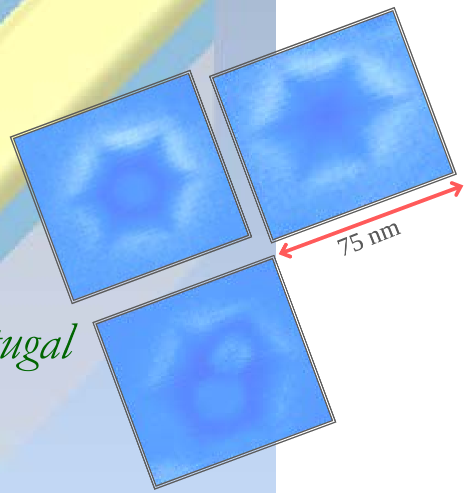
universidade de aveiro

CICECO
Centro de Investigação em Materiais Cerâmicos e Compósitos

Controlled integration of nanocrystals on the surface of group III-nitride light-emitting epitaxial heterostructures



S. Pereira ***et al.***

CICECO, Universidade de Aveiro, 3810-193 Aveiro, Portugal

NANOSPAIN 2008
Braga (Portugal) April 14-18, 2008
NanoIberian Conference

Acknowledgments

Nano Chemistry, NC synthesis and NC incorporation: M. Martins and T. Trindade

Microscopy

(AFM): I. K. Bdikin and A. L. Kholkine,

(SEM): A. B. Lopes and M. Ferro

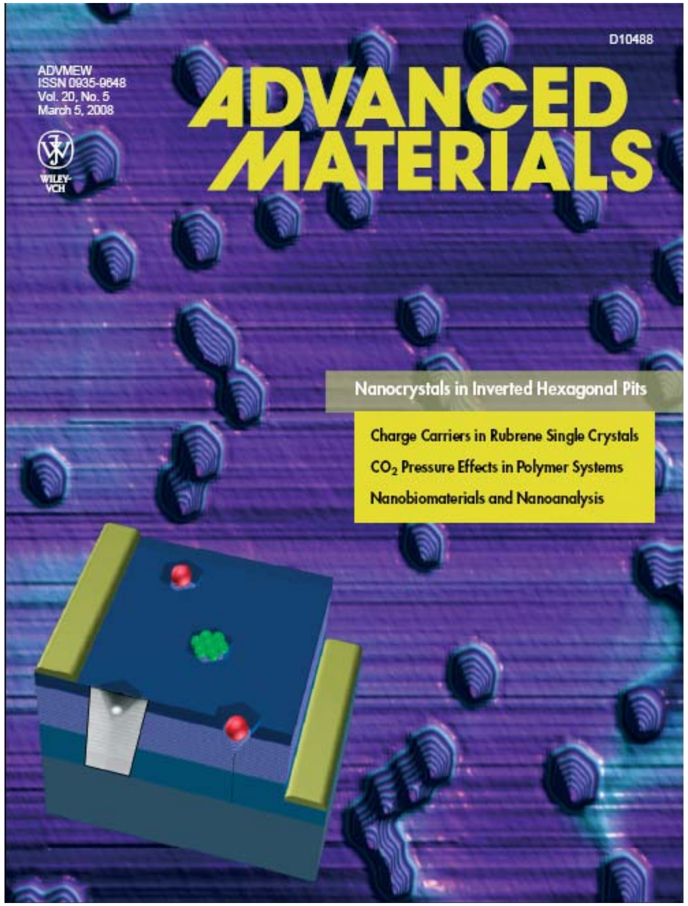
CICECO, Universidade de Aveiro, Portugal

Nitride Growth- I. M. Watson

Institute of Photonics, SUPA, University of Strathclyde, Glasgow, UK

TEM analysis- Pedro Costa, D. Zhu and C. J. Humphreys

Materials Science and Metallurgy, University of Cambridge, UK



FUNDAÇÃO CALOUSTE GULBENKIAN

Background and overview

- Currently an extensive range of colloidal nanocrystals (NCs) can be readily produced by diverse chemical methods. These nanomaterials present **novel physical properties** and can be regarded as building blocks to the nanofabrication of smaller, energy efficient and faster devices.

- These nano-building blocks have to be conveniently **arranged** and **connected**. This requires incorporation into an **electrically** and/or **optically** active framework.

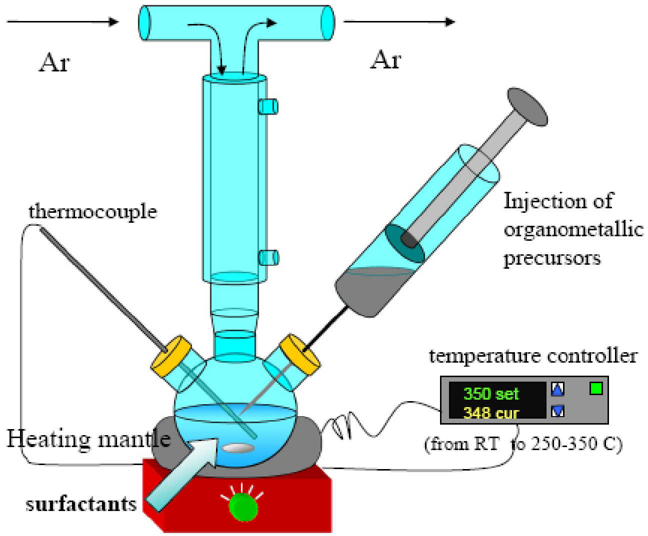
We address this through a novel and inexpensive approach that **exploits the spontaneous formation of nanoscale inverted hexagonal pits (IHPs) at the surface of In-containing III-nitride epitaxial heterostructrures**.

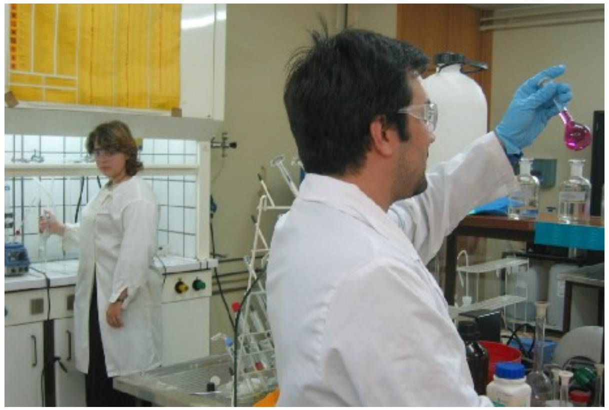
- We shall demonstrate that these morphological features, which can be designed with a **suitable size**, **depth** and **density**, can effectively **organize and control the incorporation and assembly of NCs at the surface of efficient light emitting devices**.

Bridging together the best of both worlds!

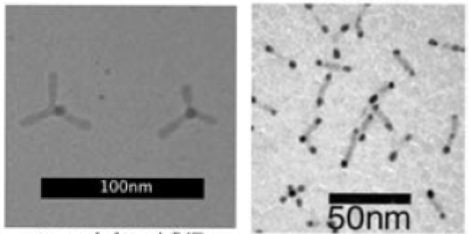
MOCVD reactor
I.M. Watson, Strathclyde

Wet chemistry
Tito Trindade, CICECO/UA





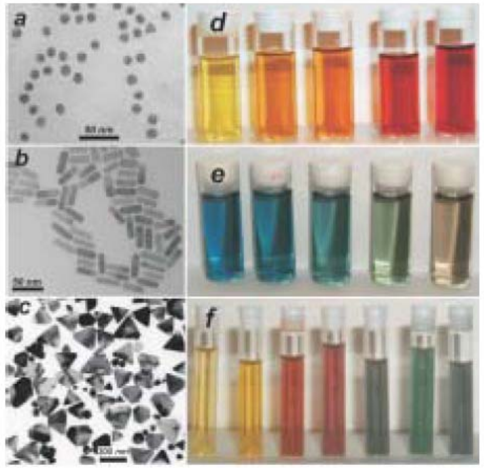
Chemical synthesis of Nanocrystals



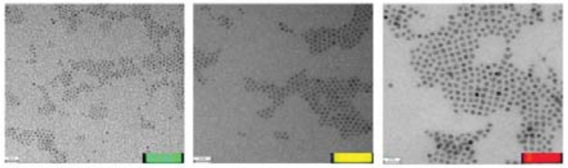
tetrapod-shaped CdTe nanocrystals

Au/CdSe/Au gymbar shaped hybrid structure

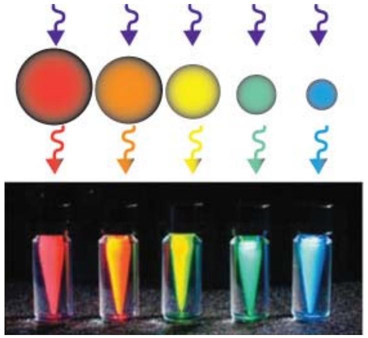
Tetrapod and gymbar shaped
Pellegrino et al. small 2005, 1, No. 1



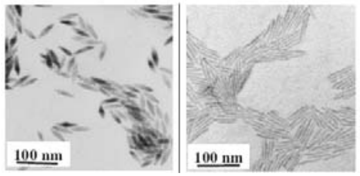
Nanocrystals: Au spheres and rods (a, b) and (c) Ag prisms.L. M. Marzán, Materials Today 2004



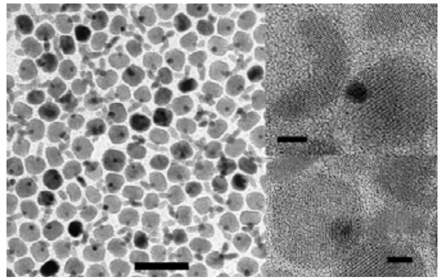
CdSe with different sizes – synthesis in olive oil!
Sapra et al. J. Mater. Chem. 2006, 16, 3391–3395



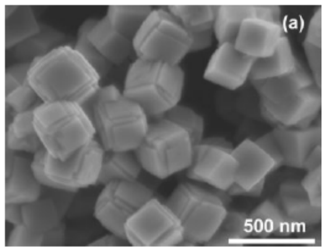
www.invitrogen.com
CdSe different sizes – different colors



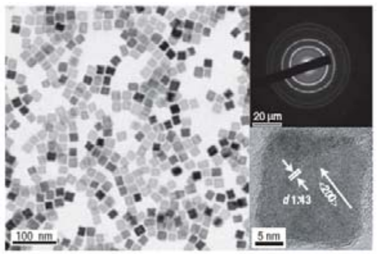
Rice- and rod-shape CdSe
Peng et al. Advanced Materials 2003, 5, 459.

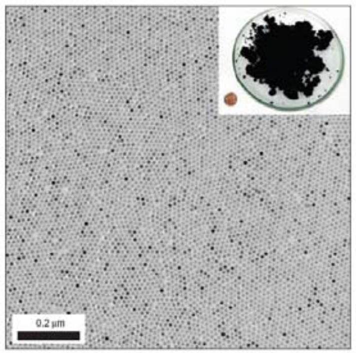


PbSe nanorods Au–Fe_3O_4 hybrid nanoparticles
Shi et al, *Adv. Mater.* **2006**, *18*, 1889–1894.



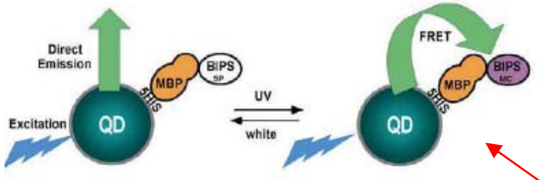
FeCo nanocubes
Kodama et al. Adv. Mater. **2006**, *18*, 3154–3159



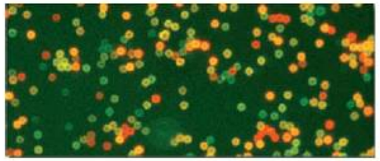


Iron cubes and magnetite spheres *Park et al. Nature Materials* 2004, 3, 891.

Wide availability of multifunctional colloidal NCs

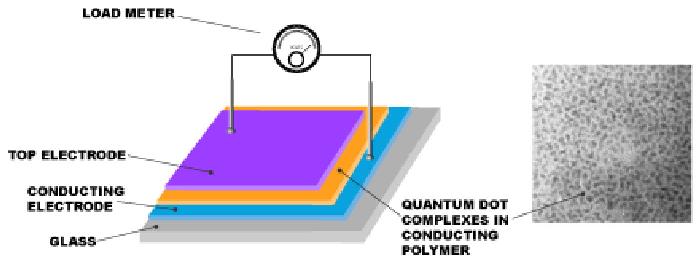


FRET-based Sensors
N. A. Kotov et al. Nanotoday May 2005

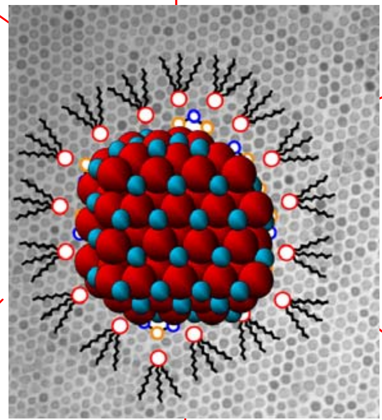


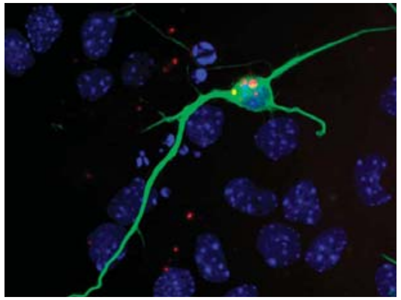
Optical encoding
Sensors
R. Wilson et al. Angew. Chem. Int. Ed. 2006, 45, 6104– 6117

Photovoltaics
www.evidenttech.com



Schematic of quantum dot solar cell and TEM of Quanum Dot doped polymer





Neural stem cells loaded with QD's
Biological probes
www.evidenttech.com

LEDs
www.evidenttech.com

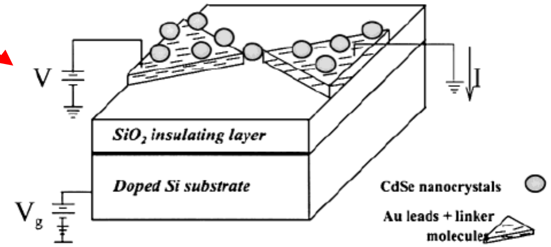
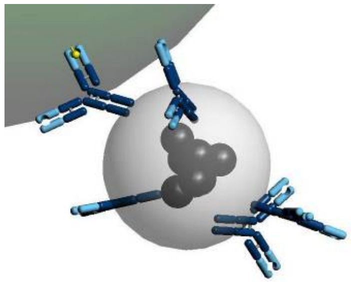


Figure 10. Idealized diagram of a single-electron transistor made from CdSe nanocrystals.[171]

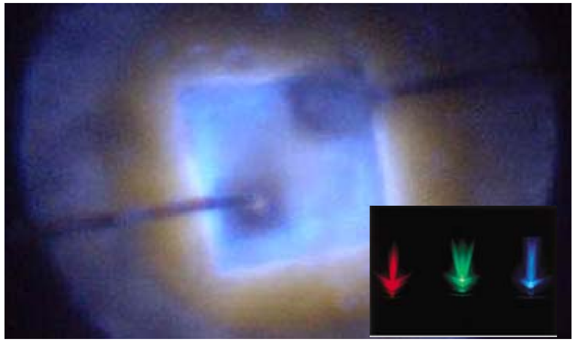
Molecular recognition
P. Alivisatos et al. Pure and Applied Chemistry, 2000, **72**, 3–9



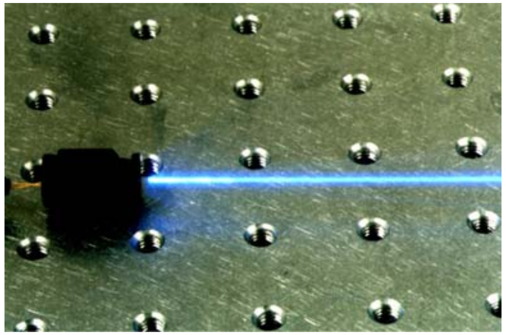
Magnetic separation and labelling
M. A. Martins et al. Nanotech. *submitted*

Single electron transistor
Weller, H. *Angew. Chem., Int. Ed.* **1998**, *37*, 1658; Klein, D. L.;Roth, R.; Lim, A. K. L.; Alivisatos, A. P.; McEuen, P. L. *Nature*, **1997**, *389*, 699.

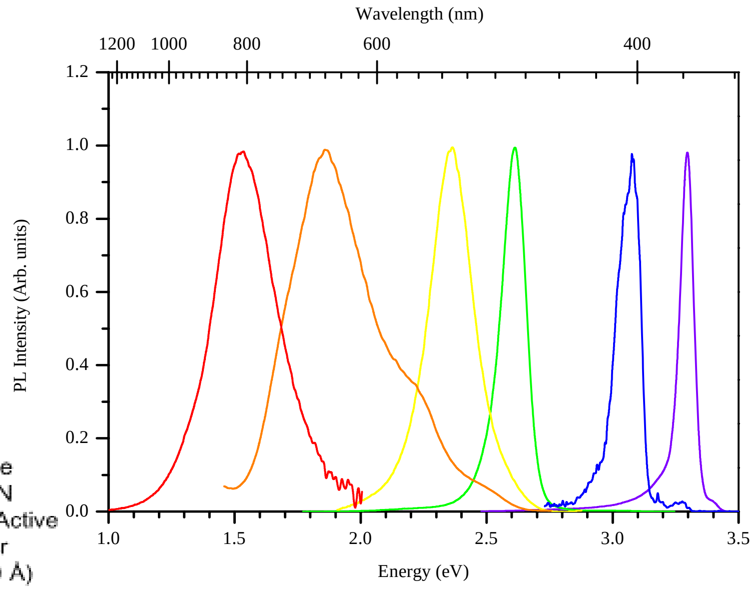
Nitrides: spectral coverage and bipolar charge injection

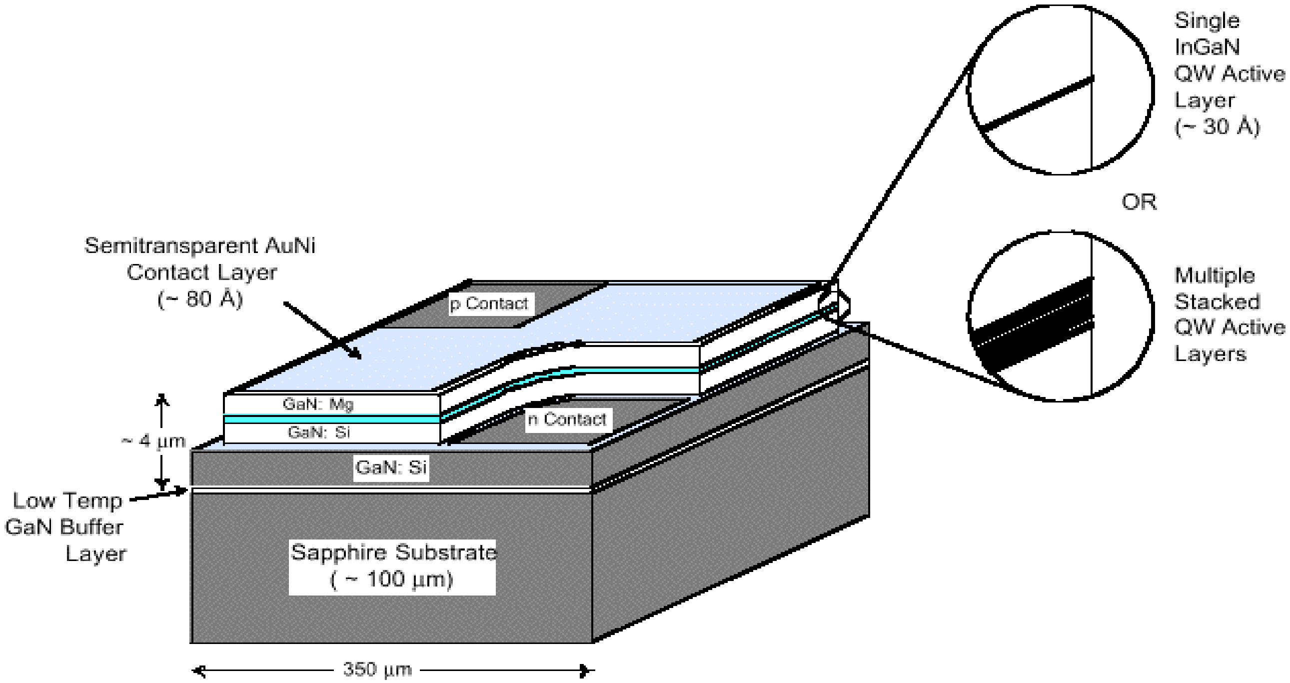


LEDs

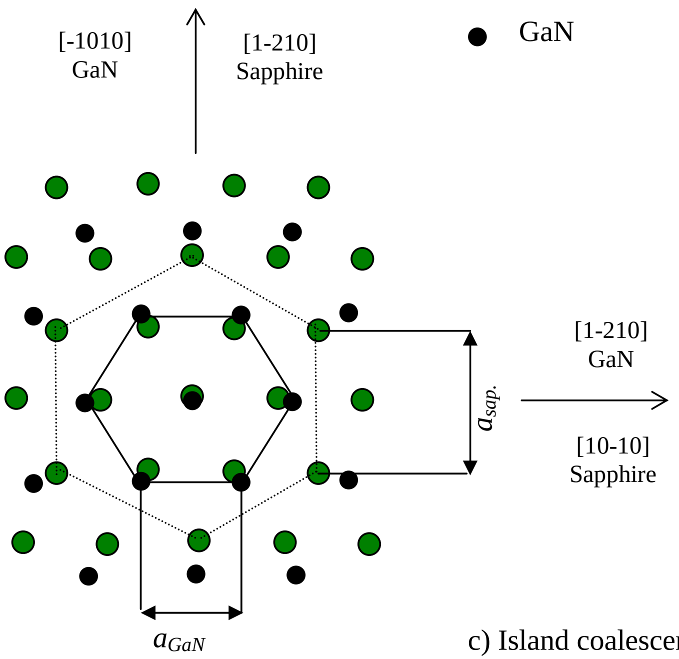


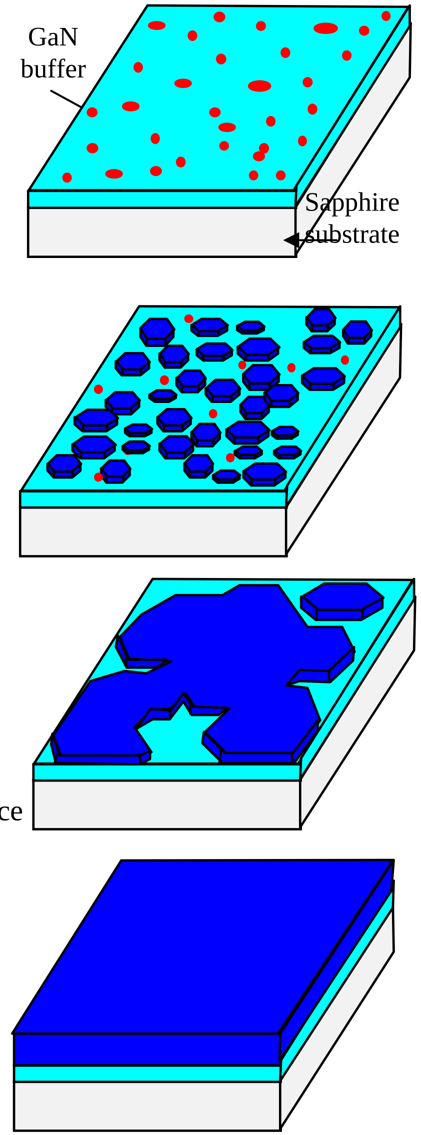
LDs





Growth of Nitrides: role of lattice mismatch



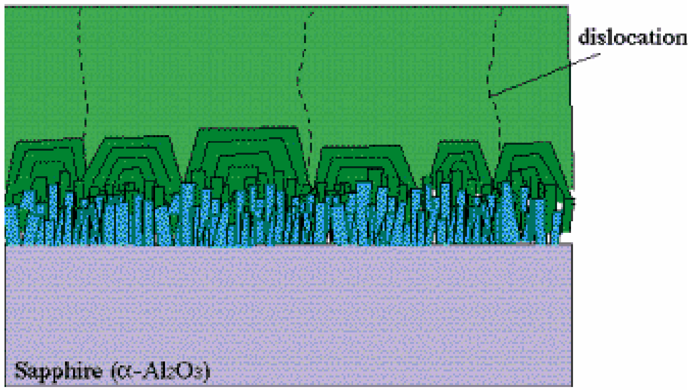


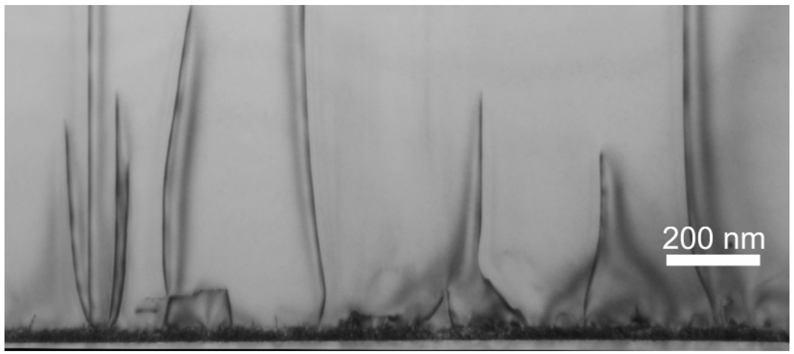
a) Dense nucleation

b) Islands *lateral* growth

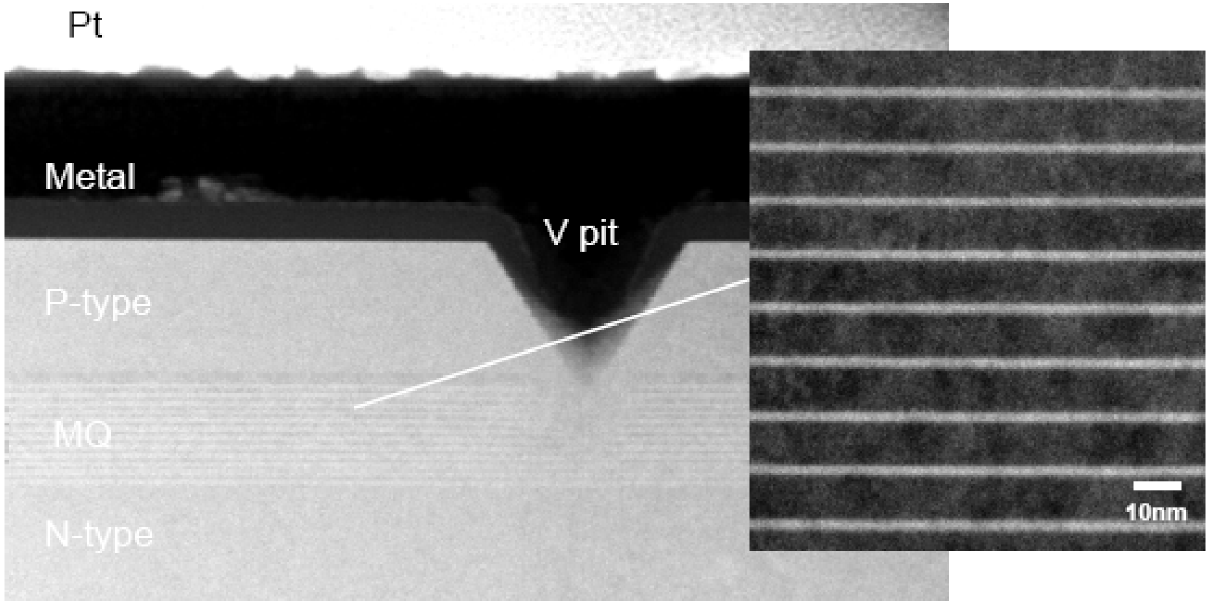
c) Island coalescence

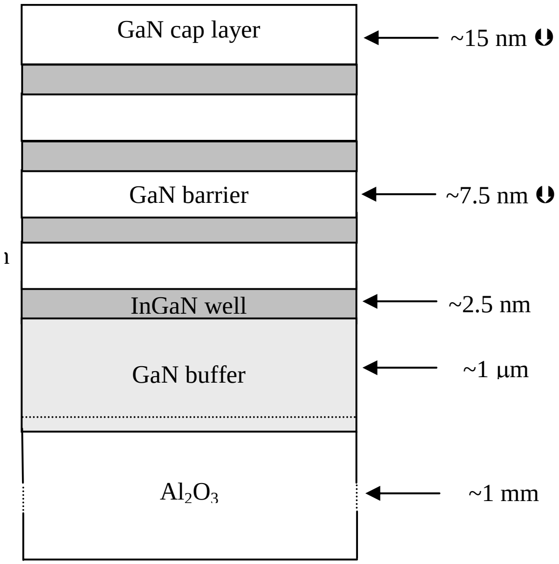
d) Final 2D growth (t>300nm)



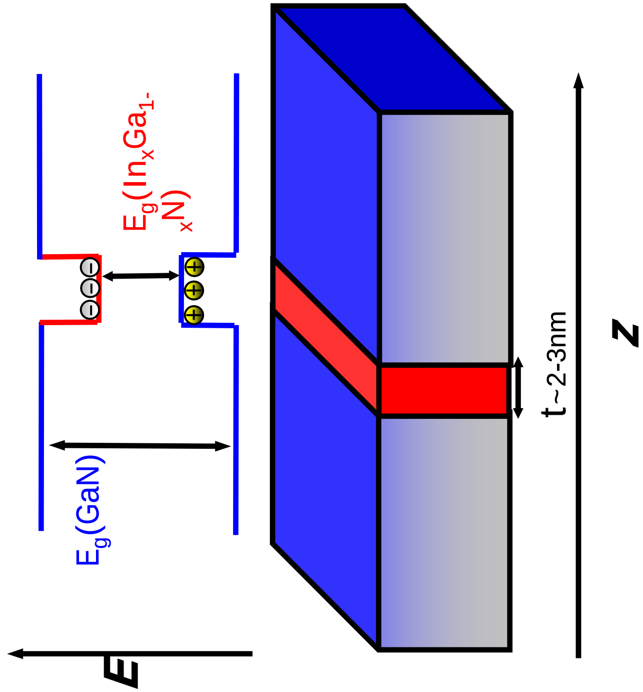


Low dimensional (2D) structures: MQWs

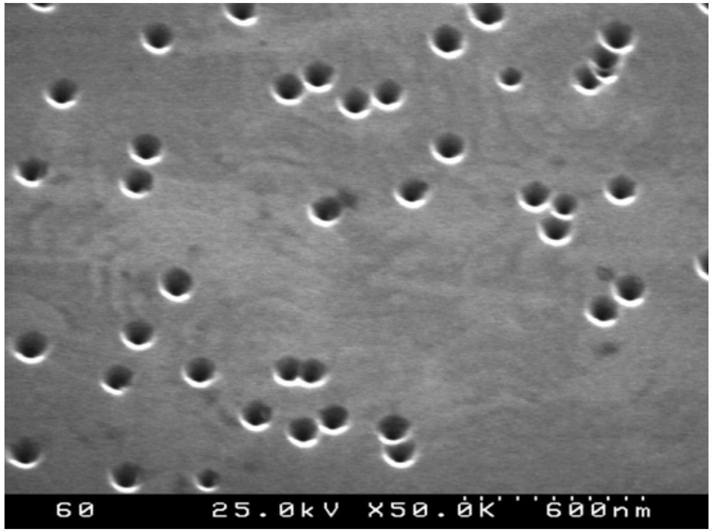


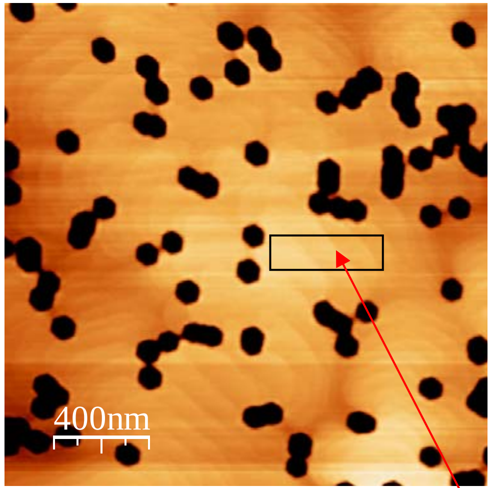


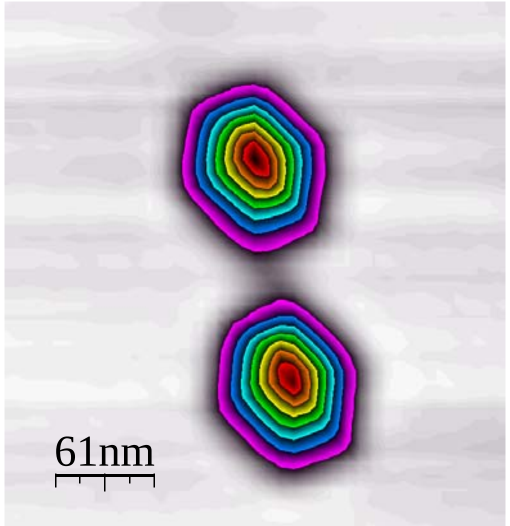
Typical MQW Structure

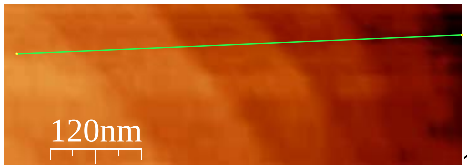


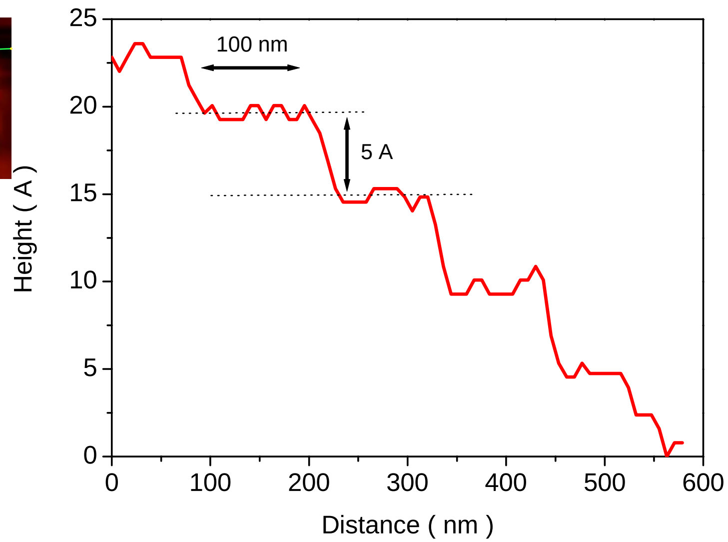
Surface morphology of In-containing nitrides





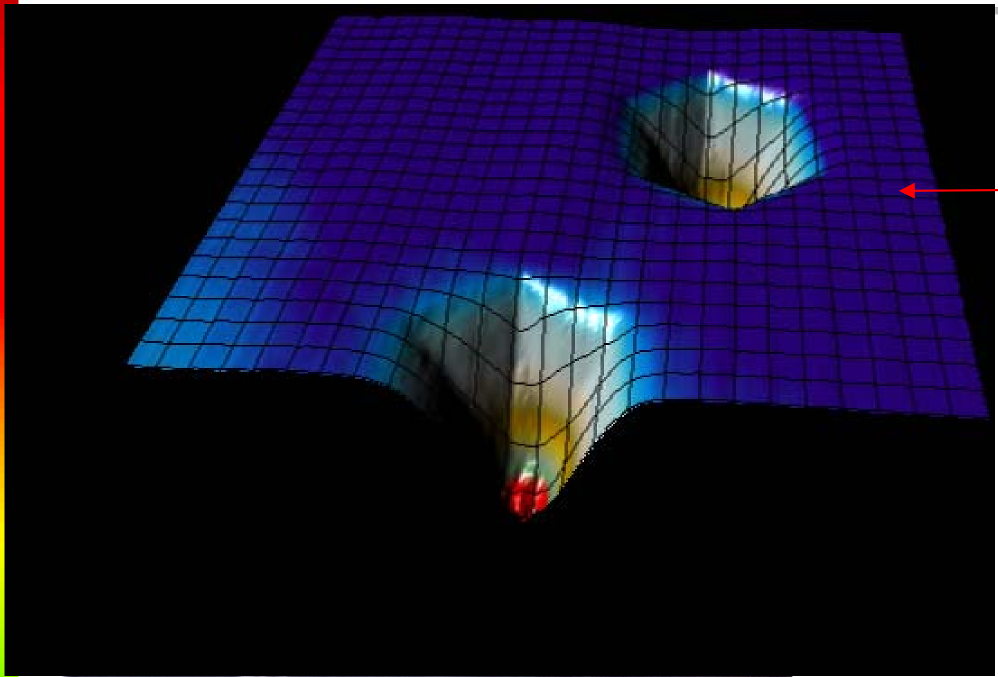


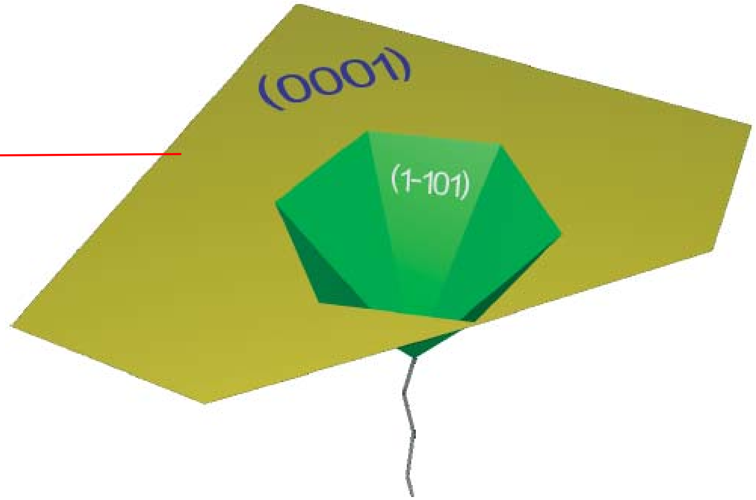


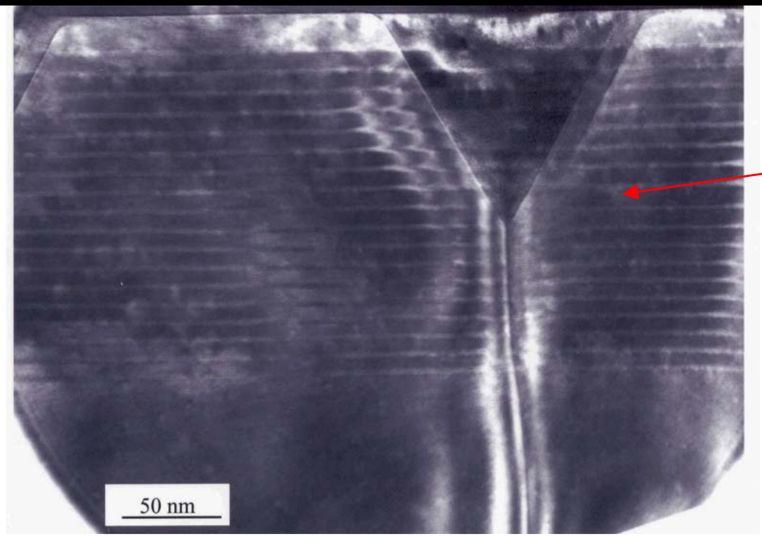


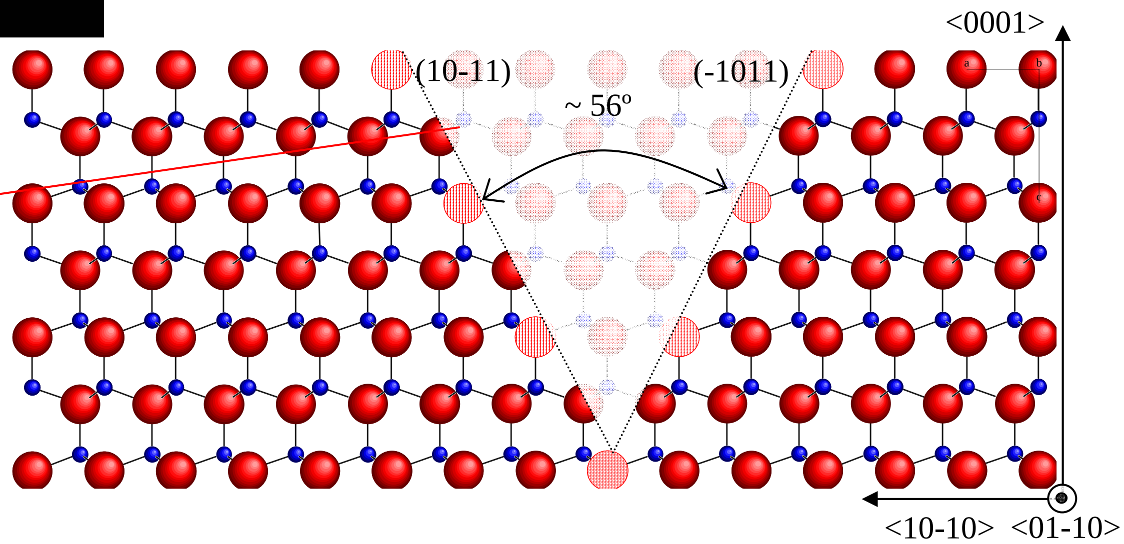
$n \sim 2 * 10^9\ cm^{-2}$

The role of inverted hexagonal pits (IHPs)

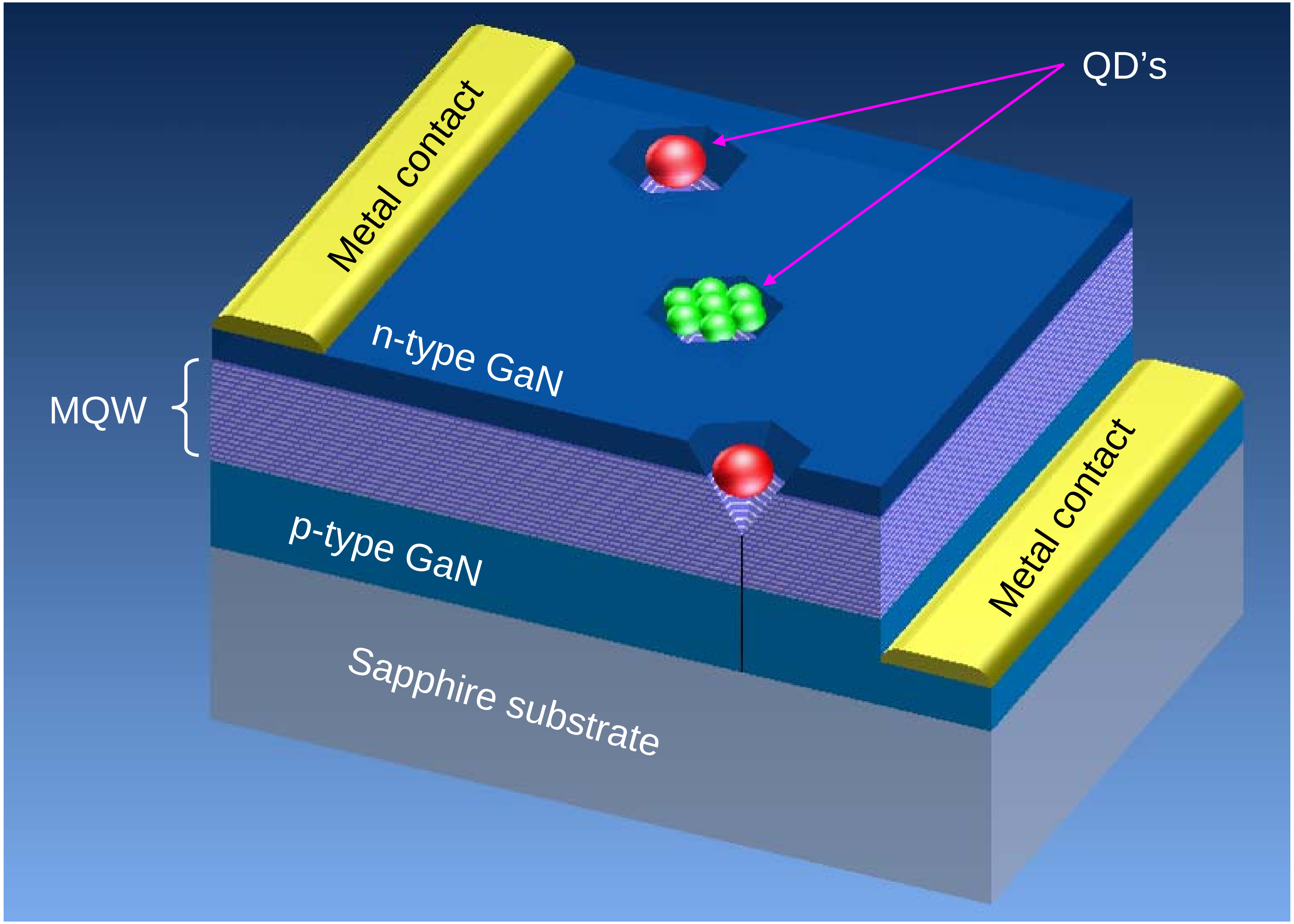




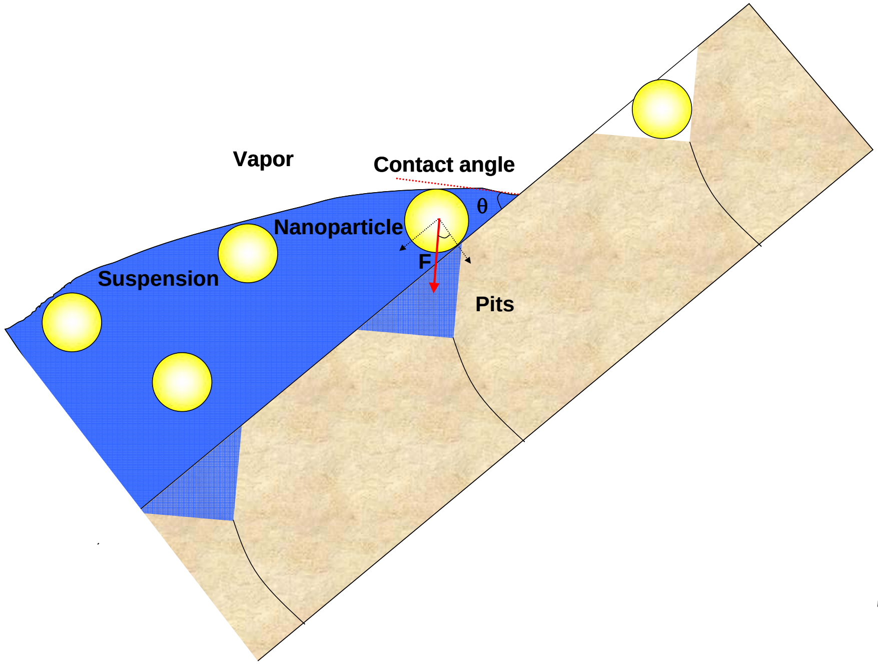


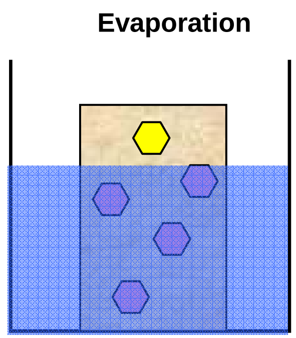


Concept: use IHPs as a geometric constriction to isolate NCs!



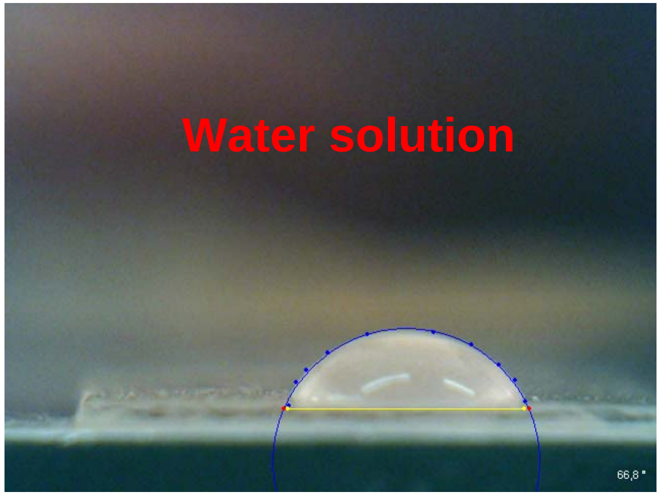
How can this be accomplished selectively?

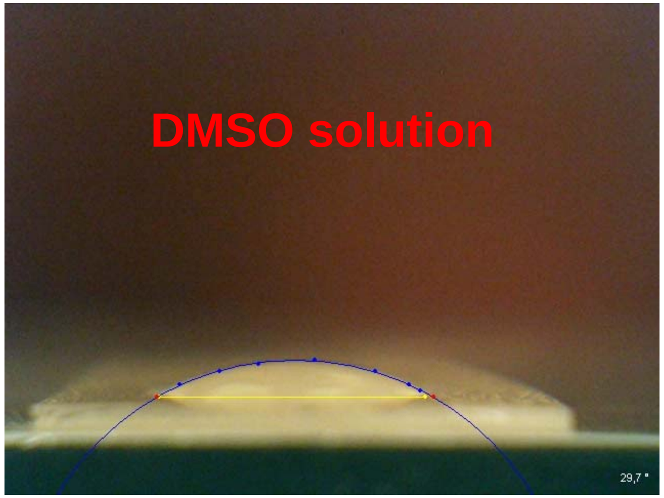




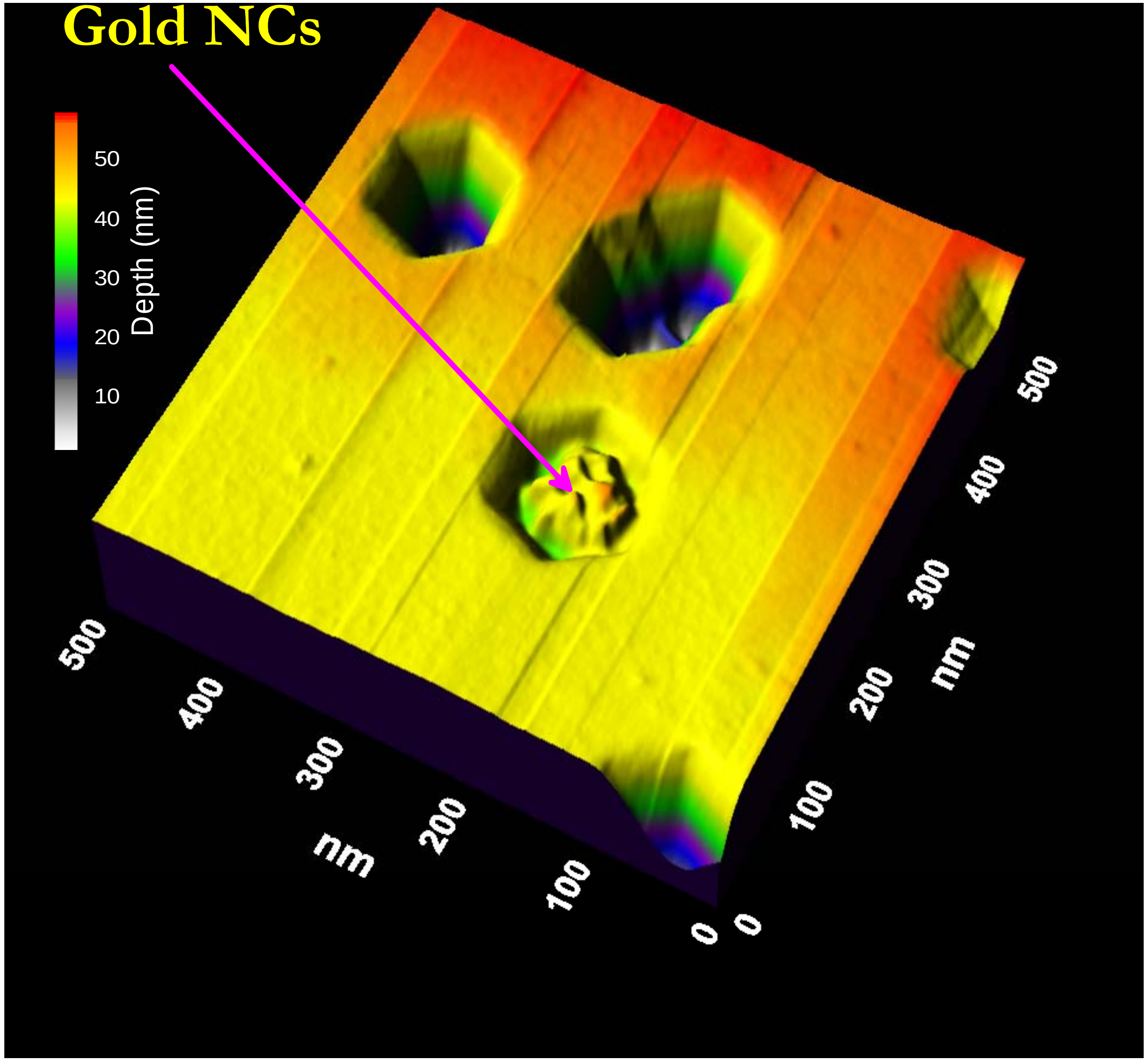
Y. Cui, *et al.*. Nano Letters **4** (6), 1093-1098 (2004);

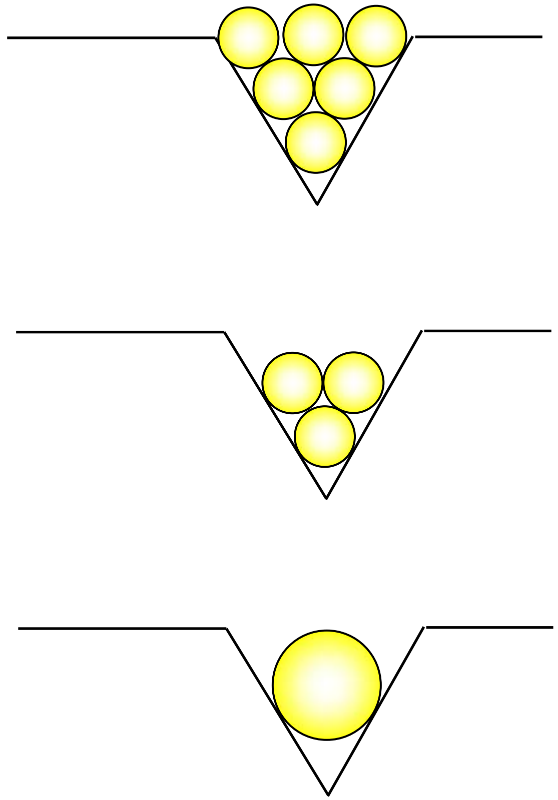
S. Pereira *et al*, Advanced Materials **20 (5)**, 1038 (2008).



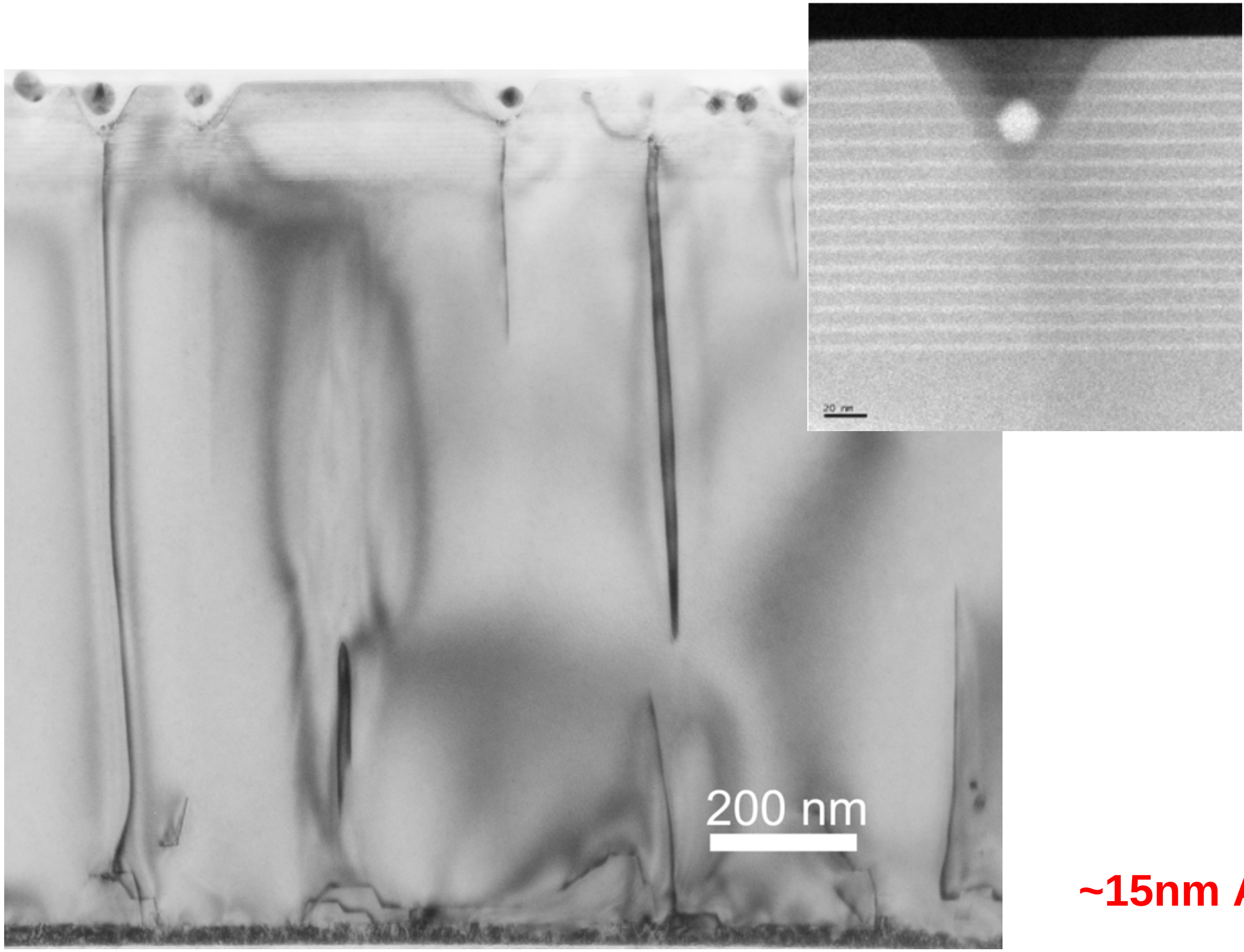


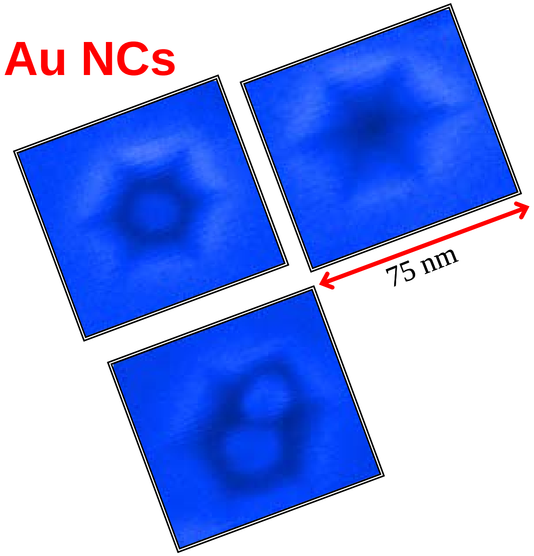
First experimental evidence with Au aggregates

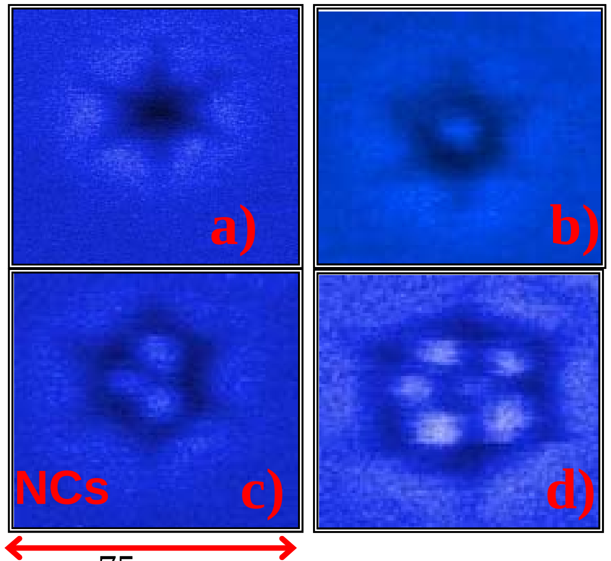




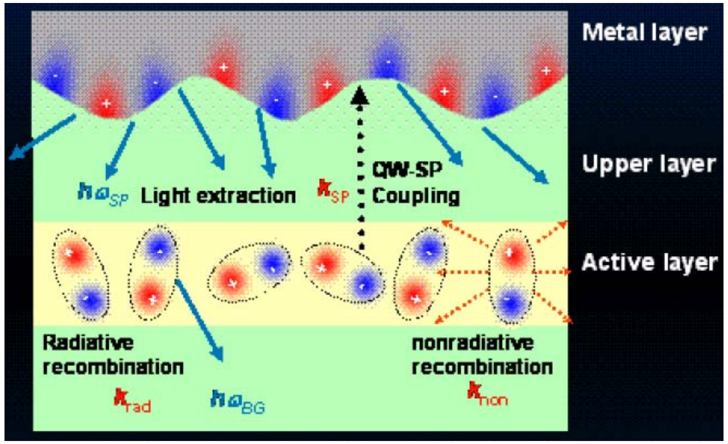
Isolation of single NCs and creation of elementary NC assemblies/clusters is possible!



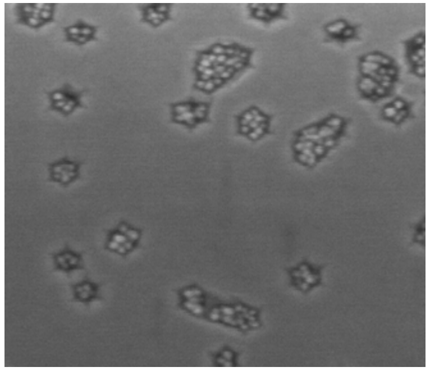


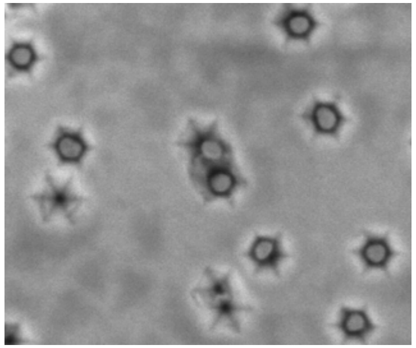


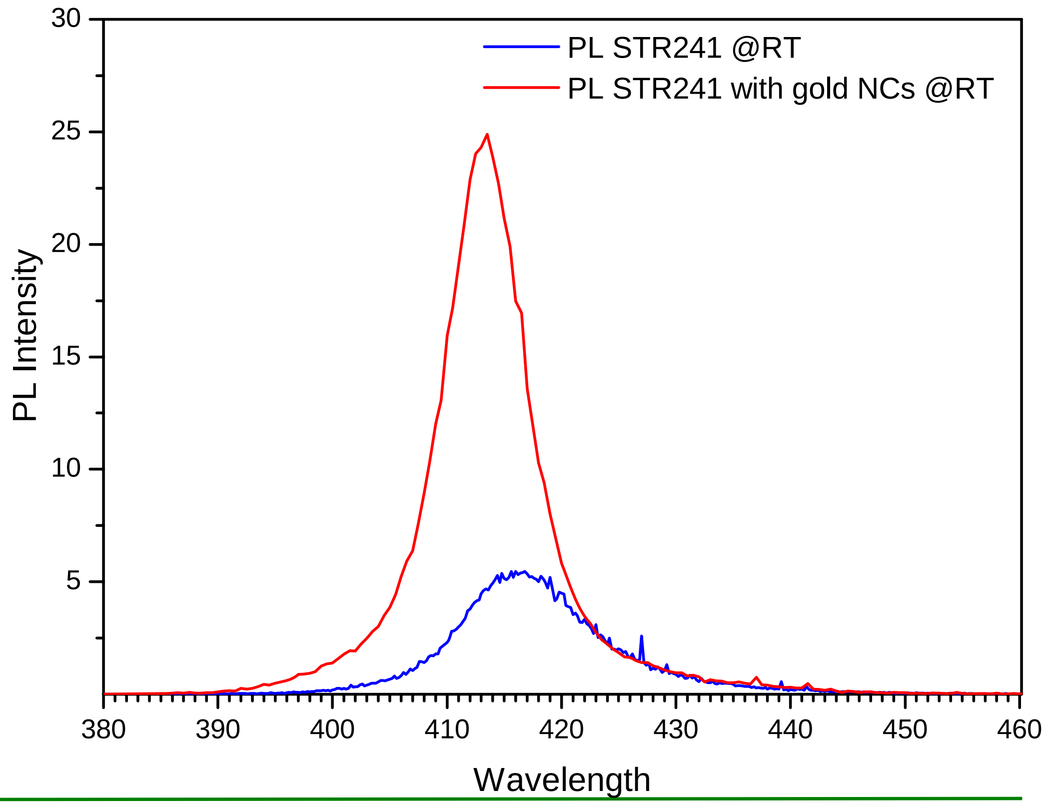
Strong PL emission enhancement: Plasmon coupling



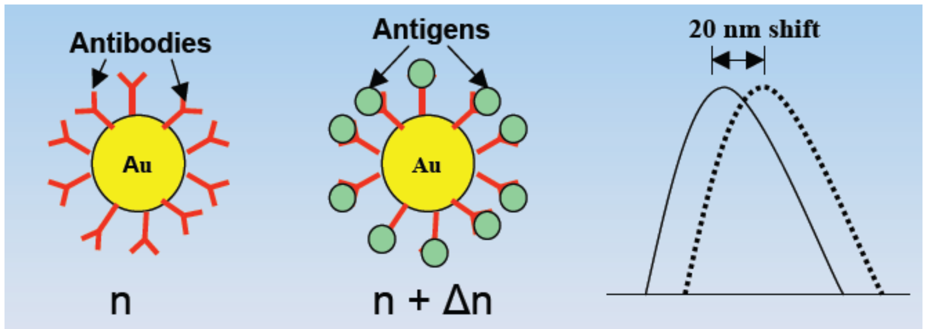
Okamoto *et al*, phys. stat. sol. **204**, 2103 (2007).







Applications on nano-diagnosis



Conclusions and Future Outlook

• It is possible to integrate nanocrystals into Nitride multilayer heterostructures with nanometer scale control to produce novel hybrid multilayer/nanocrystal heterostructures

•Using the IHPs as a geometric constriction, it is possible to isolate individual NCs, or to create NC assemblies or "lattices". Hybrid NC junctions are possible to build.

•The possibility of charge injection/collection via a bipolar (p-n junction) structure, is a very interesting prospect. It will allows to bring the benefits of multifunctional NCs into the "electronics world". Allow to exploit the unrivalled flexibility offered by wet chemistry synthesis

Future:

•Interaction of the emitted light, which can be tailored in the MQW, with various NCs.

•Bio-functionalization of the NCs: towards lab-on-chip applications and nano-diagnosis

Thank you for your attention!