奈米物理特論

半導體奈米結構之成長與光電特性

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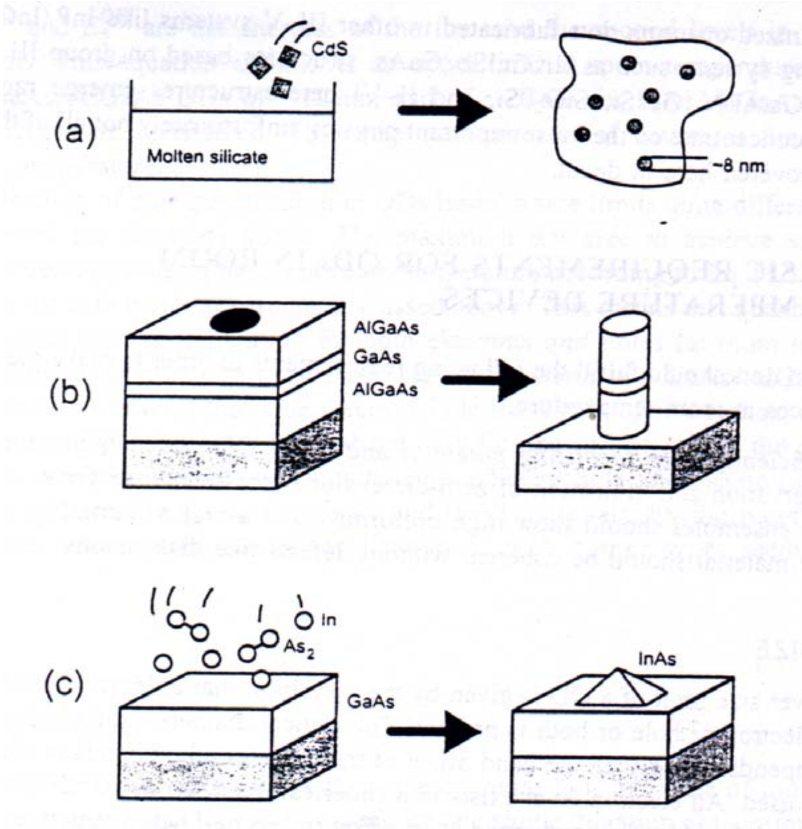
大綱:

Part I: 半導體奈米結構成長---------
分子束磊晶(MBE, molecular beam epitaxy)
半導體奈米結構形貌研究---AFM

Part II: 半導體奈米結構光電特性---Photoluminescence

Part III: 半磁性半導體奈米結構之自旋磁光特性

有幾種製作半導體奈米結構或量子點的方法?



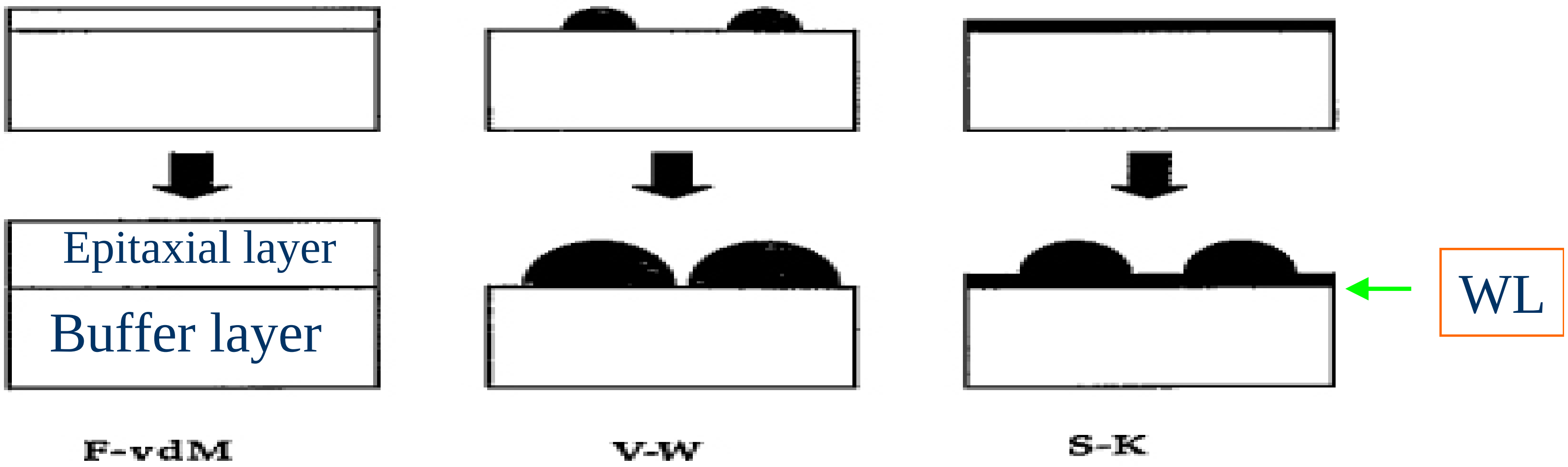
Top down

Bottom up

(a) Microcrystallites in glass

(b)Quantum dots fabricated by lithographic techniques

(c) <u>Self-organized quantum dots</u> (d) Chemical synthesis



Frank-van der Merwe
二維長晶模式

Volmer-Weber (VW)
三維長晶模式

Stranski-Krastanow (SK)
從二維到三維長晶模式
(wetting layer, WL)

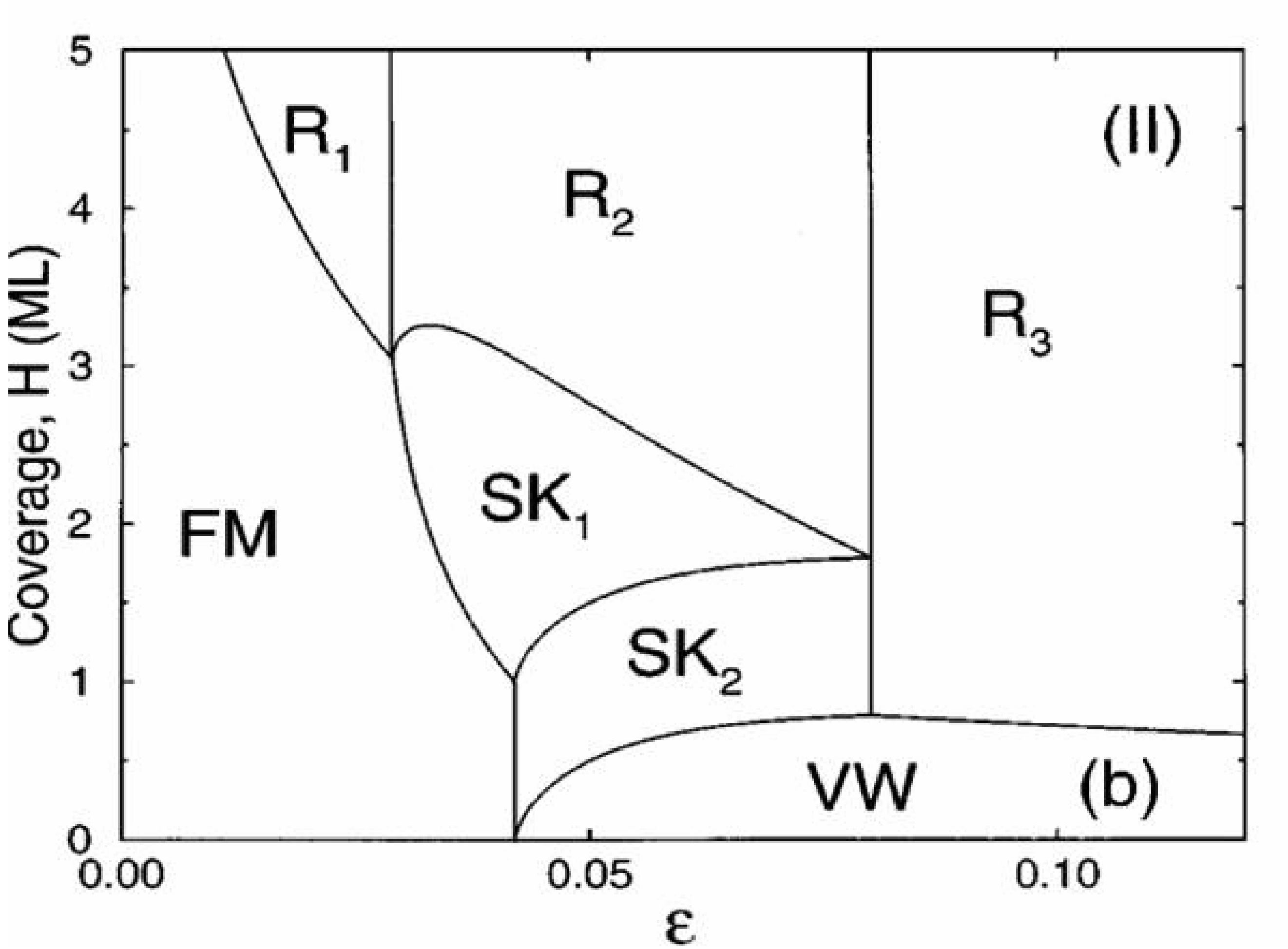
Self assembled (organized) quantum dots, SAQD.

$$u(H, n_1, n_2, \varepsilon) = E_{ml}(n_1) + n_2 E_{isl} + (H - n_1 - n_2) E_{rip}$$

$$E_{ml}(n_1) = \int dn\{G + \Delta[\Theta(1\text{-}n) + \Theta(n\text{-}1)\, e^{-(n-1)/a}]\} \qquad G = C\varepsilon^2 - \Phi_{AA}$$

$$E_{isl} = gC\varepsilon^2 - \Phi_{AA} + E_0[-(2/x^2)\ln e^{1/2}x + \alpha/x + \beta(n_2)/x^{3/2}]$$

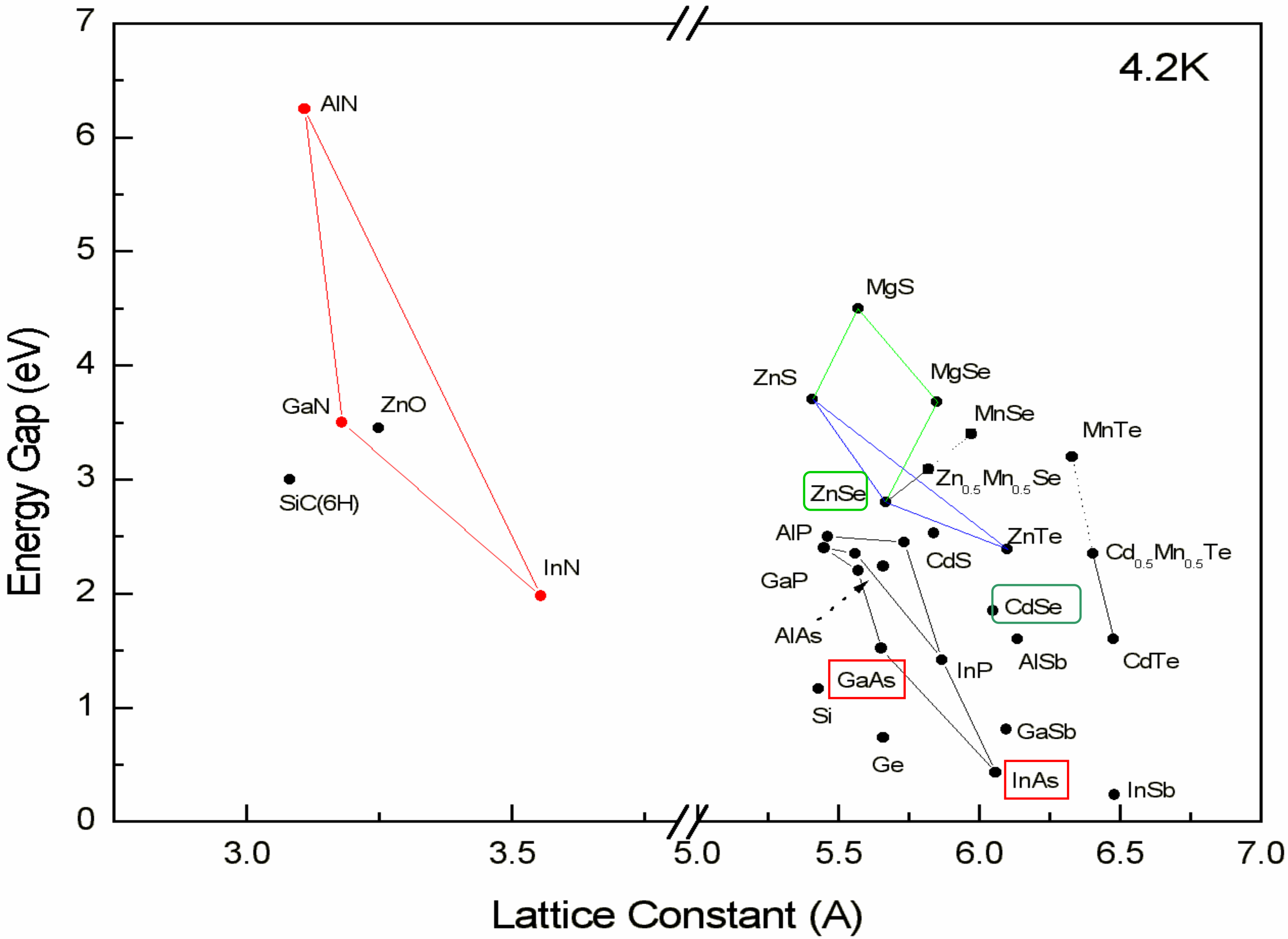
$$E_{rip} = E_{isl}(x \rightarrow \infty) = gC\varepsilon^2 - \Phi_{AA}$$



$$u(\mathrm{H}, n_1, n_2, \varepsilon) = E_{\mathrm{ml}}(n_1) + n_2 E_{\mathrm{isl}} + (\mathrm{H} - n_1 - n_2) E_{\mathrm{rip}}$$

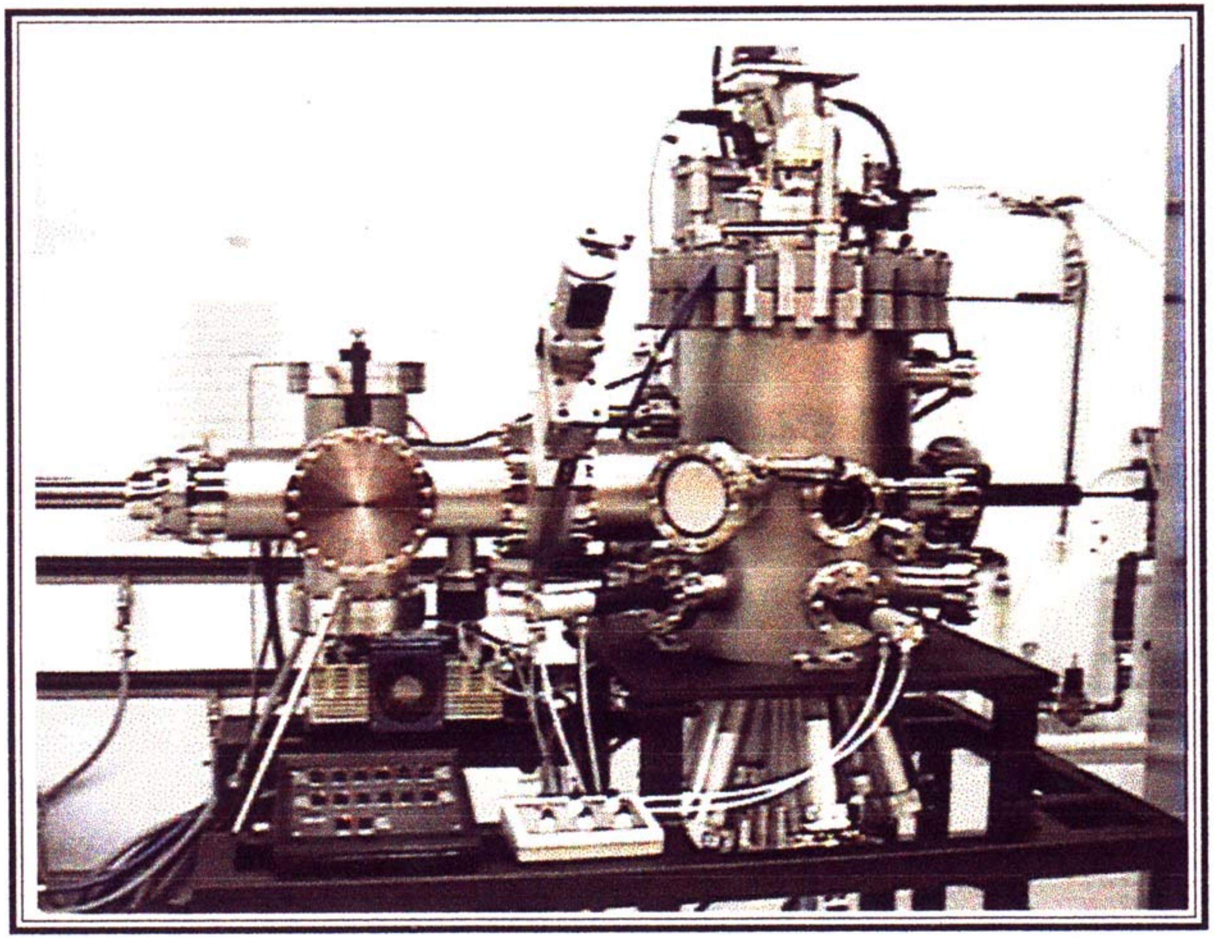
- I. Daruka and A.L. Barabasi, APL 72, 2102 (1998)

Energy Gap vs Lattice Constant
(材料)菜色豐富千變萬化



如何製作半導體奈米結構?

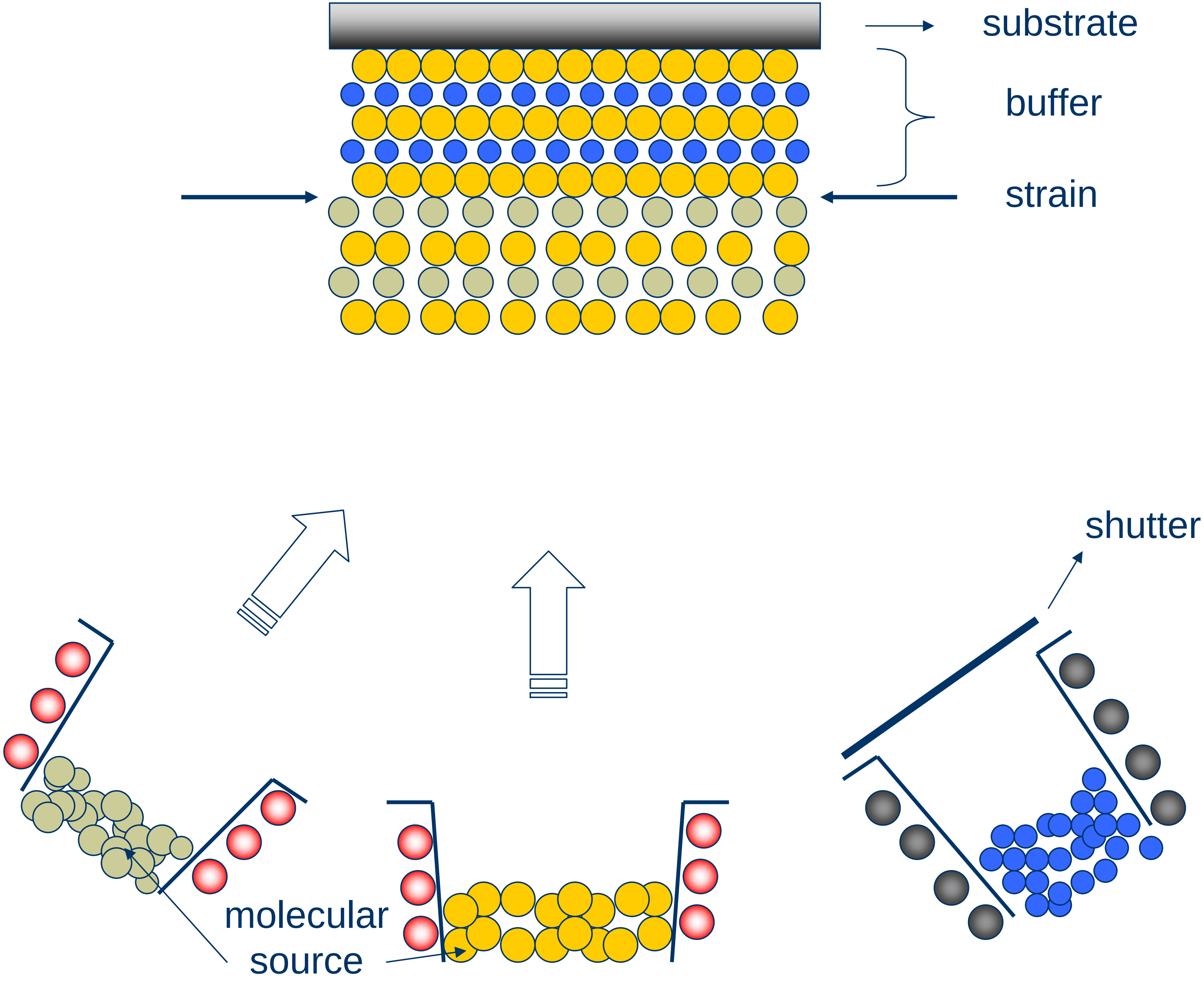
EPI
Model 620
Molecular Beam Epitaxy System

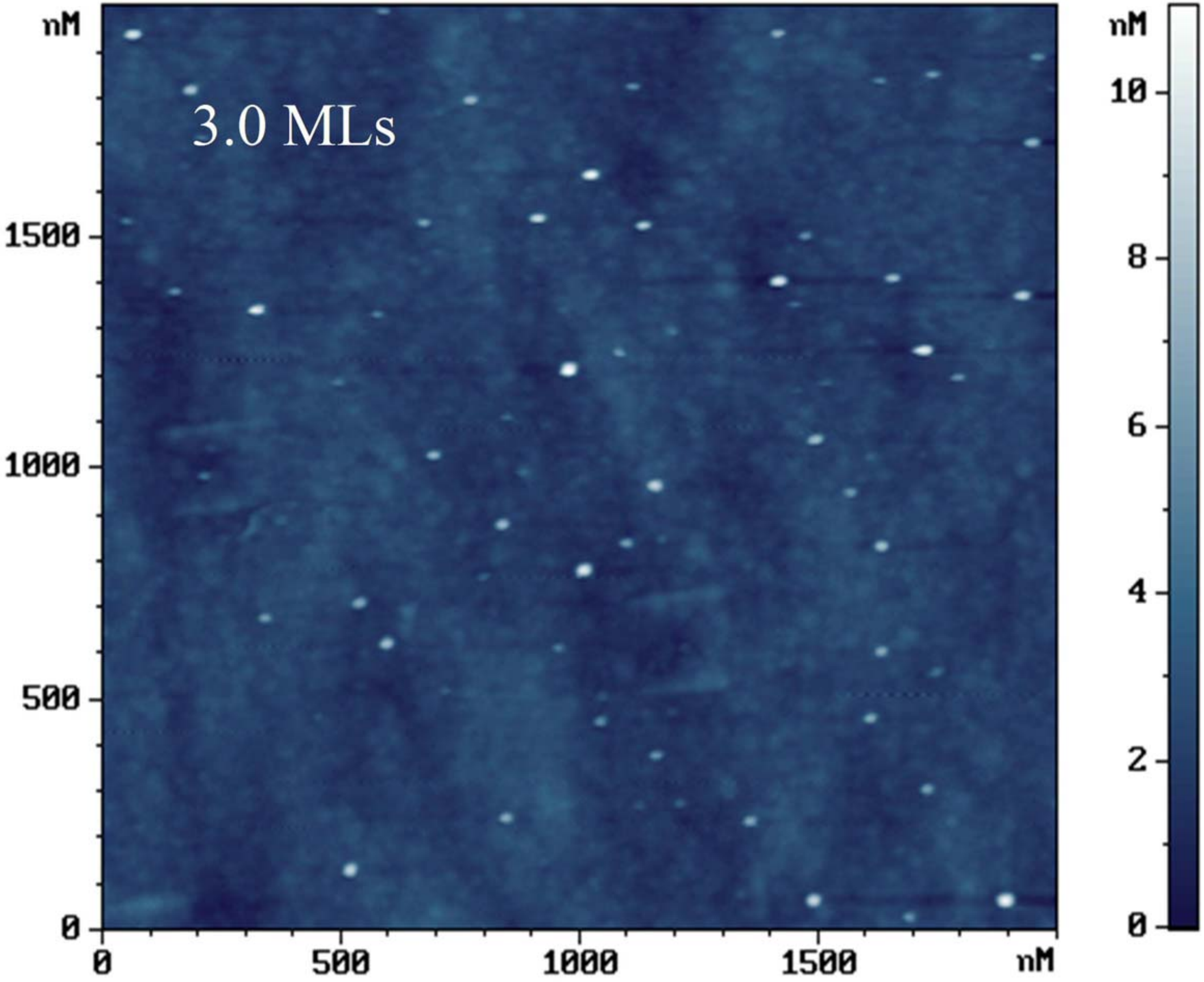


Rev Date: 11/96

超高真空操作程序與重要性、分子束源種類及調控磊晶速率

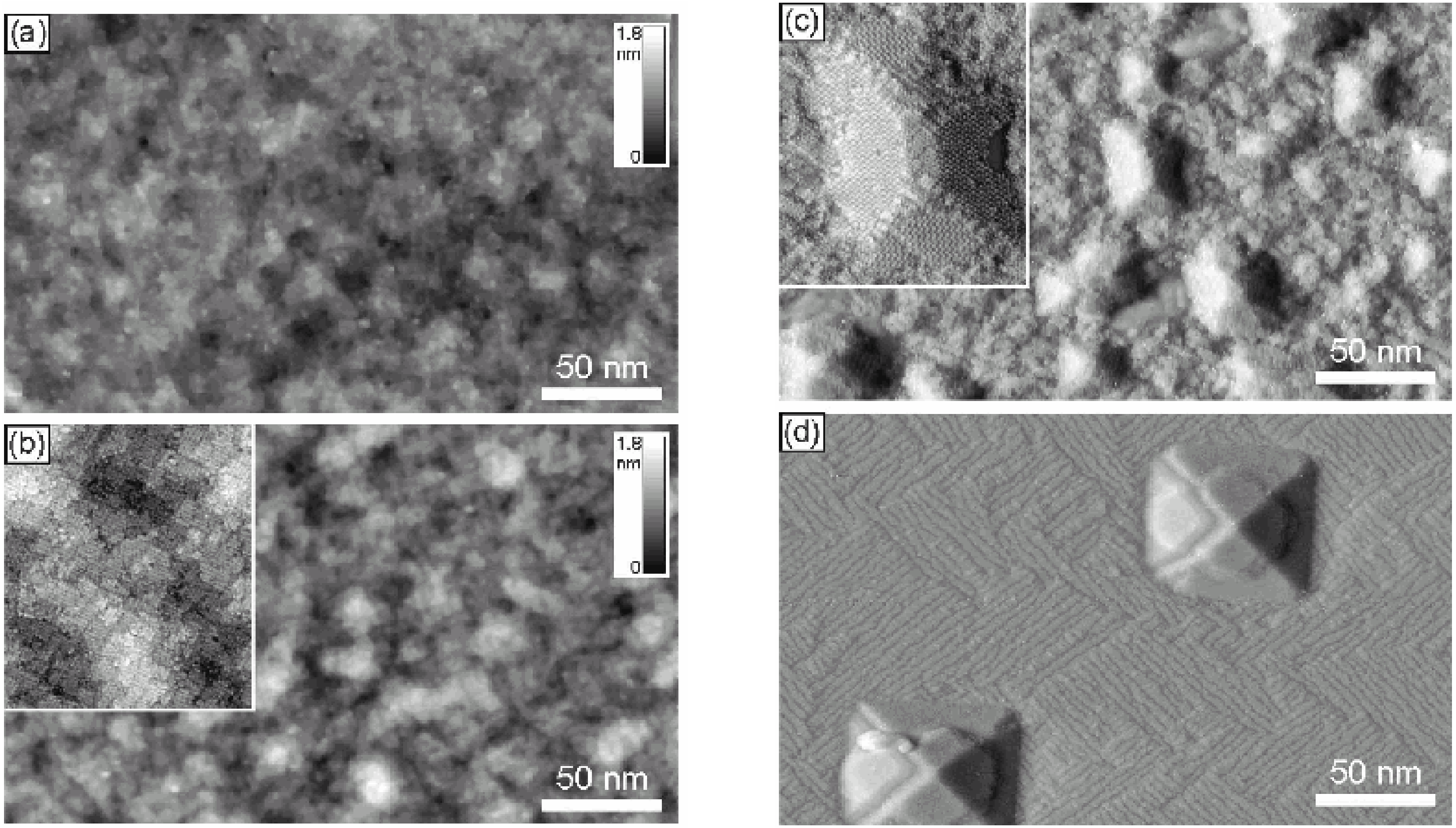
分子束磊晶術





碲化鋅量子點之表面高低(明暗)形貌直徑約10-30奈米 AFM

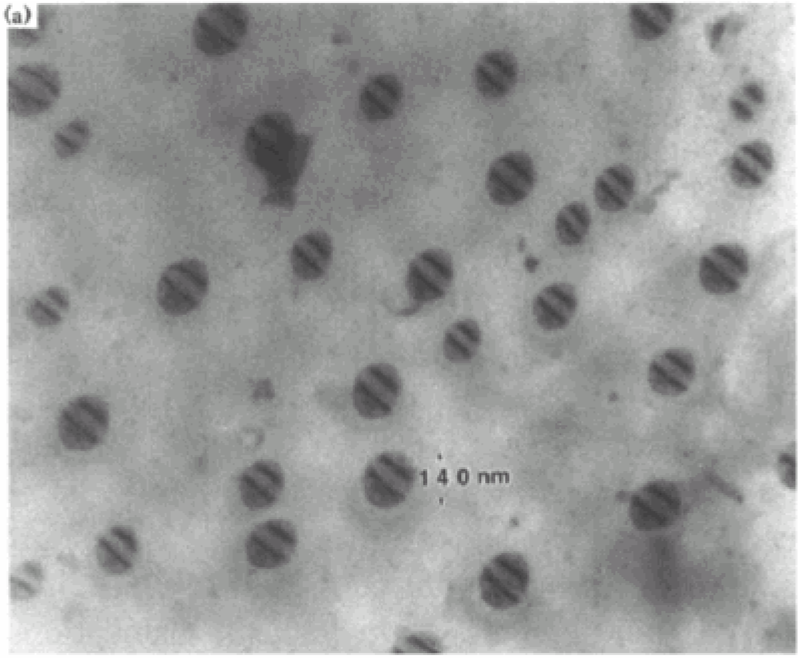
半導體奈米結構之形狀

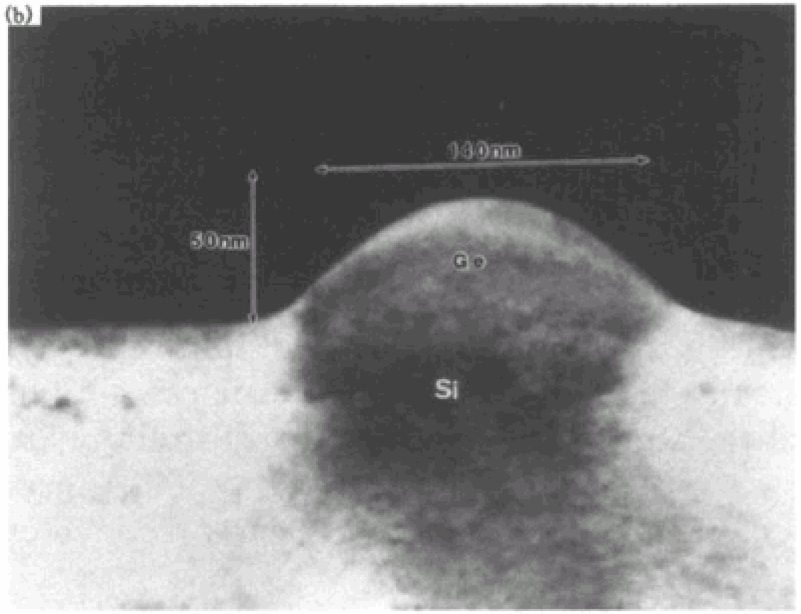


In situ **scanning tunneling microscopy study of C-induced Ge quantum dot formation on Si(100)**

O. Leifeld et al., APL74, 994 (1999)

Dislocation-Free Stranski-Krastanow Growth of Ge on Si(100)





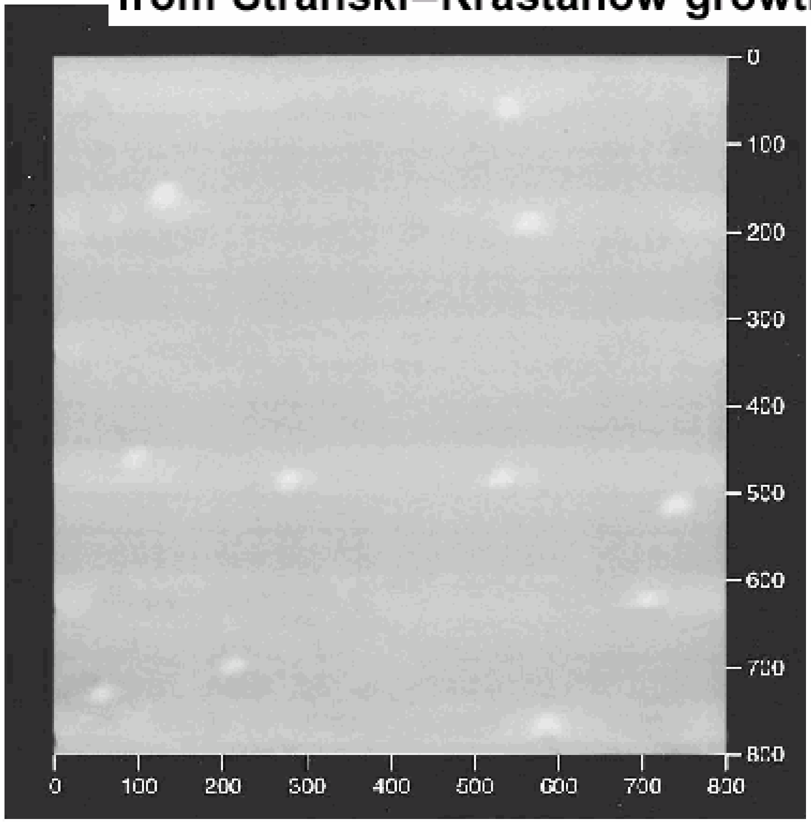
D. J. Eaglesham and M. Cerullo

PRL64, 1943 (1990)

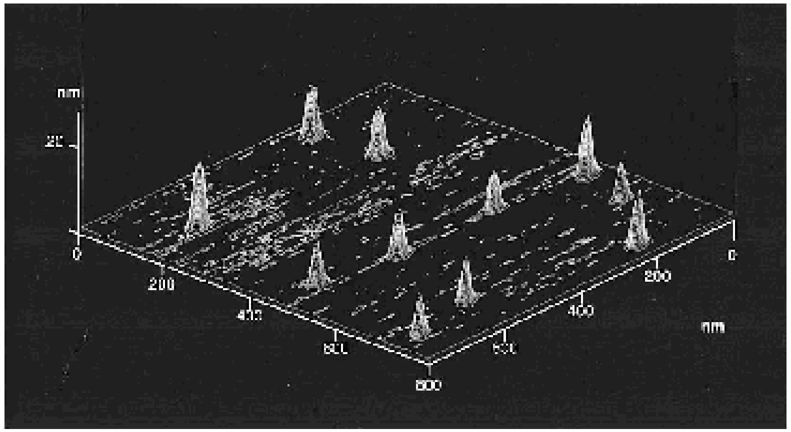
dome-shaped

半導體奈米結構之形狀

Self-organized CdSe quantum dots onto cleaved GaAs (110) originating from Stranski–Krastanow growth mode



(a)



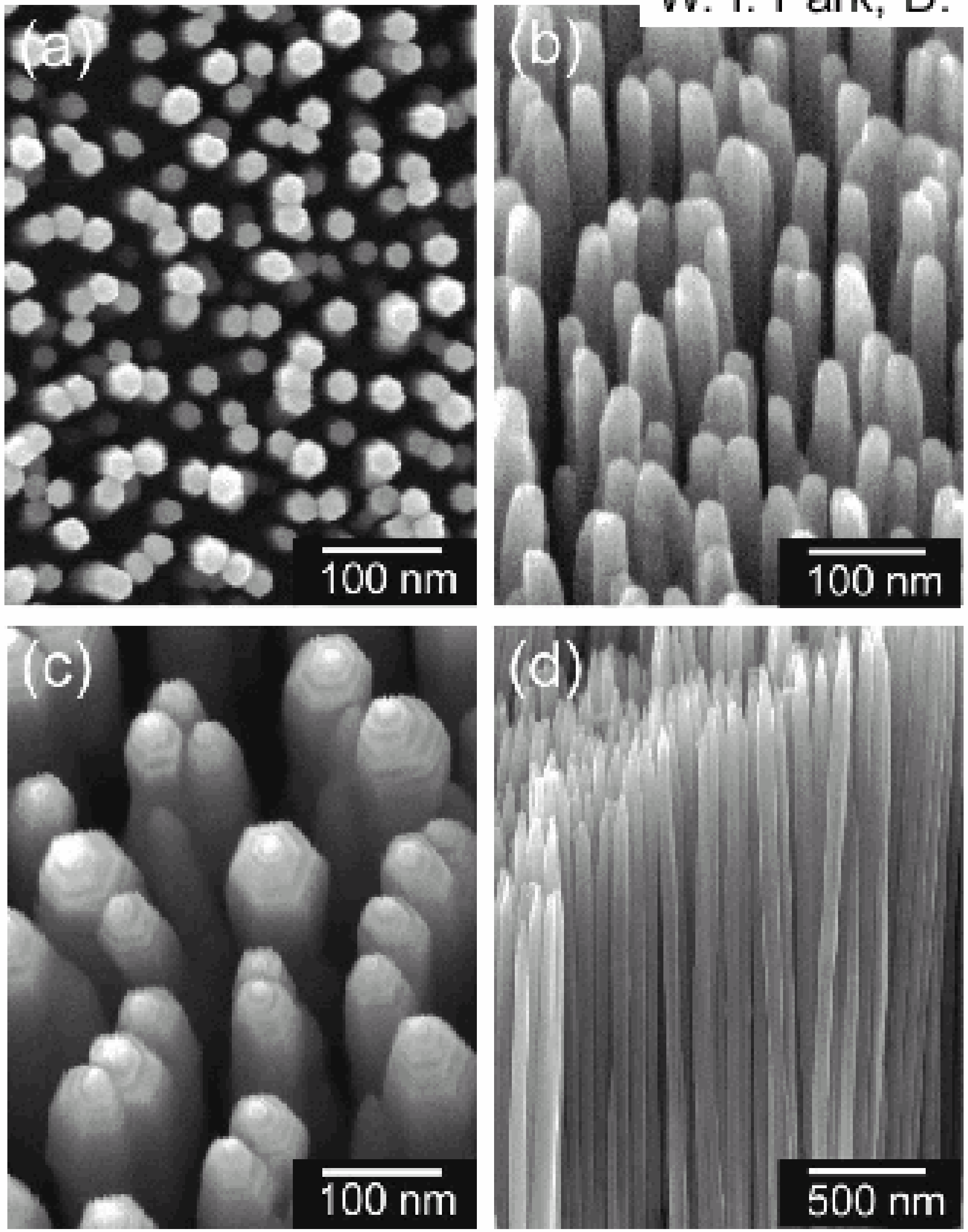
(b)

H.C. Ko et al., APL70, 3278 (1997)

半導體奈米結構之形狀

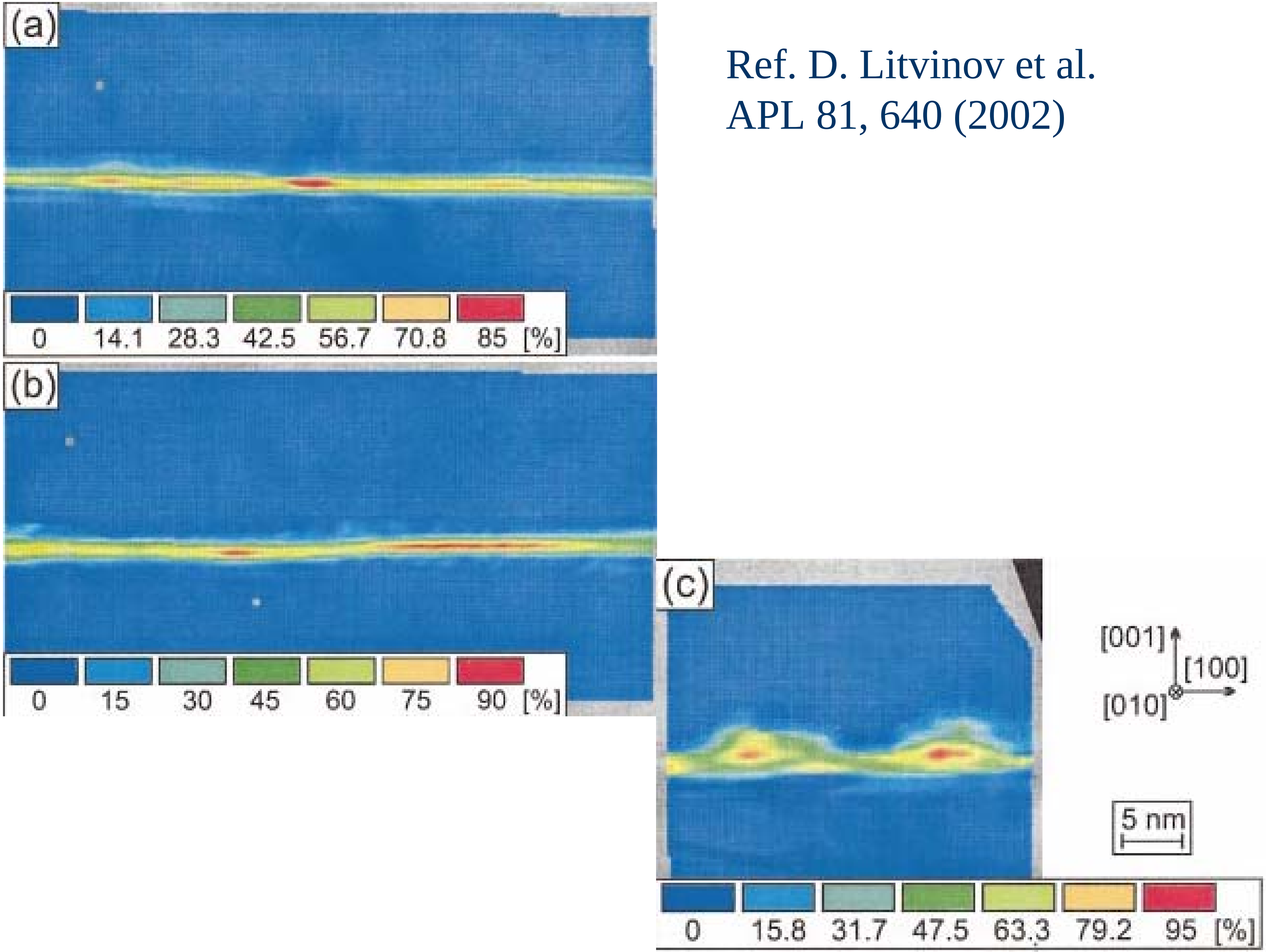
Metalorganic vapor-phase epitaxial growth of vertically well-aligned ZnO nanorods

W. I. Park, D. H. Kim, S.-W. Jung, and Gyu-Chul Yi[a)]

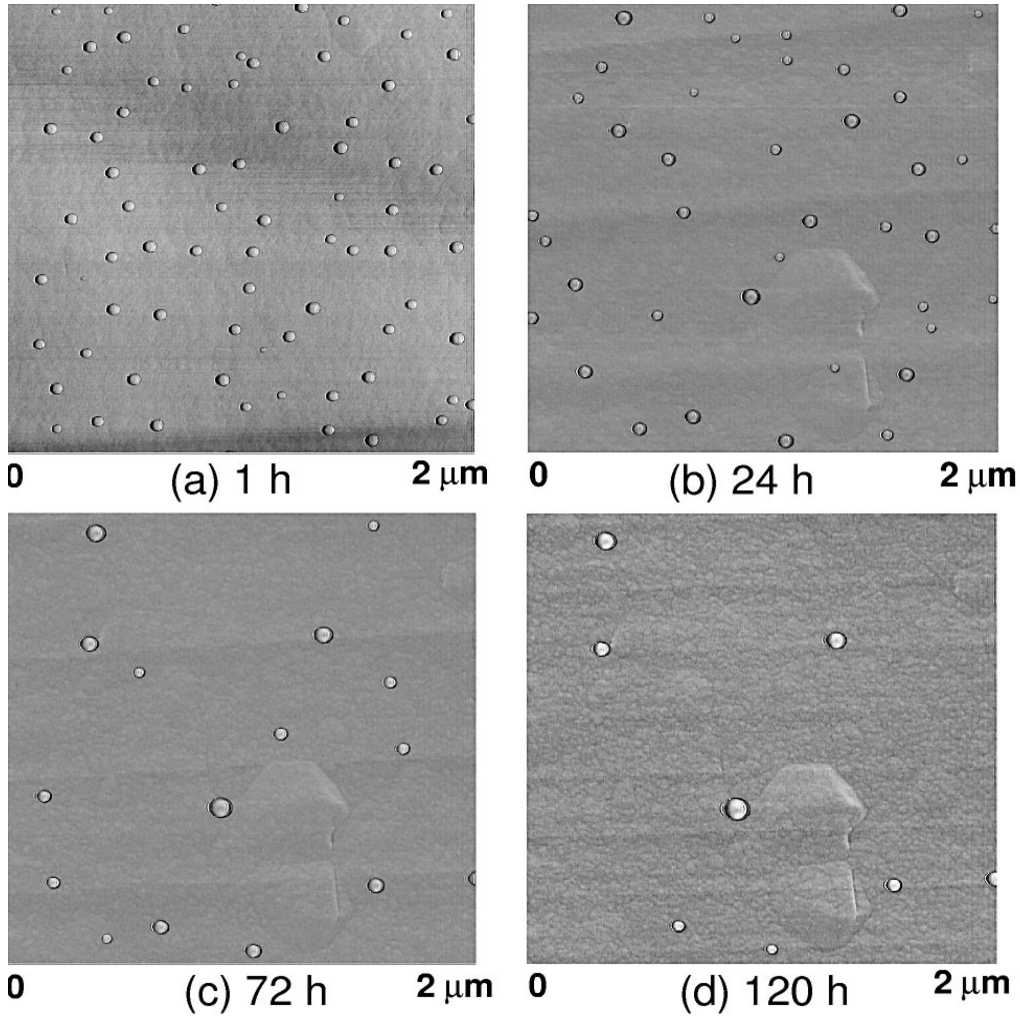


APL80, 4232 (2002)

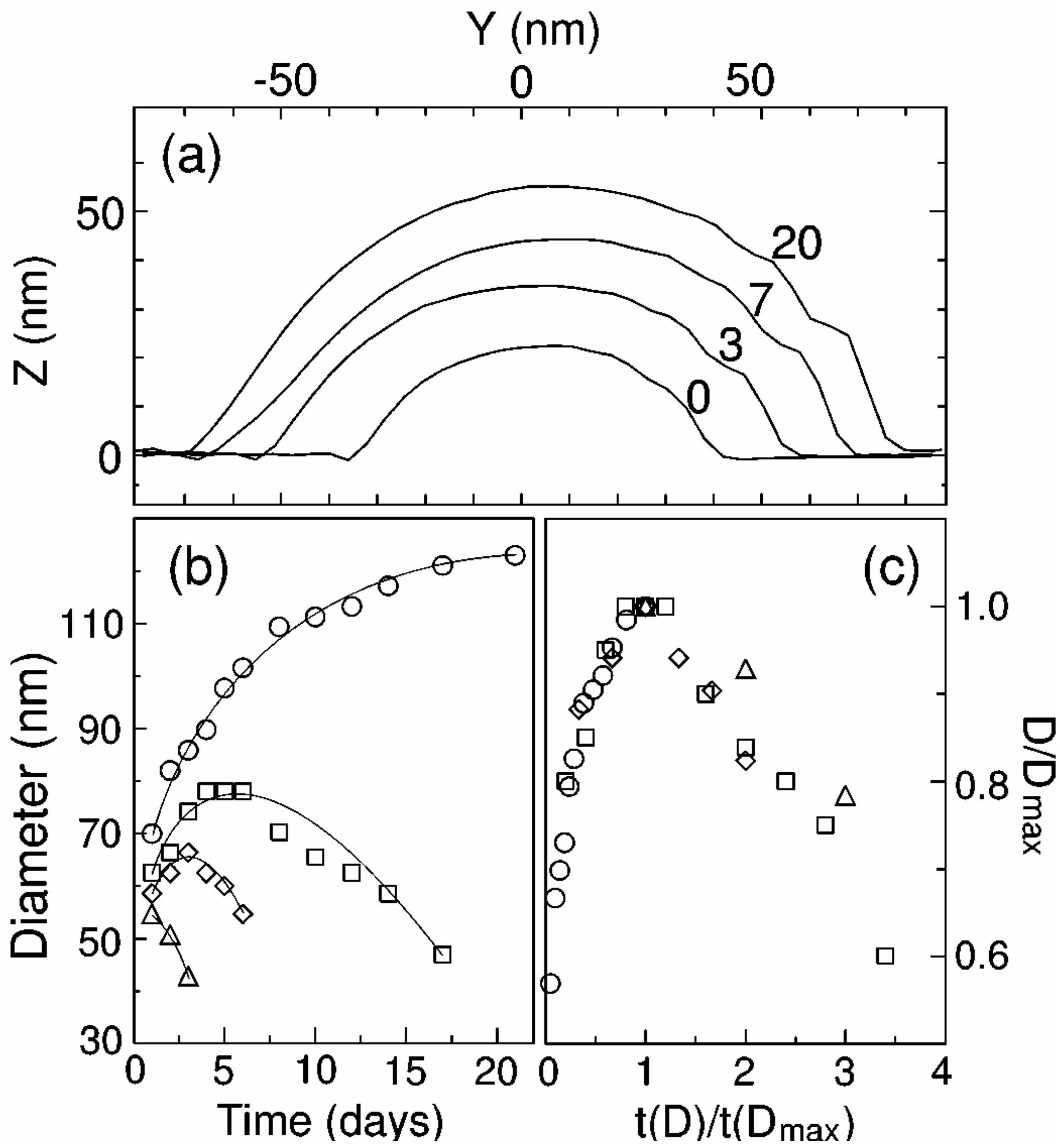
半導體奈米結構之形狀



Ref. D. Litvinov et al.
APL 81, 640 (2002)

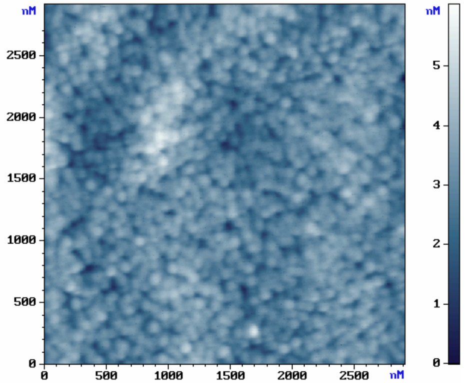


Ref. S.Lee et al., Phys. Rev. Lett. 81, 3479 (1998)

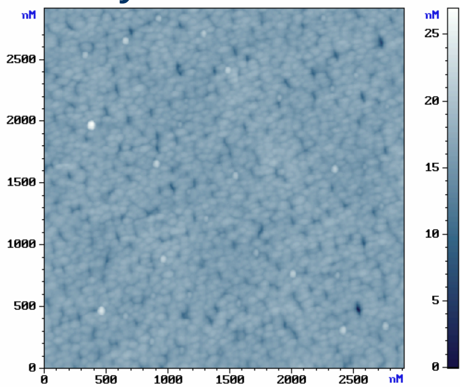

Y (nm)
-50
0
50
(a)
Z (nm)
50
0
20
7
3
0
(b)
Diameter (nm)
110
90
70
50
30
0
5
10
15
20
Time (days)
(c)
D/D_max
1.0
0.8
0.6
0
1
2
3
4
t(D)/t(D_max)

CdSe QDs 3 ML

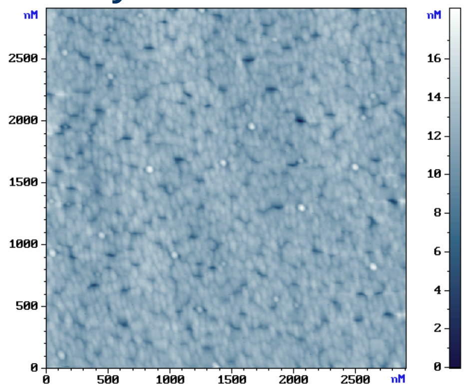
Day1



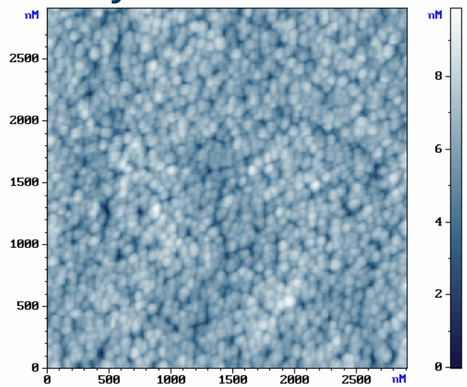
Day2 RT air



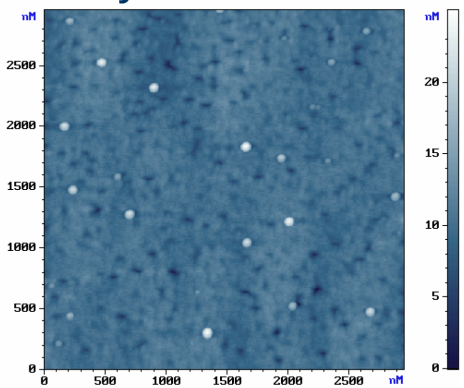
Day2 RT N2



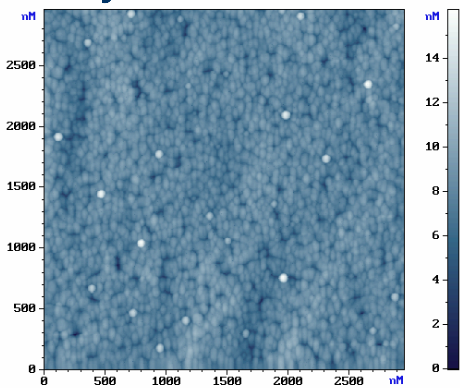
Day2 LT N2



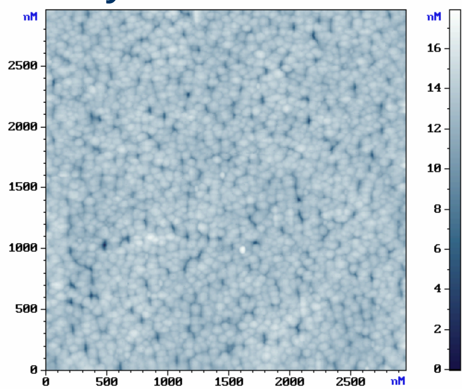
Day3 RT air

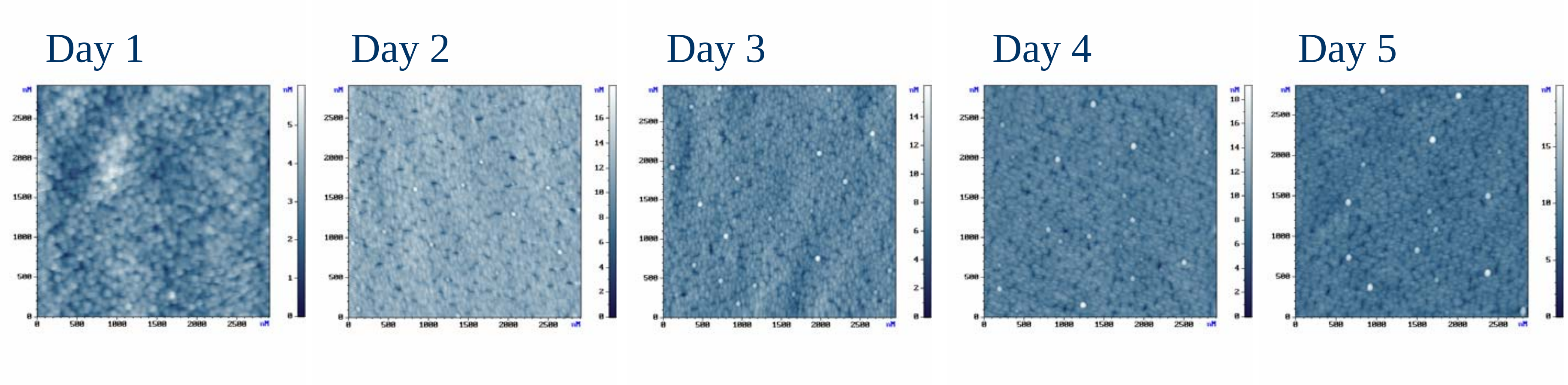


Day3 RT N2

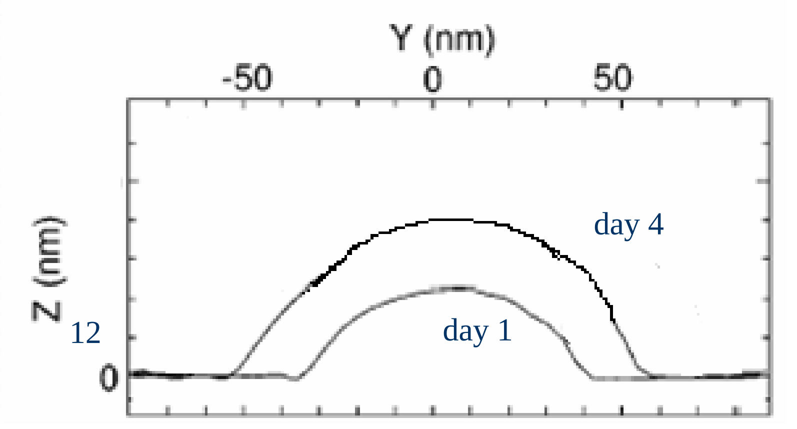


Day3 LT N2

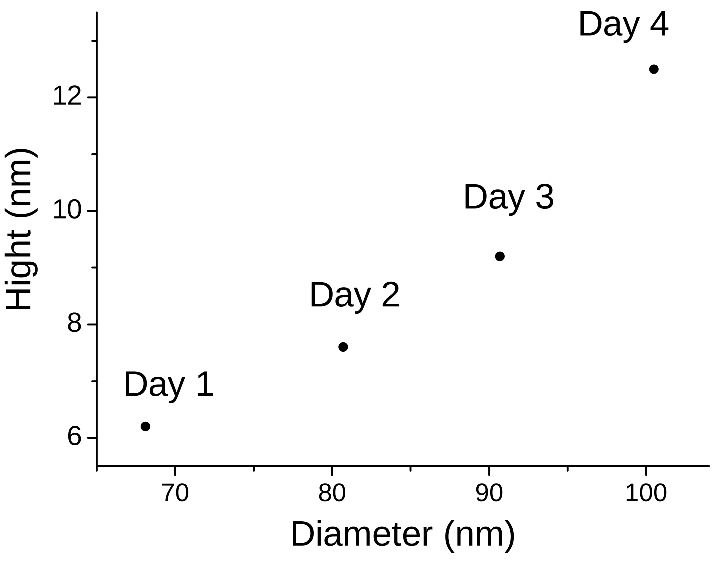


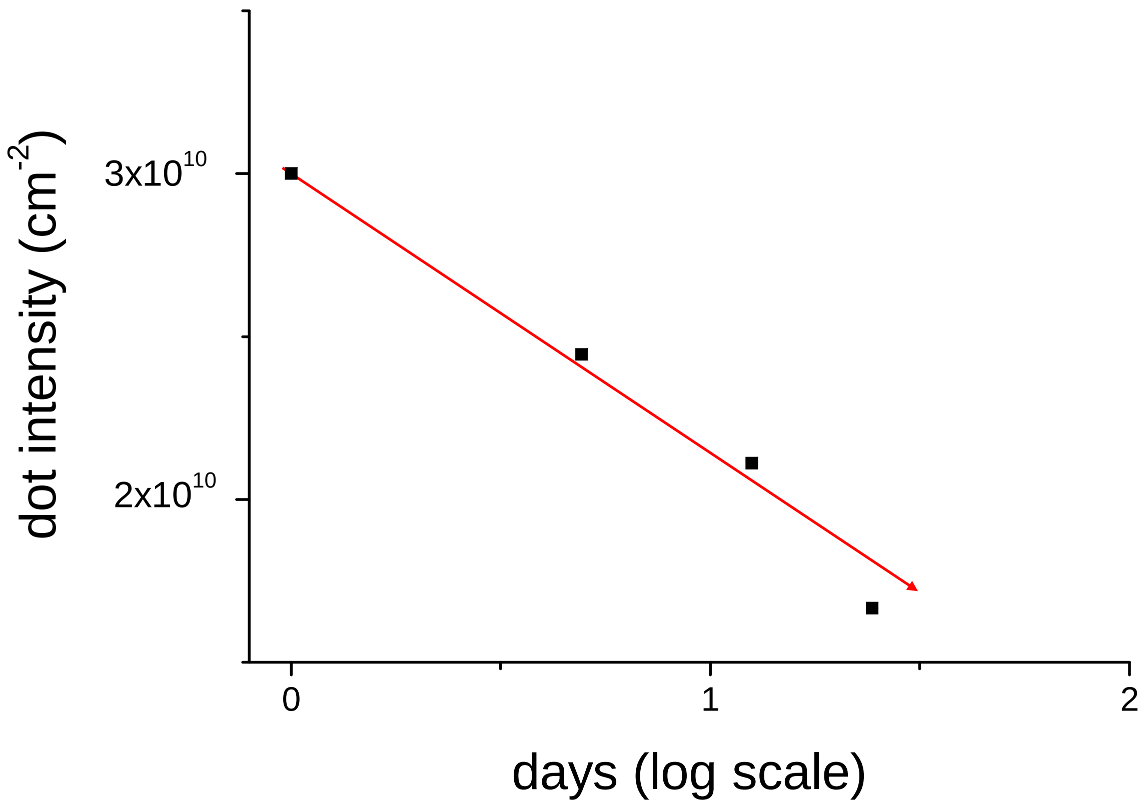

Day 1
Day 2
Day 3
Day 4
Day 5

Dot size vs. Time



T (days)	D (nm)	H (nm)
4	100.5	12.5
3	90.7	9.2
2	80.7	7.6
1	68.1	6.2





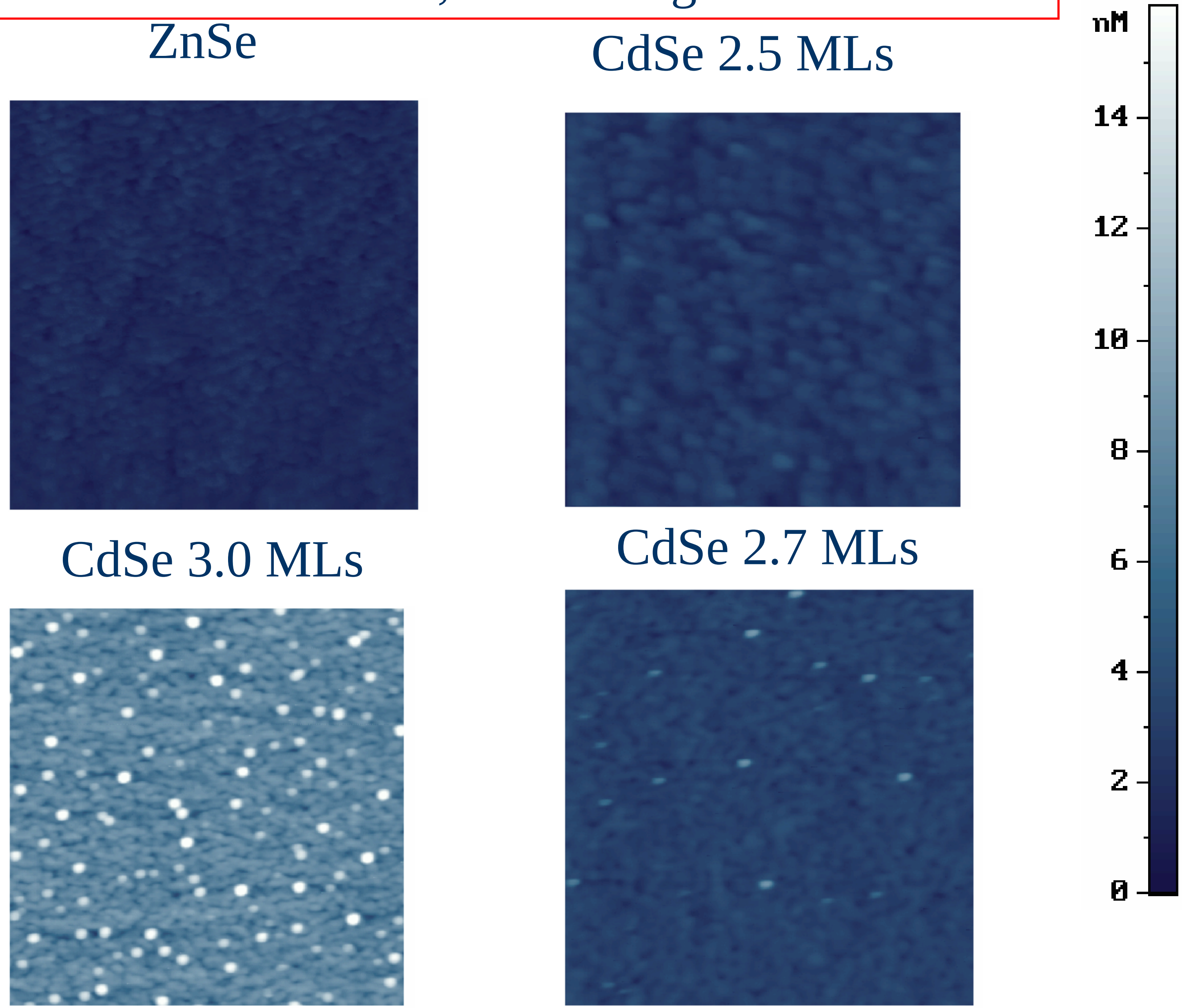
$V_{av}(t)\,\rho\,(t)=\text{const.}\qquad \rho\,(t)=\text{const.}\ R_{av}(t)^{-3}$

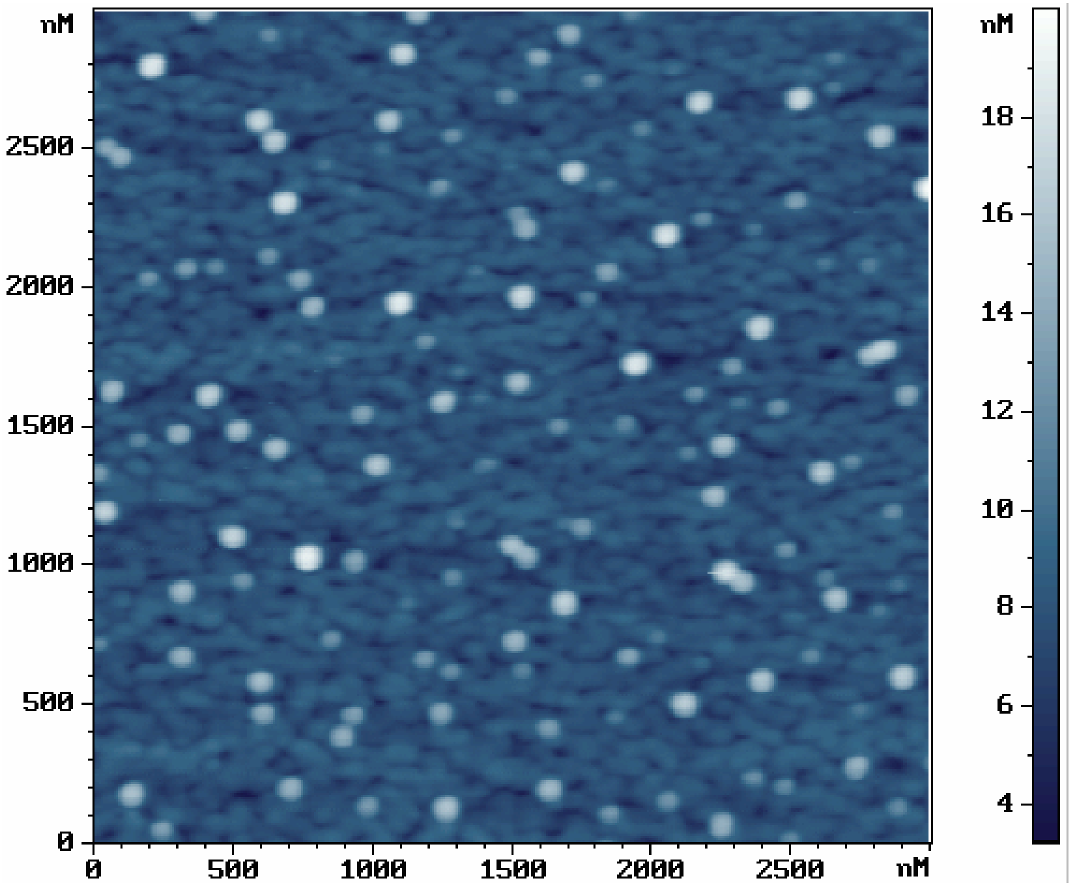
Mass transfer involves kinetic surface barrier for the atom detach from the edge of island $R_{av}(t) \sim t^{1/3}$

Therefore, $\rho\,(t) \sim t^{-1}$

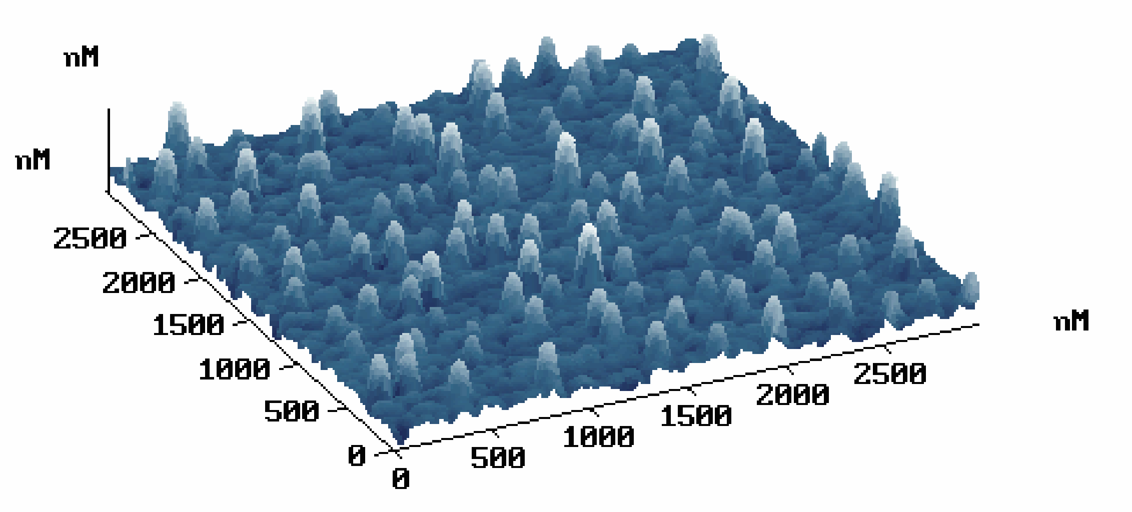
AFM non-contact mode

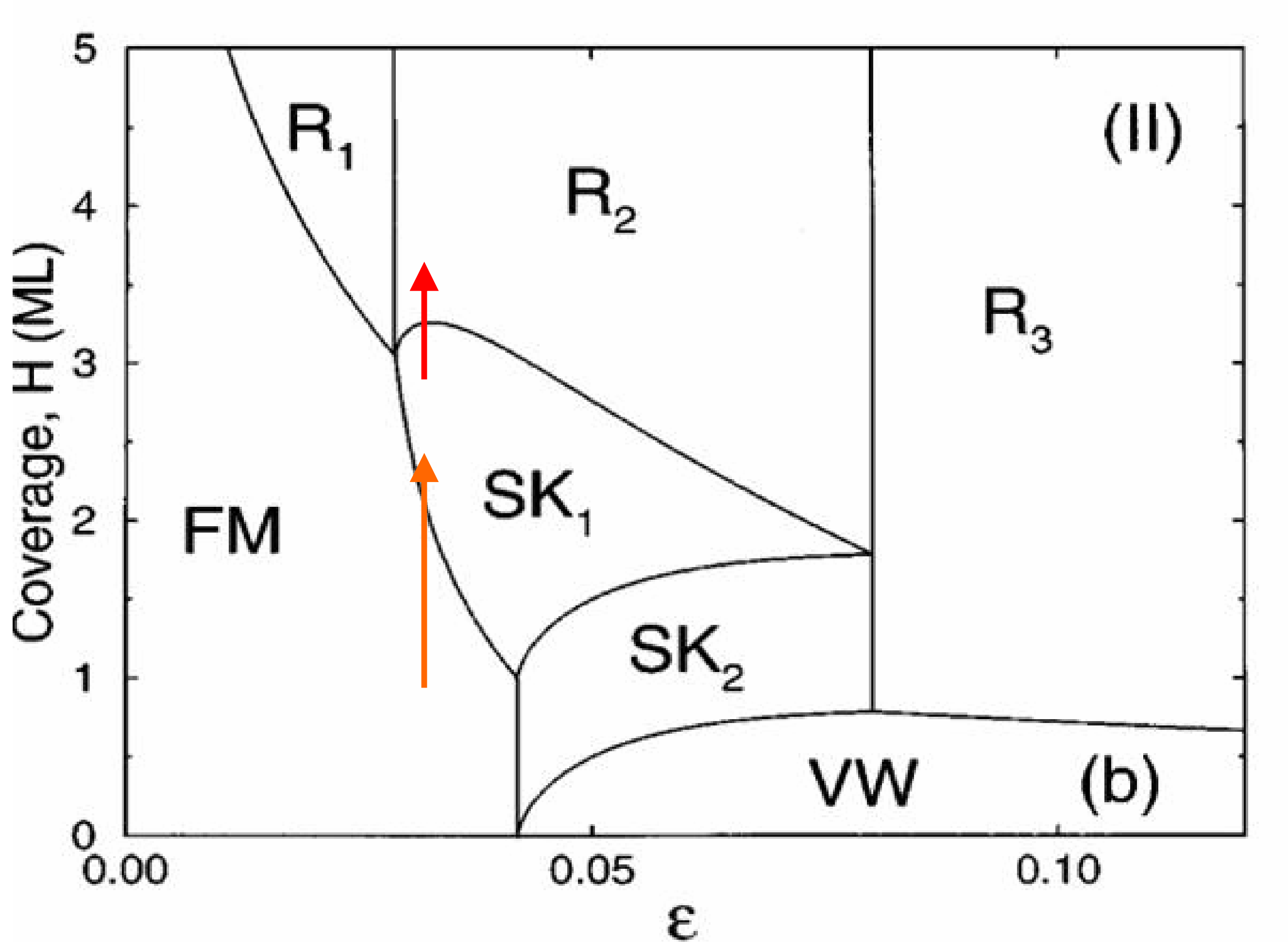
Find the WL thickness, 2D to 3D growth transition.





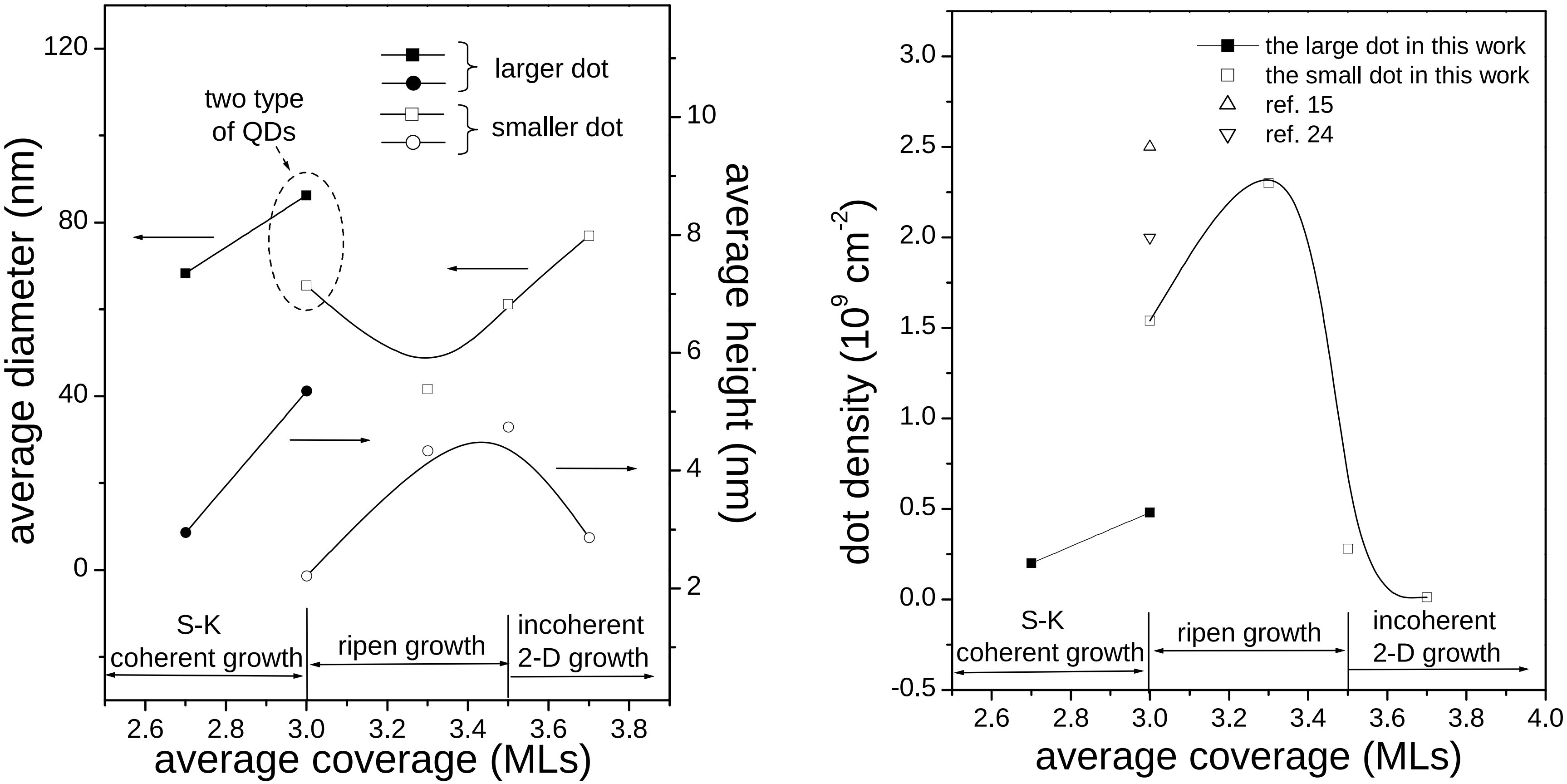
CdSe (3.0 MLs)/ZnSe





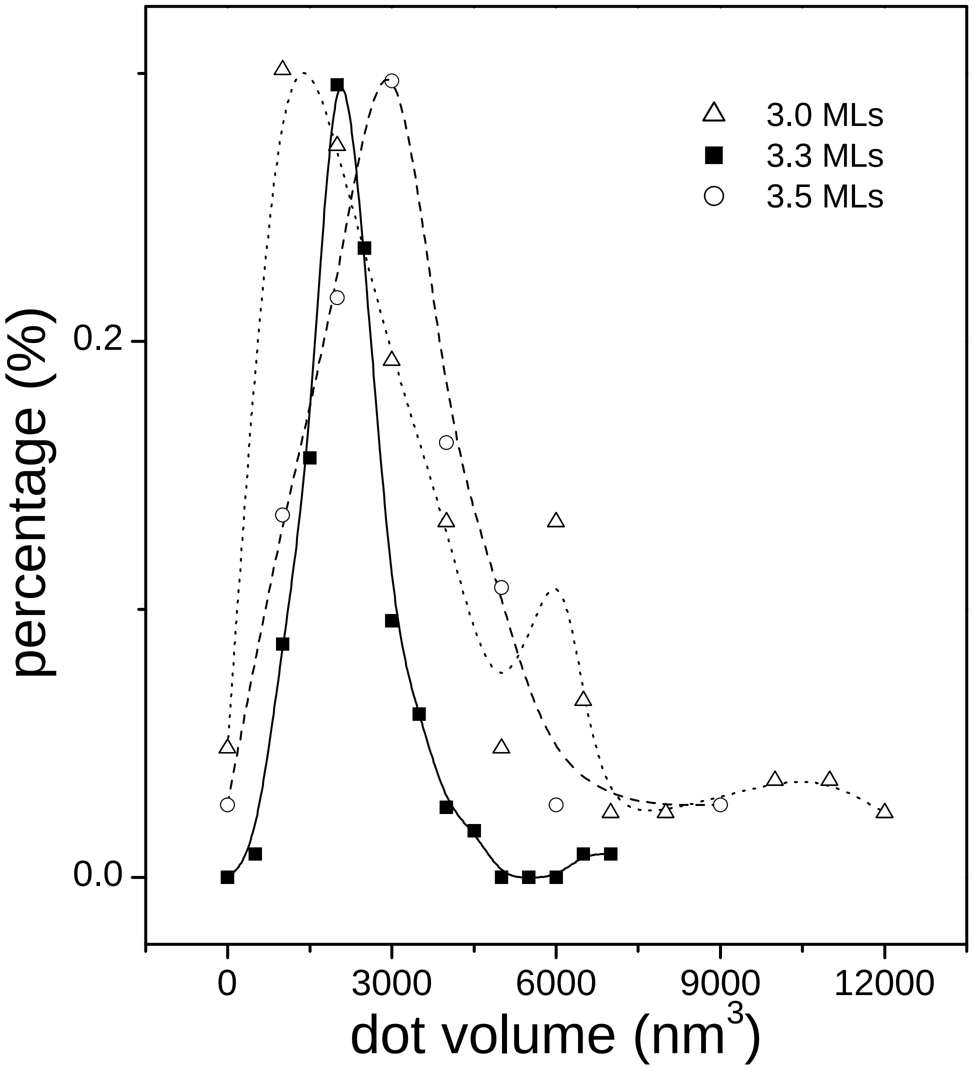
$$u(H, n_1, n_2, \varepsilon) = E_{ml}(n_1) + n_2 E_{isl} + (H - n_1 - n_2) E_{rip}$$

- I. Daruka and A.L. Barabasi, APL 72, 2102 (1998)



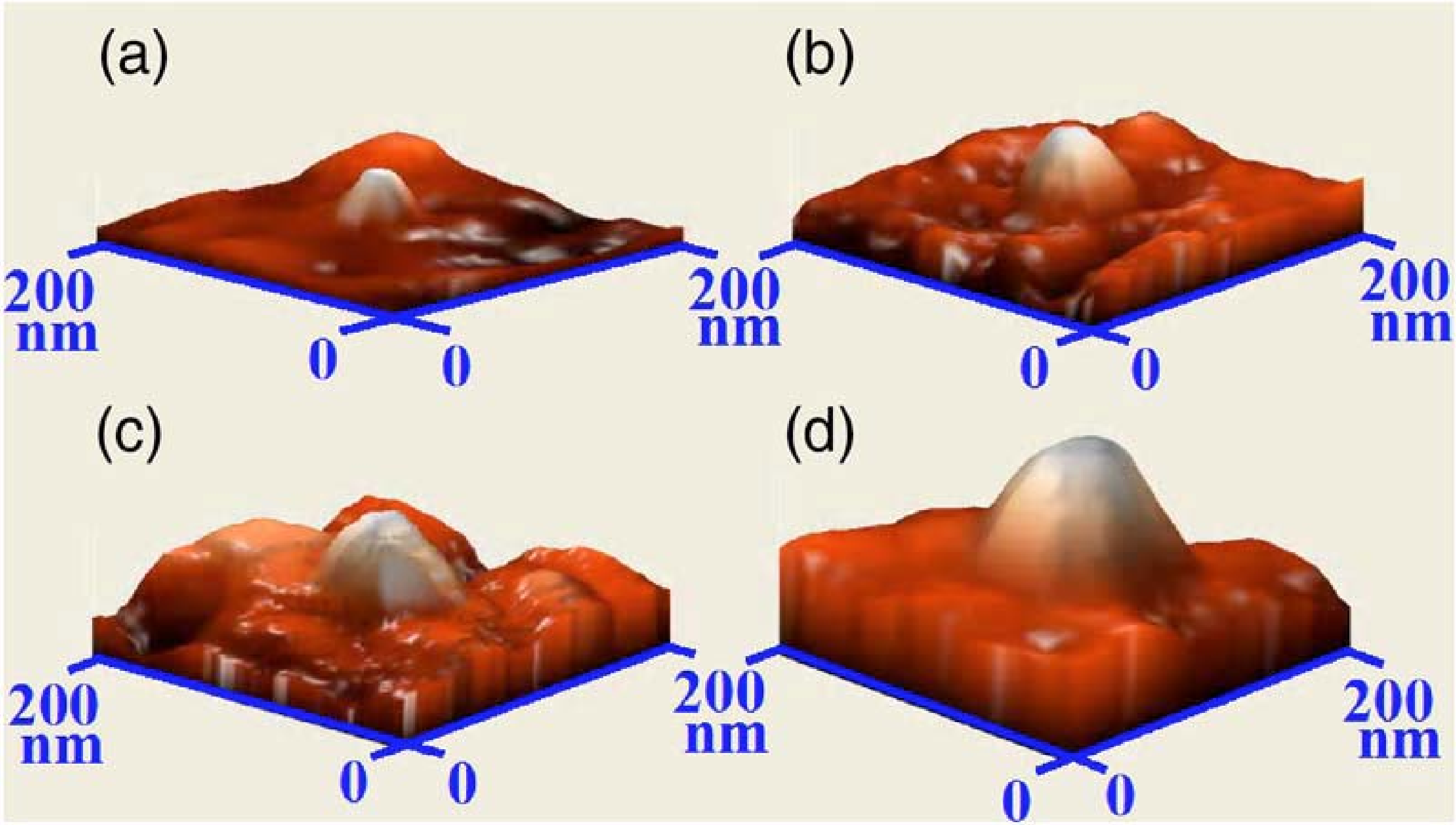
average diameter (nm)
average height (nm)
larger dot
smaller dot
two type
of QDs
S-K
coherent growth
ripen growth
incoherent
2-D growth
average coverage (MLs)
dot density (10^9 cm^{-2})
the large dot in this work
the small dot in this work
ref. 15
ref. 24

The importance of size control

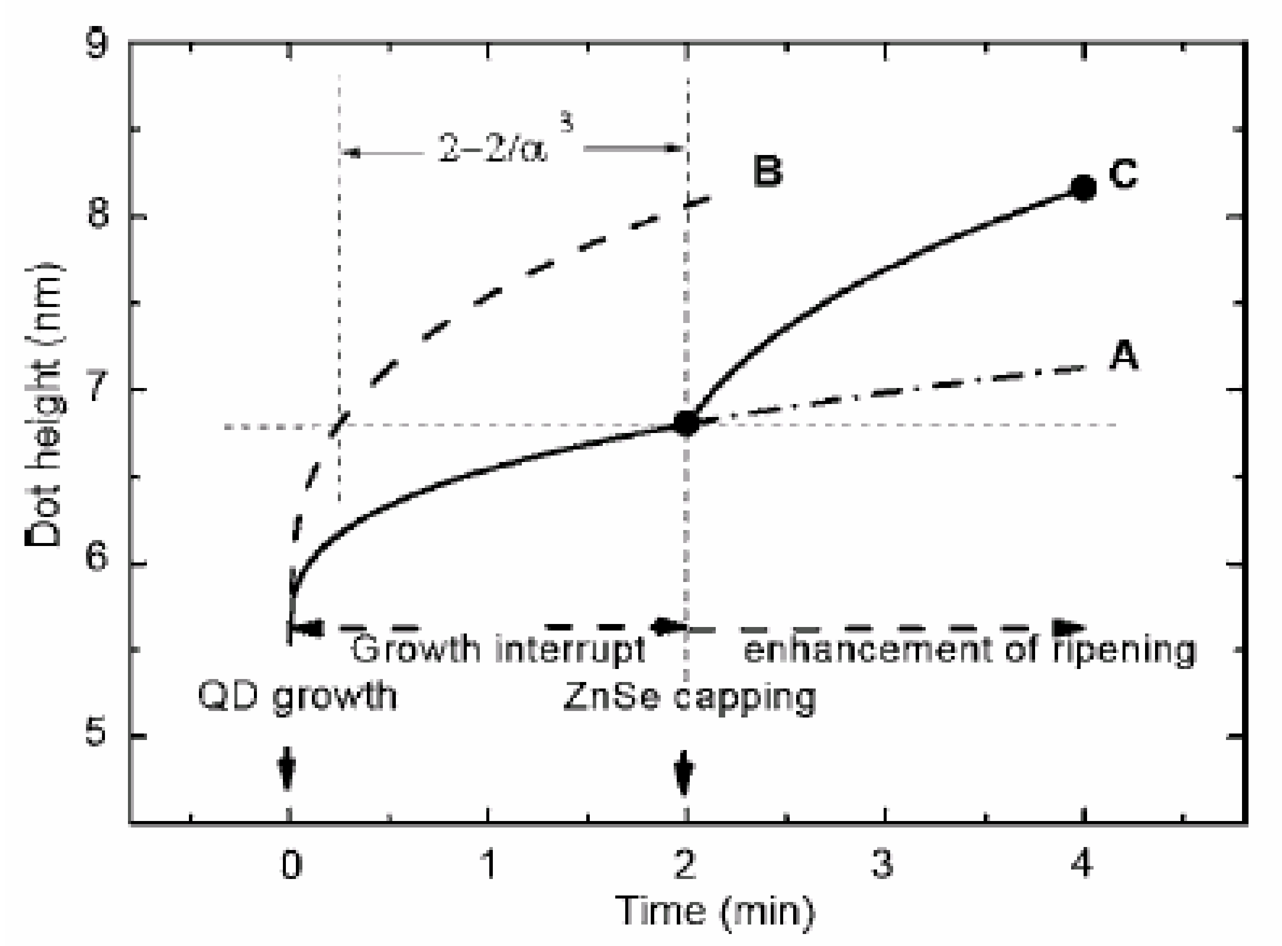


Two types of QDs.

Effect of ZnSe partial capping on the ripening dynamics of CdSe quantum dots



Typical AFM images of CdSe QDs samples capped with ZnSe layers of (a) 0, (b) 1, (c) 2, and (d) 3 ML. The temperature for ZnSe capping was 260 °C.



Dependence of dot height on time. Curve A dashed dots expresses

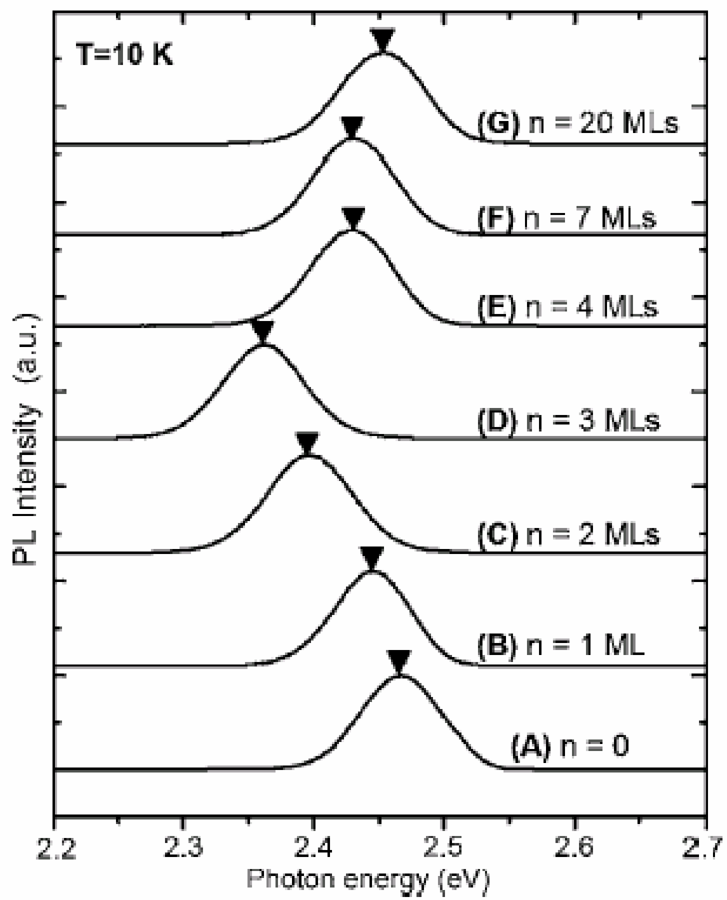
$$H(t) = H_0 + V_0 \times t^{1/3},$$

Curve B dashed line represents the ripening of a QD which has a faster ripening rate.

Curve C solid line describes

$$H(t) = H_0 + V\left[t - \left(2 - \frac{2}{\alpha^3}\right)\right]^{1/3},$$

Lai et al.
APL 90, 083226 (2007)



T=10 K
(G) n = 20 MLs
(F) n = 7 MLs
(E) n = 4 MLs
(D) n = 3 MLs
(C) n = 2 MLs
(B) n = 1 ML
(A) n = 0
PL Intensity (a.u.)
2.2
2.3
2.4
2.5
2.6
2.7
Photon energy (eV)