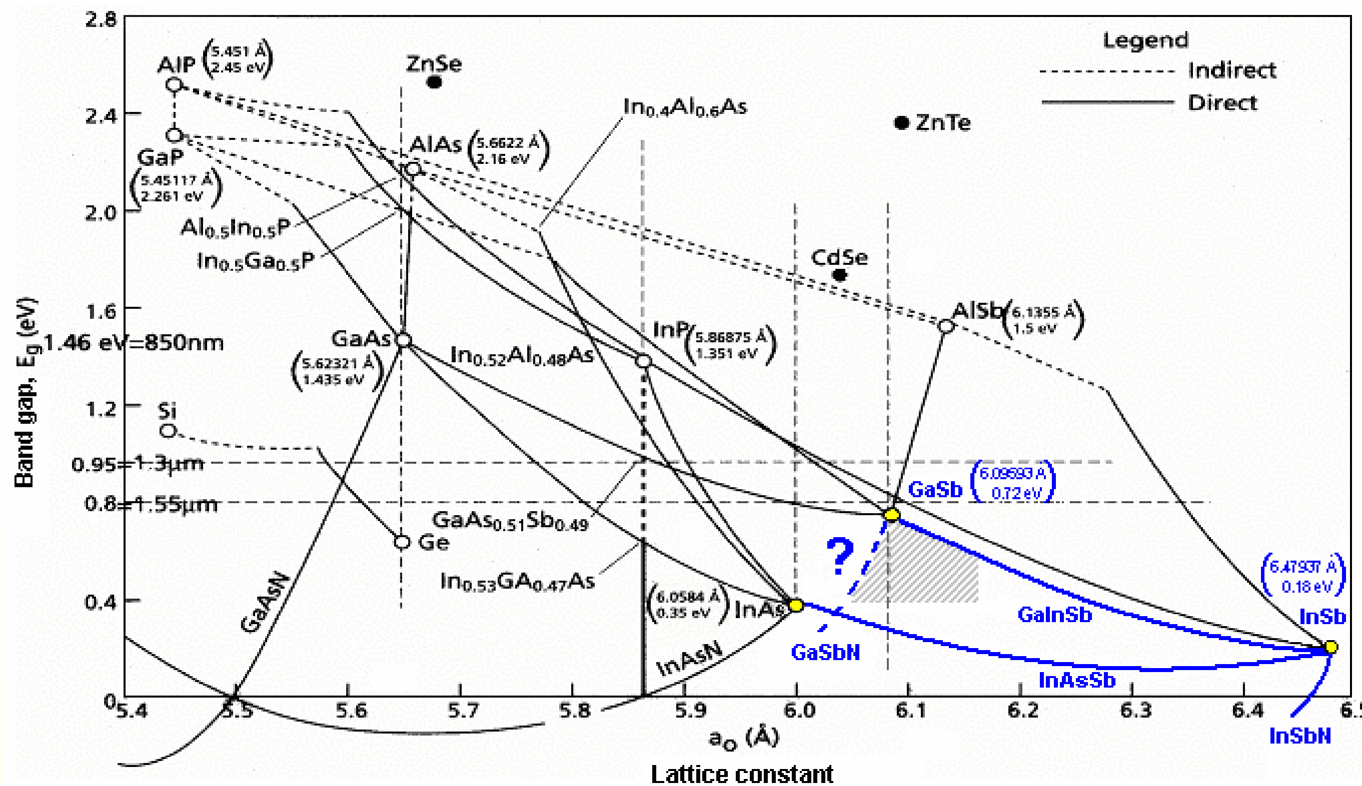
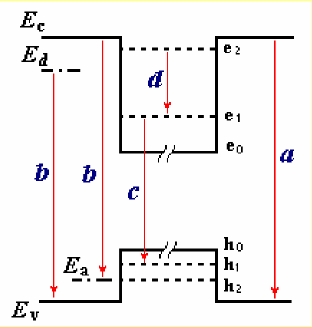
nanodots and nanocrystals for infrared photodetectors

Yossi Paltiel
Solid State Physics Group
Soreq NRC

III-V compounds



Most of our work Are bulk devices for MWIR



<u>Quantum detectors</u>

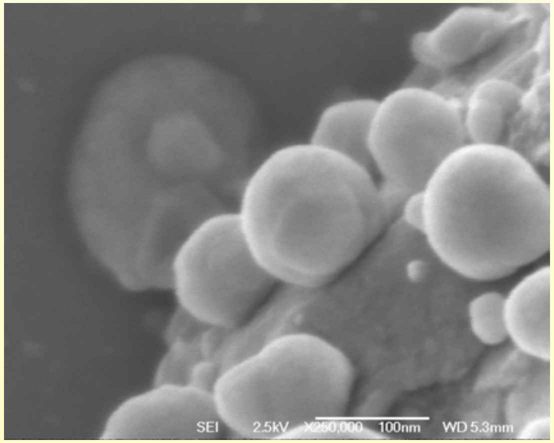
SWIR- Nano-crystals
MWIR- Nanodots
LWIR-Quantum wells
THz Quantum wells

Bulk problems and possible solution

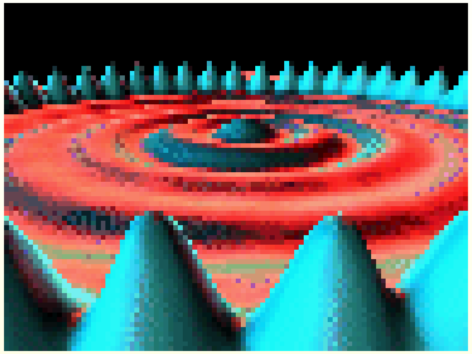
- Low temperature operation
- Wide band wavelength response
- Restricted flexibility in choosing the peak wavelength

↓

Nano



Why Nano and Meso?



Call for Research Proposals in Advanced Materials and Nanotechnology, Israel-Ukraine Cooperation

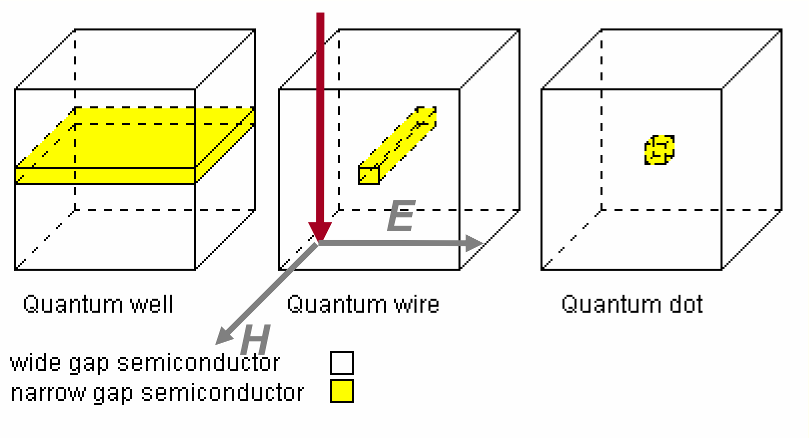
Impressive

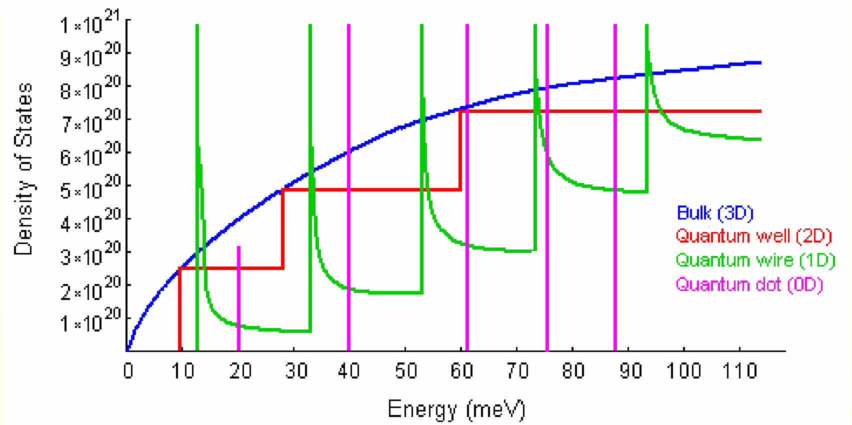
A lot of money

Using Quantum effects in the world of high temperatures (300K)

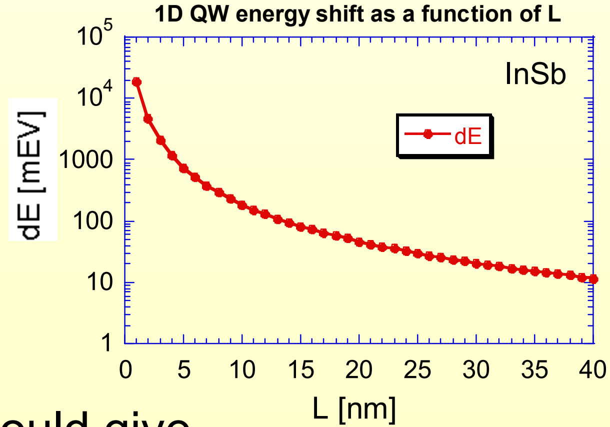
Nanodots in lasers and detectors

Light prorogation





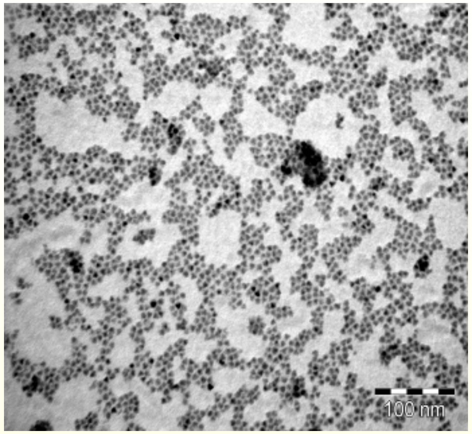
- Theoretically, high temperature operations.

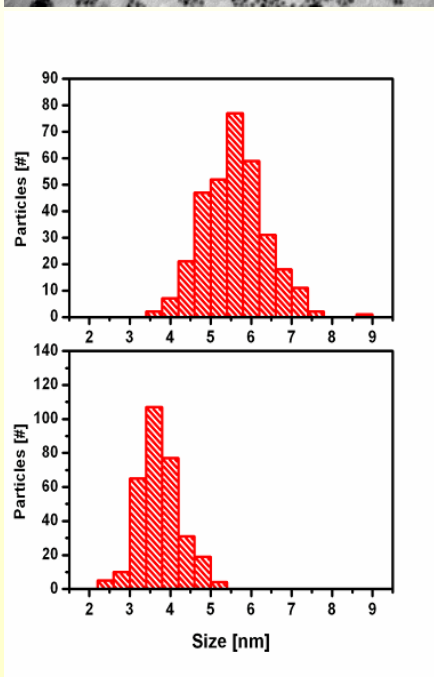


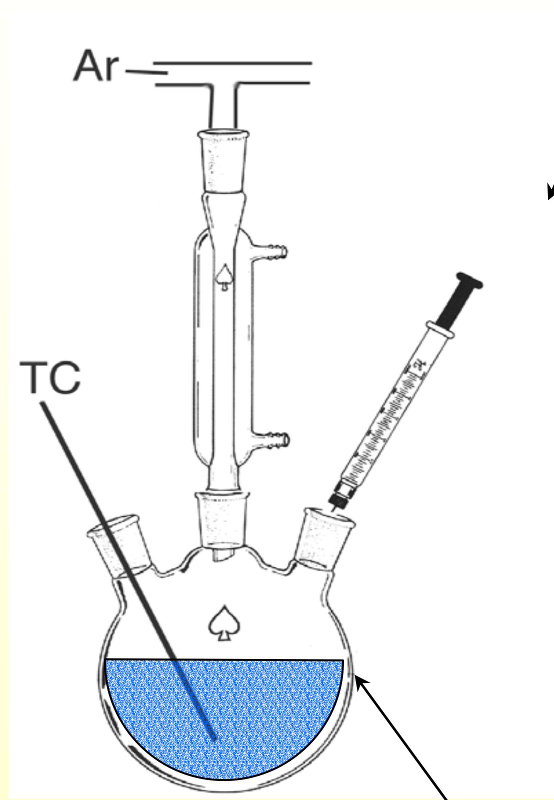
- Long lifetime
- Normal light absorption
- Narrow absorption lines
- Changing dots size will change the blue shift and could give multispectral detection

Nano crystals for shorter wavelength

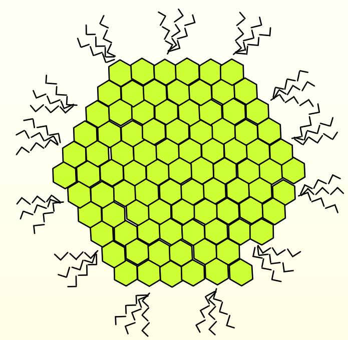
Uri Banin

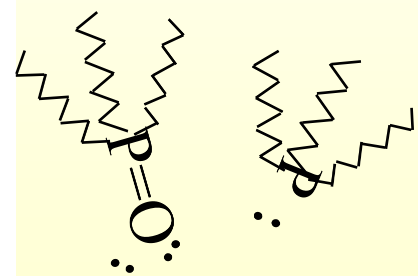






room T precursors
In/GaCl_3 and
P/As$(SiMe_3)_3$

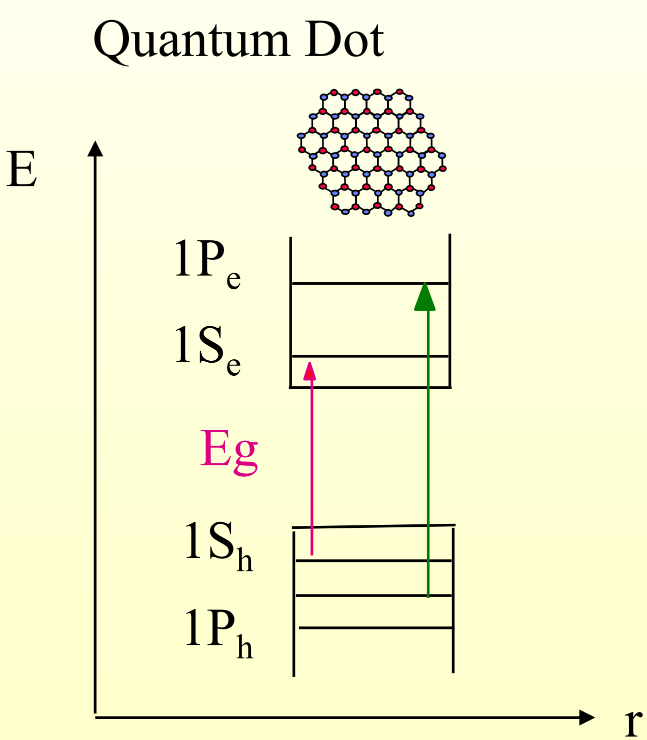




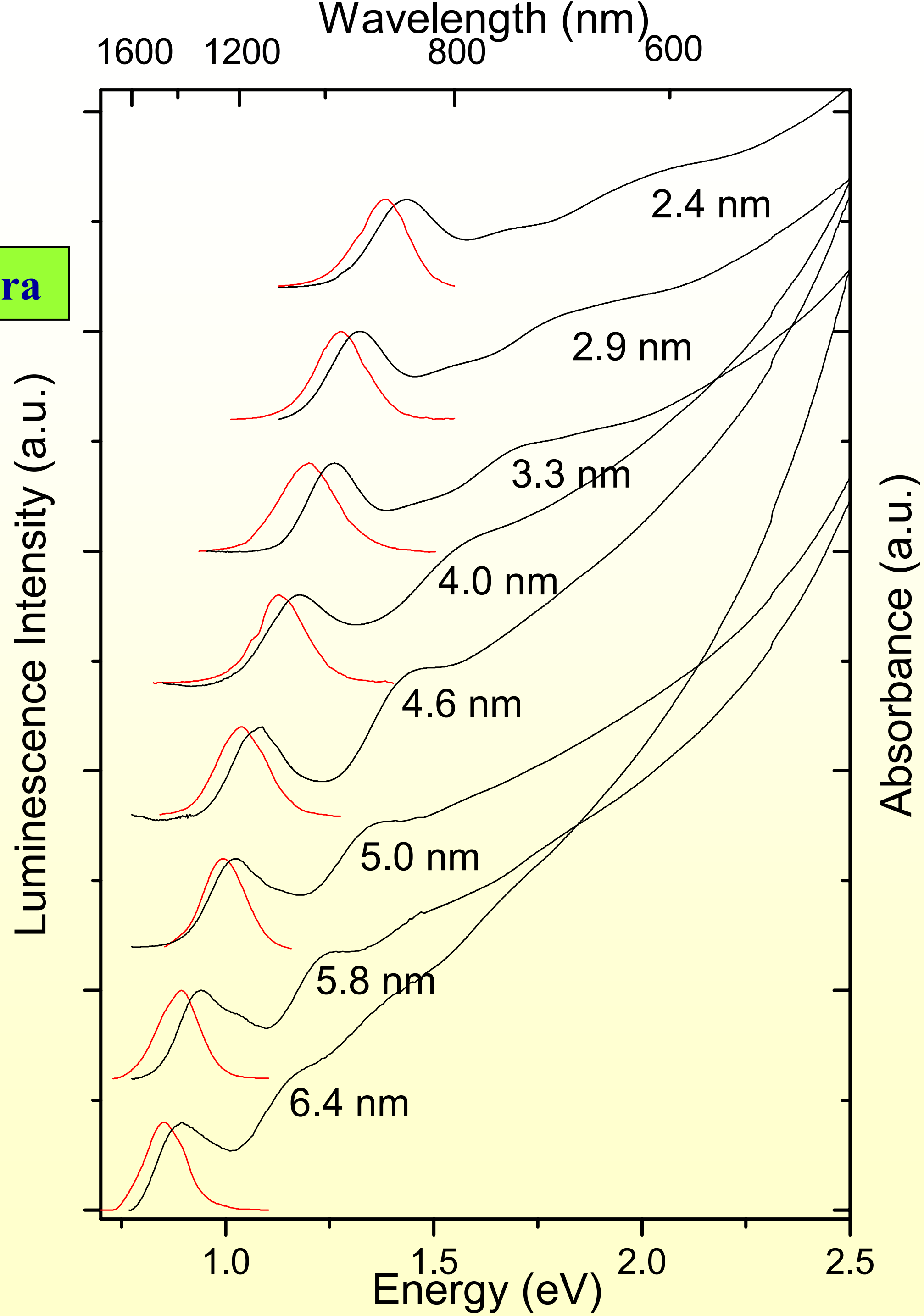
liquid surfactant,
stirring and at
“high T,” 250-300 ^{o}C

$InCl_3 + As(SiMe_3)_3 \longrightarrow InAs + 3Me_3SiCl$

Quantum confinement in InAs nanocrystals

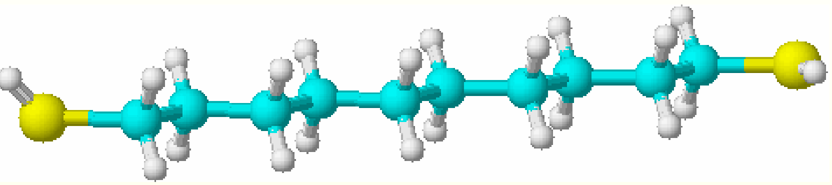


Optical spectra



Transport and dissipation

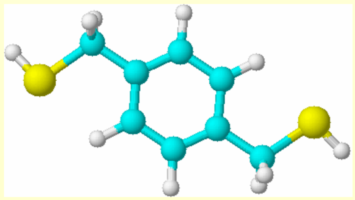
The molecules used

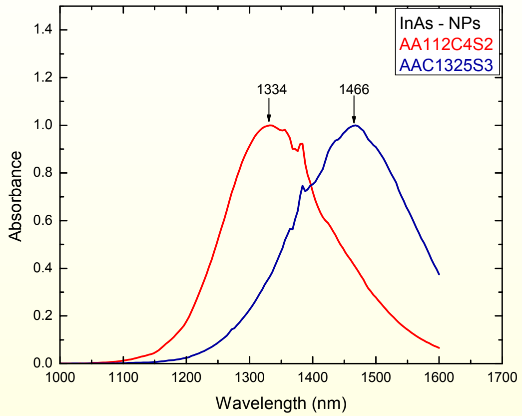


HS-$(CH_2)_{10}$-SH DT

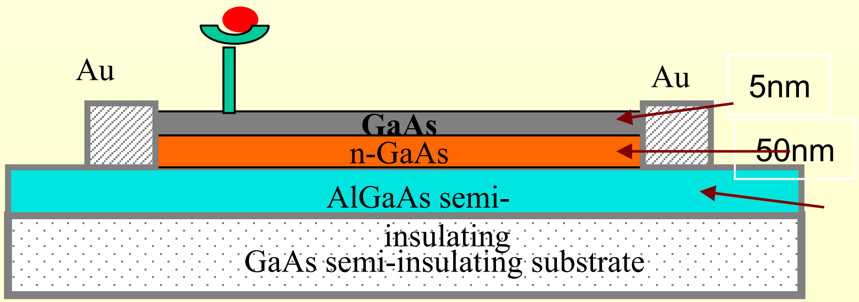
HS- $(CH_2)_2$-SH EDT

HS-CH_2-φ-CH_2-SH BDMT

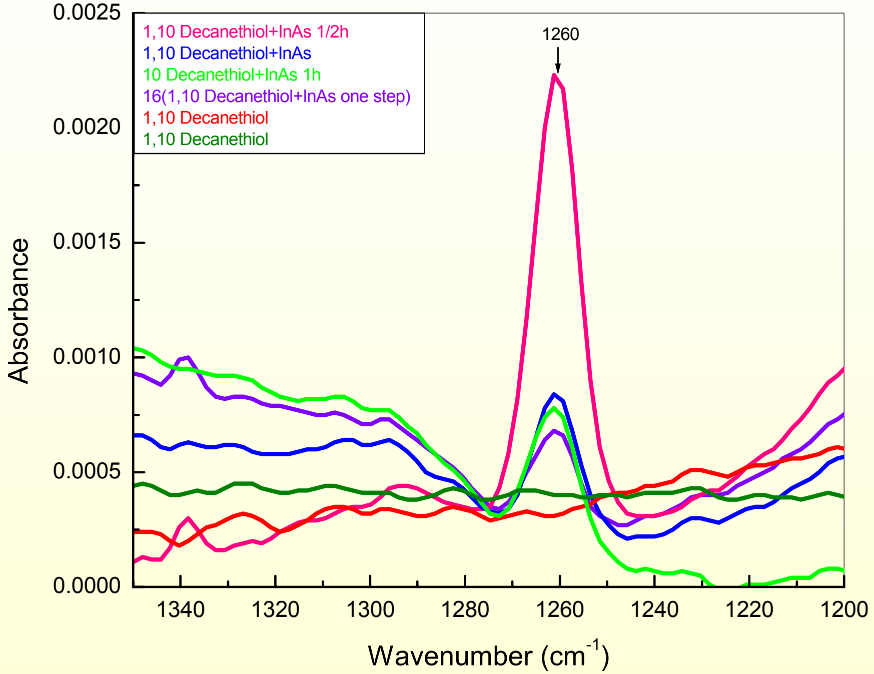




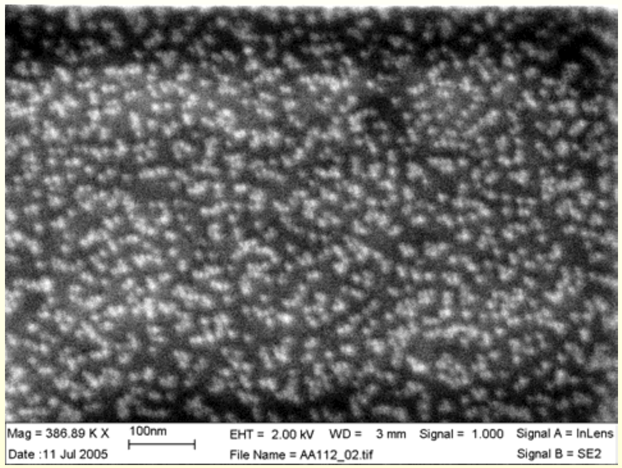
5nm and 6 nm InAs nanocrystals



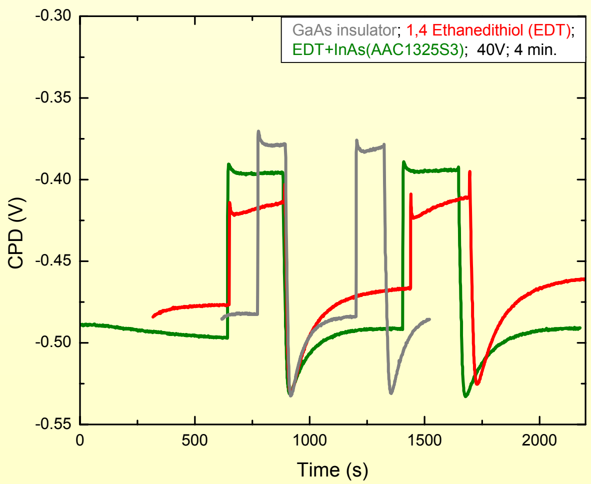
FTIR spectra of GaAs slides with 1,10 Decanethiol Monolayer and with InAs 6 nm NPs connected



CH_2 Vibration mode



Contact Potential Difference (Kelvin Probe)- Traps



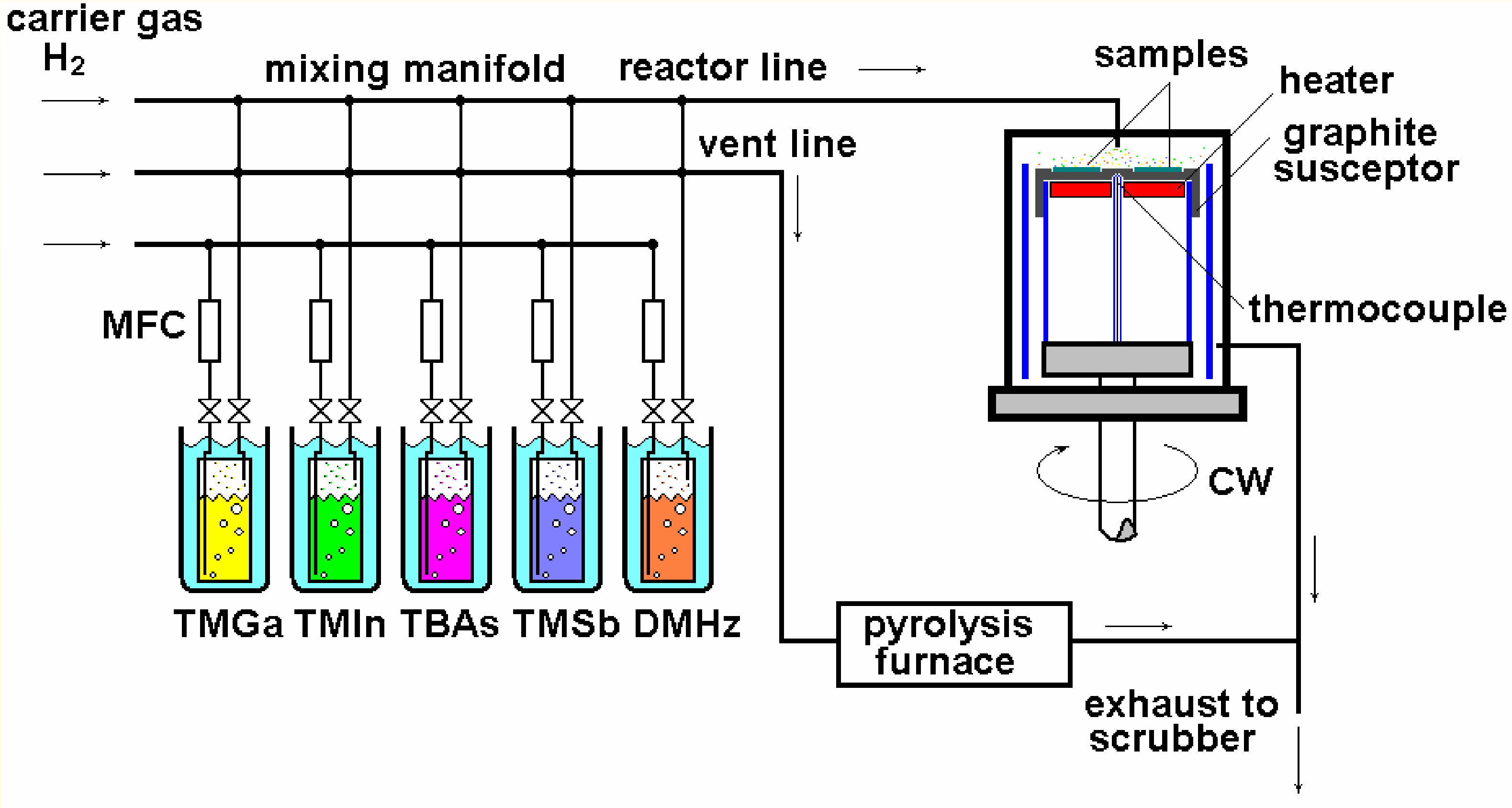
MOCVD (MOVPE) growth system

Growth Machine- Thomas Swan with Vertical Reactor

Substrates –Te doped InSb (100) or (100) 2^0 off towards (111), up to 2” wafers

Metal Organics- TMSb, TMIn

Dopants- Zn for p-type, S or Si for n-type, DEZn and H_2S/H_2 or SiH_4/H_2

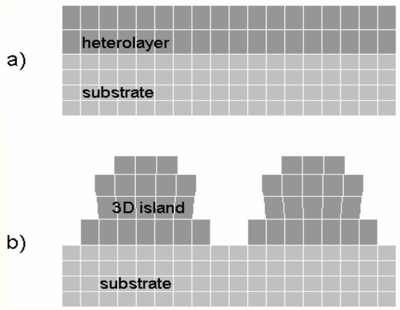


Soreq

Growth methods

Stranski-Krastanov growth mode

$\gamma_2 > \gamma_{12} + \gamma_1 + \mu_1(d)$



$\gamma_2 < \gamma_{12} + \gamma_1 + \mu_1(d)$

γ_1 – surface free energy of deposited material

γ_2 – surface free energy of substrate

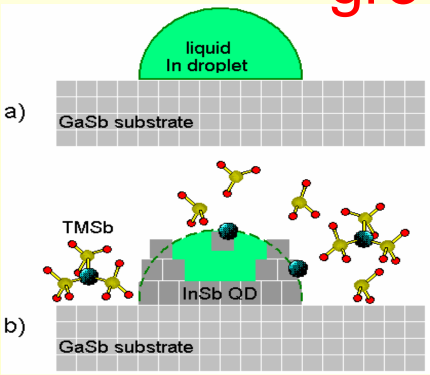
γ_{12} – interface energy

$\mu_1(d)$ – strain energy of the layer

Conventional method

(SK)

Droplet heteroepitaxy (DHE) growth mode



First stage of the growth:

group III element nano-droplets formation on the substrate

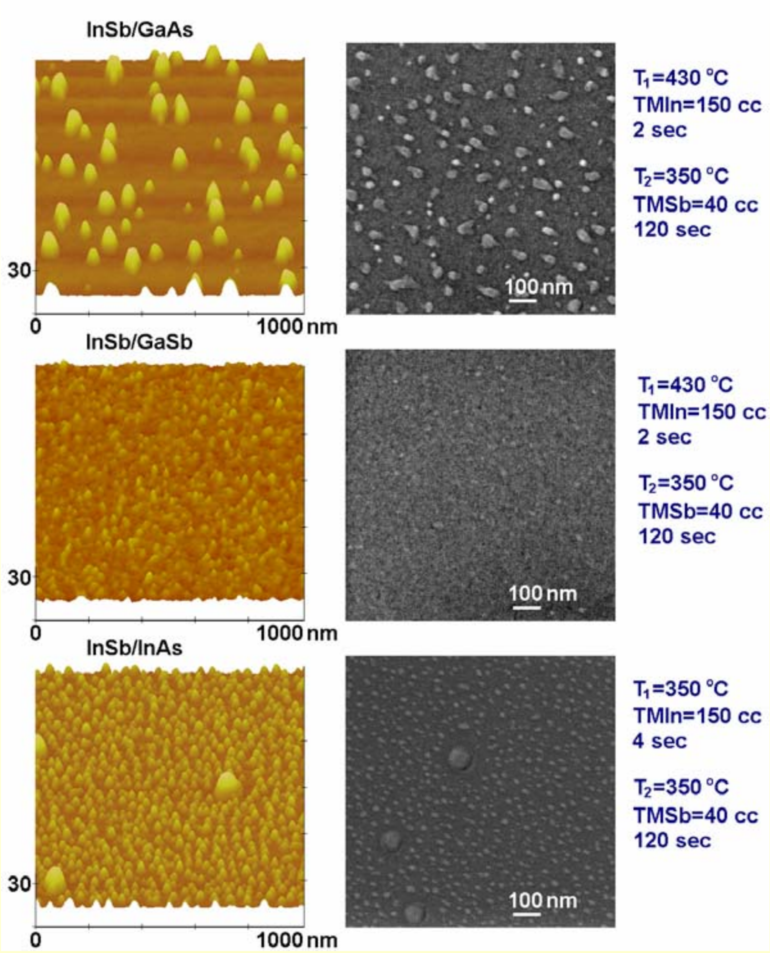
Second stage of the growth:

reaction of these droplets with one or more group V elements in the gas phase

(DHE)

Interest in the last years
M. Gherasimova *et al.*
APL **85** 2346 (2004)

InSb dots on different substrates



InSb/GaAs

Density: $1x10^{10}$ cm^{-2}

Size distribution: 15-40nm

Q factor: ~0.35

InSb/GaSb

Density: $4x10^{10}$ cm^{-2}

Size distribution: 15-50nm

Q factor: ~0.1

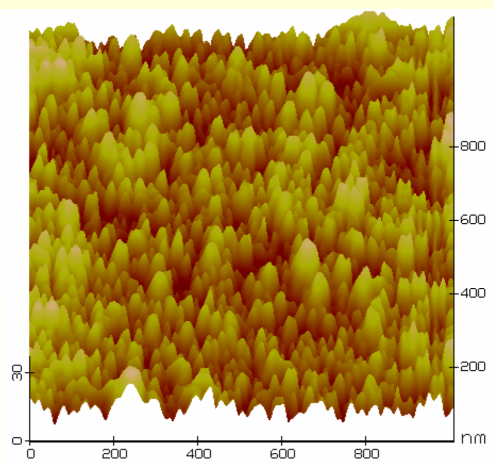
InSb/InAs

Density: $8x10^{10}$ cm^{-2}

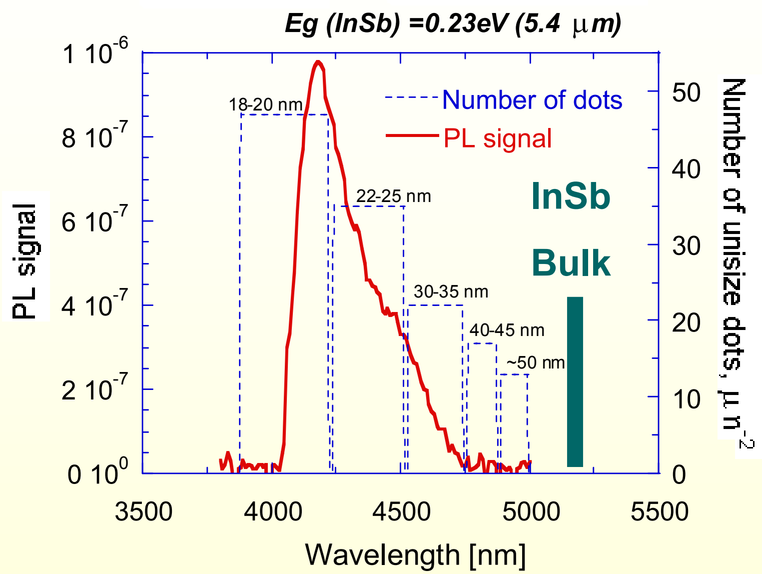
Size distribution: 15-25nm

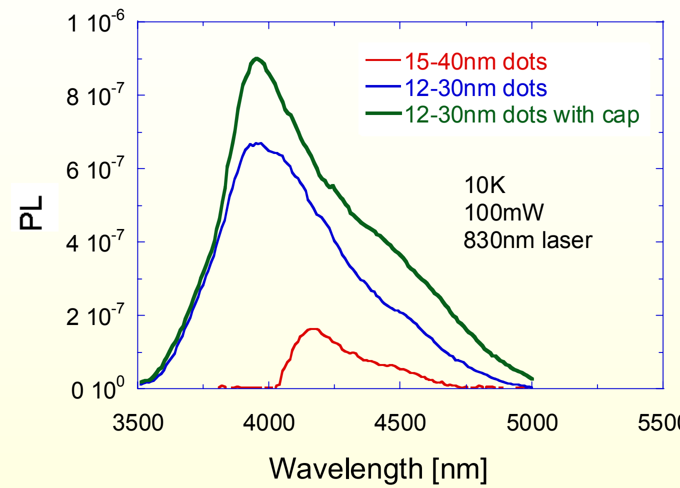
Q factor: ~0.4

Growing on SOG



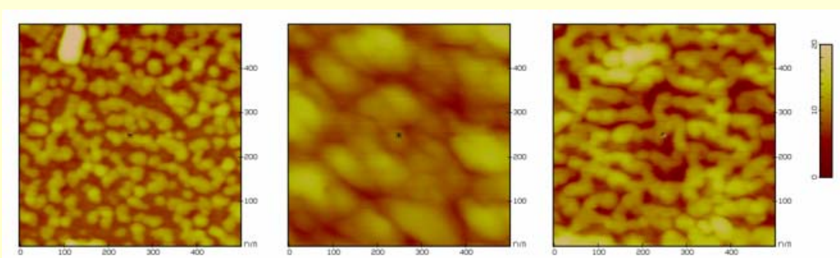
PL signal of InSb nanodots on GaAs



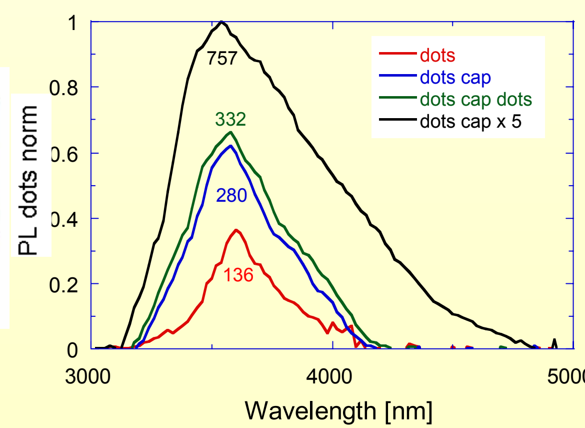


Size and density

Blue shift

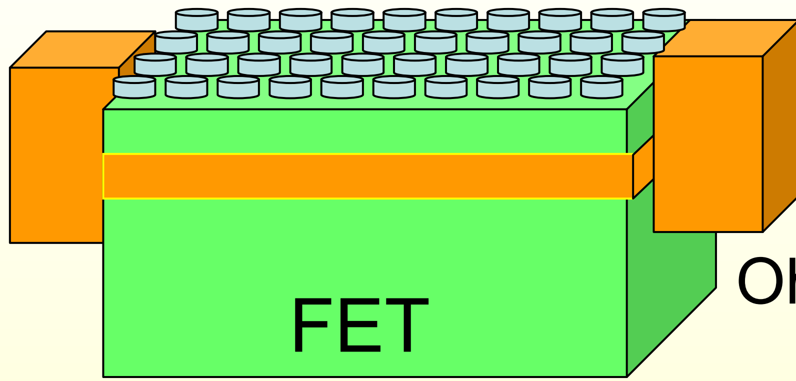


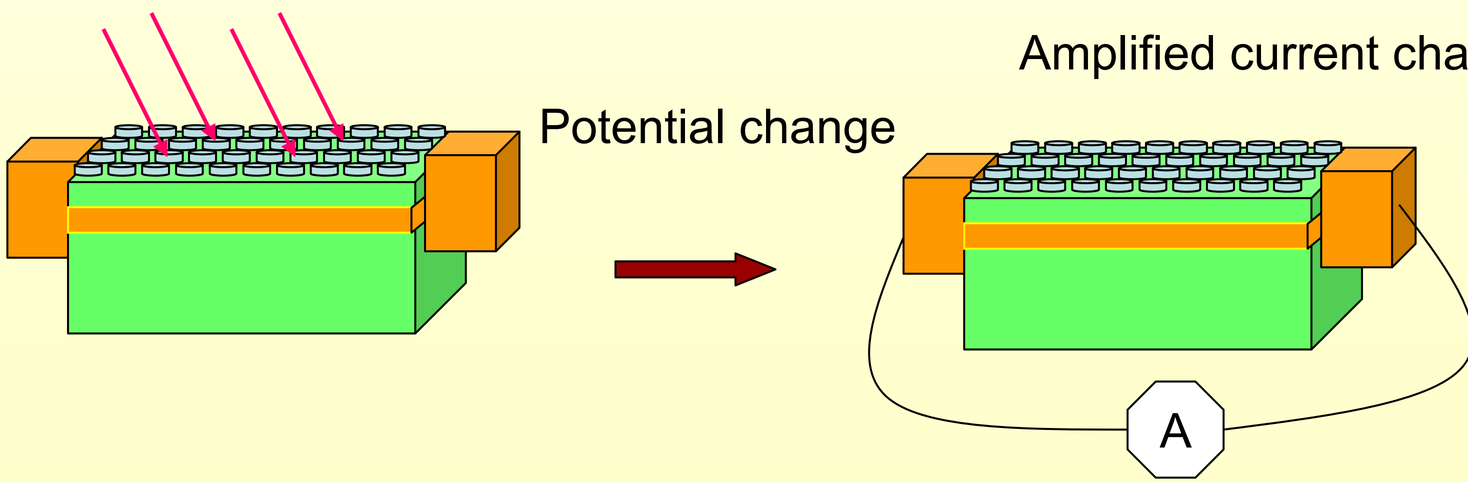
dots Dots and cap Dots+cap X5



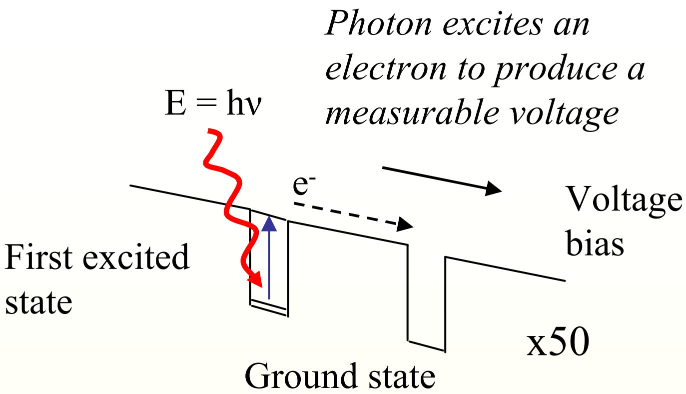
Main idea- Well or dots as a gate

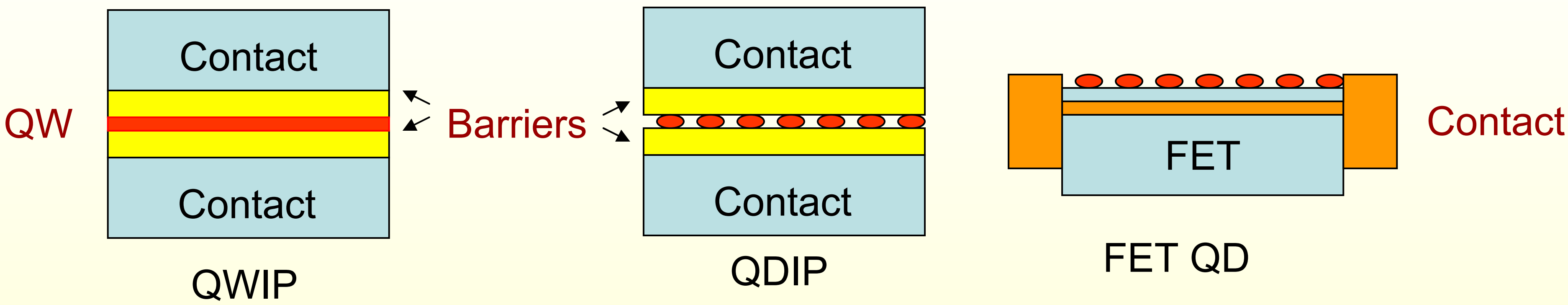
FET transistor with Sb based nanodots acting as a gate





QWIP QDIP and MESFET QD





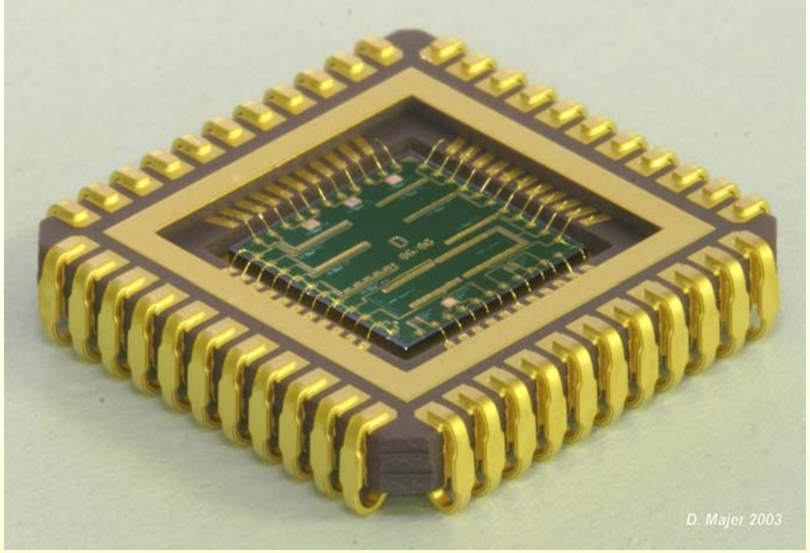
QWIP - Mature working technology working at 70K, needs grating. Everything under control.

QDIP - Theoretically could work at higher temperatures and absorb normal light. Currently no seen advantages over QWIP.

FET QD – Taking all the advantages of the QDIP with improved signal to noise ratio and wider material options.

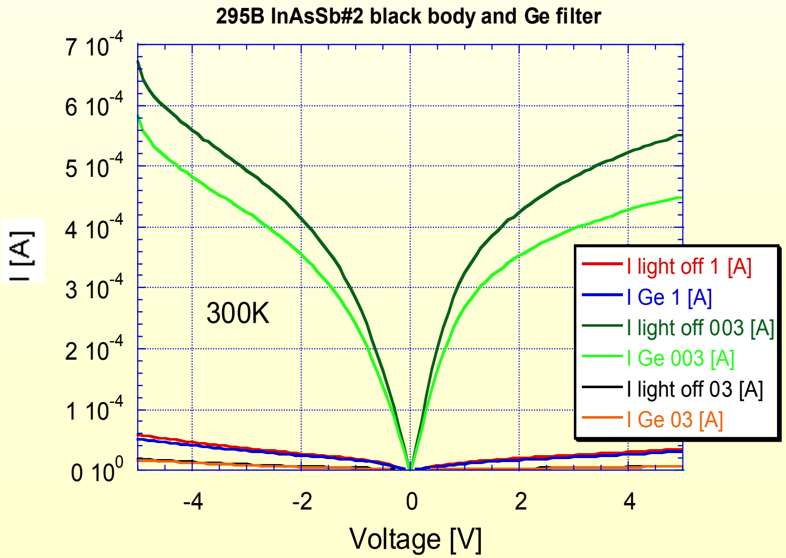
Single photon detector at 77K – A. J. Shields et al., APL **76** 3673 (2000)

Transistor response to a thin layer of InAsSb (Chiaro, Ron aaman)



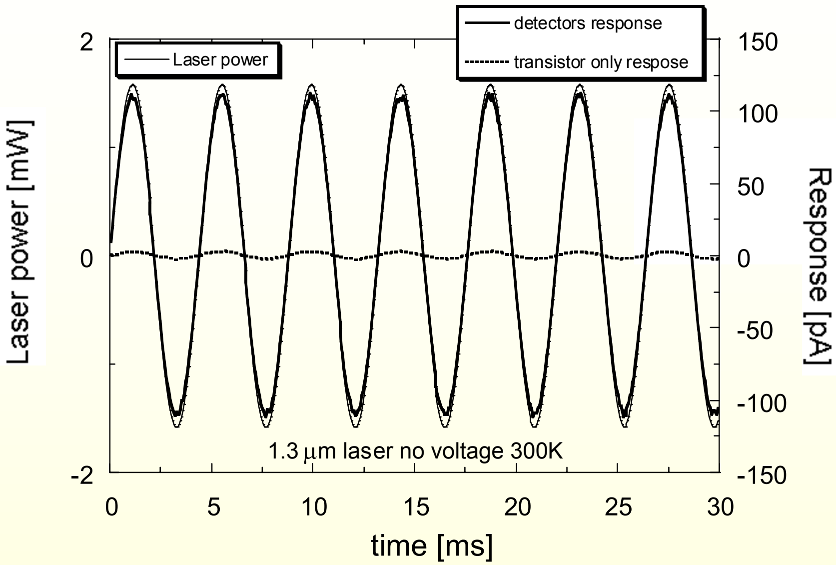
The detector on a test chip fabricated in Chiaro

Accepted for publication in IEEE sensors journal



Room temperature response

Amplified response



Room temperature zero voltage AC response of the FET with 10nm InAsSb absorber deposited on the gate area .A 1.3 µm laser modulated by a chopper

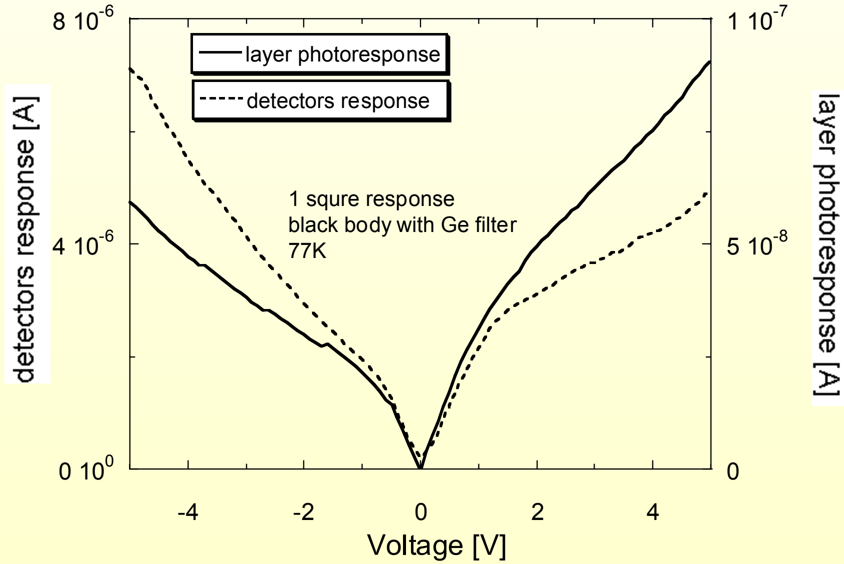
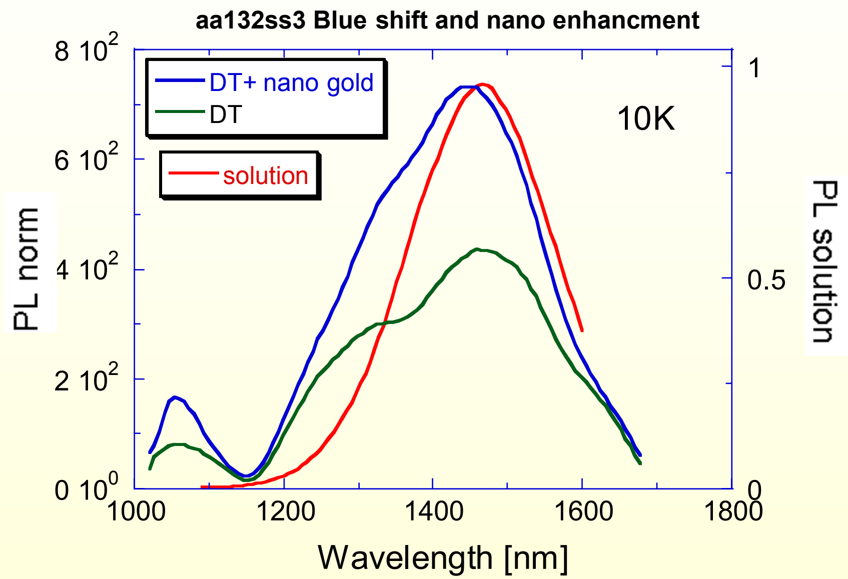


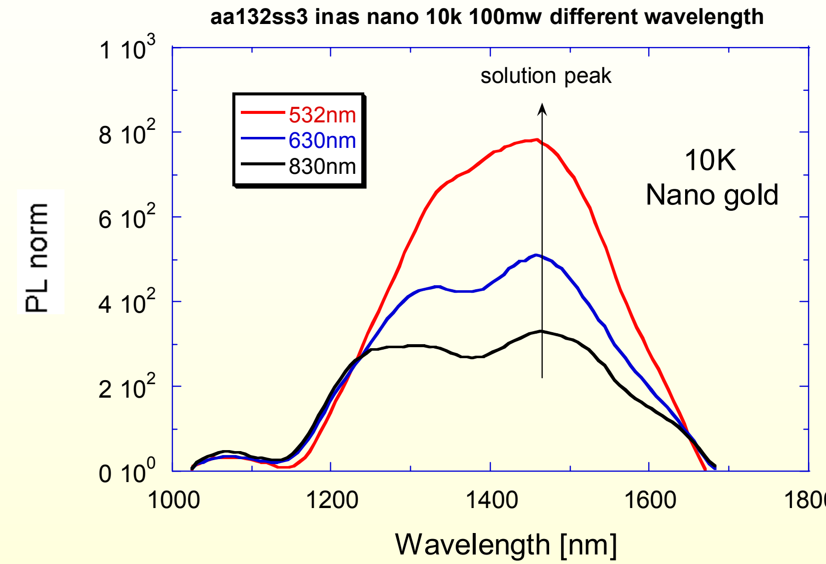
Photo response of the thin InAsSb layer compared with the full detector response, When illuminated with a filtered 1000C blackbody radiation presenting a gain of 100.

Nano gold local field enhancement

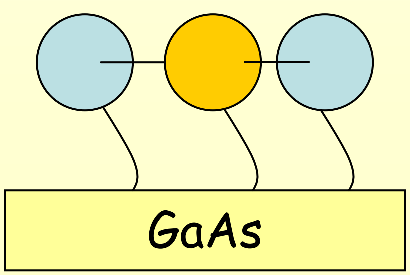
With and WO the nanogold



Local field enhancement



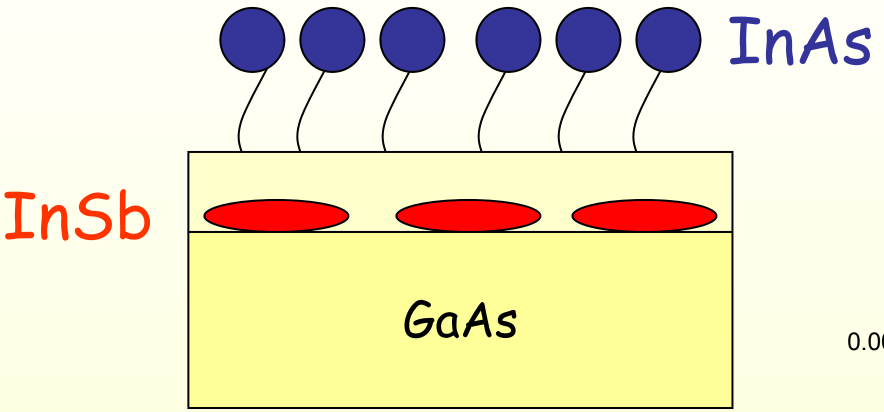
Building new molecules combined with metal nano particles and semiconductor nano

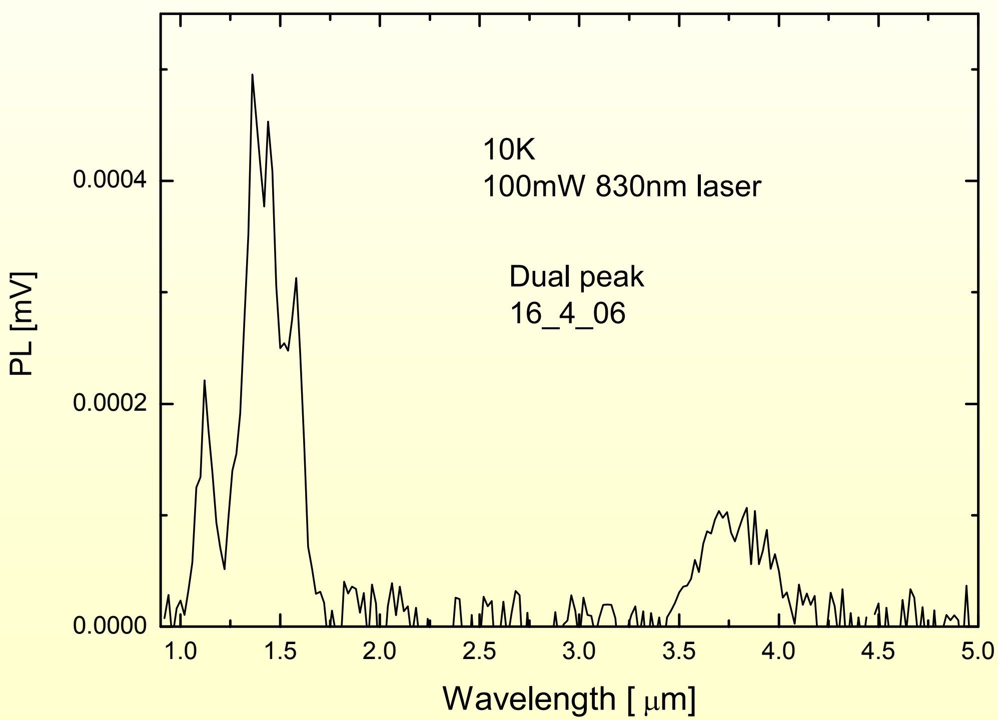


Future work

Building artificial molecules with local field enhancement

Combination of the two





PL signal from the two nano structures

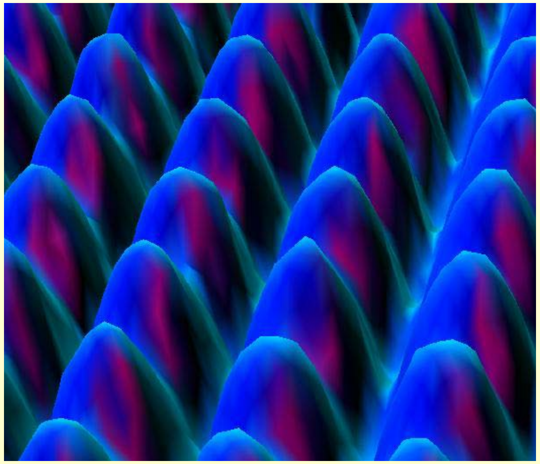
Two different worlds?

Mesoscopic and nano physics Bulk

Most works use one option only:

- Semiconductor bulk properties
- Quantum ideal calculations

nickel



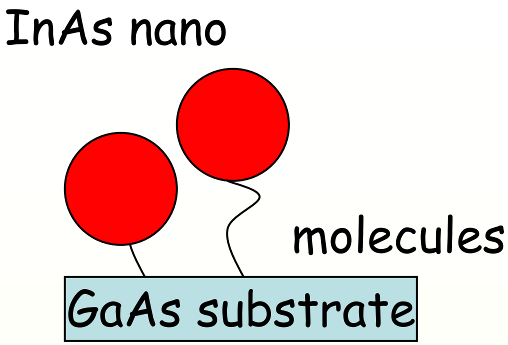
3 Angstroms = 0.3 nm

In the real life they all coupled to the bulk environment

Very complex relations between our robust world and the nano world

The environment effects on quantum properties

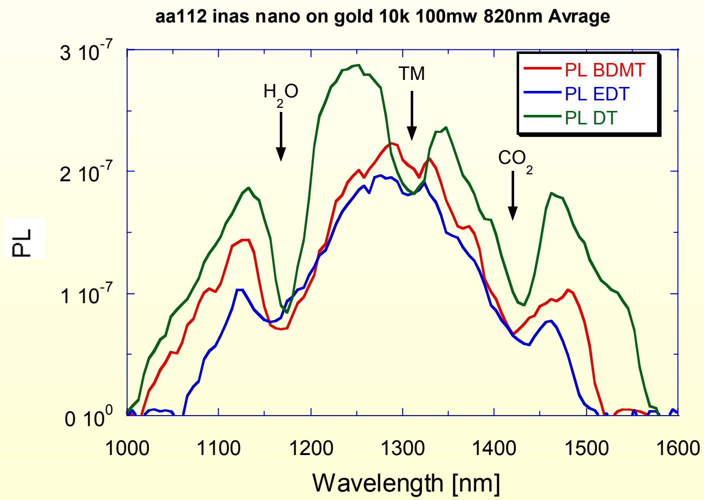
- Strain
- Doping
- Bend alignment
- Discreet levels coupled to continuum
- Life time
- Dissipation
- Conservation laws



Are the dots free?

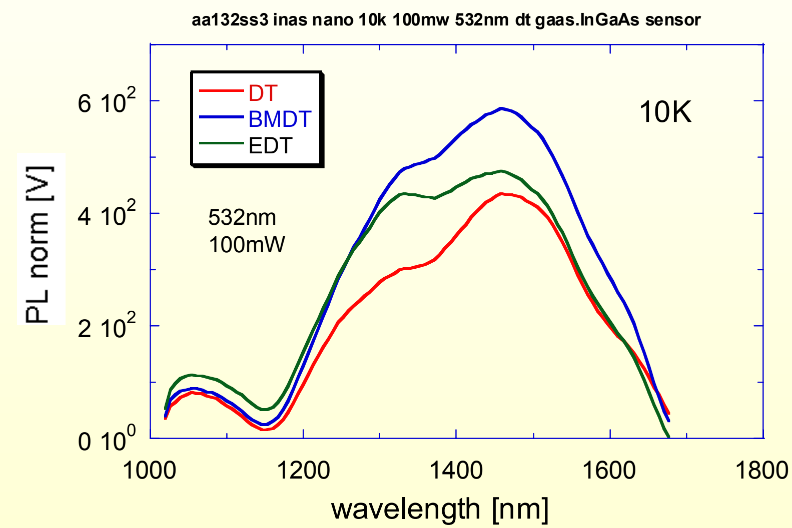
820nm

Distance to the substrate



532nm

Transport from the substrate to the nono crystal



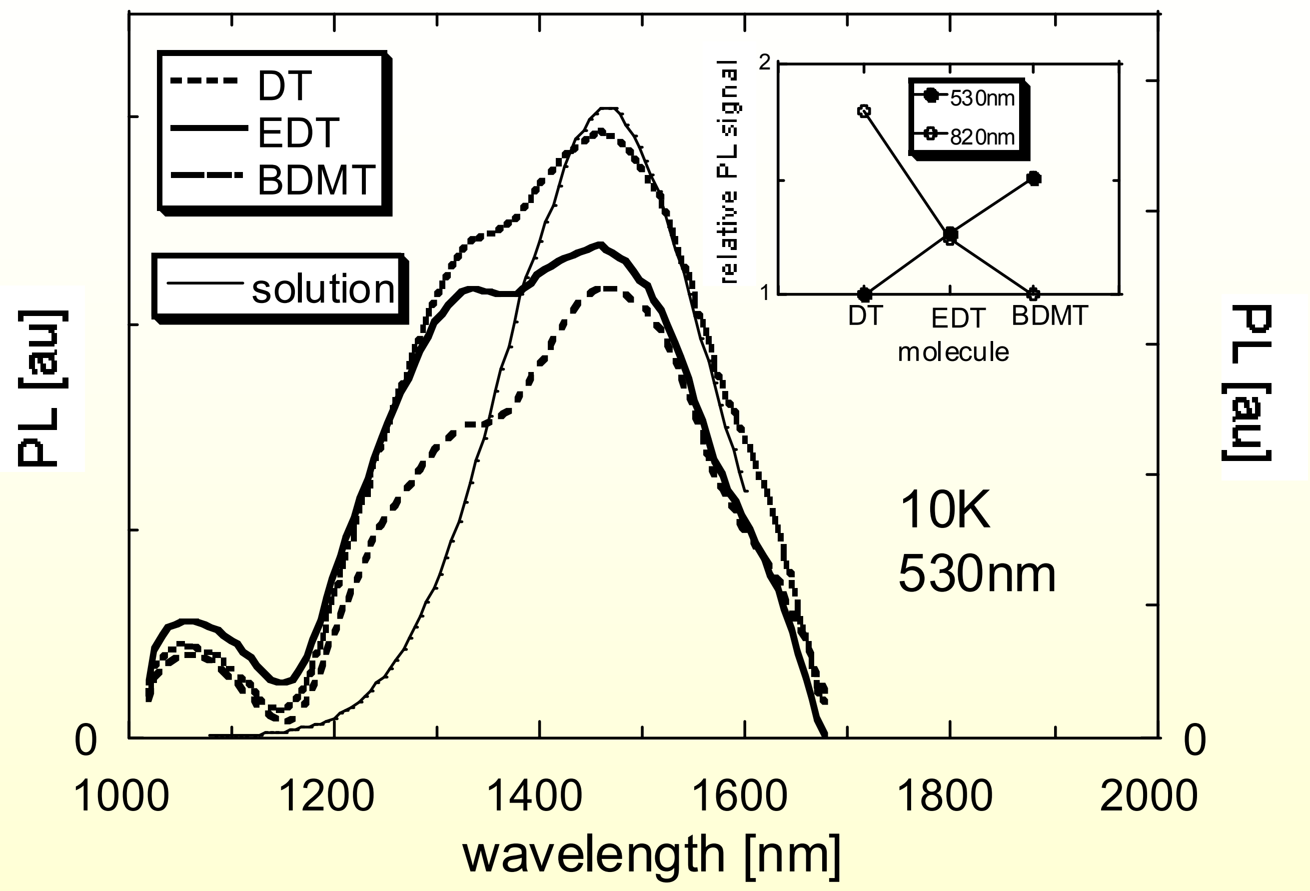
life time , transport properties , coupling

820nm - coupling

520nm- transport

Future work

DNA transport studies



life time , transport properties , coupling

Future work

DNA transport studies

Coupling between the np and the GaAs substrate

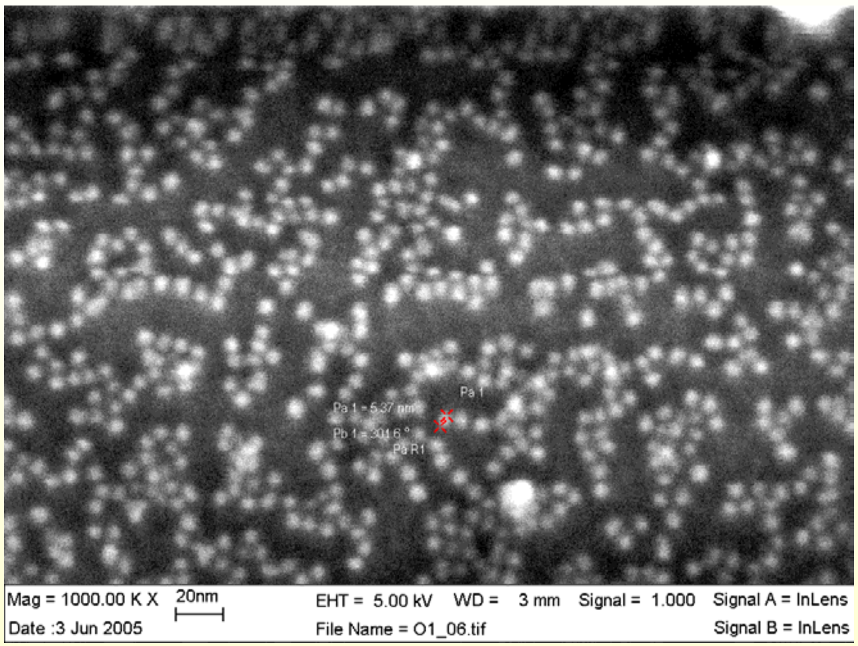
1. There is coupling between the np and the GaAs as is evident by the SPV and PL studies.

2. The coupling varies with the molecules-

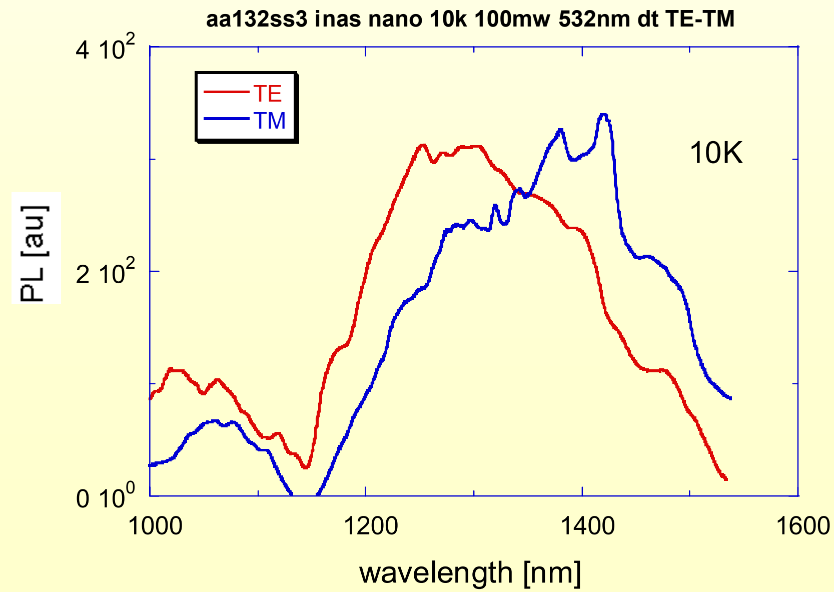
In the order- BDMT>EDT>DT

3. Transport of charges

interactions between nano particles



polarization



Substrate effects

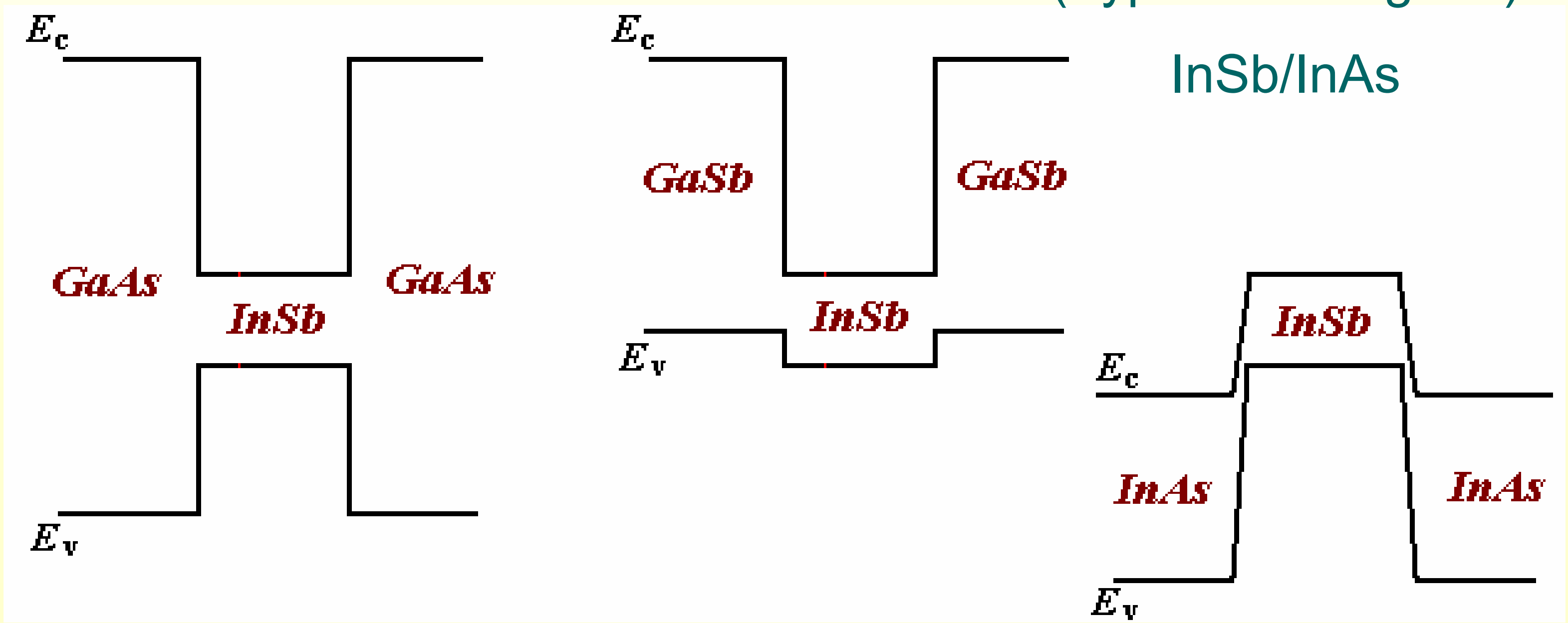
1. **Lattice mismatch (strain)**

2. **Energy band-gap alignment**

Type-I | Type-II Staggered | Type-III

InSb/GaAs | InSb/GaSb | (Type-II Misaligned)

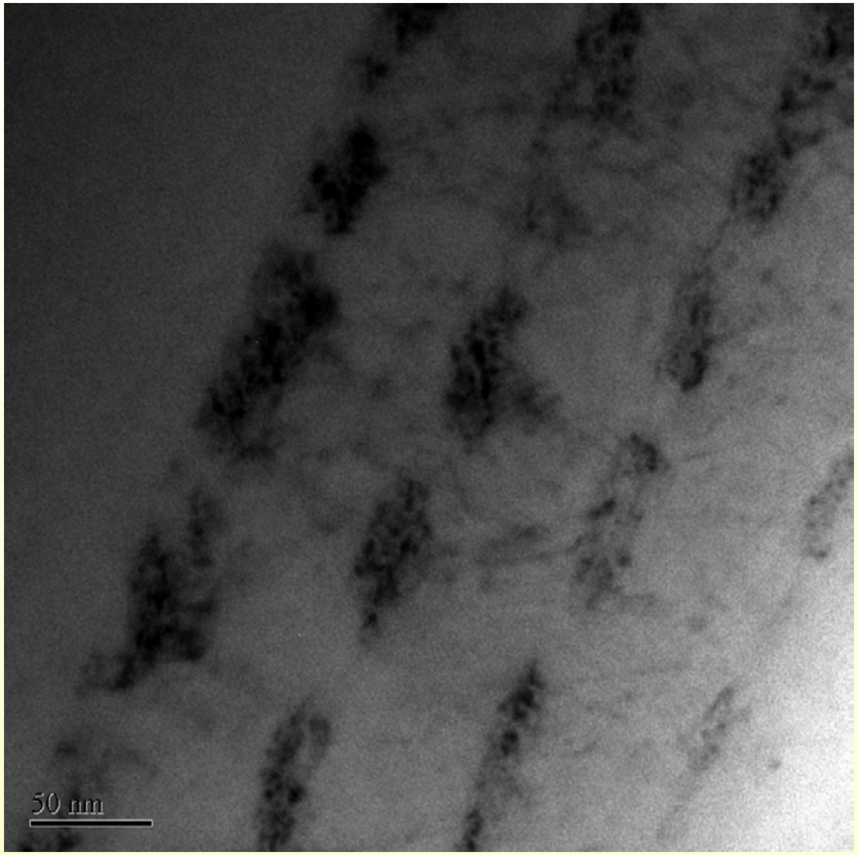
InSb/InAs



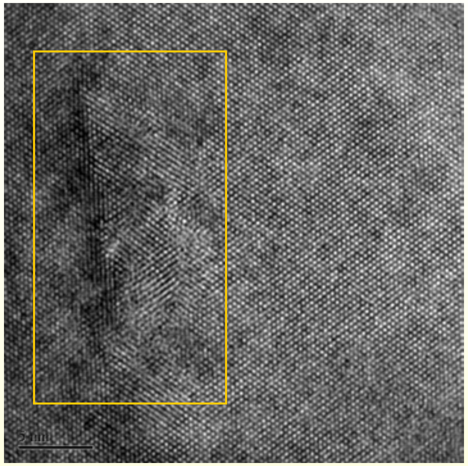
I.T. Sorokina, K.L. Vodopyanov *Solid-State Mid-Infrared Laser Sources*, 89 TAP

Band alignment between bulk and nanodot

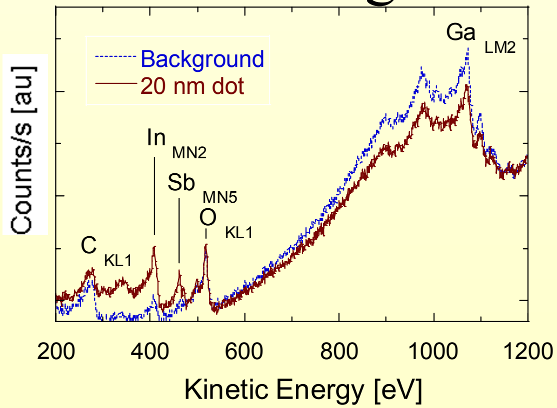
TEM images



Strain ⟶ dipole



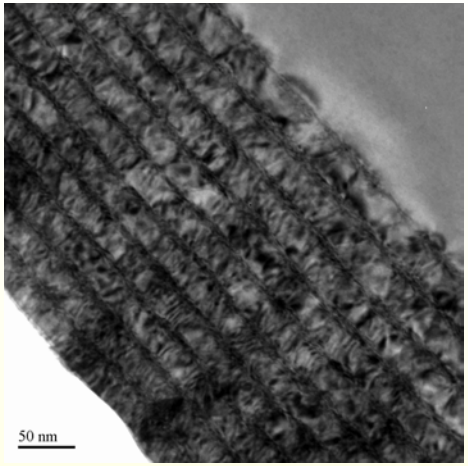
Nano Auger

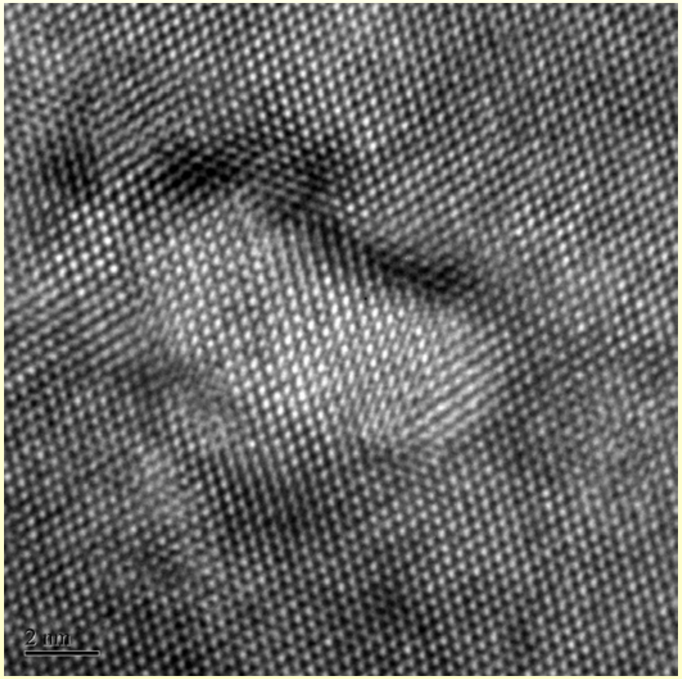


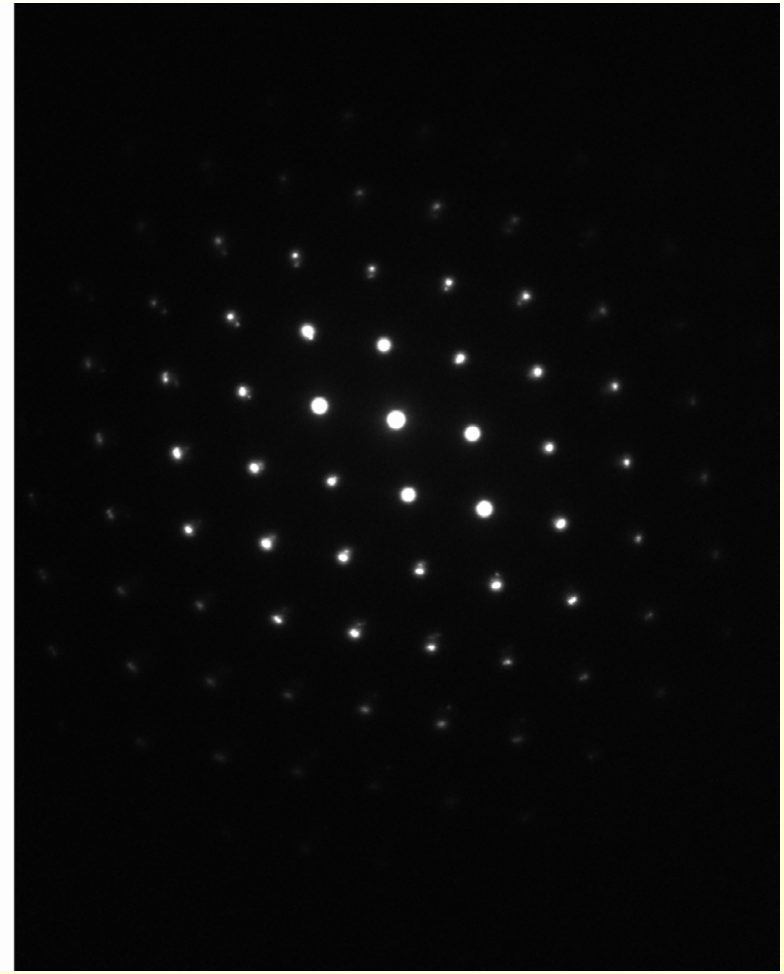
Band diagram?

Stress, doping , Quantum effects

Strain and lattice constant





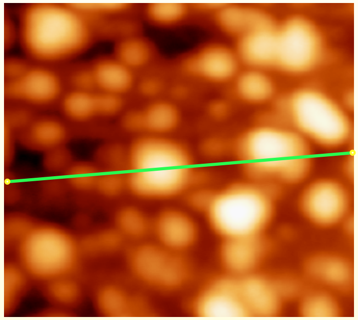


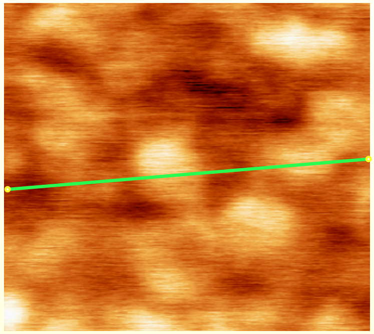
Kelvin-probe measurement

collaboration with **Y. Rosenwaks, A. Schwartzman**
Tel-Aviv University

Kelvin Probe measure the affinity: Fermi level to vacuum level

300K



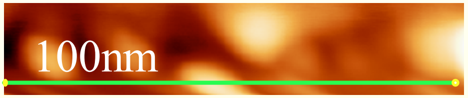


Topography: Zoom, Plane, - 6.5 – 12 nm

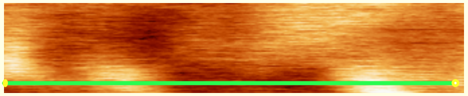
-CPD (Vtip): 204 – 316 mV; Profile: S7

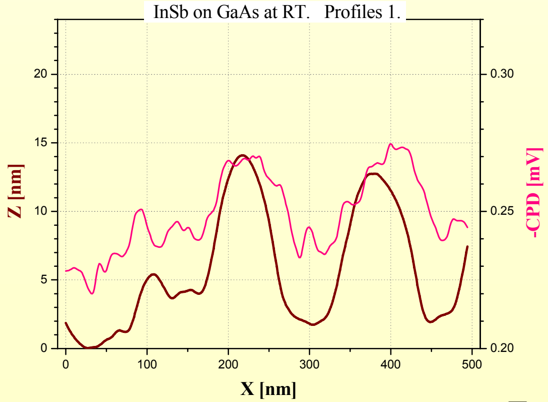
27K

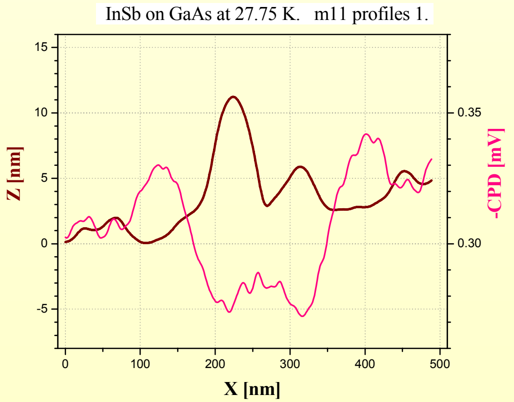
Topography



CPD







InSb dots on GaAs

Summary

Nano is interesting brings new and flexible physics

But In all nano systems the coupling to the bulk environment is crucial:

<u>Two approaches:</u>

- Be aware of it and use it.
- Find a weakly coupled system - that will give you long enough time to do your measurements.

More money is needed

Contributors

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