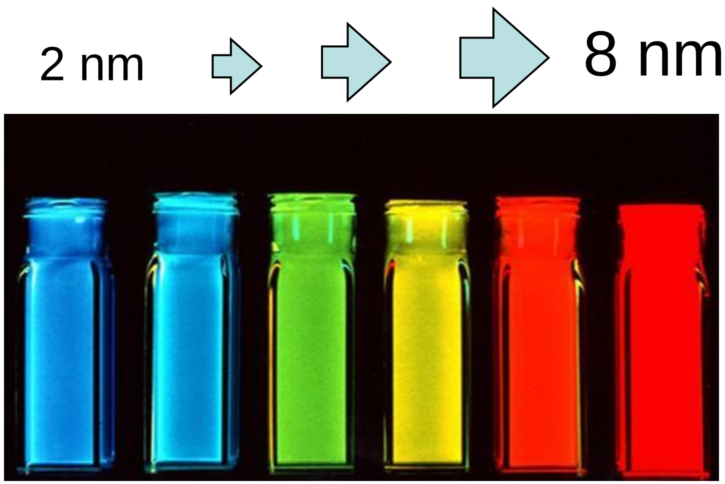
Quantum Confinement

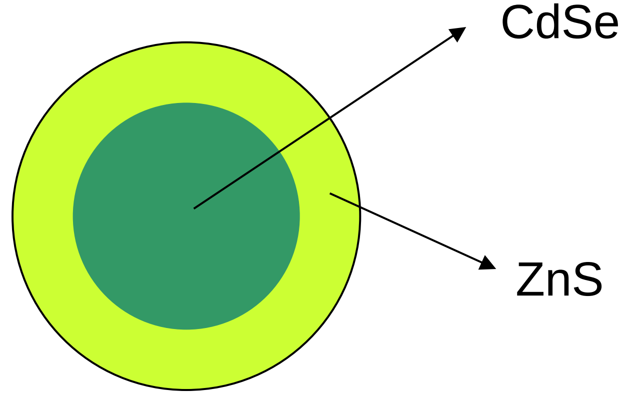


Correlation of quantum object dimension and its transition energy.

Introduction

CdSe nanoparticles



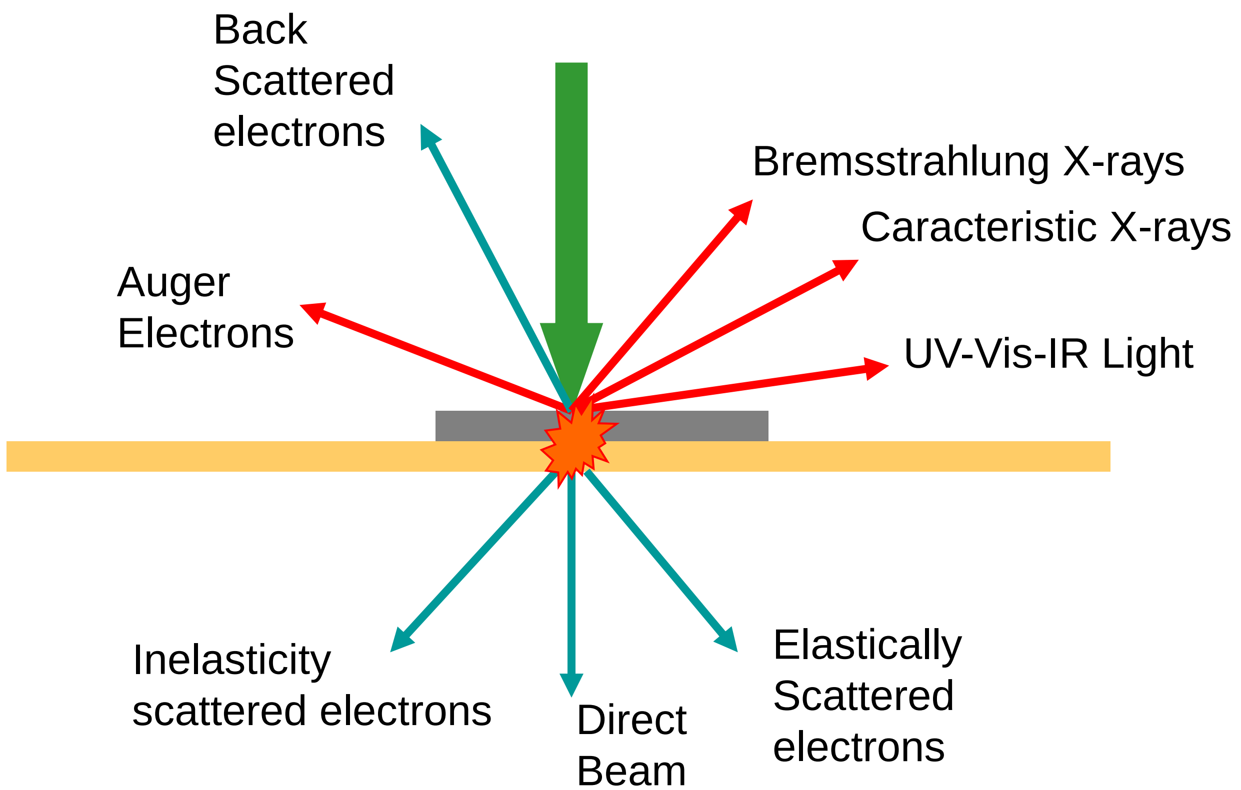


M. G. Bawendi

J. Phys. Chem. B **1997,** *101,* 9463−9475

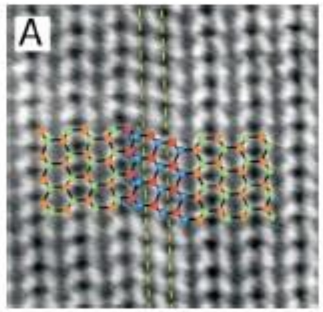
Cathodoluminescence

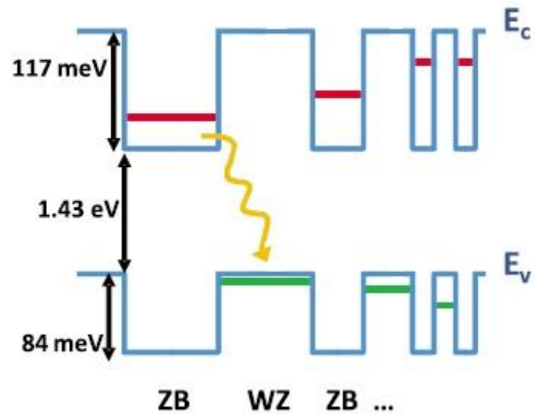
Electron – Matter interactions

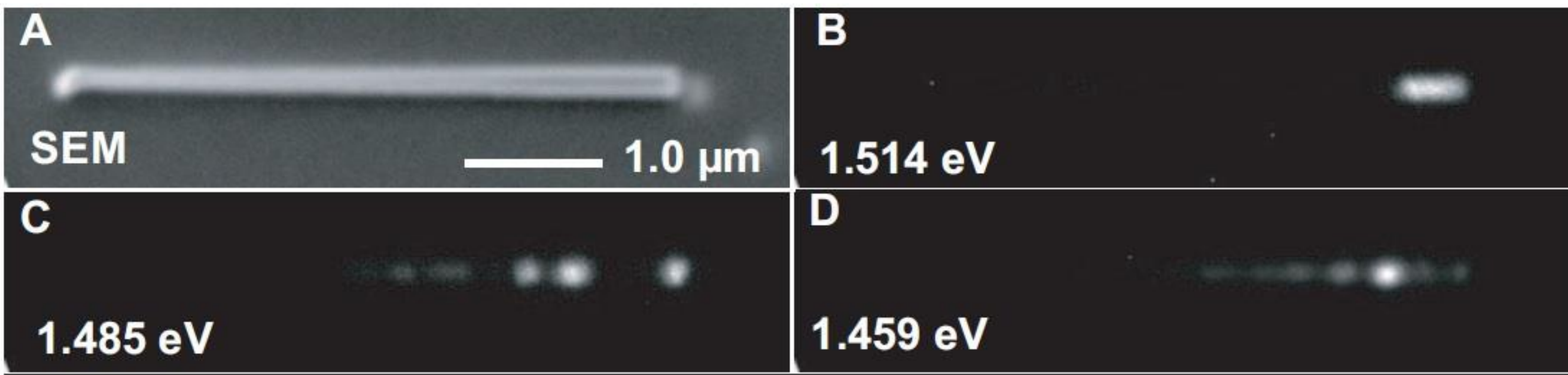


Cathodoluminescence

zinc-blende/wurtzite GaAs nanowire heterostructures



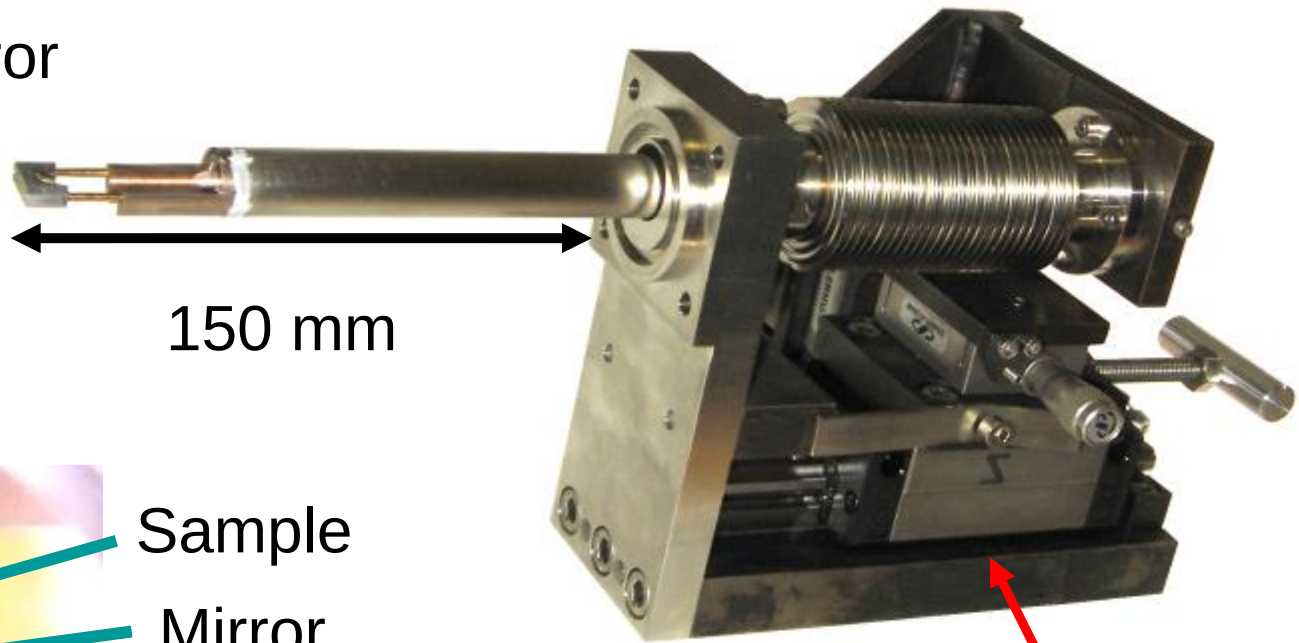


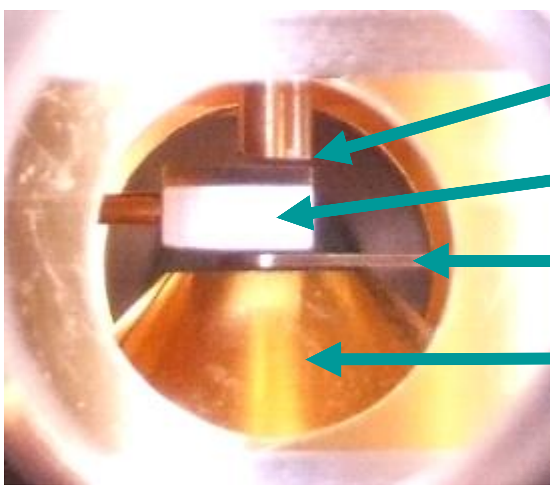


D. Spirkoska et al., PHYSICAL REVIEW B **80, 245325 2009**

Cathodoluminescence System

Positioning the mirror is crucial to its efficiency.

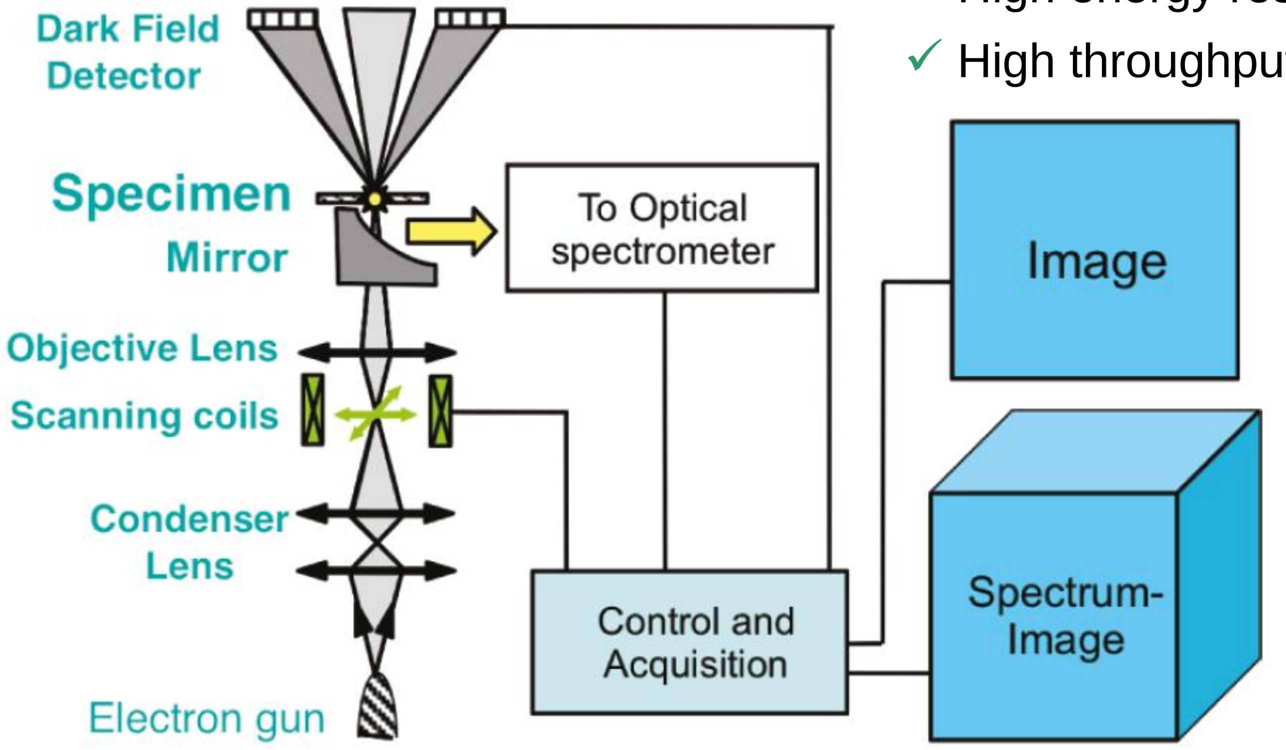




Cathodoluminescence System

An Optimized CL detector:

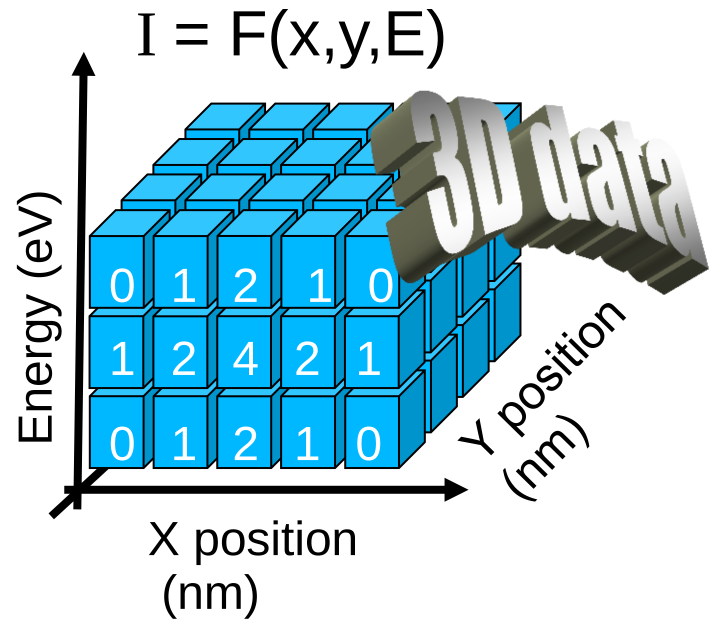
- ✓ High collecting angle (35% of 4π sr).
- ✓ High energy resolution (~5 meV).
- ✓ High throughput.



Cathodoluminescence System

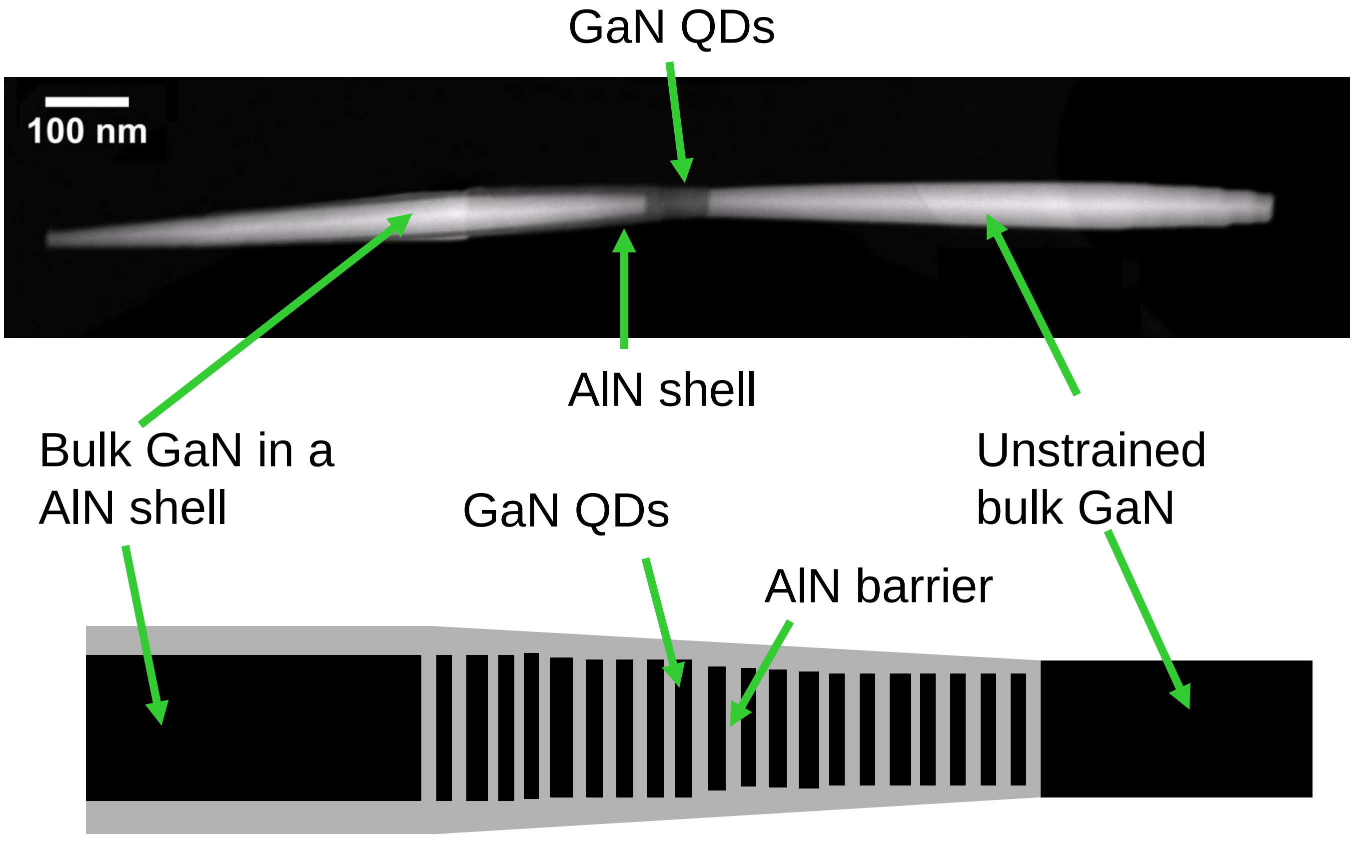
Microscopic Probe – STEM:

- **STEM HB 501 by VG operating at 60kV**
- Spatial resolution of <1 nm.
- Probe current of about ~200pA.
- Liquid Nitrogen Sample stage (150K).
- 3D Spectrum-Image acquisition.

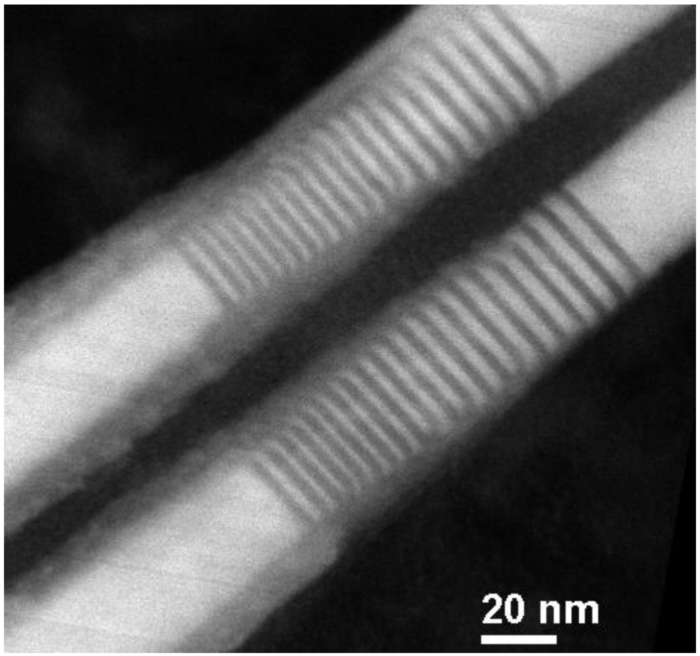


Sample: GaN quantum discs

GaN nanowires with GaN quantum discs with AlN barrier and shell.



Sample: GaN quantum discs



Catalyst-free growth on Si (111) (RF-PA-MBE).

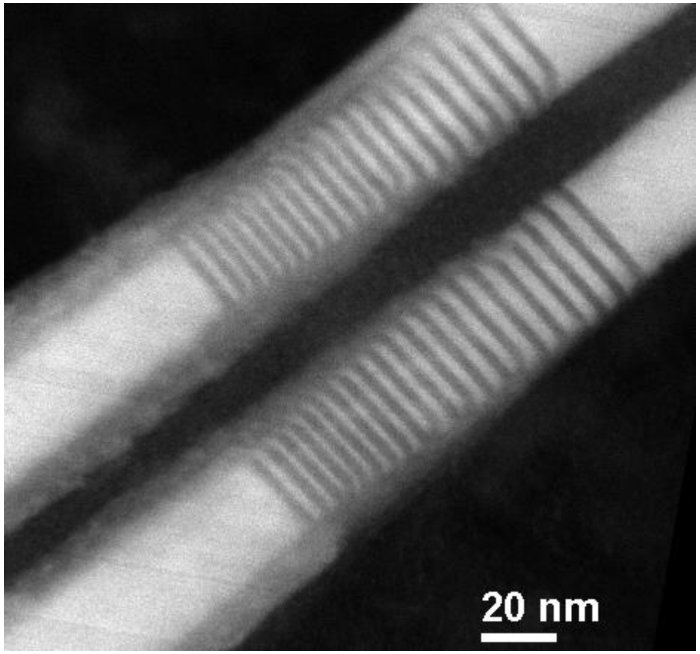
GaN nanowires with GaN quantum discs with AlN barrier and shell.

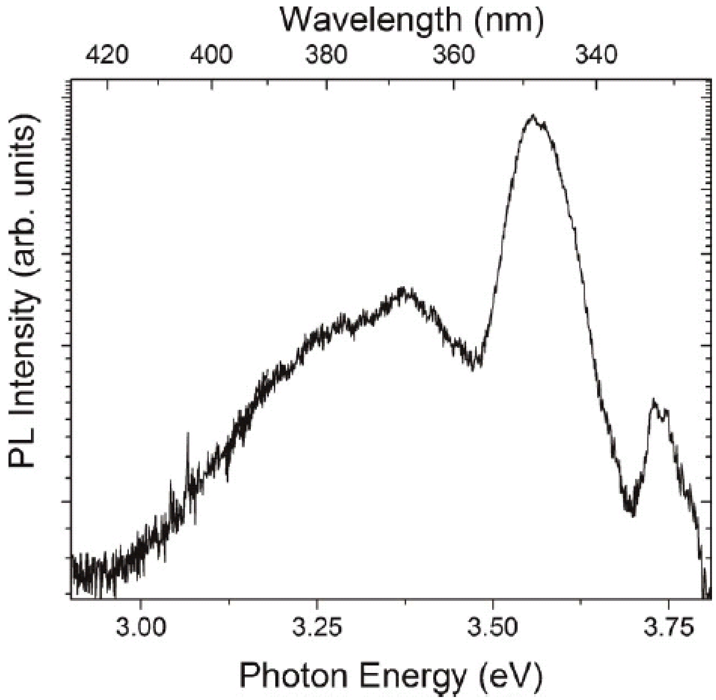
Nanowire length = ~ 2.1 µm
Nanowire diam. = 20 to 50 nm

Number of QD's = 20.

Disc Thickness: ~3.5 nm
Barrier Thickness: ~4.1 nm

Sample: GaN quantum discs

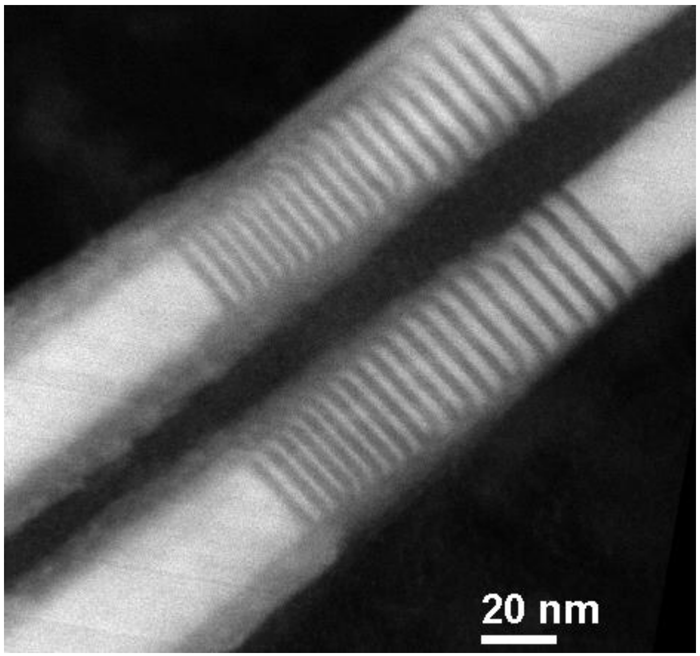


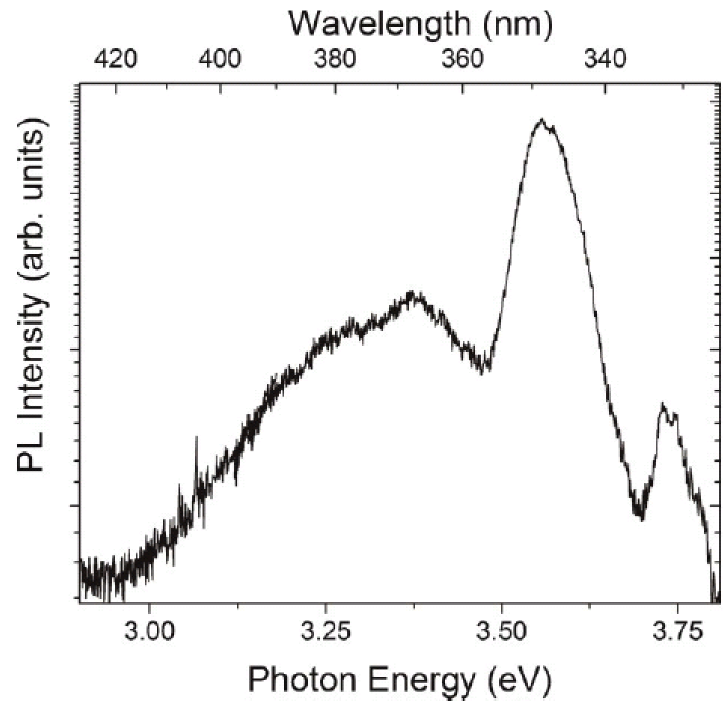


Emissions below and above the GaN Band gap

L. Rigutti et al. Nano Lett. 2010, 10, 2939–2943

Sample: GaN quantum discs

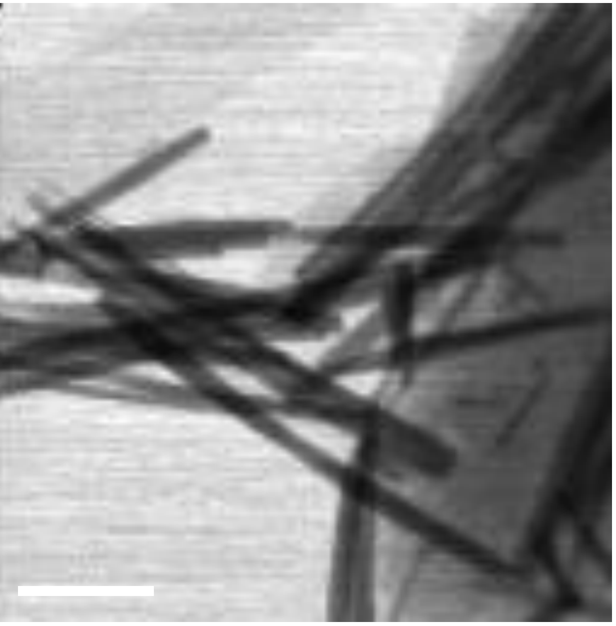




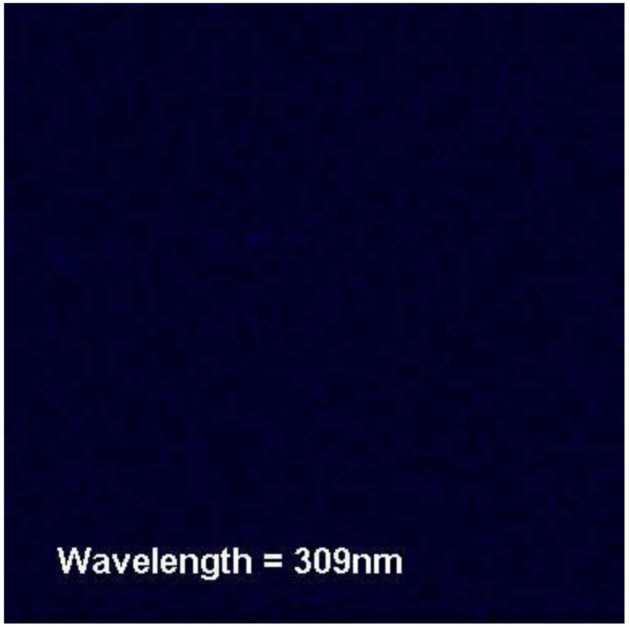
Where do they come from?

L. Rigutti et al. Nano Lett. 2010, 10, 2939–2943

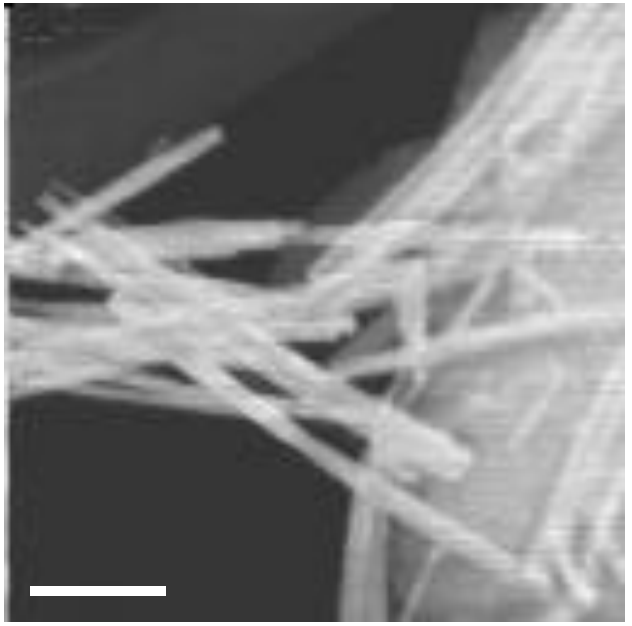
GaN Quantum discs



Bright field image

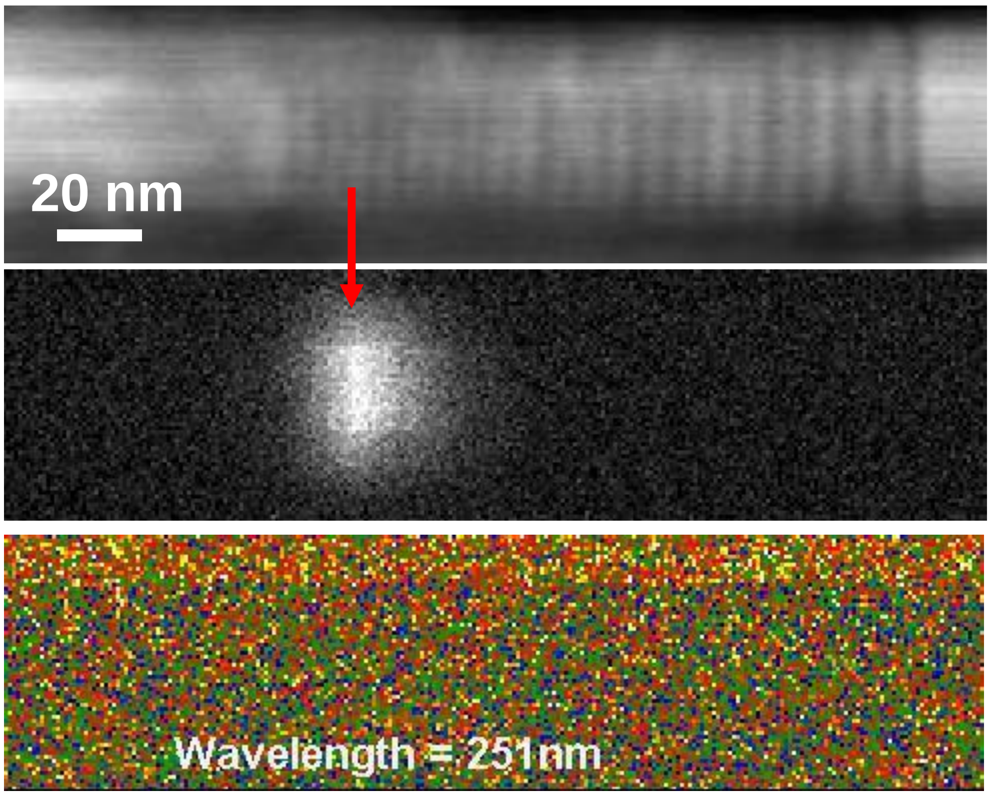


CL Spectrum Image



Dark field image

GaN quantum discs



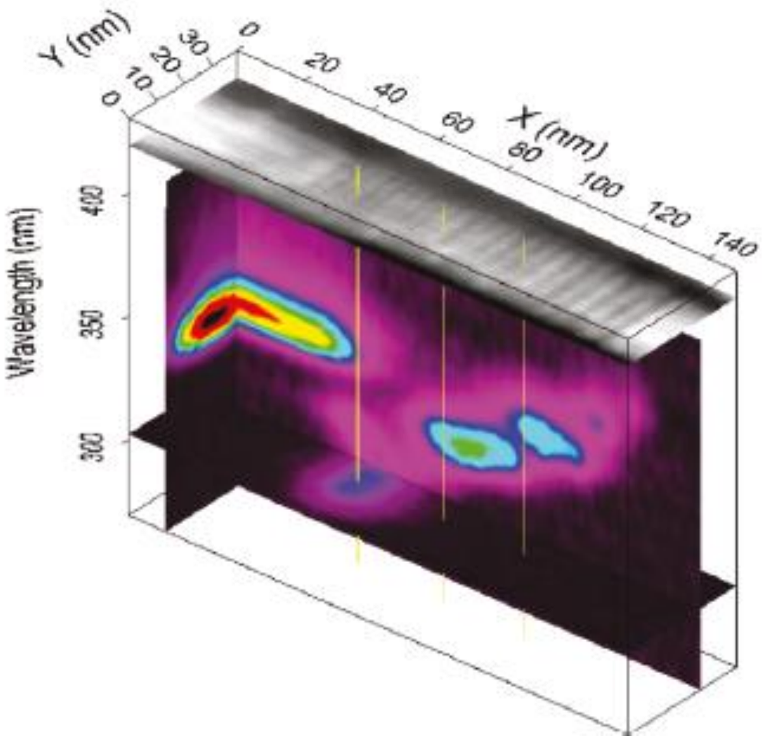
HADF acquired simultaneously with CL spectrum-image

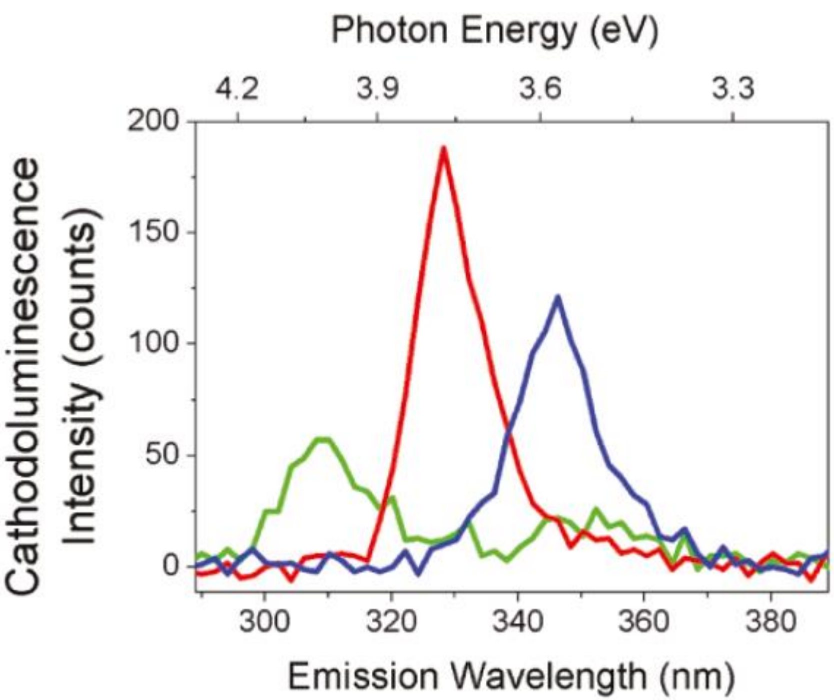
Monochromatic image extracted from the Datacube at 300 nm.

Datacube from 271 to 390 nm.

Spatial sampling: 0.6 nm per pixel
Spectral sampling: 2 nm per pixel
Dwell time: **20 ms per pixel**
Spectrum image size: 256 x 64 x 256 pixels

GaN quantum discs

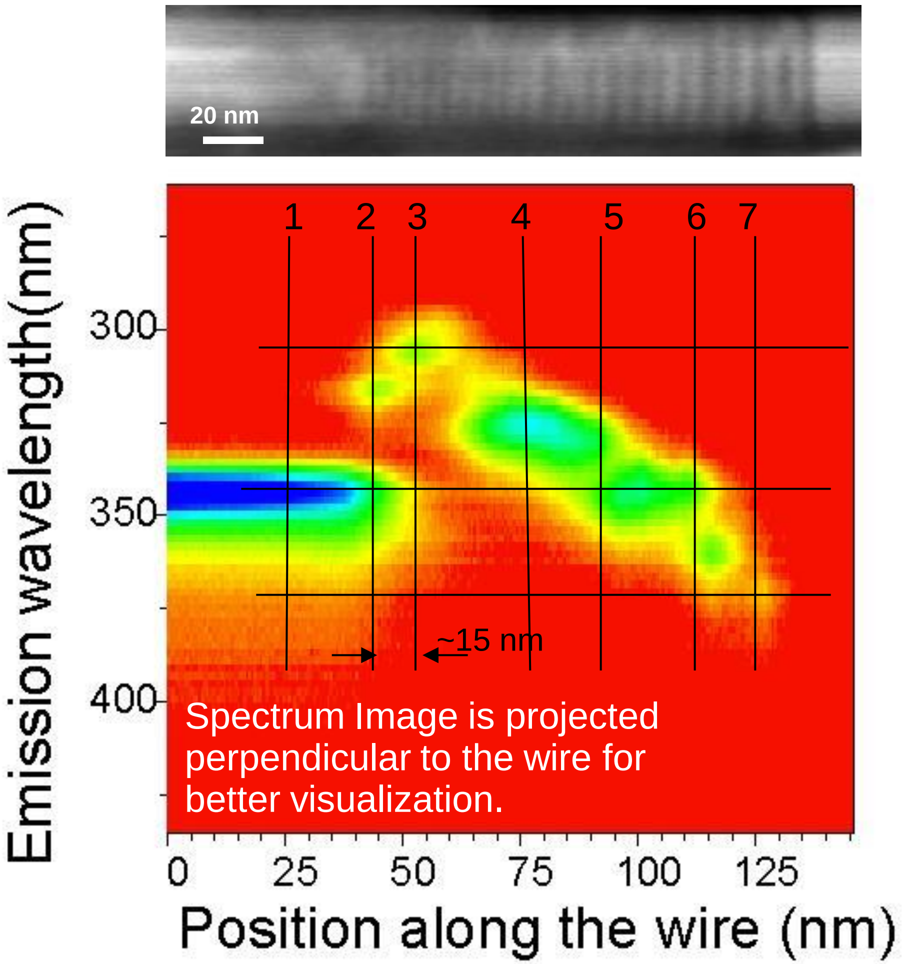


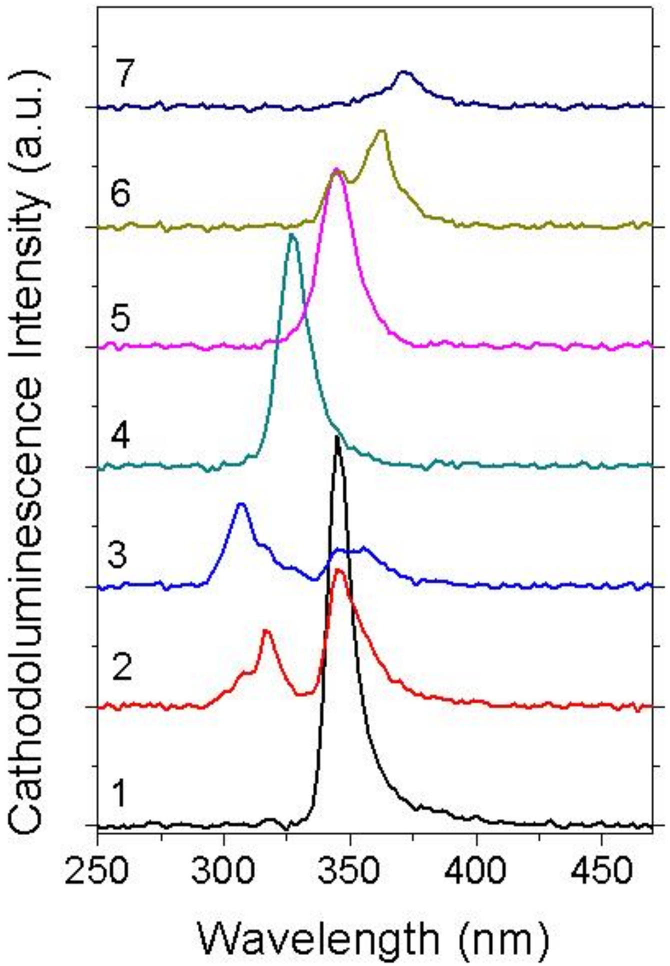


HAADF Image and
the cathodoluminescence datacube.

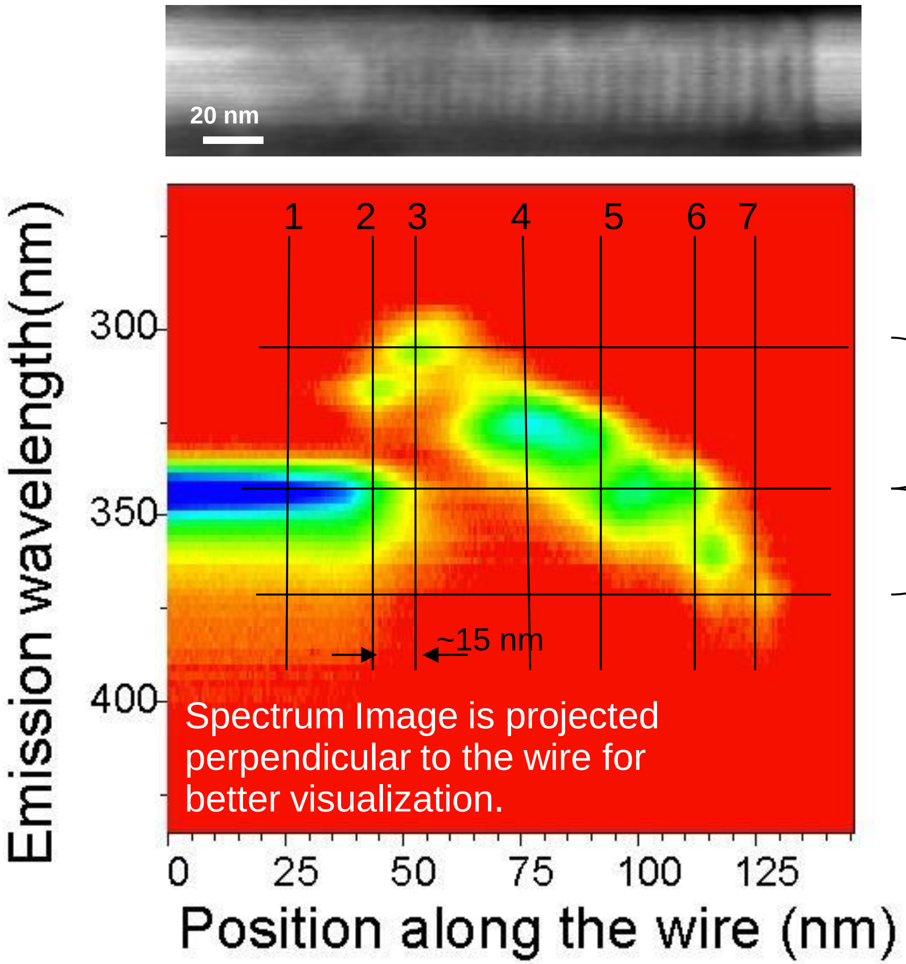
Single pixel spectra.

GaN quantum discs





GaN quantum discs



Only the QDs and the bulk GaN are emitting.

Energy higher than Gap Band Gap: Dominated by Quantum Confinement

Energy lower than Gap Band Gap: Dominated by Stark Effect

Nanowire Morphology

Quantum confinement effect is more important in smaller discs.

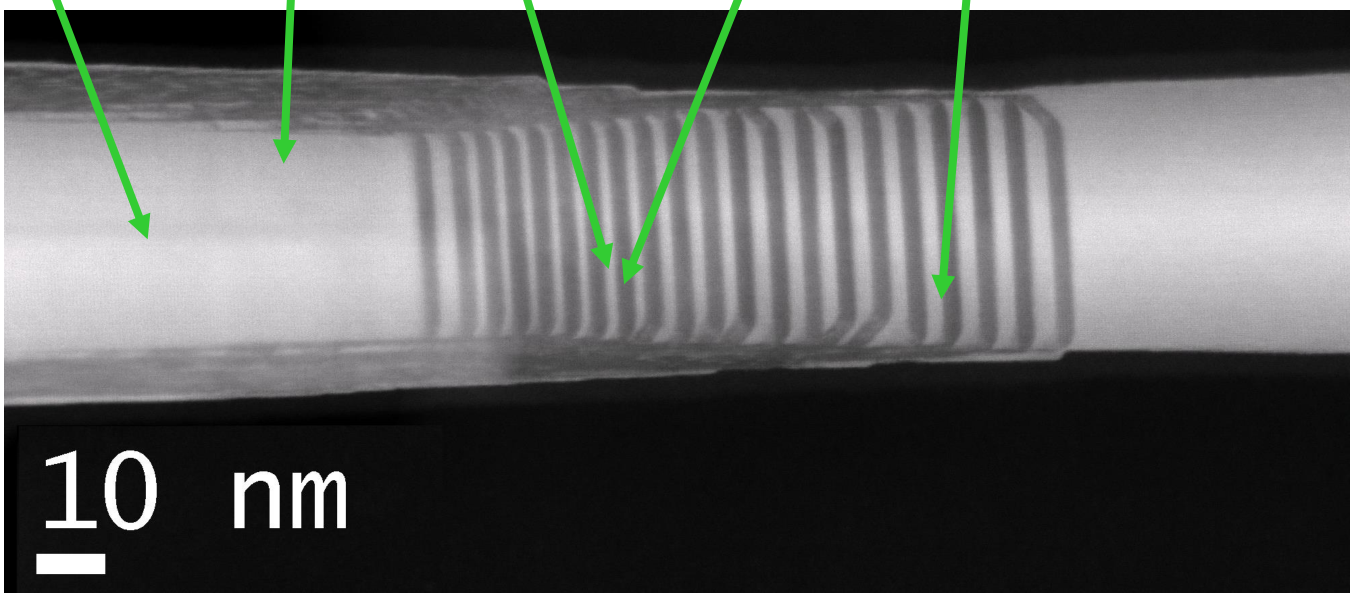
Bulk GaN in a AlN shell

GaN QDs

Unstrained bulk GaN

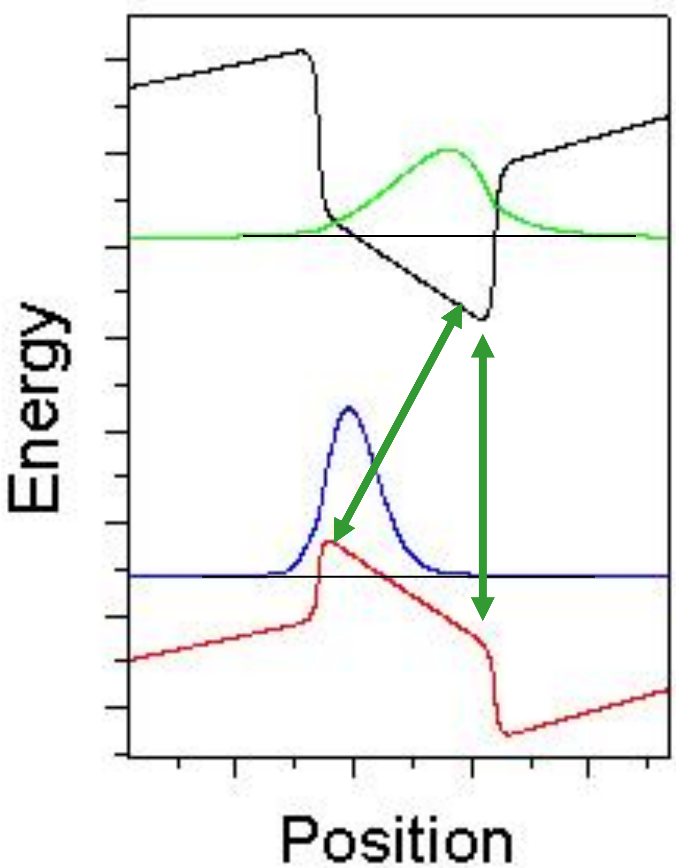
AlN shell

AlN Barrier



Disc Diameter:
Increases from
1 nm (4 ML)
to 3.4 nm (13 ML)

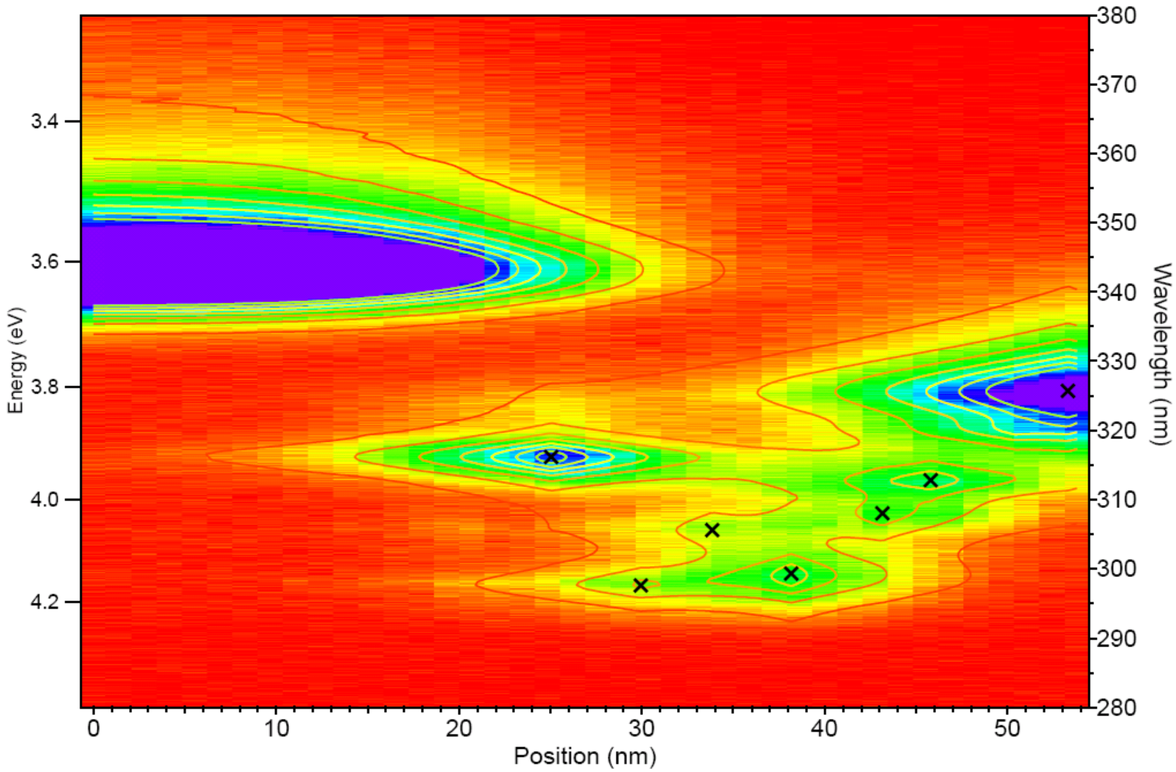
Quantum confinement Stark Effect



Gap GaN = 3.47 eV
Gap AlN = 6.20 eV

The band bending due to internal electric field is the origin of the observed QCSE and therefore the redshift emission for large QDs.

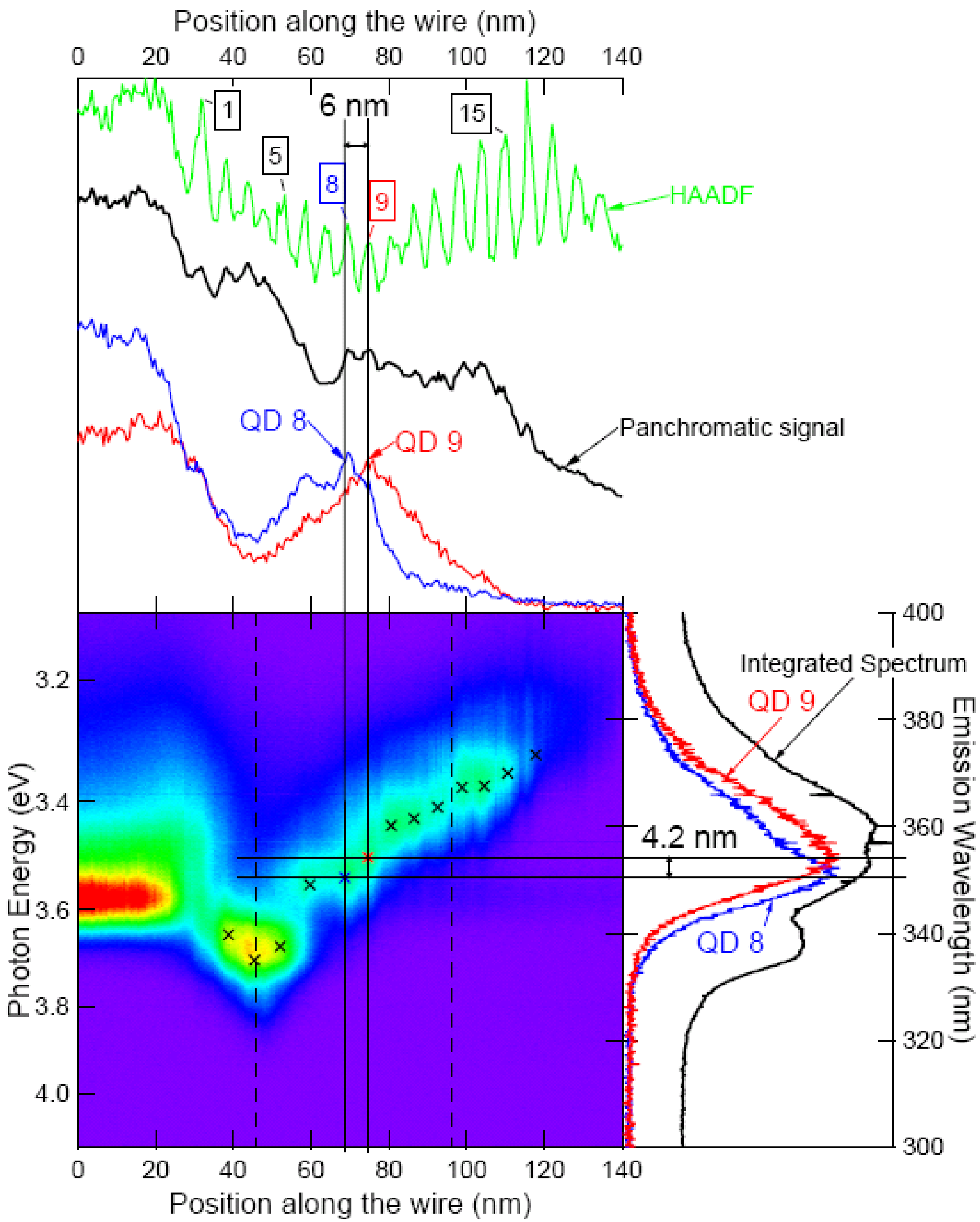
Identifying single QD emissions



The partial overlapping of all QD emission can be distinguished by fitting.

L. F. Zagonel et al.,
Nano Lett. 2011, 11, 568–573

Identifying single QD emissions

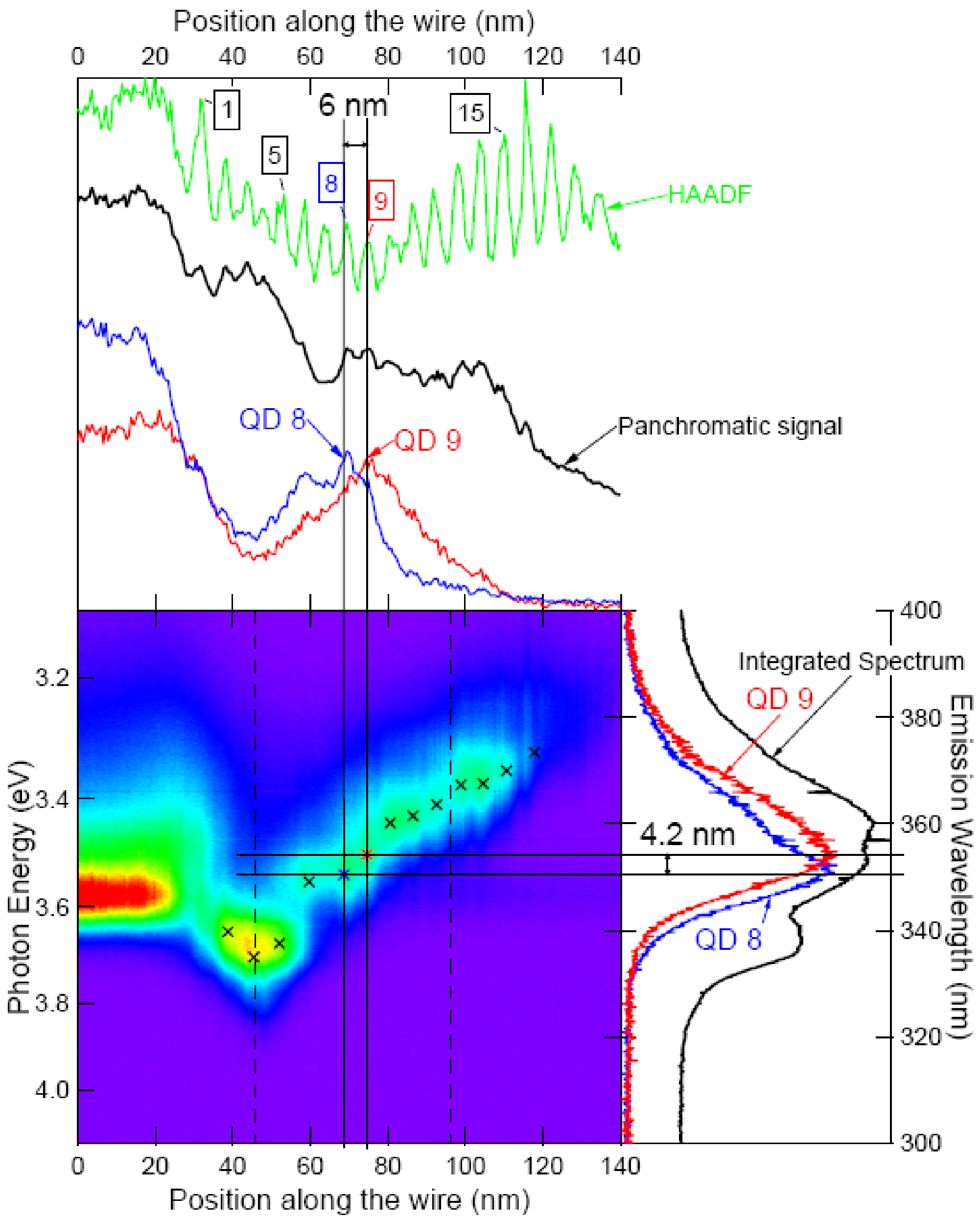


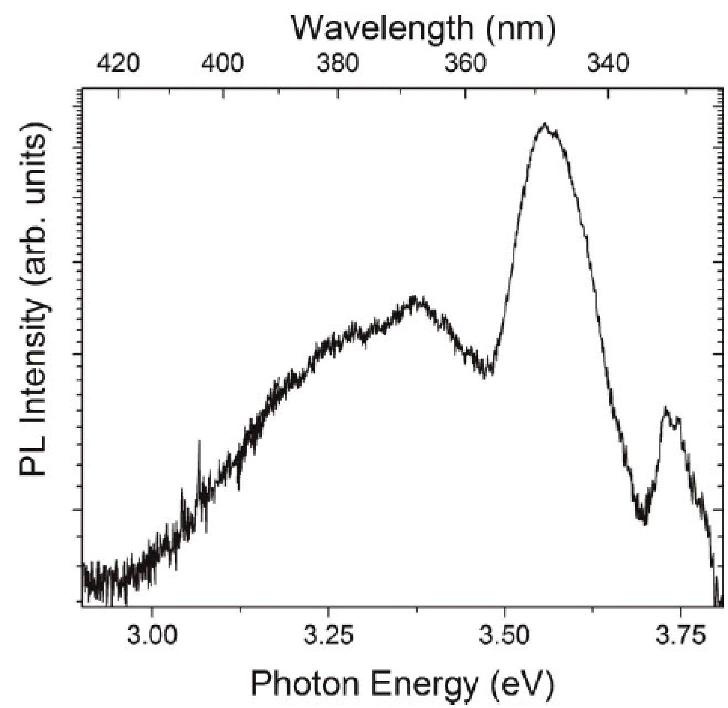
Each individual QD appears as a peak in the combined spatial-spectral plot.

High spatial and spectral resolutions and sampling are need to find and distinguish each of these peaks.

L. F. Zagonel et al.,
Nano Lett. 2011, 11, 568–573

Identifying single QD emissions

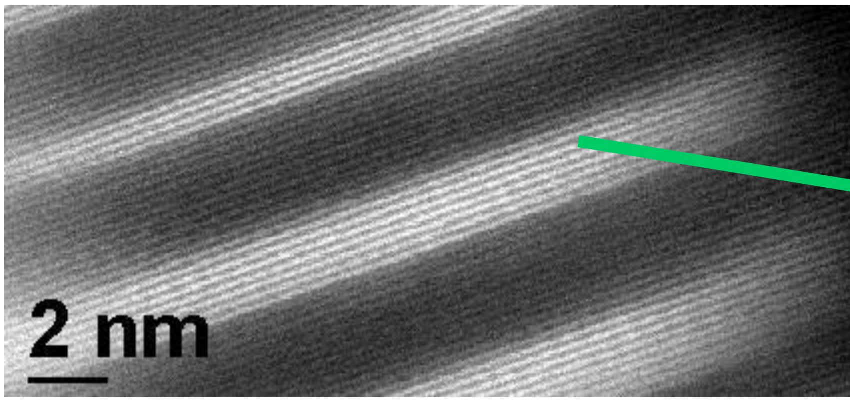


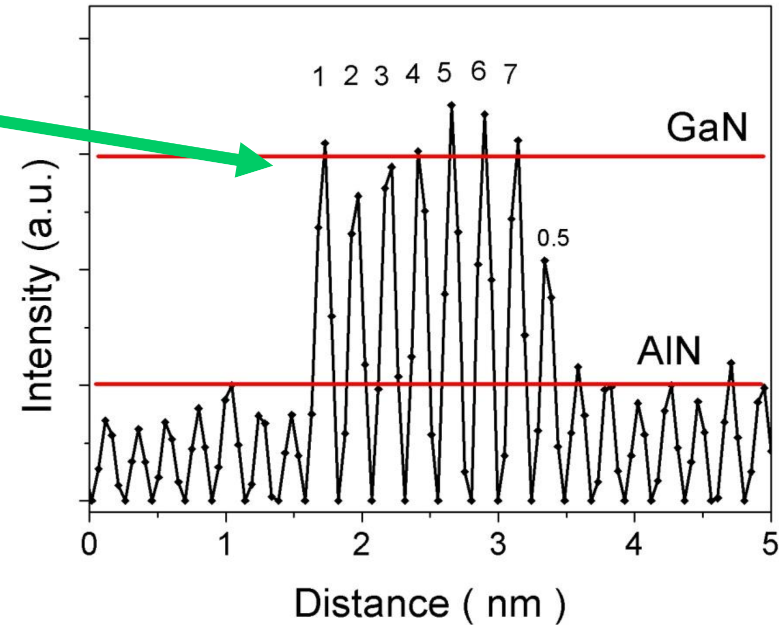


Previous micro-PL data compare well with spatially integrated signal on CL.

L. F. Zagonel et al.,
Nano Lett. 2011, 11, 568–573

Measurement of QD thickness

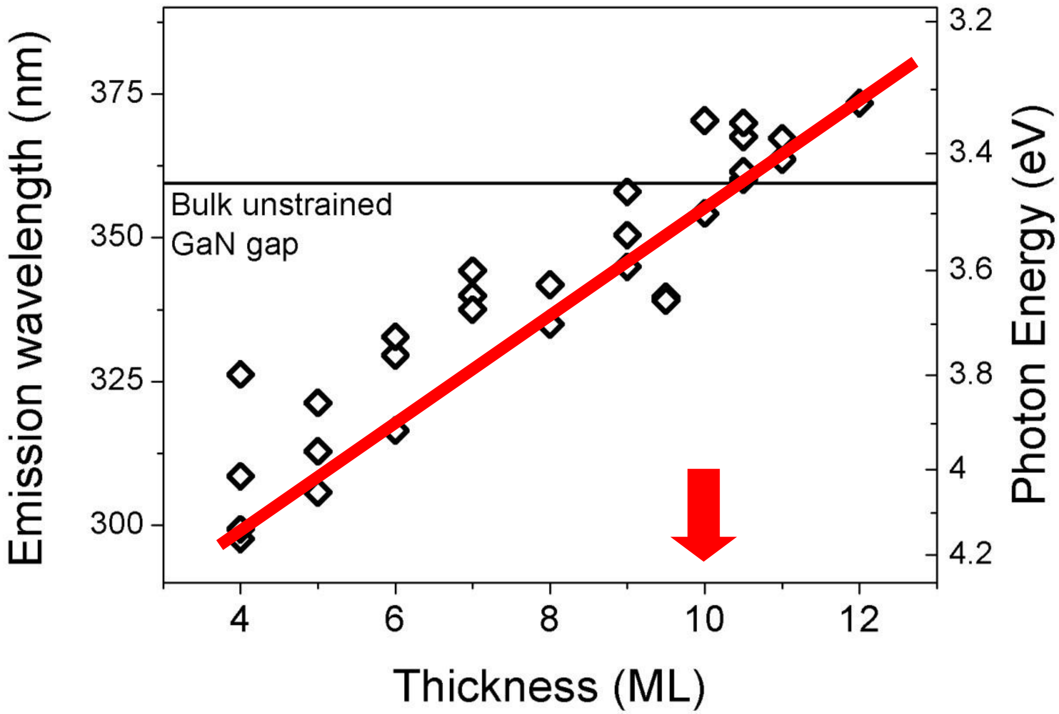




HAADF HR-STEM images were acquired to determine the thickness of each QD.

L. F. Zagonel et al.,
Nano Lett. 2011, 11, 568–573

Relation QD thickness vs. emission energy

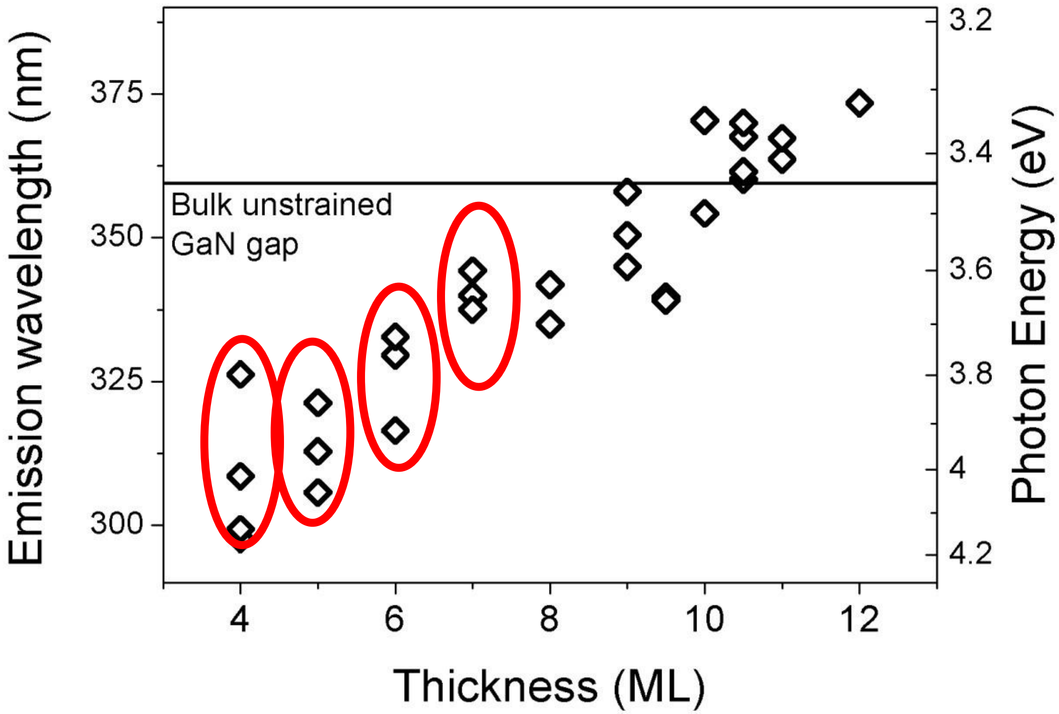


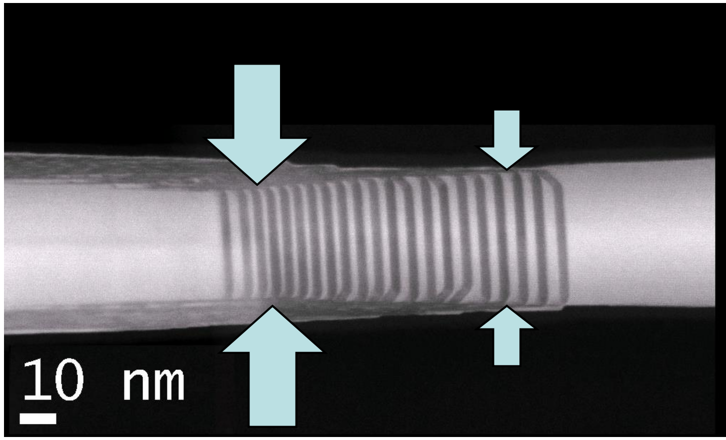
Each data point represents a single QD of known size and emission energy!

The Quantum Confinement is clearly evidenced by the relation of QD thickness and emission energy.

L. F. Zagonel et al.,
Nano Lett. 2011, 11, 568–573

Relation QD thickness vs. emission energy

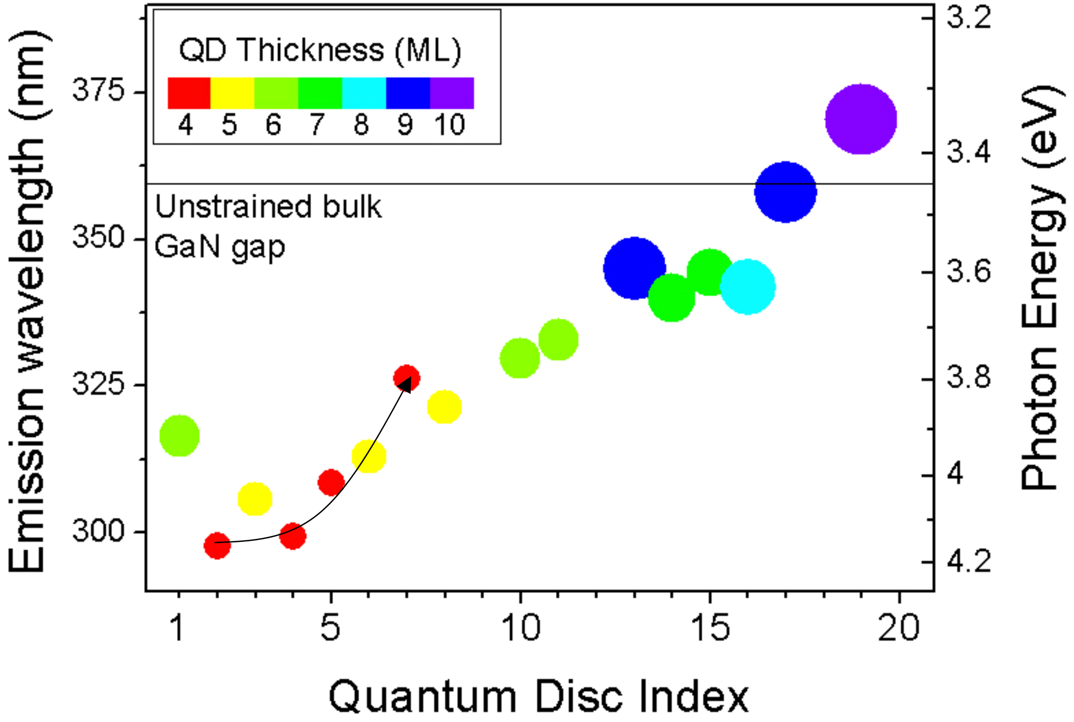


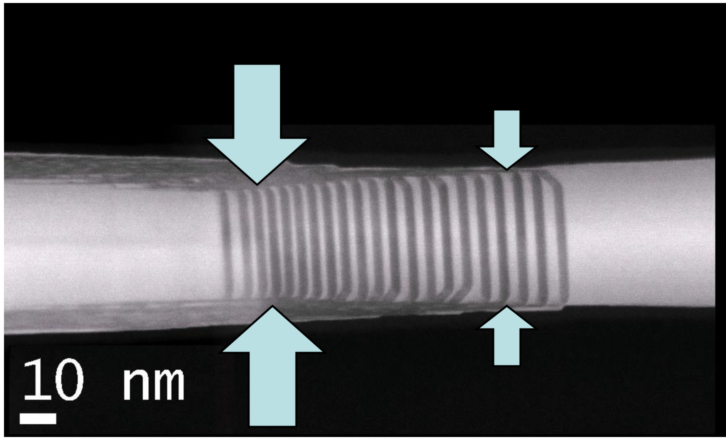


The dispersion in the curve is possibly caused by strain.

L. F. Zagonel et al., Nano Lett. 2011, 11, 568–573

Effect of the AlN Shell

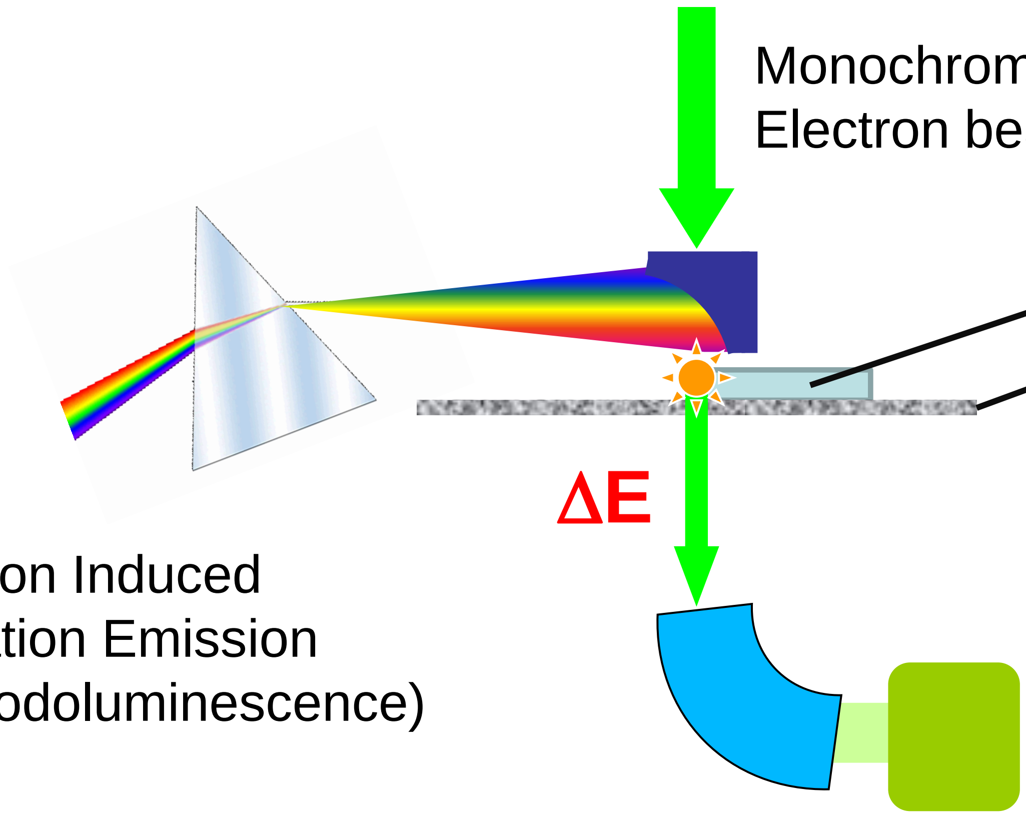




At equal thickness, QD's emission red-shift from the begin to the end of the QD stack.

L. F. Zagonel et al., Nano Lett. 2011, 11, 568–573

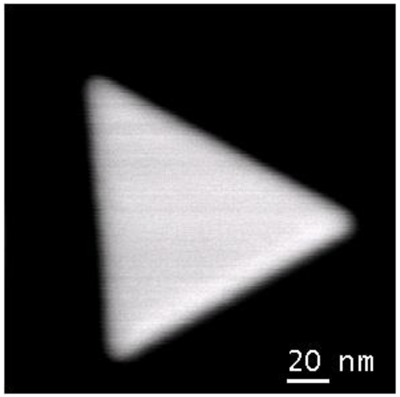
Emission and absorption with electrons



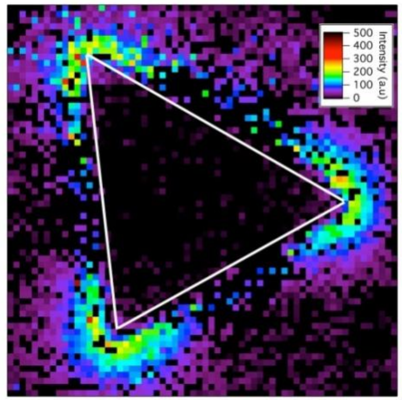
Emission by CL

Absorption by EELS

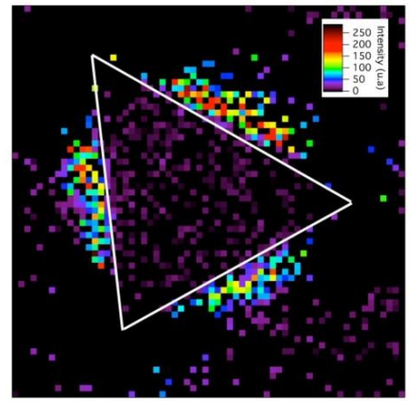
Plasmon modes on Au Triangles



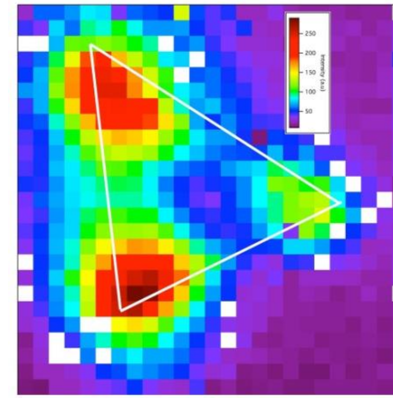
STEM VG
DF Image



Absorption (EELS)
mode at ~2.4 eV



Absorption (EELS)
mode at ~2.7 eV



Emission (Cathodo)
mode at ~2.3 eV

Collaboration with

Luis M. Liz-Marzán
J. B. Rodriguez
Vigo University
Spain

Summary

Quantum confinement and Stark effect is clearly evidenced in individual GaN quantum discs.

High localization of CL signal is shown.

Emission and absorption on the same metallic nanopartiple has been performed.

Analysis, simulations and new experiments are in progress.

Thank you for your attention!

Merci de votre attention!

Acknowledgements

Financial Support