Enhanced infrared absorption of spatially ordered quantum dot arrays

Wenquan Ma

Laboratory of Nano-Optoelectronics,

Institute of Semiconductors,

Chinese Academy of Sciences

Tuesday, June 20th, 2006 in Sri Lanka

Presentation Outline

(1), Introduction
- (a), advantages of QDIP
- (b), disadvantages of QDIP

(2), Enhanced infrared absorption of spatially ordered QDs
- (a), growth
- (b), absorption measurements

(3), Summary

Advantages of QDIP

1， Allowed normal incidence intersubband transition

2， Longer electron lifetime

background limited performance: $\Phi > n_{th}/\alpha\tau$,

α: absorption coefficient, τ: electron lifetime,

n_{th}: thermal generated carrier density, Φ: photon flux

M.A. Kinch, J. Electronic Materials, **29**, 809 (2000)

M.A. Kinch and A. Yariv, Appl. Phys.Lett. 55, 2093 (1989)

0.75 ns, InGaAs/GaAs QDs,

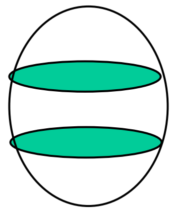
J. Urayama *et al*, Phys. Rev. Lett. **86**, 4930 (2001)

Disadvantages of present QDIP

1, relatively low areal density of QDs (<$10^{11}cm^{-2}$)

e.g. S. Charkrabarti *et al,* J. Phys. D: Appl. Phys. 38, 2135(2005)

2, normal incidence absorption efficiency is very low due to disk-like dot shape

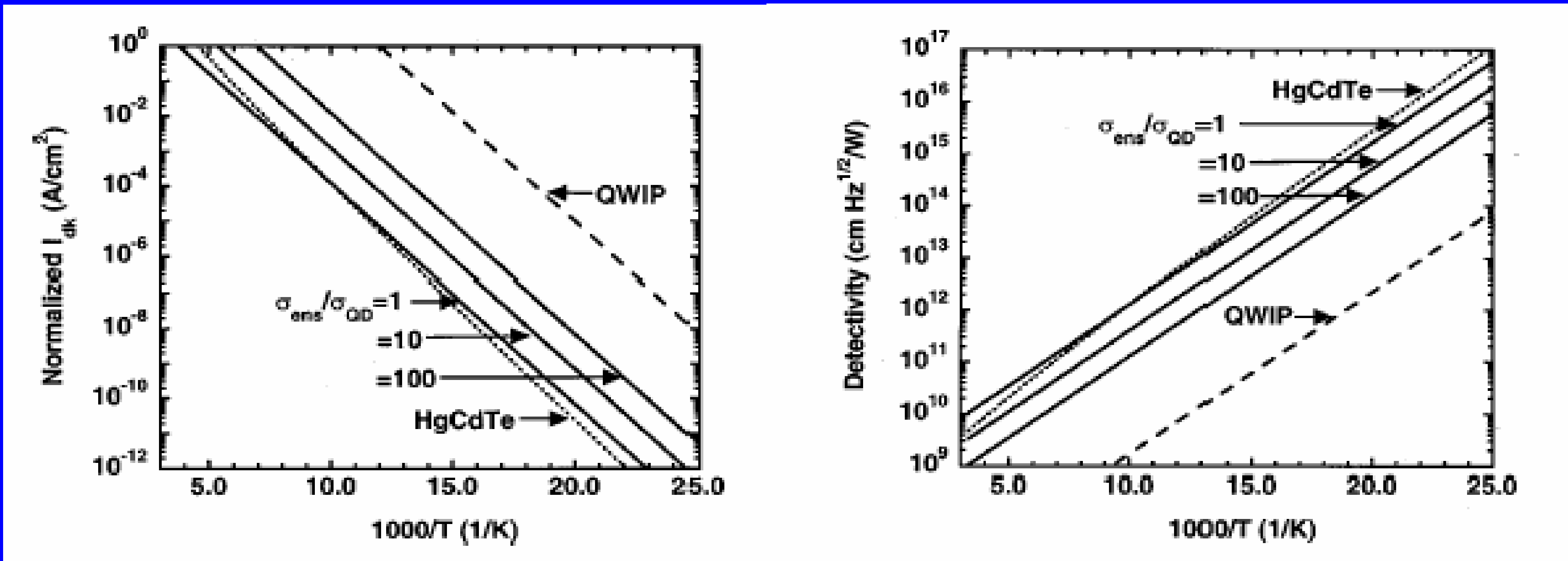


wave function coupled QDs,

e.g. A.M. Adawi *et al*, Appl. Phys. Lett. 82, 3415(2003)

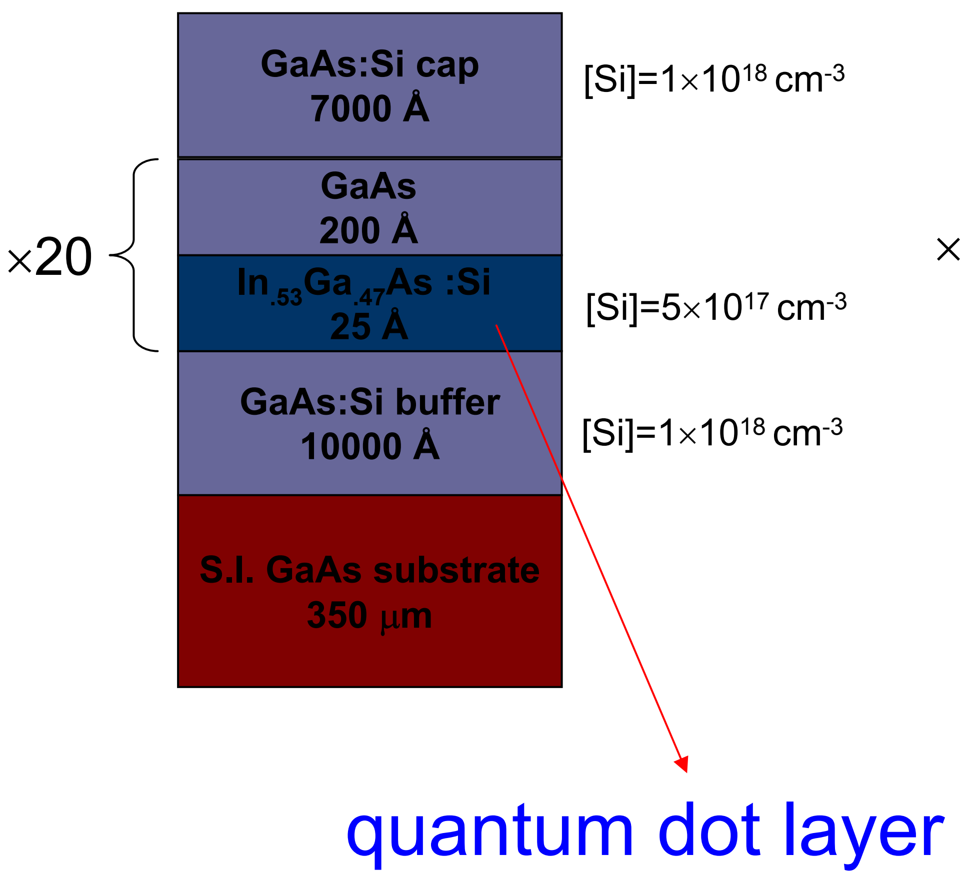
3, large size fluctuation

Theoretical calculation of detectivity, dark current for MCT, QWIP, QDIP

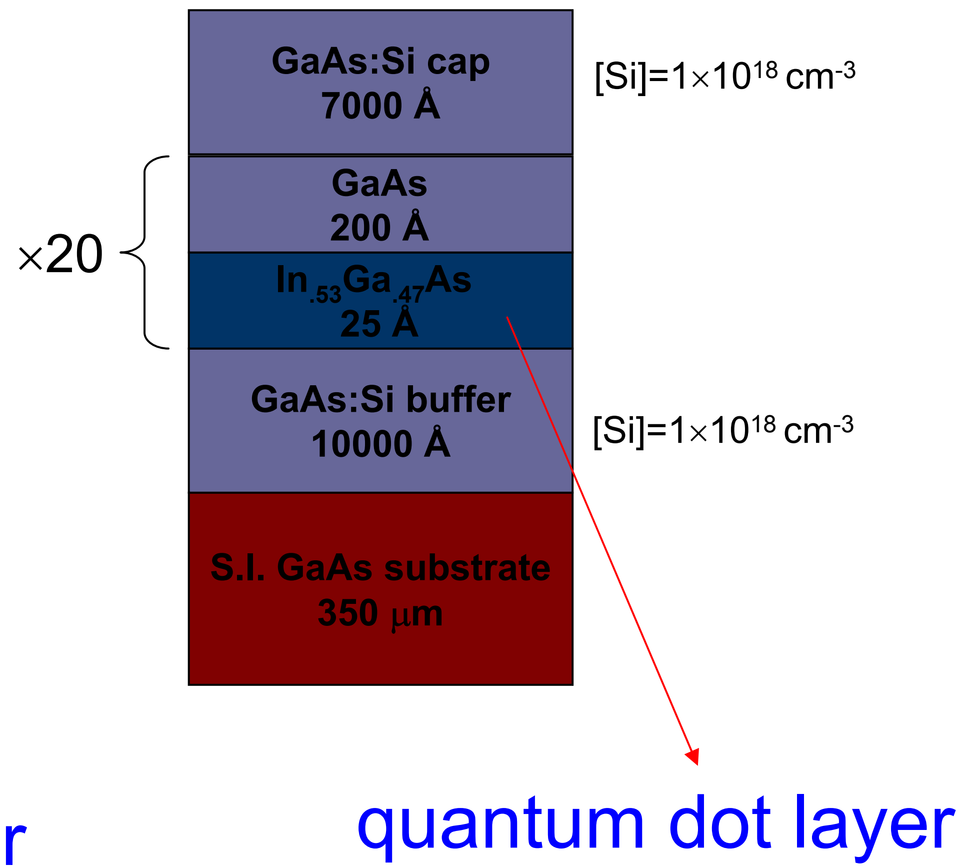


J. Phillips, J. Appl. Phys. 91, 4590 (2002)

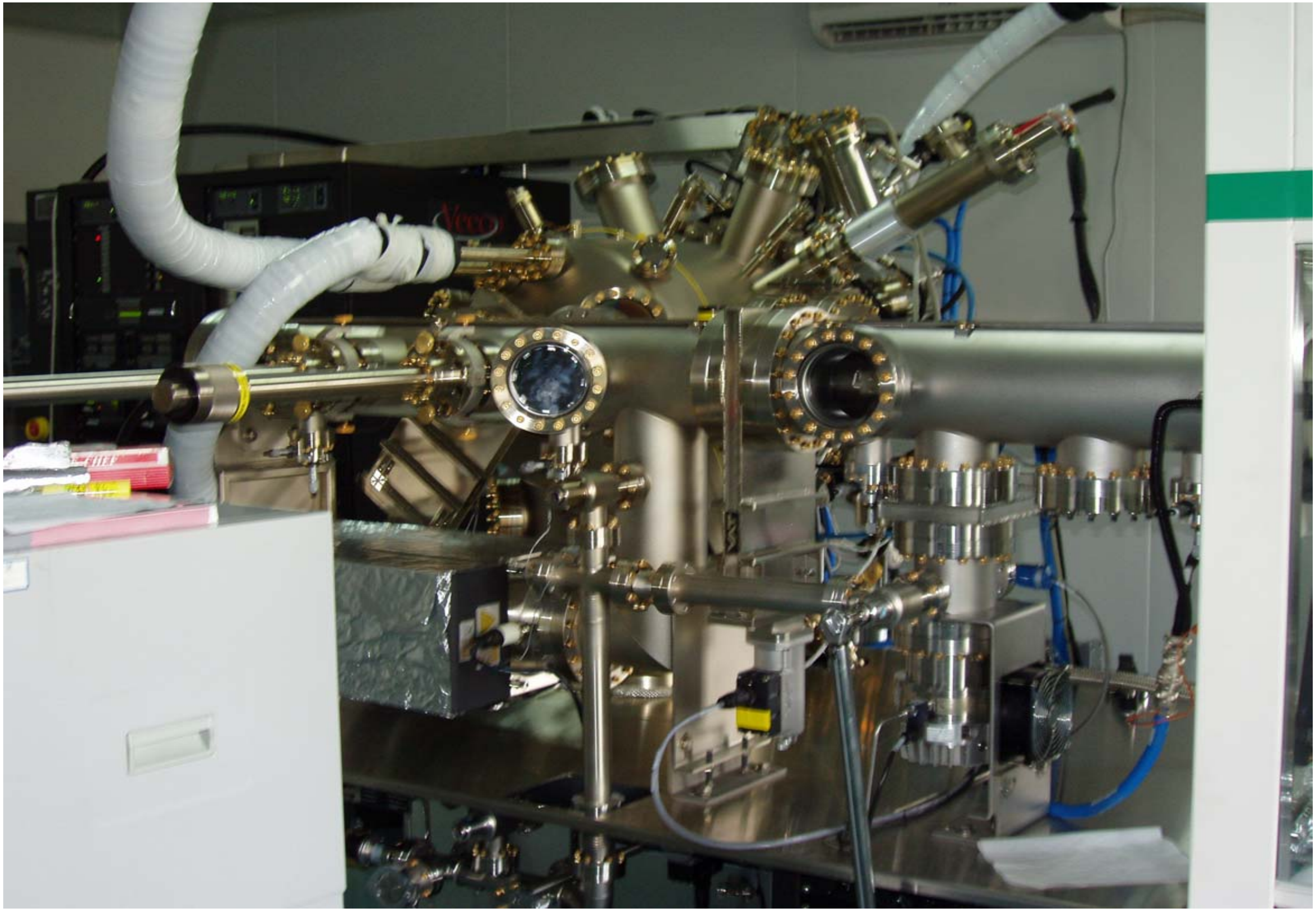
QDIP sample



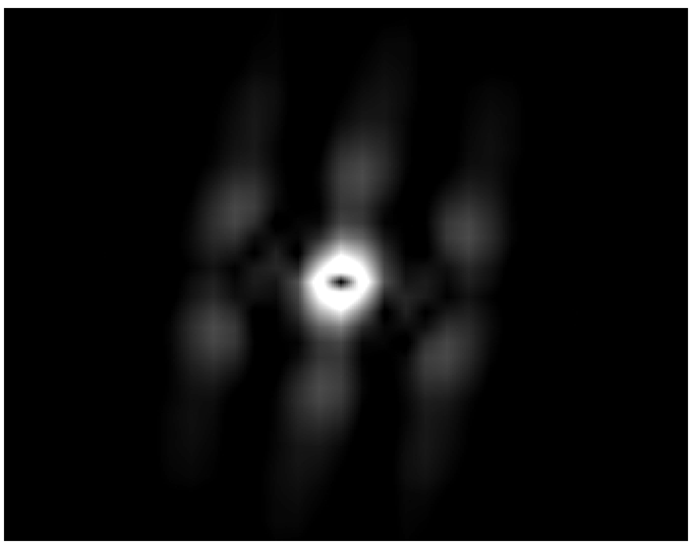
Reference sample

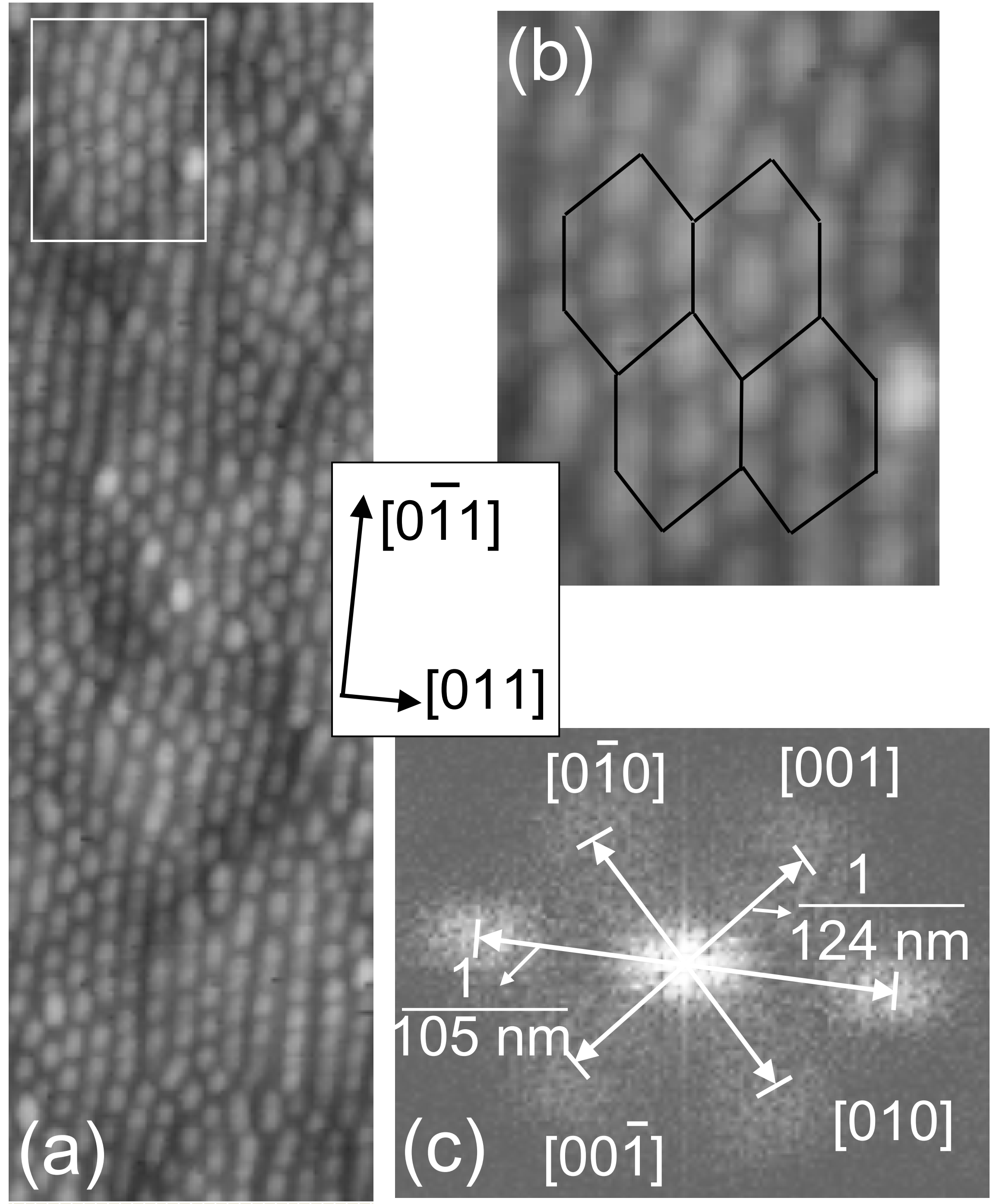


Veeco MBE

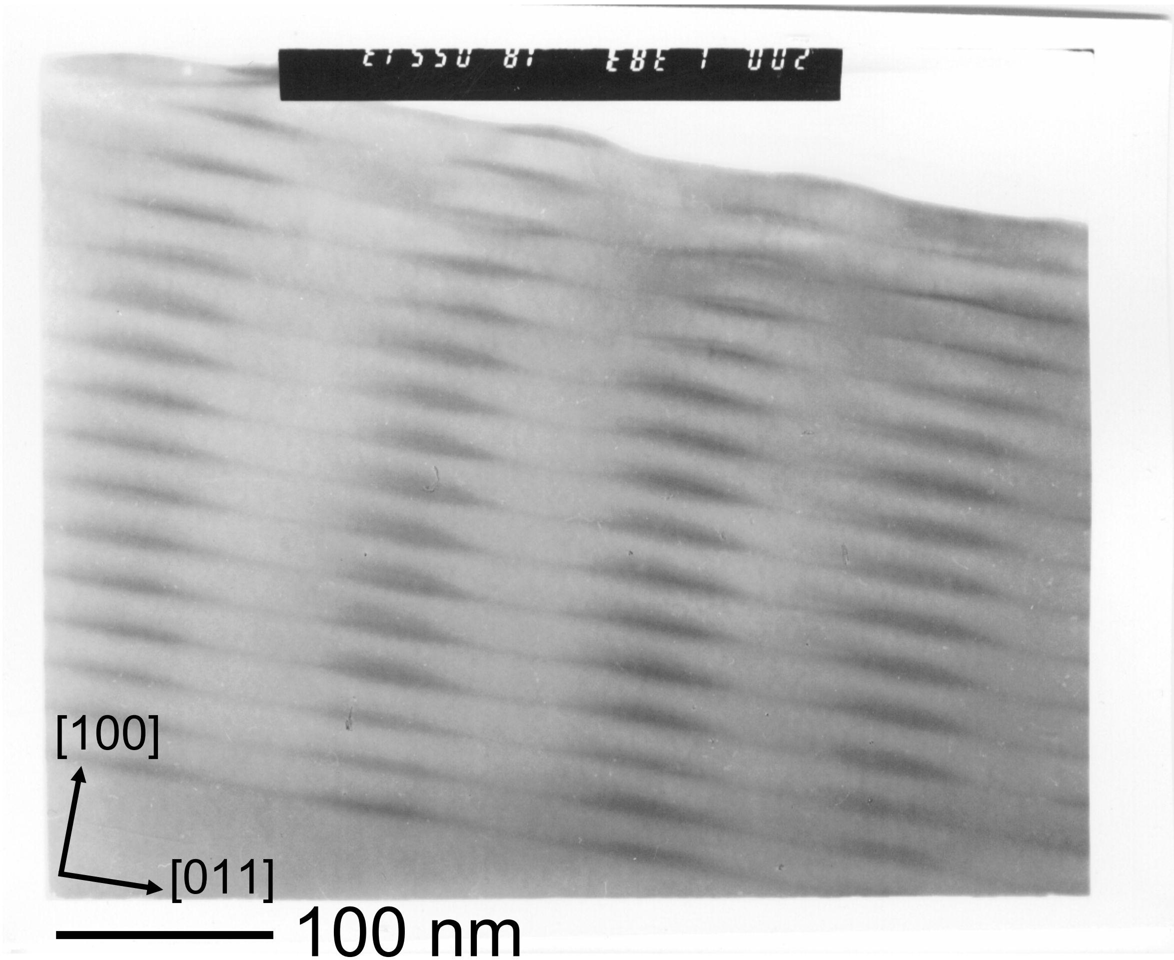


Hexagonally ordered QD arrays

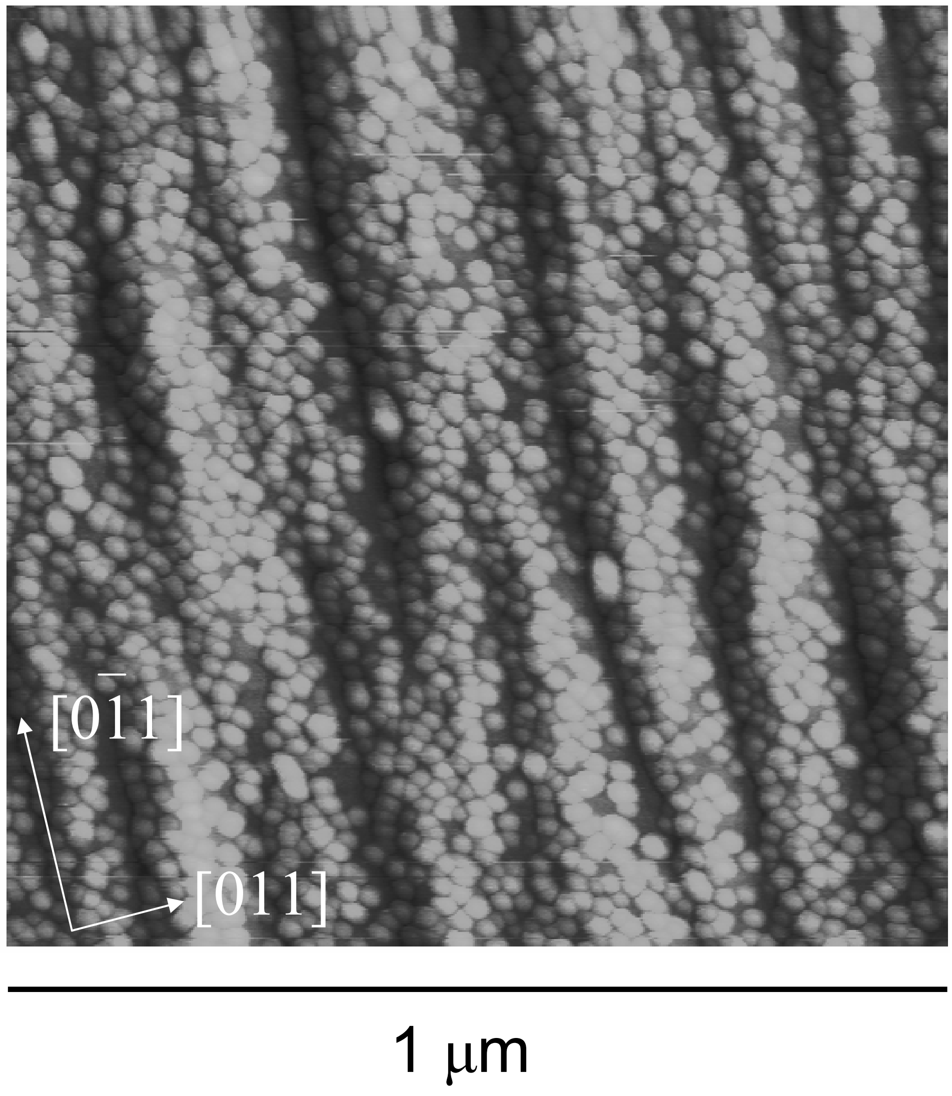




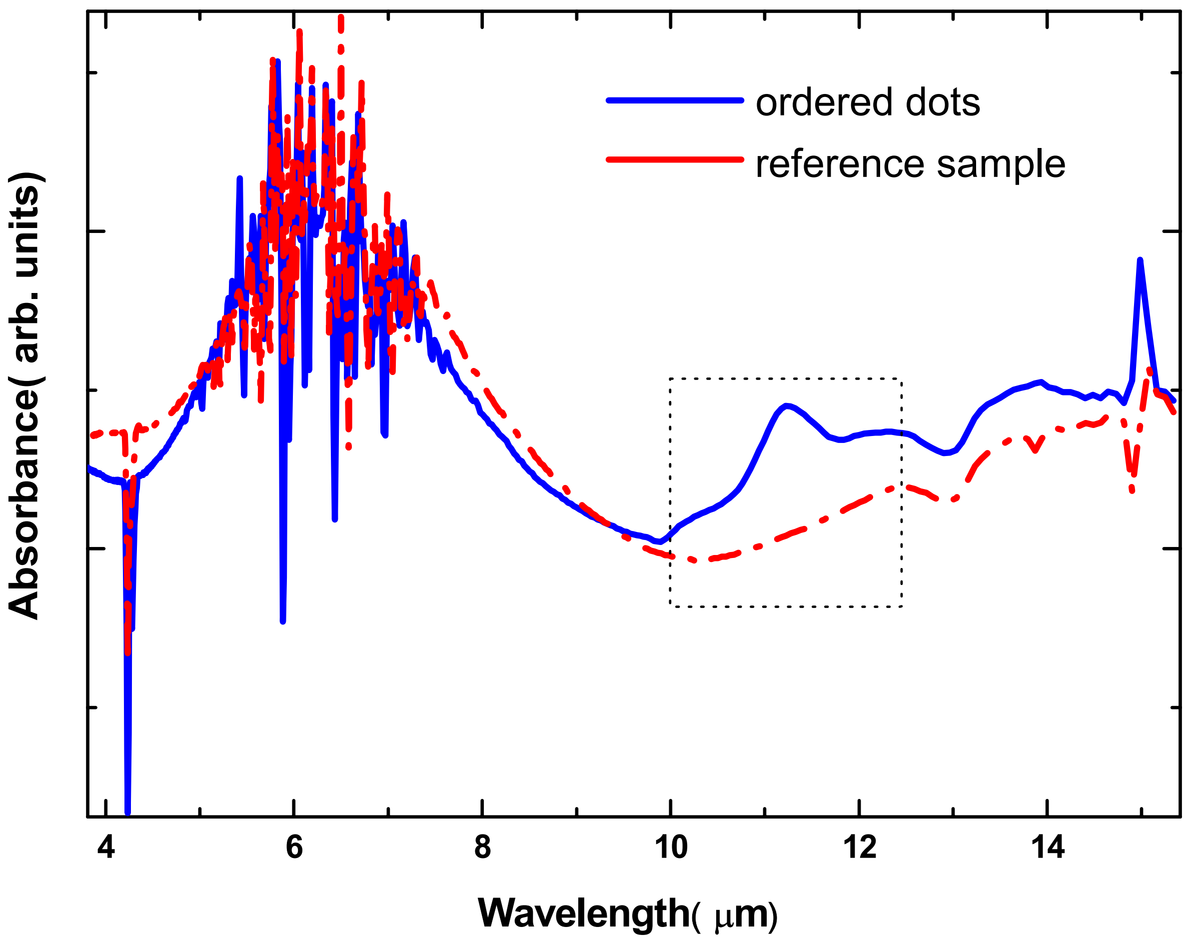
X-sectional TEM image



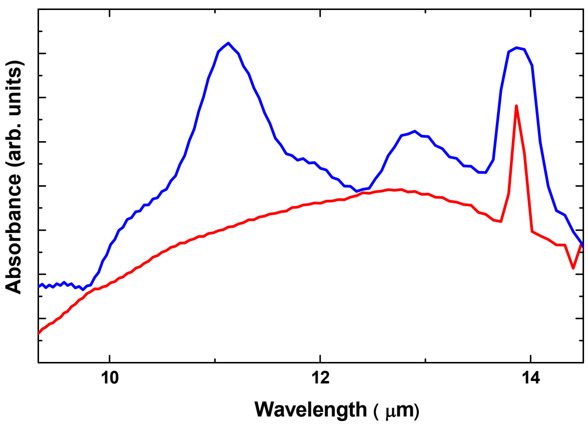
Non-ordered QDs

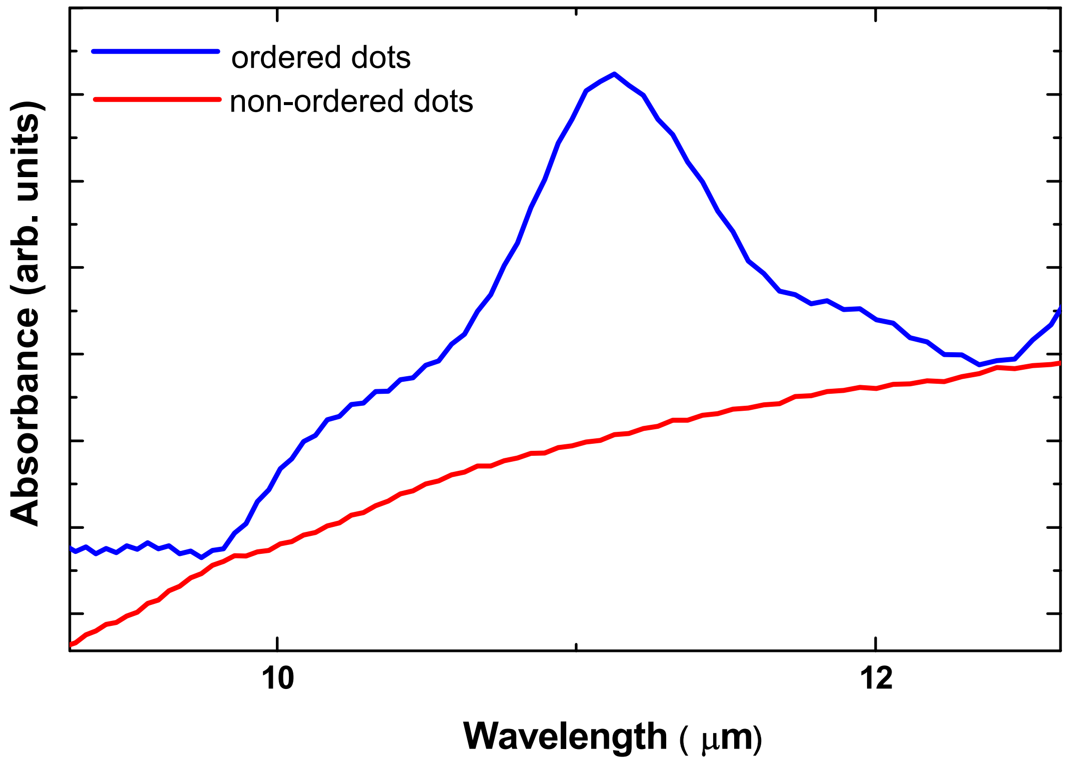


FTIR spectra using air as reference under nornal incidence geometry

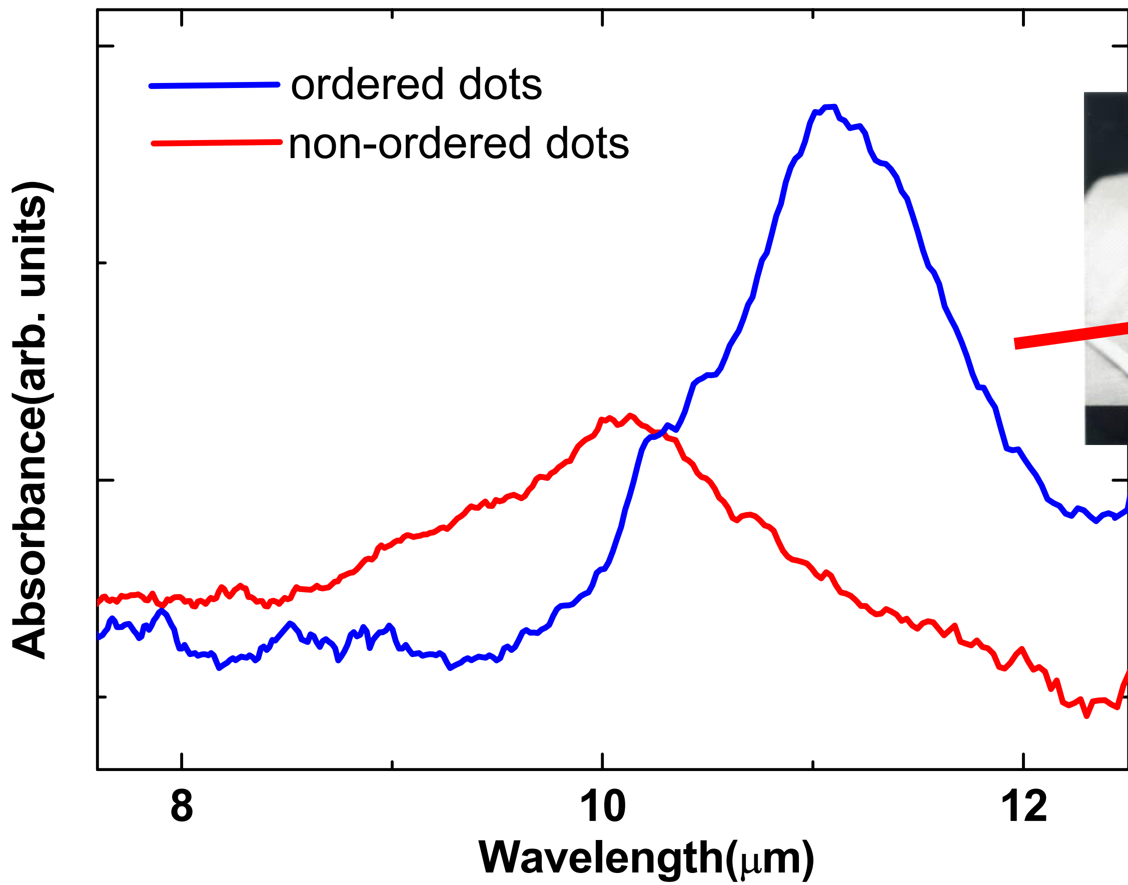


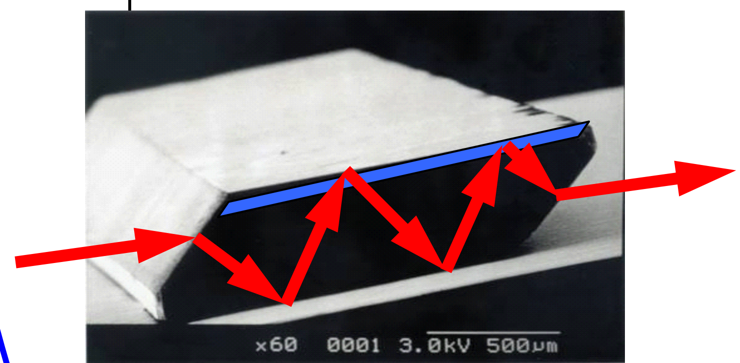
FTIR spectra using undoped sample as reference under nornal incidence geometry



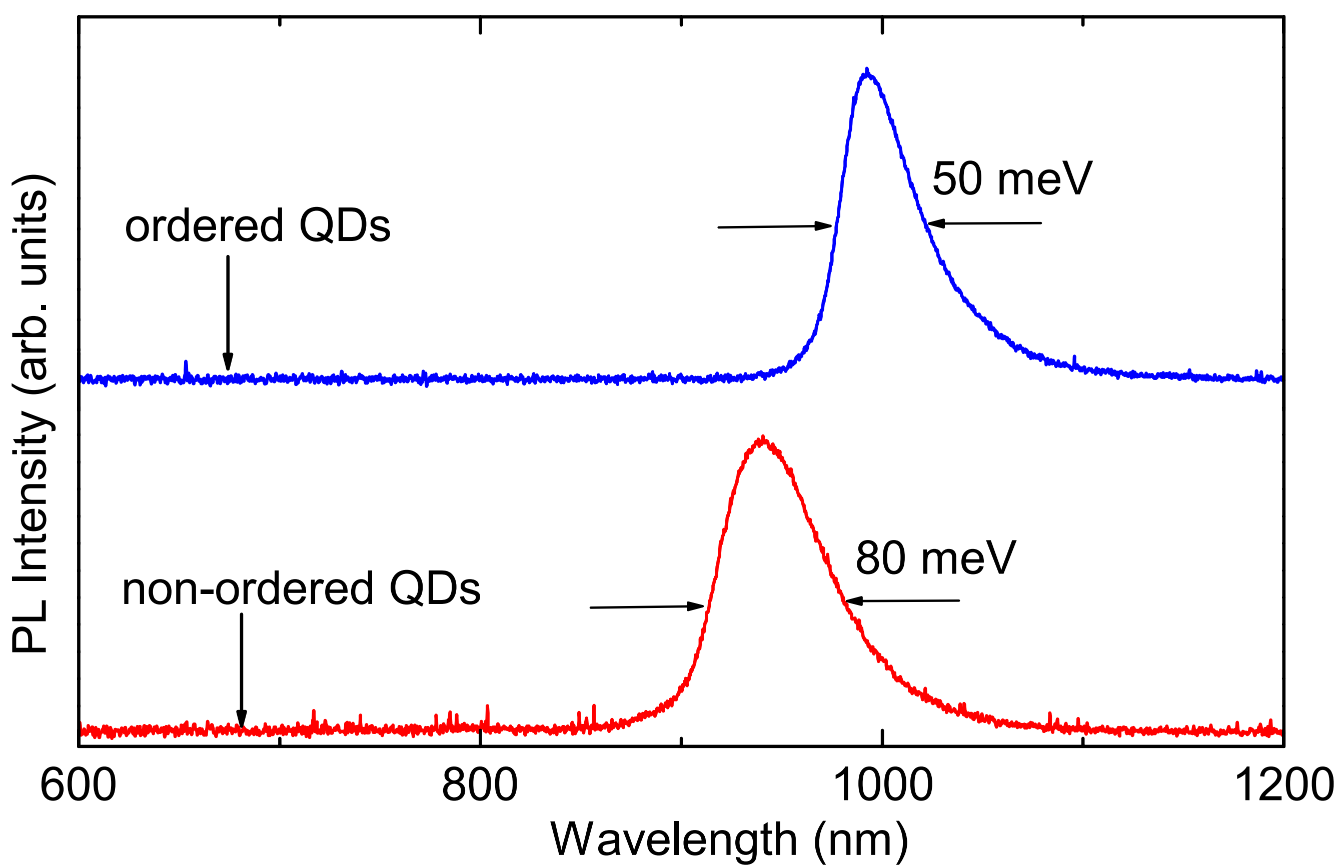


Absorption spectra under waveguide geometry

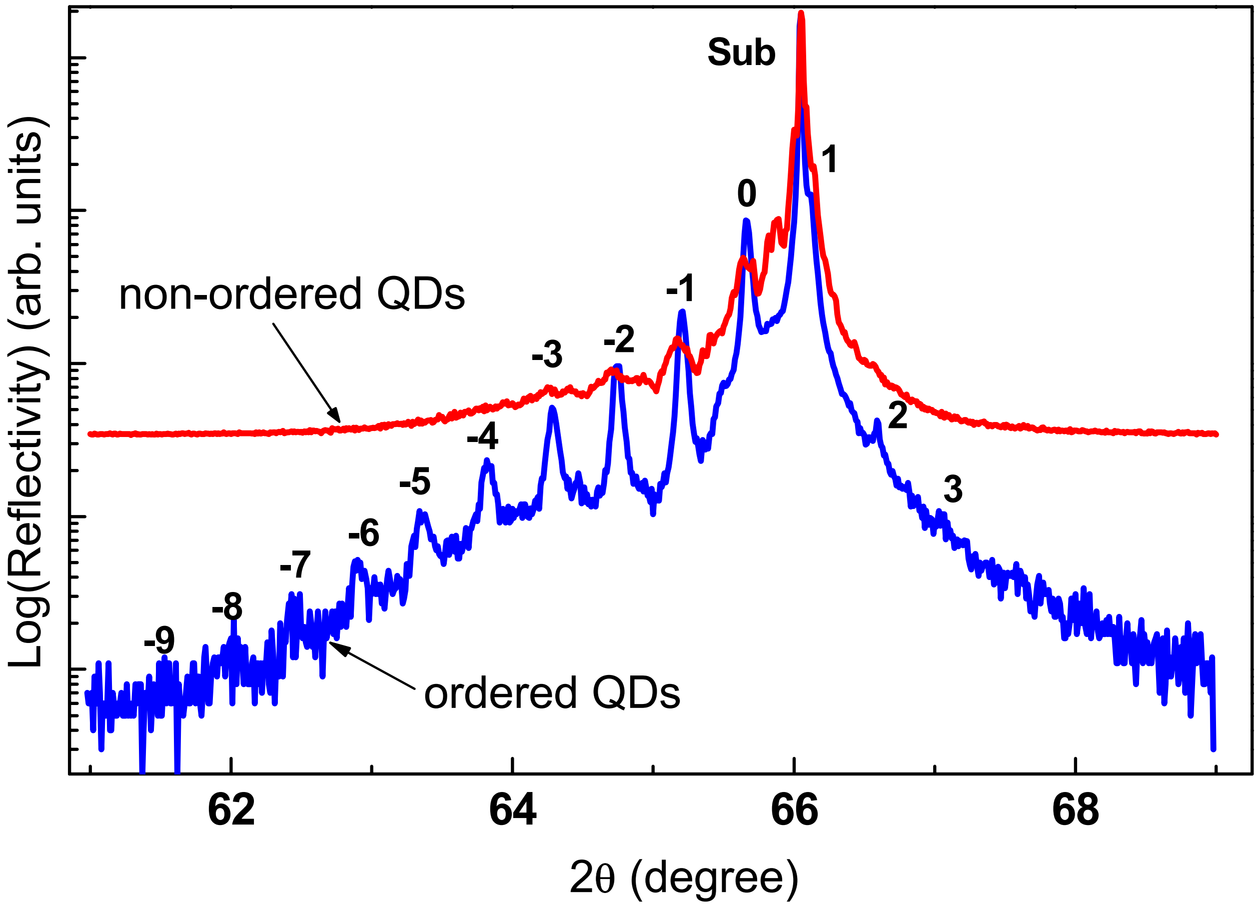




RT PL spectra

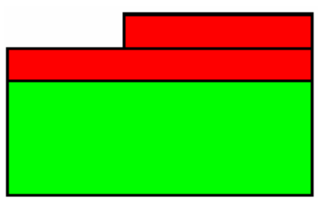


Symmetric (400) reflection of XRD



Growth modes

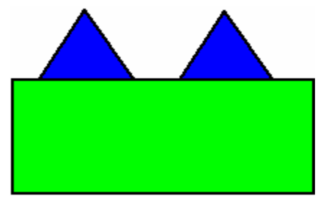
Frank-
van der Merwe



High substrate surface energy

Planar growth

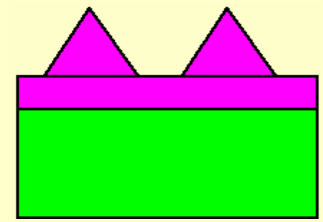
Volmer-
Weber



High interface and epilayer surface energy

Island growth

**Stranski-
Krastanov**

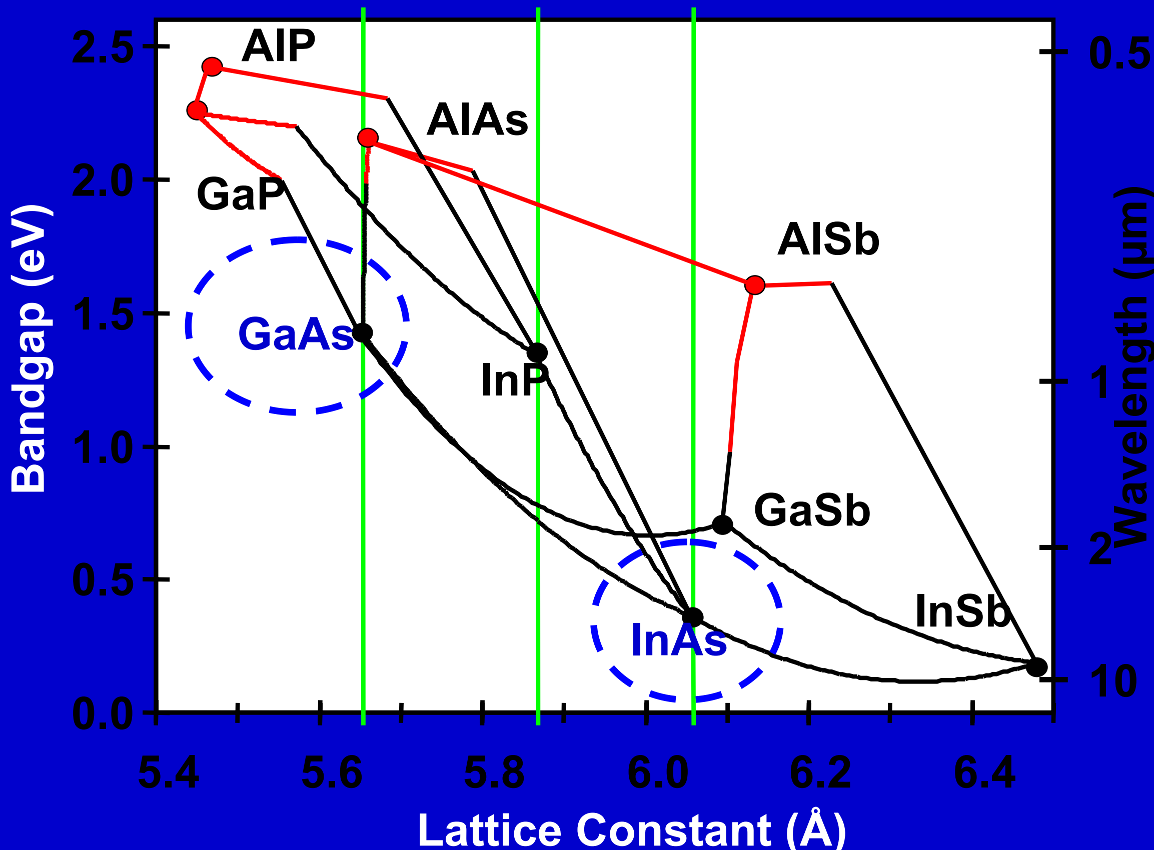


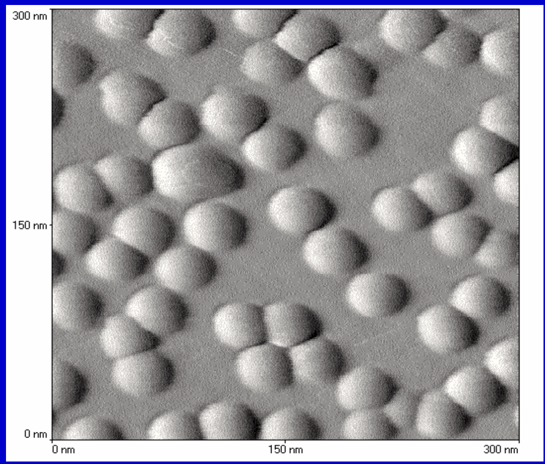
Relaxation of strain by forming islands

Planar and island growth

Growth mode of self-assembled QDs

InGaAs/GaAs QDs





- Best developed QD system
- Everywhere direct
- Lasers to 1.3 μm

Why a hexagonal lateral ordering?

Vertical island-island interaction is attractive while lateral Island-island interaction is repulsive. Therefore, degree of the lateral ordering depends on the complicated tradeoff of the two counteracting elastic interactions.

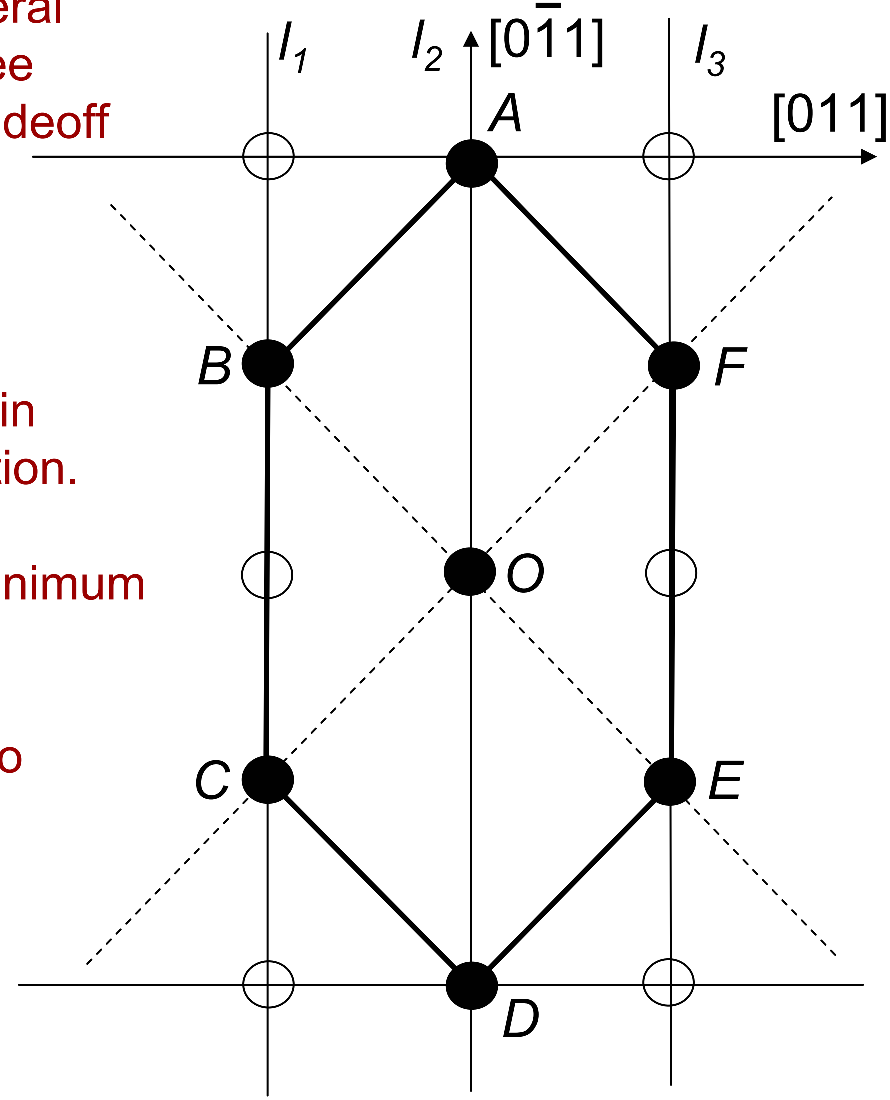
(1), Multilayer growth ⟶ vertical stacking of islands.

(2), anisotropic adatom migration ⟶ anisotropic strain relaxation ⟶ islands lined up along the [0-11] direction.

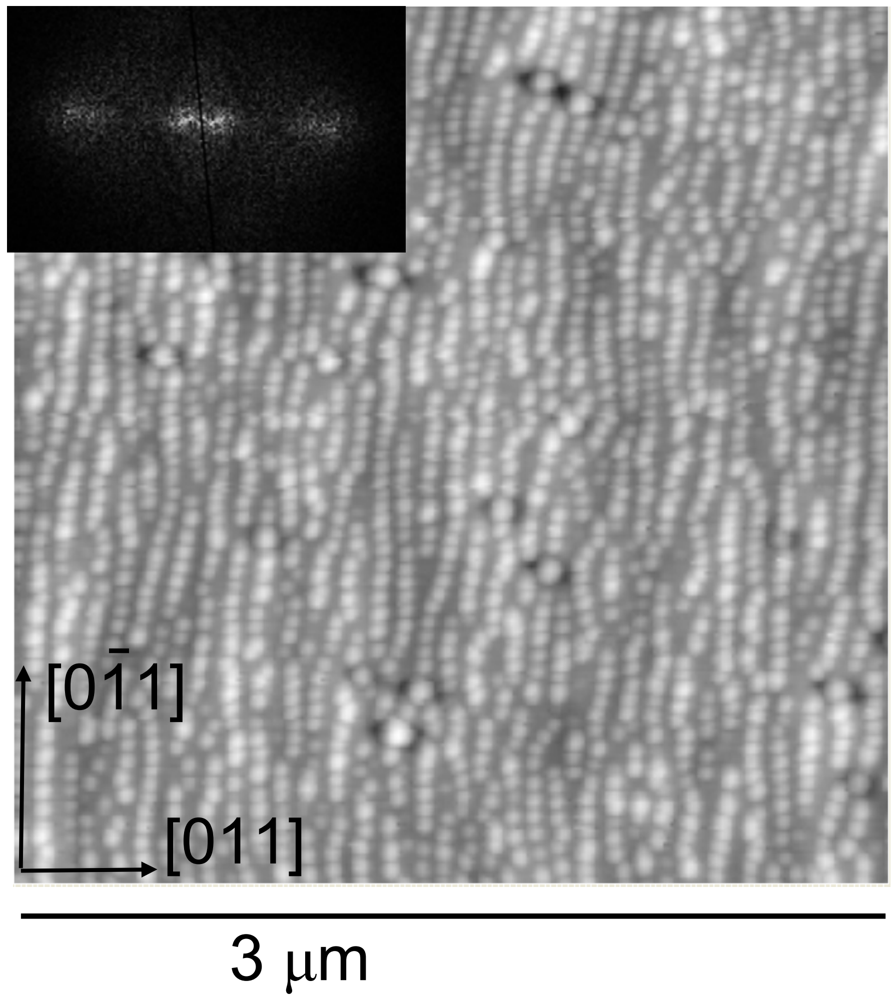
(3), the lateral island-island interaction energy is at minimum for a hexagonal arrangement.

(4), to realize the lateral ordering, the adatoms need to respond to the small energy barrier change in a short enough time.

High T, small growth rate, small V/III ratio



Linear chains



Summary

Conclusions

- Enhanced infrared absorption is observed for spatially ordered QDs.
- Enhanced absorption is attributed to enhanced uniformity of QDs.
- For FTIR measurement under normal incidence geometry, using a undoped sample as a reference can remove the multiple reflection effect.

Problem

Smaller areal density for spatially ordered QDs

Acknowledgments

Yongwei Sun
Xiaojie Yang
Ming Chong
Desheng Jiang
Lianghui Chen

$E = \frac{f_{OA}}{OA^3} + \frac{f_{OB}}{OB^3} + \frac{f_{OC}}{OC^3}$,

$OM \equiv r_0$ and $OA \equiv \eta r_0$, then $OB = r_0 \cos^{-1}\alpha$ and $OC = r_0\sigma^{\frac{1}{2}}$, where $\sigma \equiv 1 + (\eta - \tan\alpha)^2$.

$E = (\eta^{-3} f_{OA} + \cos^3\alpha \cdot f_{OB} + \sigma^{-\frac{3}{2}} f_{OC}) r_0^{-3} \Rightarrow \frac{\partial E}{\partial \alpha} = -3r_0^{-3}(f_{OB}\cos^2\alpha\sin\alpha + \frac{1}{2} f_{OC}\sigma^{-\frac{5}{2}}\frac{\partial\sigma}{\partial\alpha})$.

For a hexagonal ordering where $\tan\alpha = \frac{1}{2}\eta$, we get

$$\frac{\partial E}{\partial \alpha} = 3\cos^2\alpha\sin\alpha(1 - f_{OB}/f_{OC}) \cdot f_{OC} \cdot r_0^{-3}. \quad (1)$$