清華大學物理系 奈米物理特論 2013/03/28 上課內容 （I）

半導體奈米結構之成長與光電特性

交通大學電子物理系 周武清 教授

大綱:

Part I: 半導體奈米結構成長---------

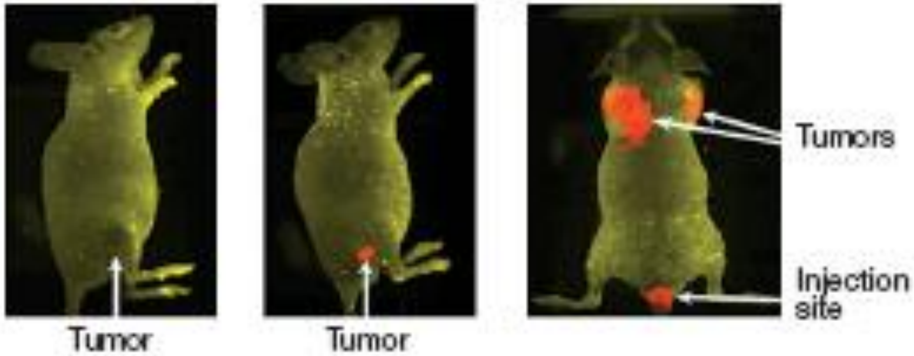
分子束磊晶(MBE, molecular beam epitaxy)

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

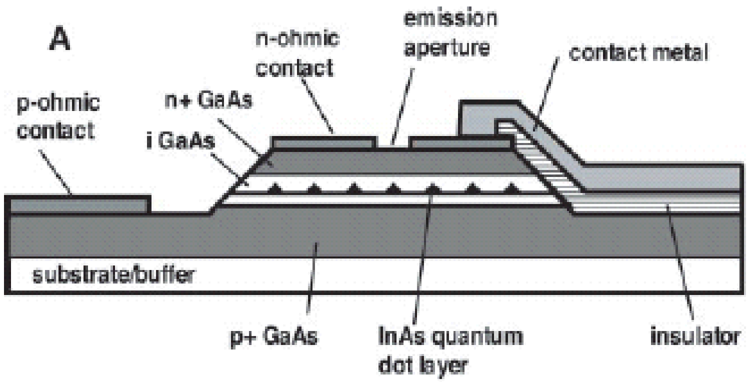
Part III: 半磁性半導體奈米結構之自旋磁光特性

半導體奈米結構的應用



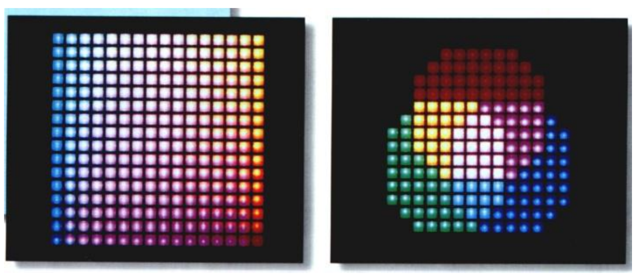
In vivo cancer targeting

Nature biotechnology
22, 969 (2004)



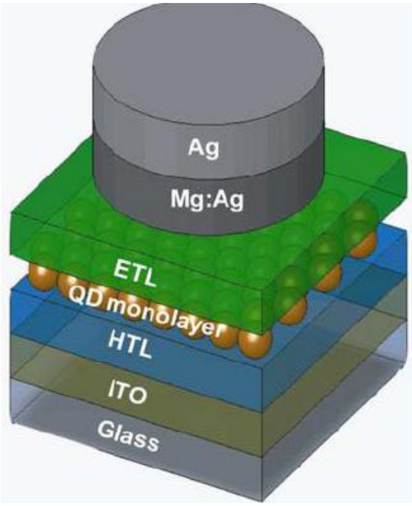
Single photon source

Z. Yuan et al.
Science **296**, 102 (2002).

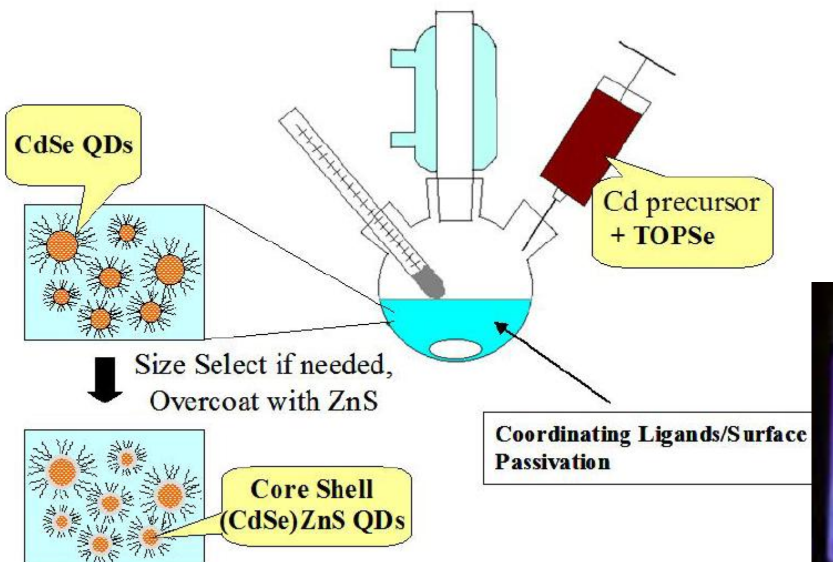


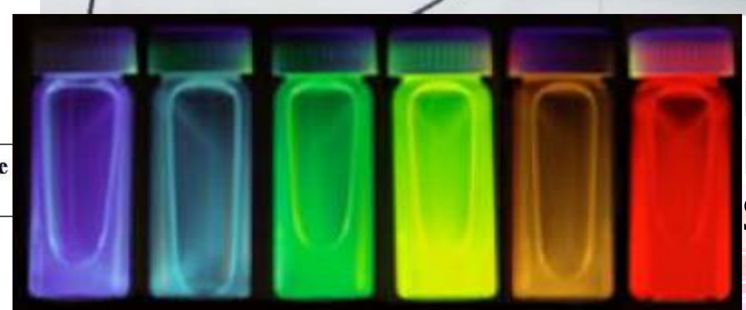
有幾種製作半導體奈米結構或量子點的方法?

1. 化學合成法



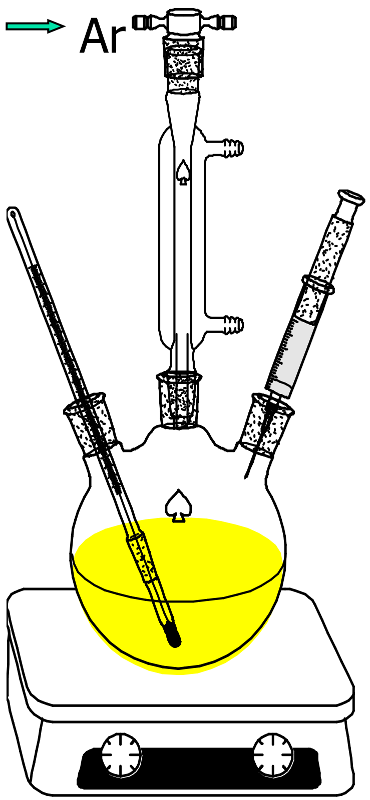
Synthetic Scheme





Bio-labelling
LED
Solar cell

化學合成半導體奈米晶體

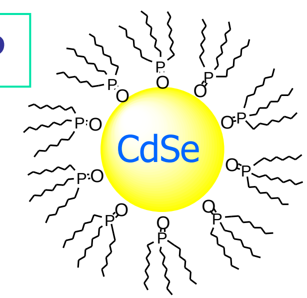


Preparation of Cd/Se/TOP and Zn/S/TOP stock solution

1.4mL
(0.13mmol Cd, 0.2mmol Se)
Cd/Se/TOP

5.5mL
(0.62mmol Zn, 0.88mmol S)
Zn/S/TOP

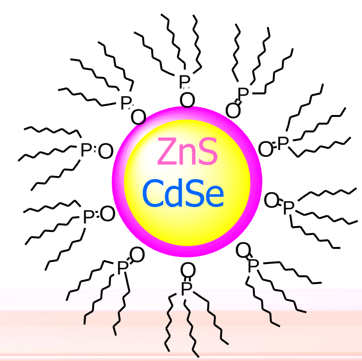
Rapidly injection of Cd/Se/TOP



350℃ → **300℃**

Injection of Zn/S/TOP in five 1.1 mL portion at 20s intervals

300℃ → **100℃**

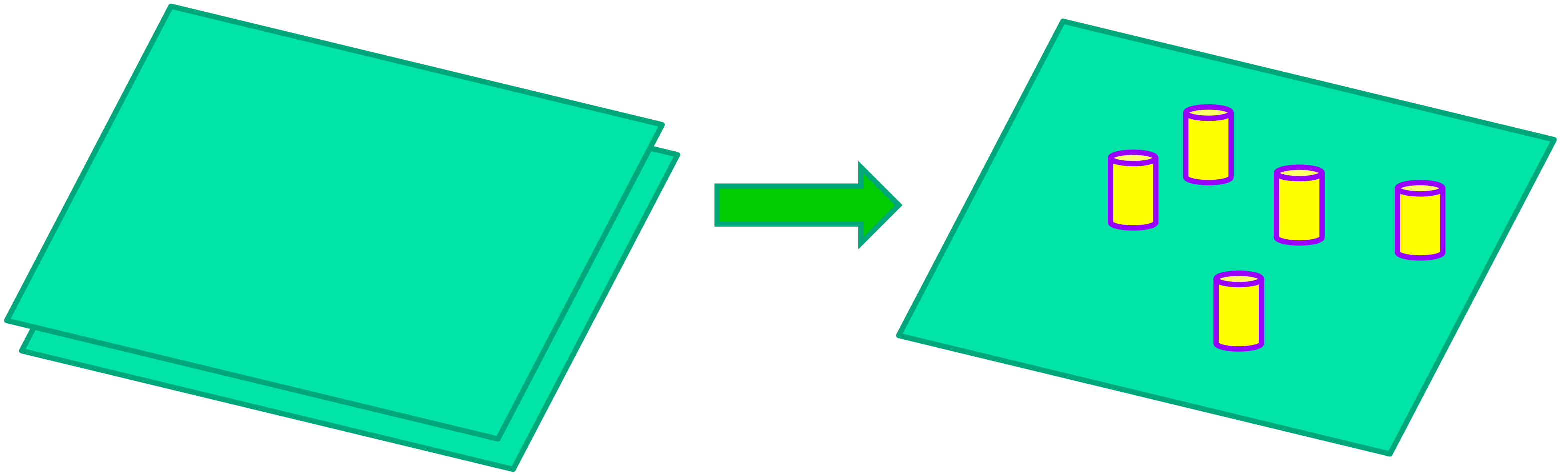


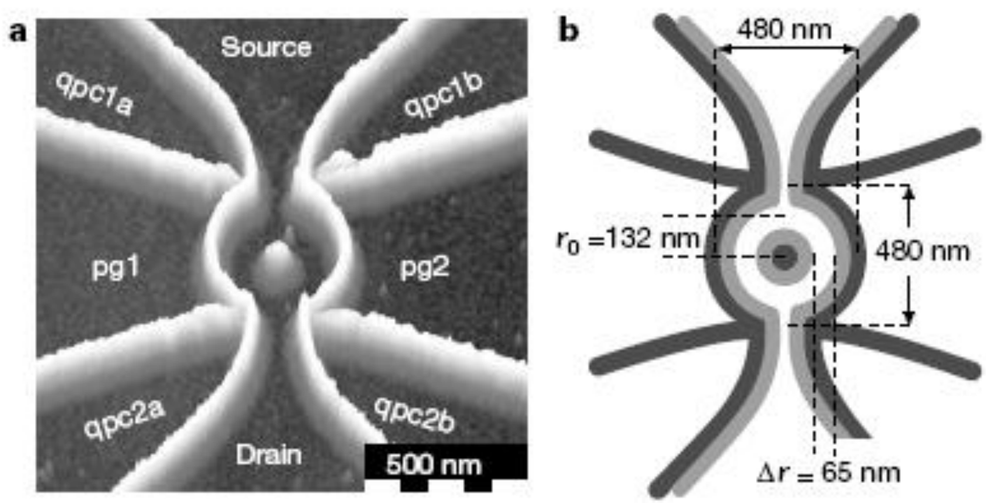
TOPO was heated to **200** ℃ under **vacuum** to remove H_2O

Tri-n-octylphosphine oxide (TOPO)

有幾種製作半導體奈米結構
或量子點的方法?

2. 半導體製程(化學蝕刻)

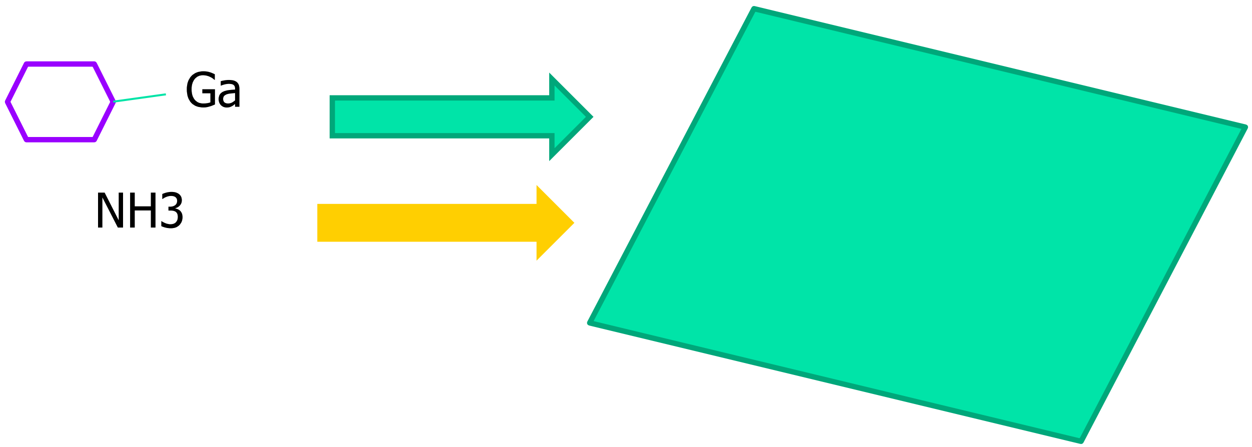




有幾種製作半導體奈米結構或量子點的方法?

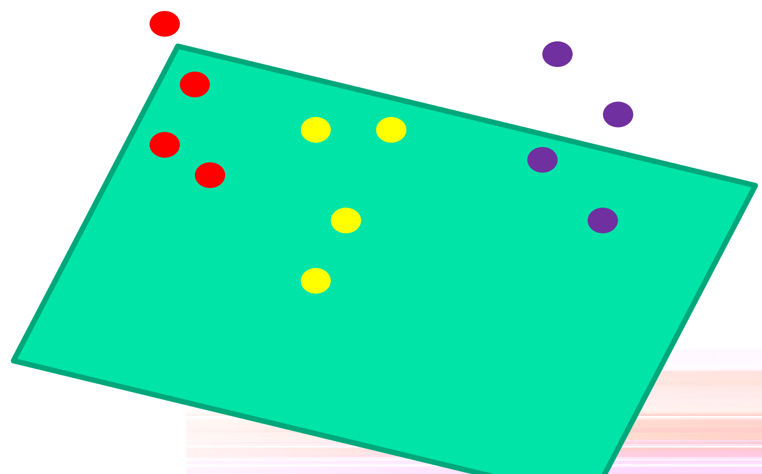
3. Self-assemble (self-organized)自組成(Bottom-up)

Metal organic chemical vapor deposition (MOCVD)



GaN/InN

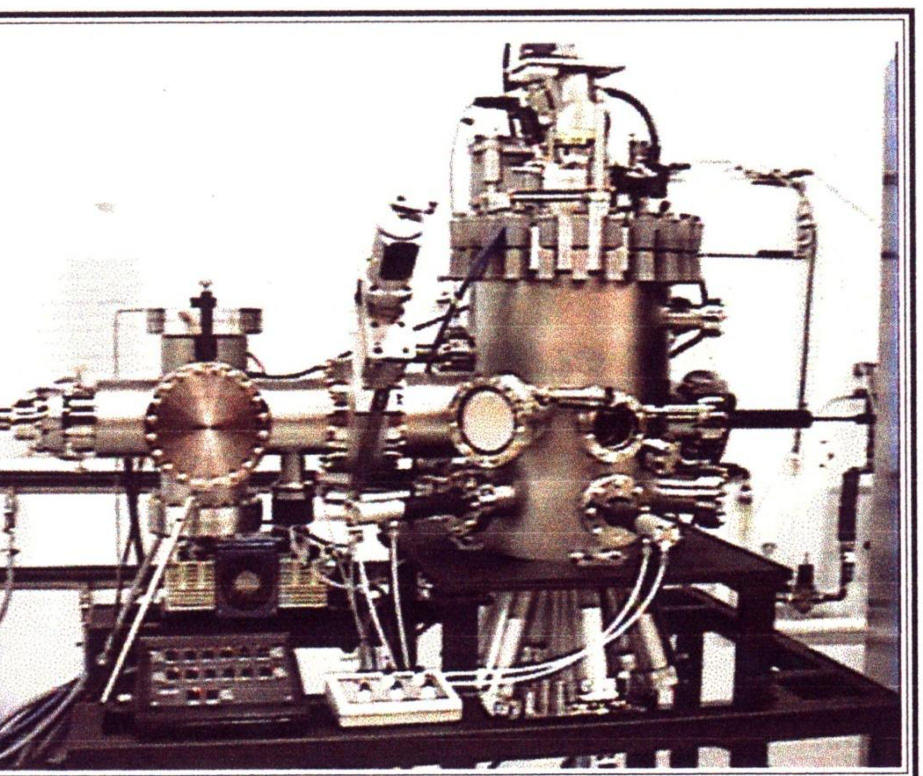
Molecular beam epitaxy分子束磊晶技術



如何製作半導體奈米結構?

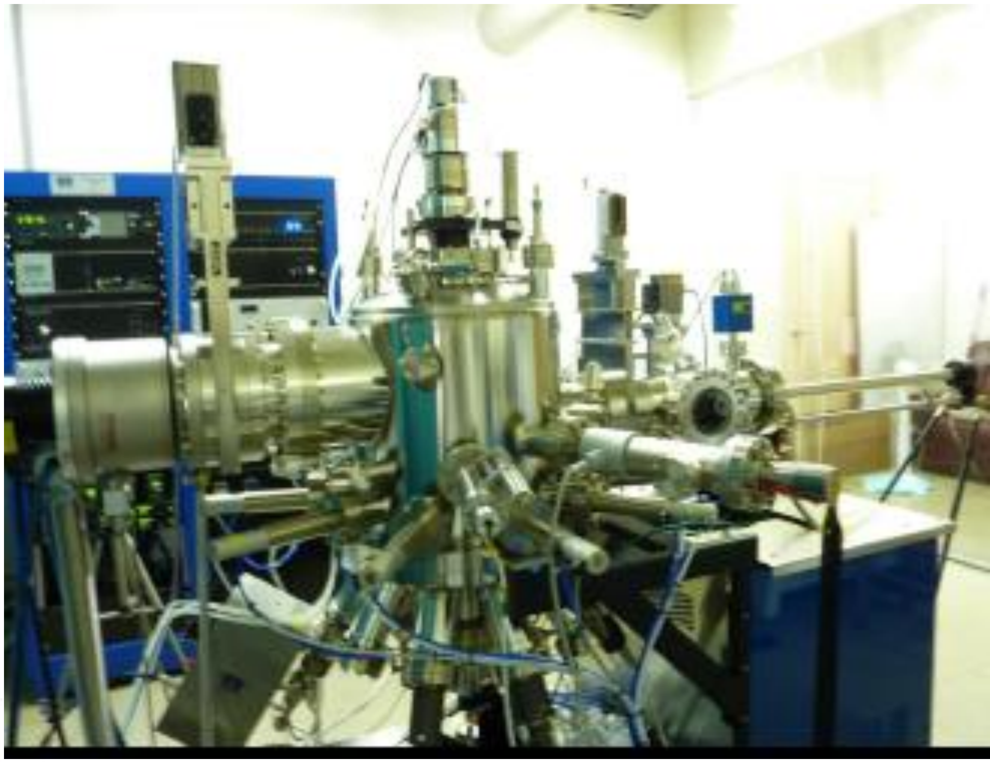
Self-assemble (self-organized)自組(Bottom-up)分子束磊晶技

EPI
Model 620
Molecular Beam Epitaxy System



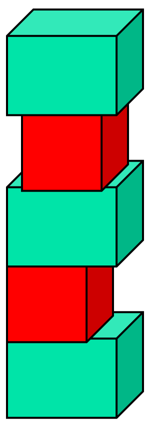
e: 11/96

SVT molecular beam epitaxy (MBE) system

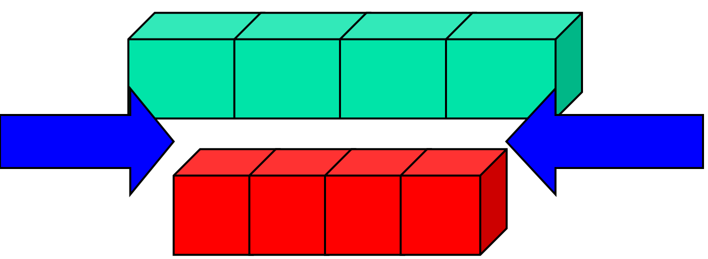


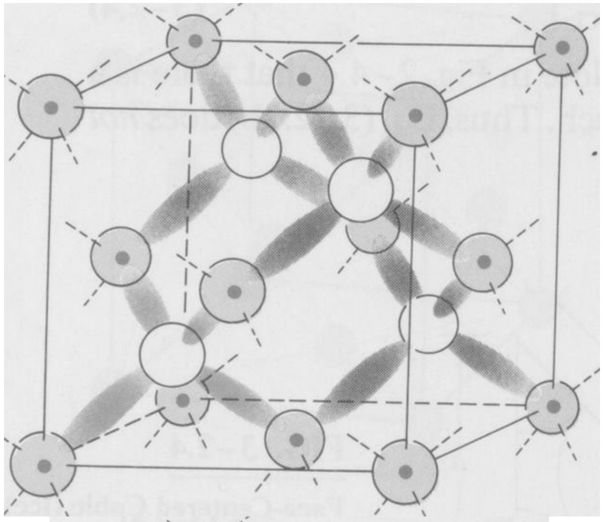
超高真空操作程序與重要性、分子束源種類及調控磊晶速率

Hetero-structure epitaxy 異質結構磊晶



Compressive strain 壓縮應變

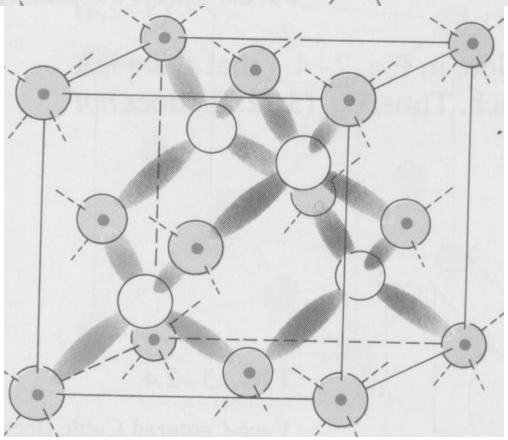




Zn

Te

Eg=2.4 V



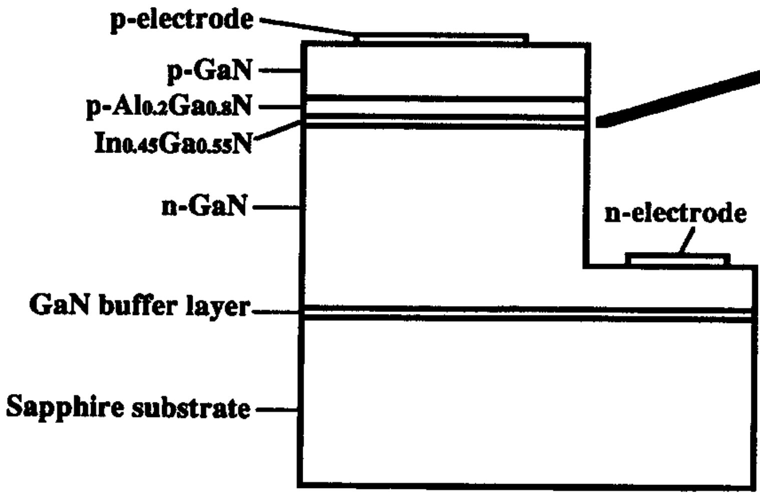
Zn

Se

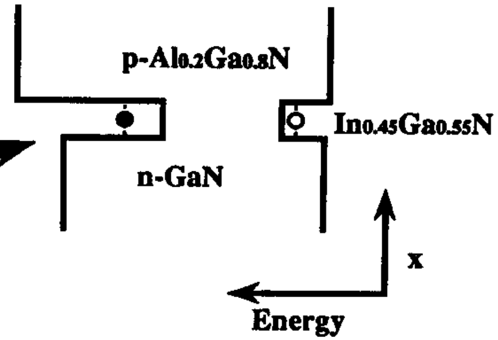
Eg=2.8 V

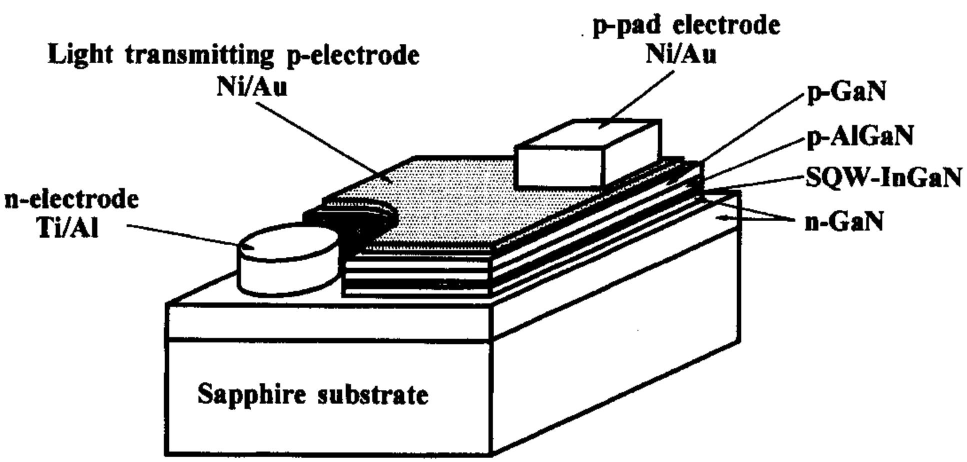
原子排列與堆疊 魔術師:操控晶格常數 能隙等

InGaN green SQW LEDs

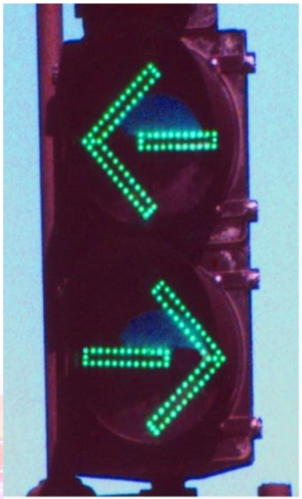


The structure of a green SQW LED





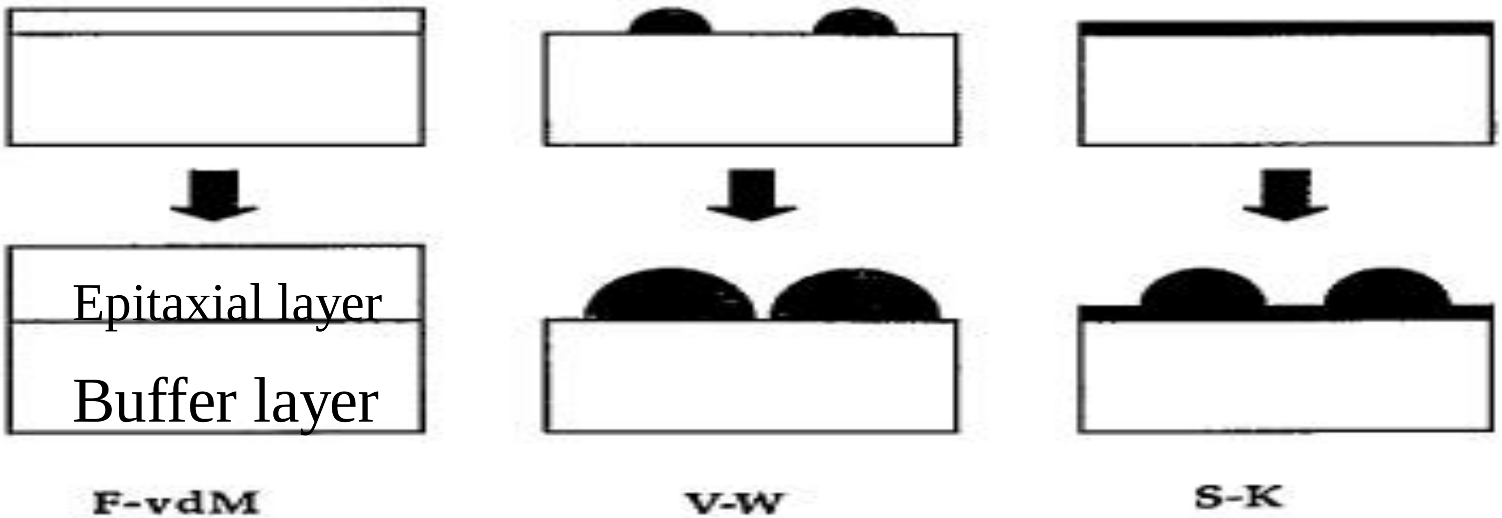
Schematic drawing of the SQW LED



D.J. Eaglesham and M. Cerullo, PRL 64, 1943 (1990)

Self-assembled nanostructures, Self-organized quantum dots (QDs)

自聚性量子點



WL

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)**

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

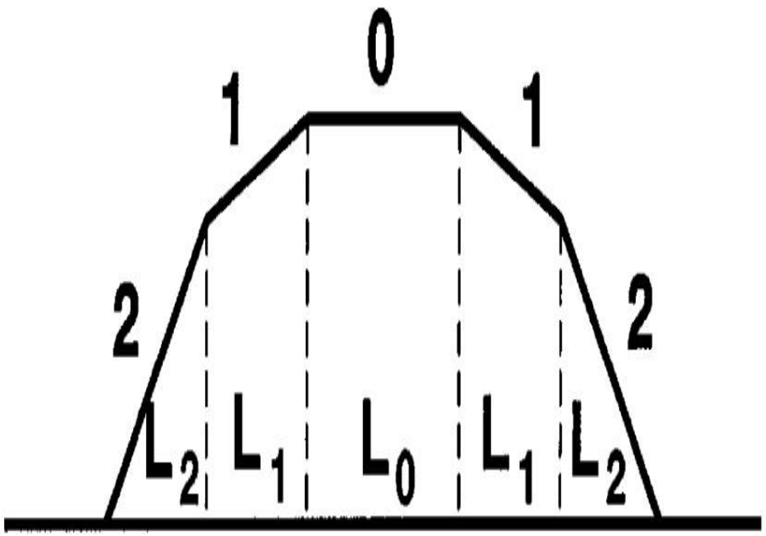
$$E_{ml}(n_1) = \int dn \{G + \Delta[\Theta(1-n) + \Theta(n-1)\, e^{-(n-1)/a}]\}$$

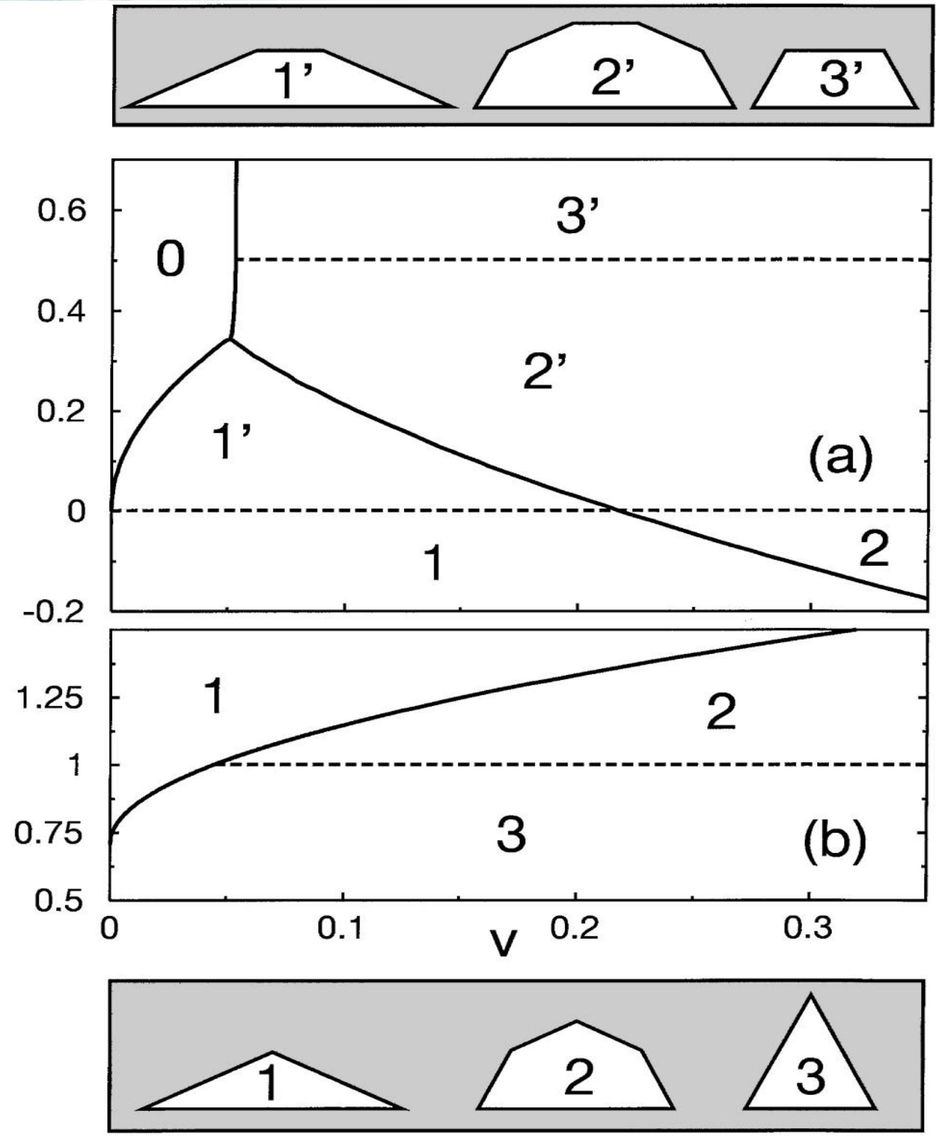
$$G = C\varepsilon^2 - \Phi_{AA}, \quad \Delta = \Phi_{AA} - \Phi_{AB}$$

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

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

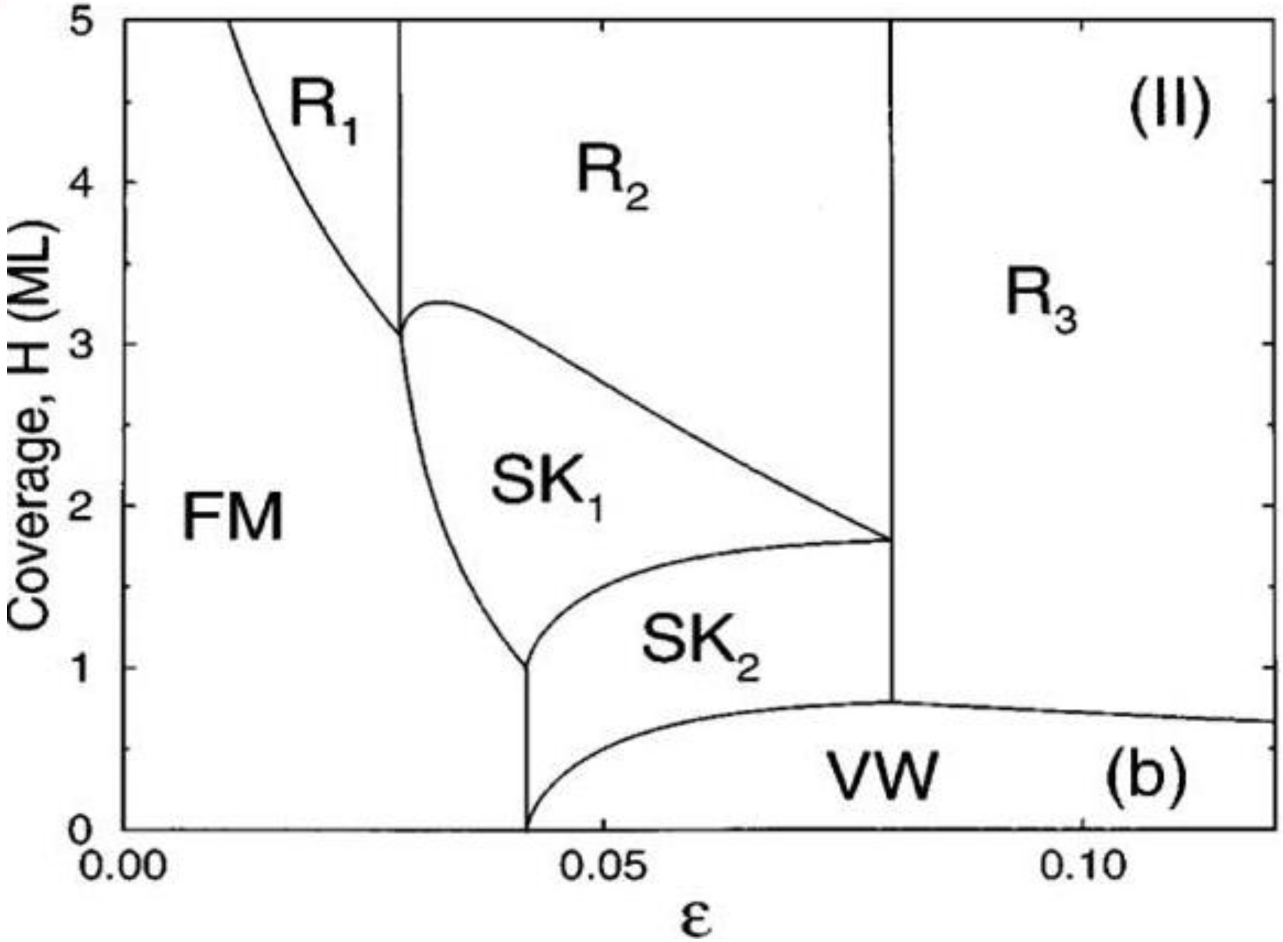
I. Daruka and A.L. Barabasi, APL 72, 2102 (1998)





Key: strained islands **change shape during growth**, **phase diagram**, **surface energy controls the sequence of island shapes**.

I Daruka et al., PRL 82, 2753 (1999)

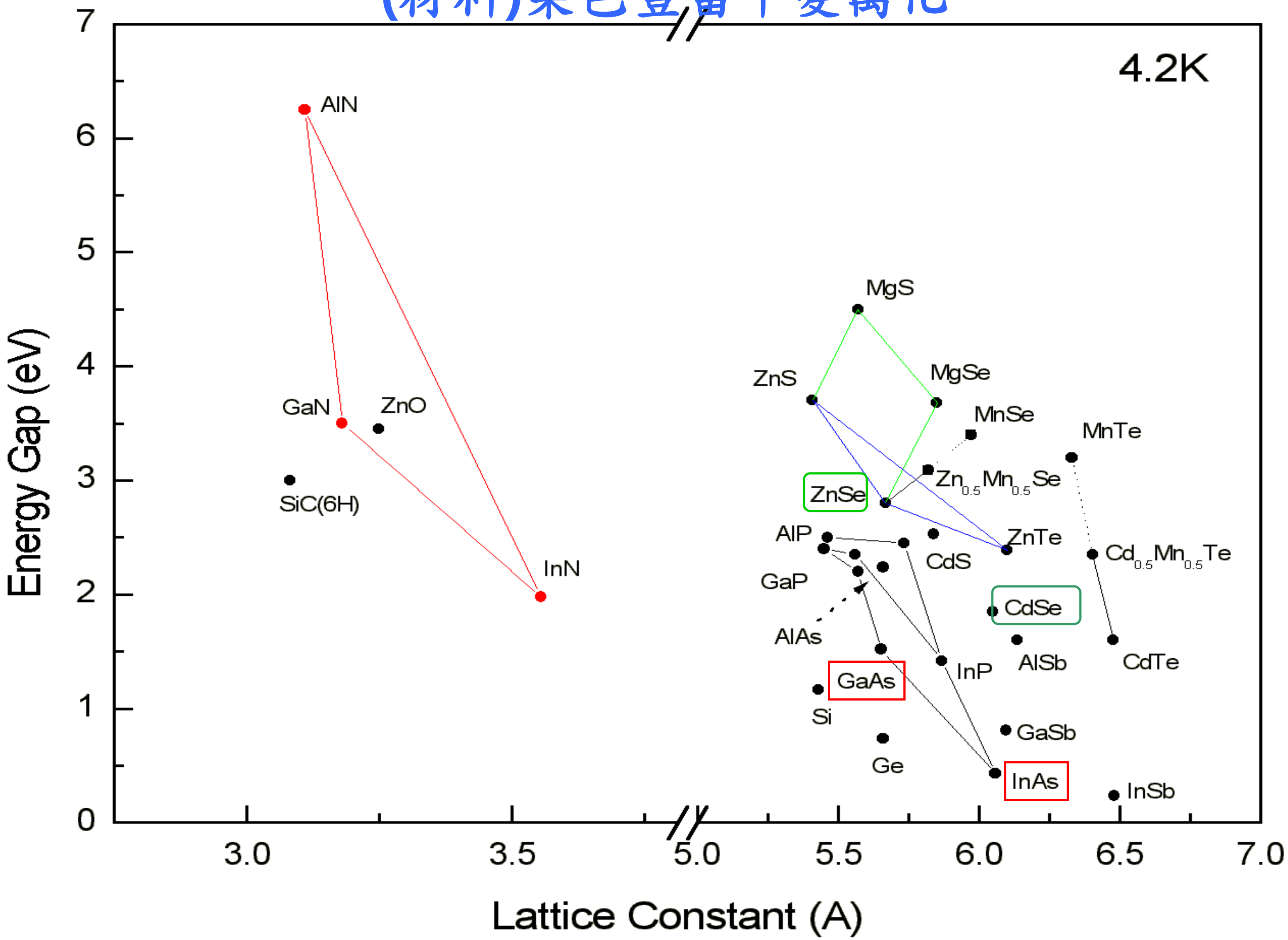


$$u(H, n_1, n_2, \varepsilon) = E_{ml}(n_1) + n_2 E_{isl} + (H - n_1 - n_2)E_{rip}$$

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

Energy Gap vs Lattice Constant

(材料)菜色豐富千變萬化



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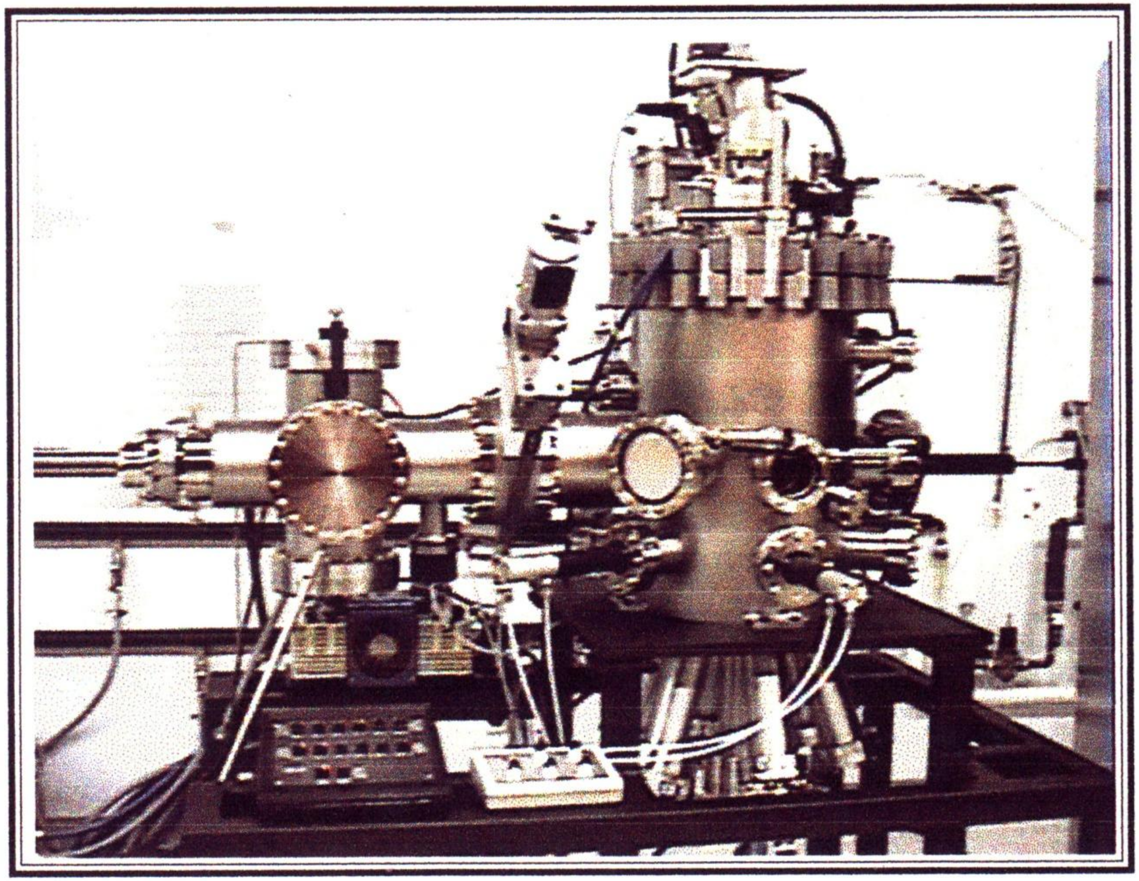
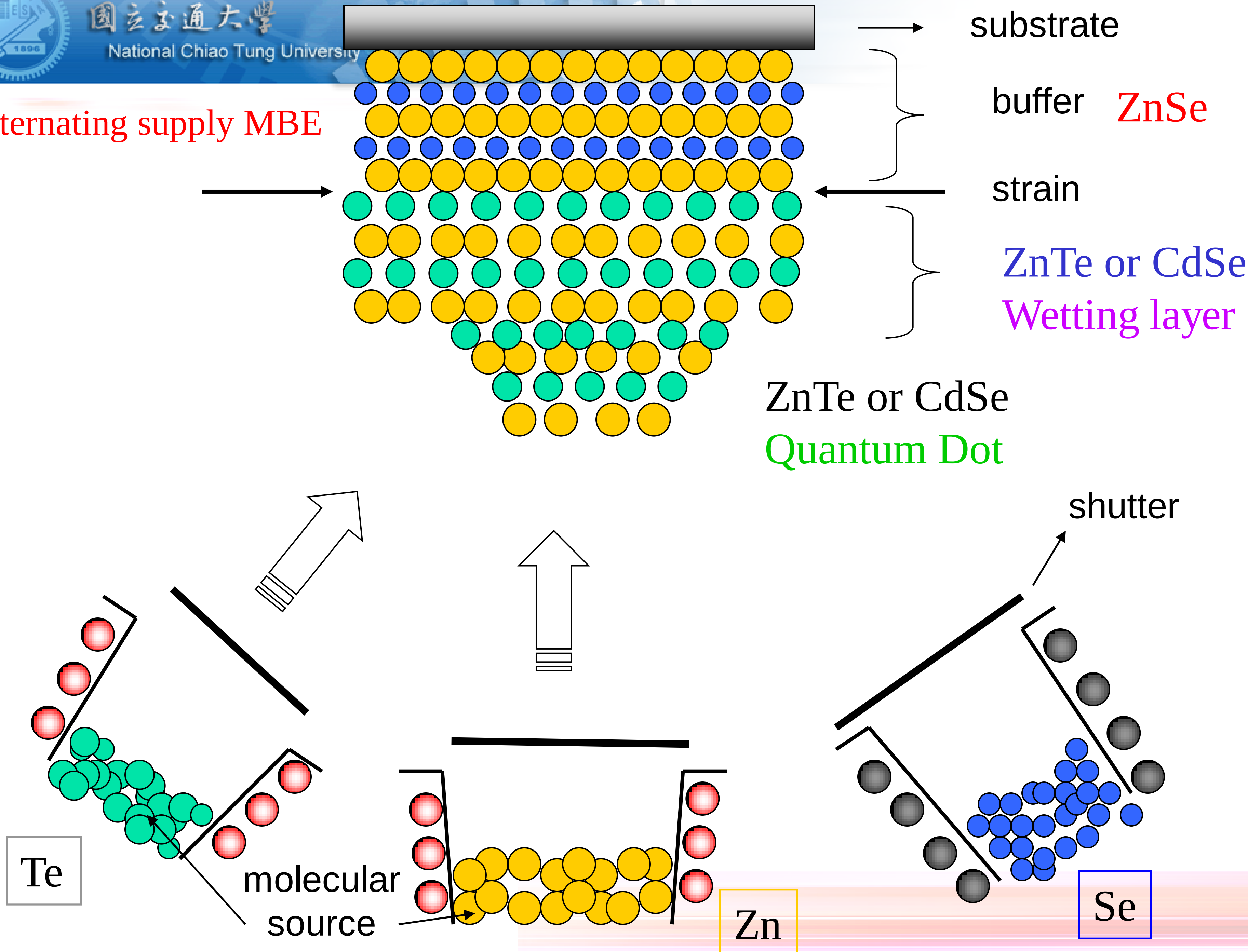


Rev Date: 11/96

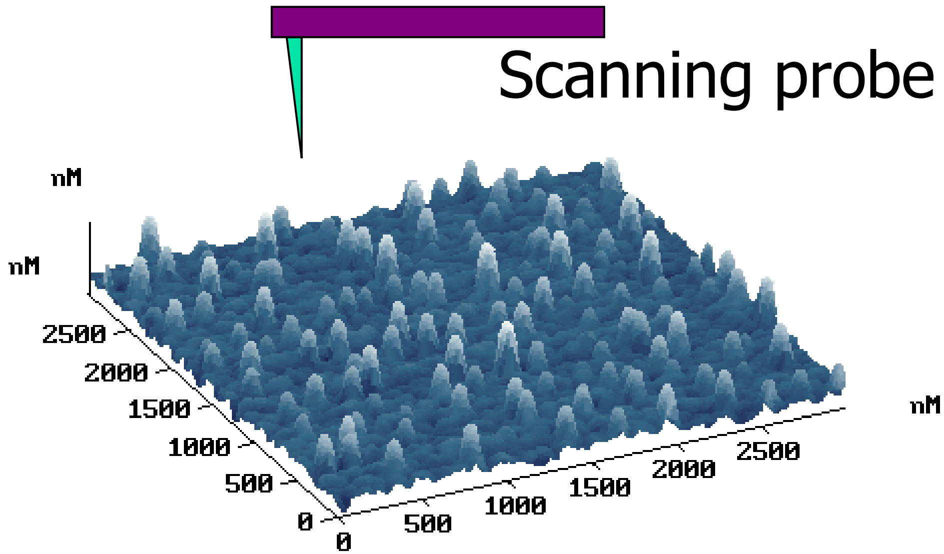
超高真空操作程序與重要性、分子束源種類及調控磊晶速率

Alternating supply MBE



Atomic force microscopy, AFM

Scanning probe microscopy



1982IBM蘇黎世研究所的Gerd Binnig和Heinrich Rohrer及其同事研製第一臺達到原子分辨解析度的表面分析儀器，掃描穿隧顯微鏡(Scanning Tunneling Microscope, STM)。1986G. Binnig和同事發明原子力顯微鏡(Atomic Force Microscopy, AFM)。 (Note:scanning, computer control bit)

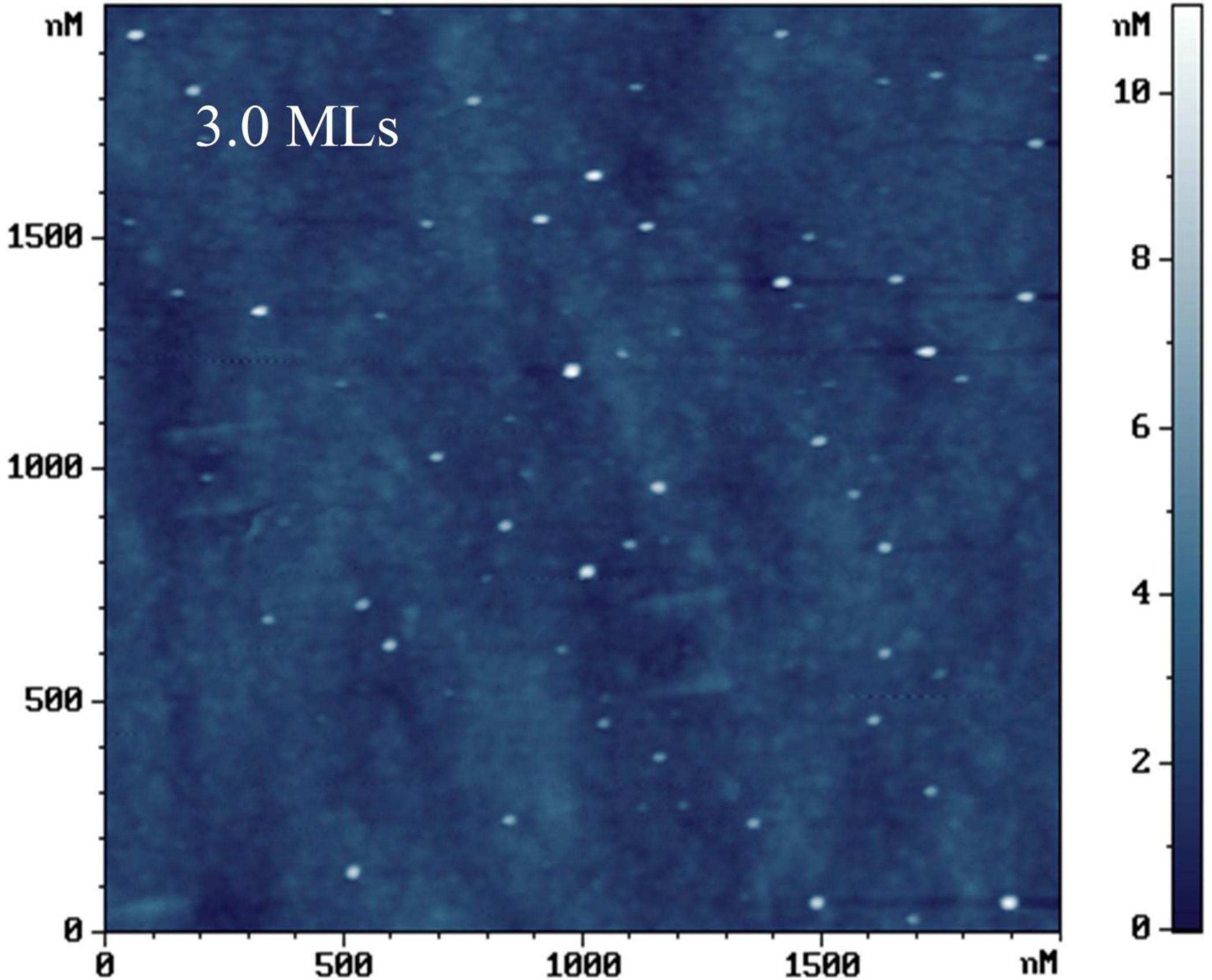
Scanning probe microscopy (SPM), SNOM

Gerd Binnig

Heinrich Rohrer

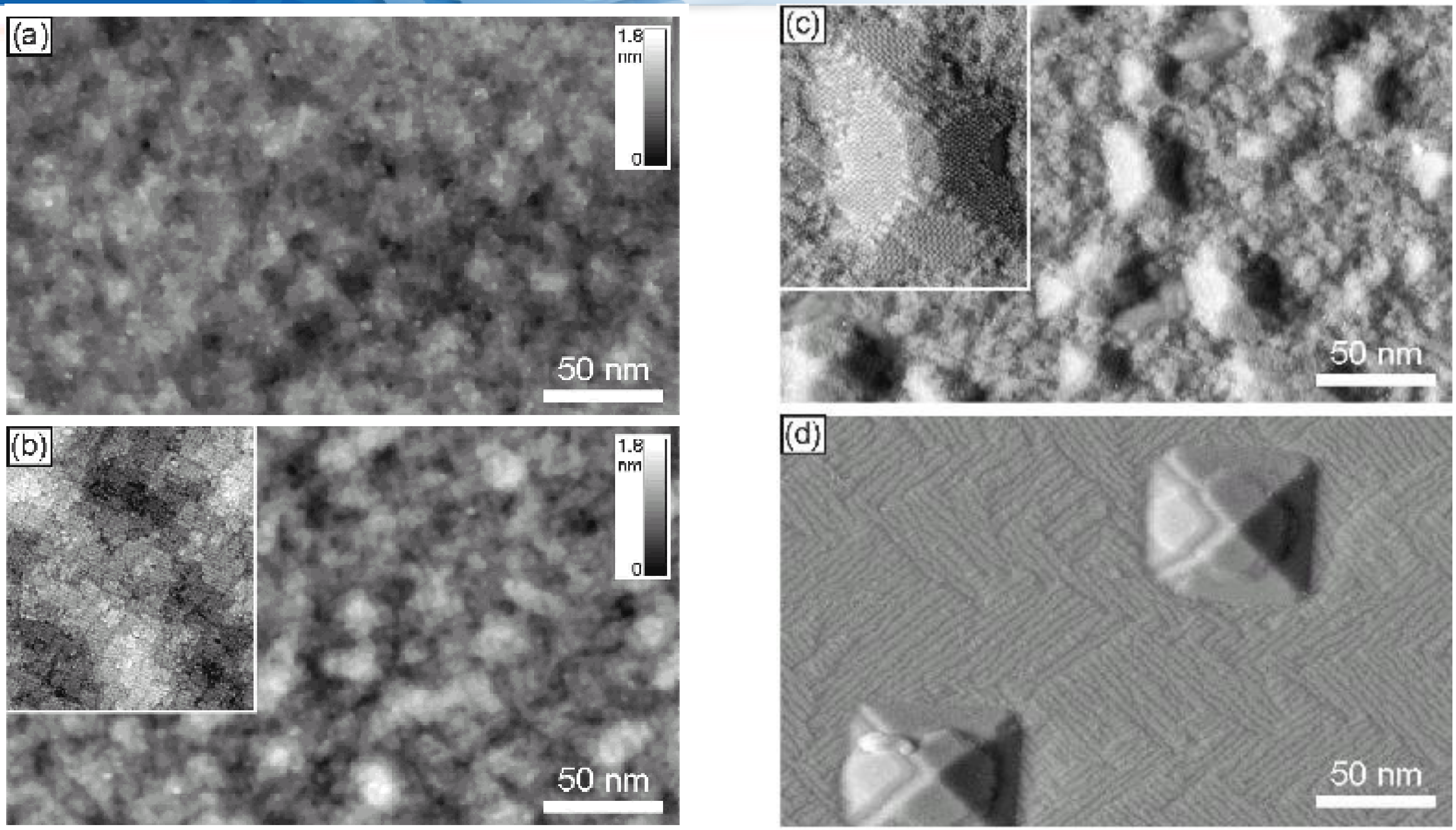
The Nobel Prize in Physics 1986

"for their design of the scanning tunneling microscope"



碲化鋅量子點之表面高低(明暗)形貌直徑約10-30奈米 AFM

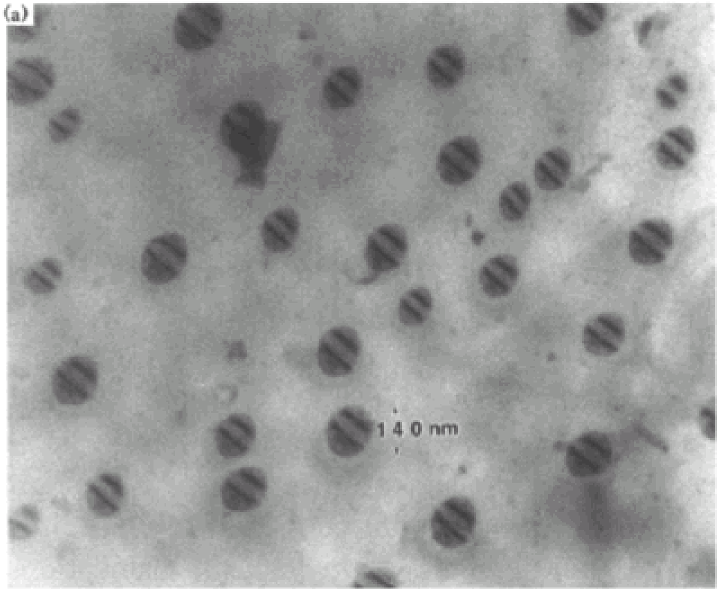
半導體奈米結構之形狀

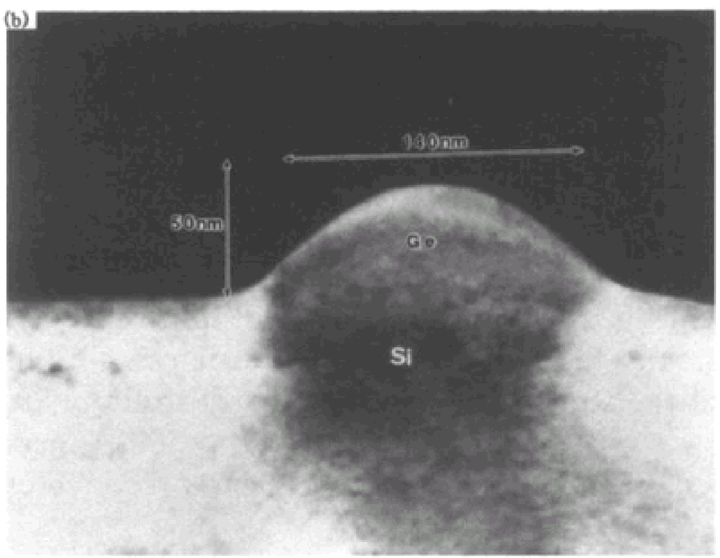


In situ **scanning tunneling microscopy study of C-induced Ge quantum dot formation on Si(100)**

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

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





D. J. Eaglesham and M. Cerullo

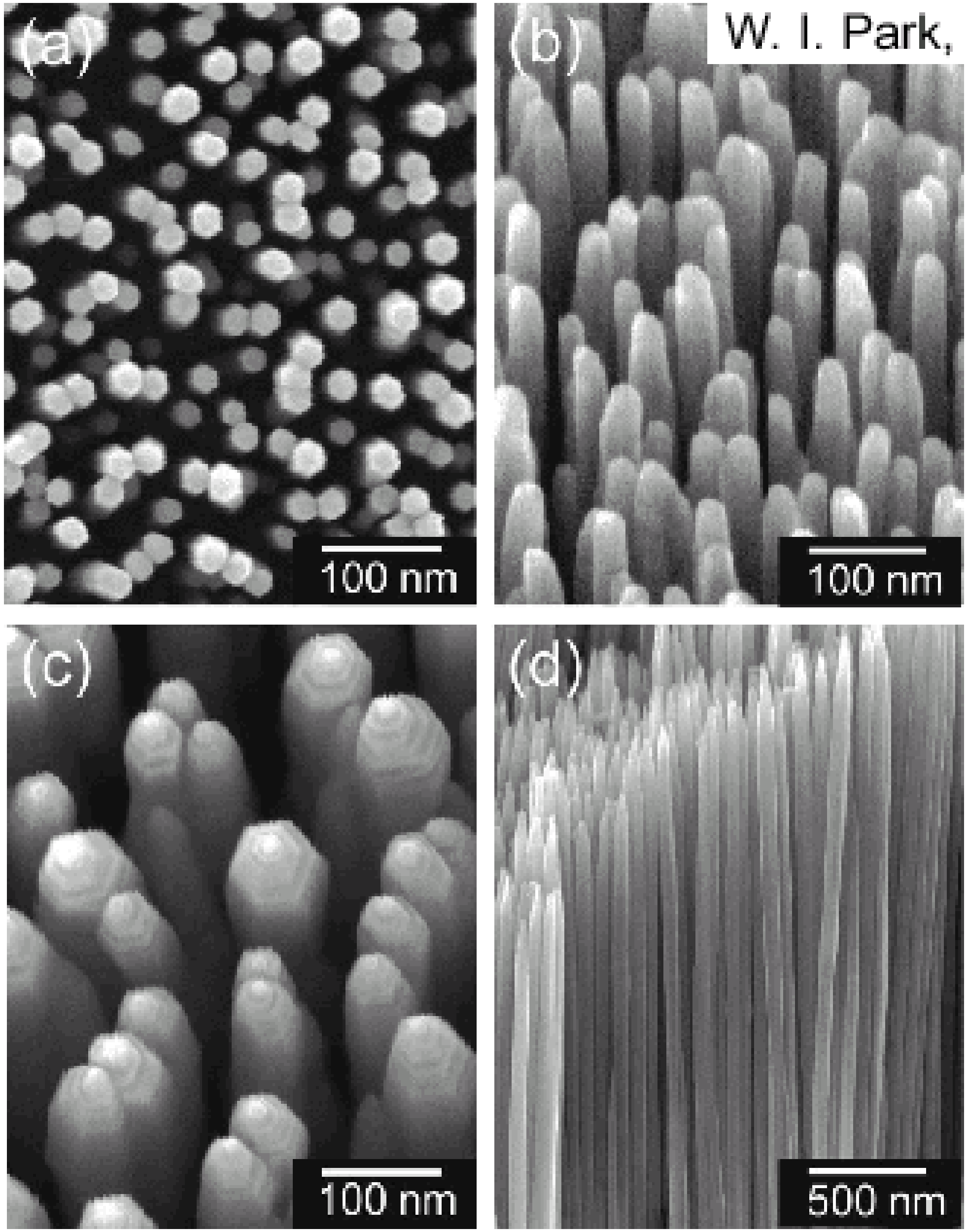
PRL64, 1943 (1990)

dome-shaped

半導體奈米結構之形狀

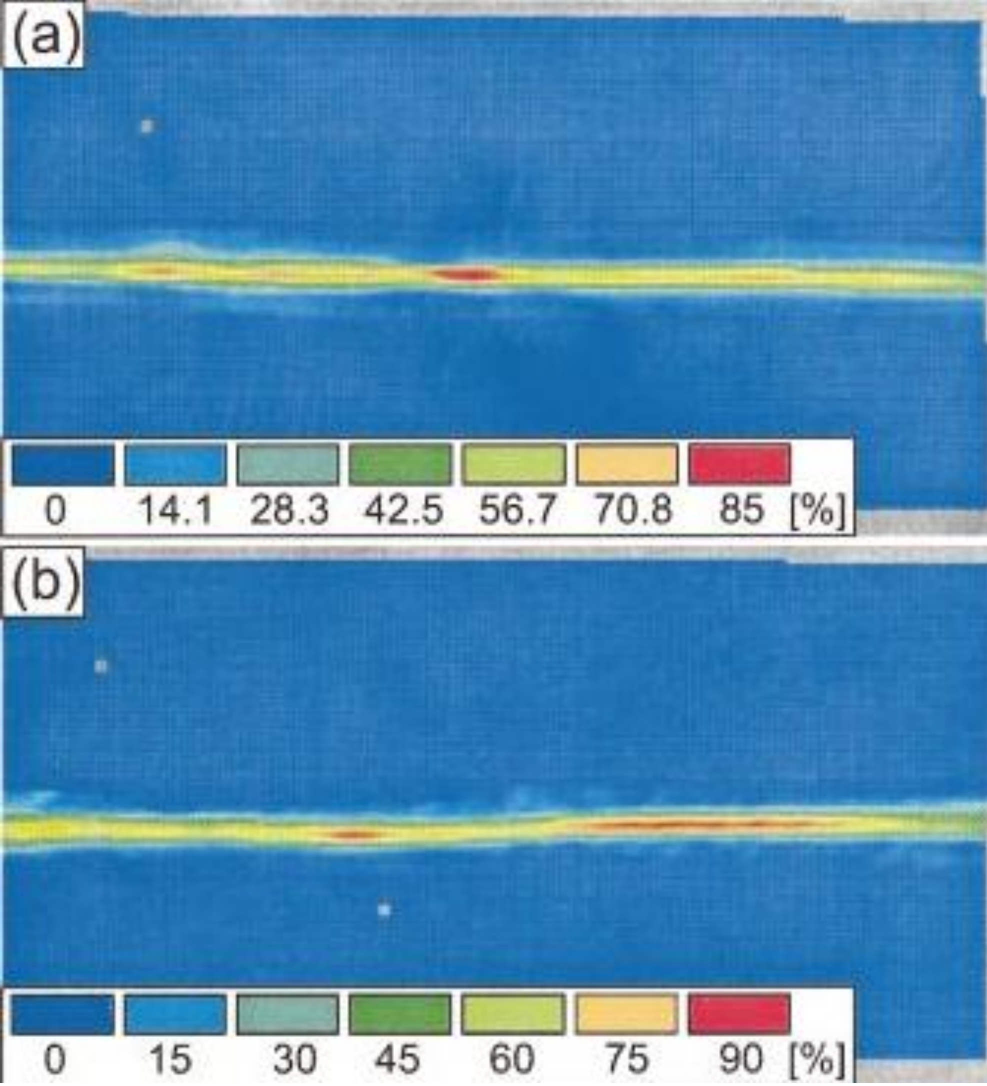
Metalorganic vapor-phase epitaxial growth of vertically well-aligned ZnO nanorods

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

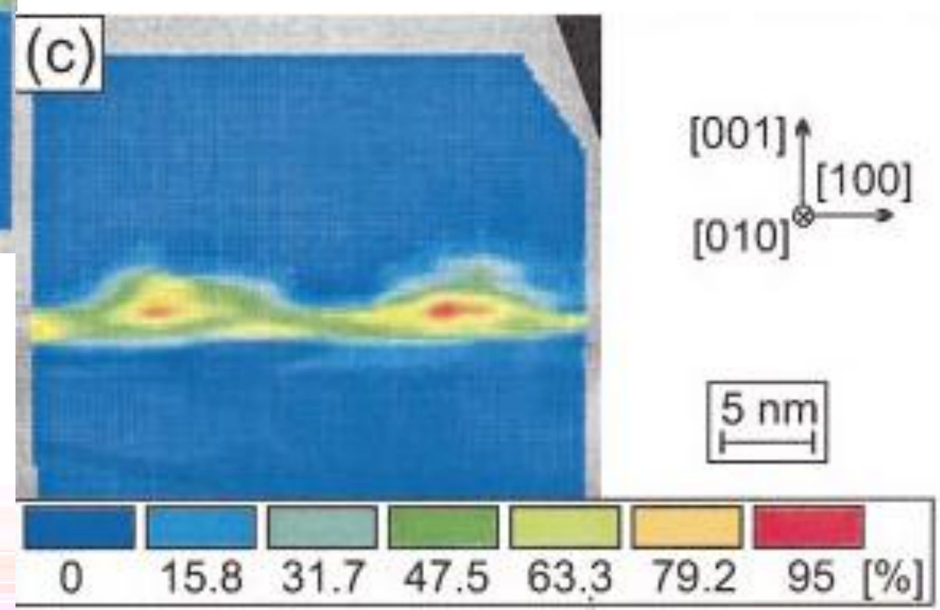


APL80, 4232 (2002)

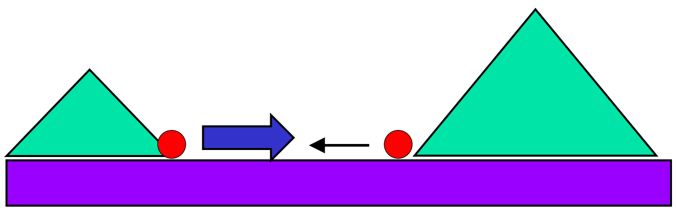
半導體奈米結構之形狀



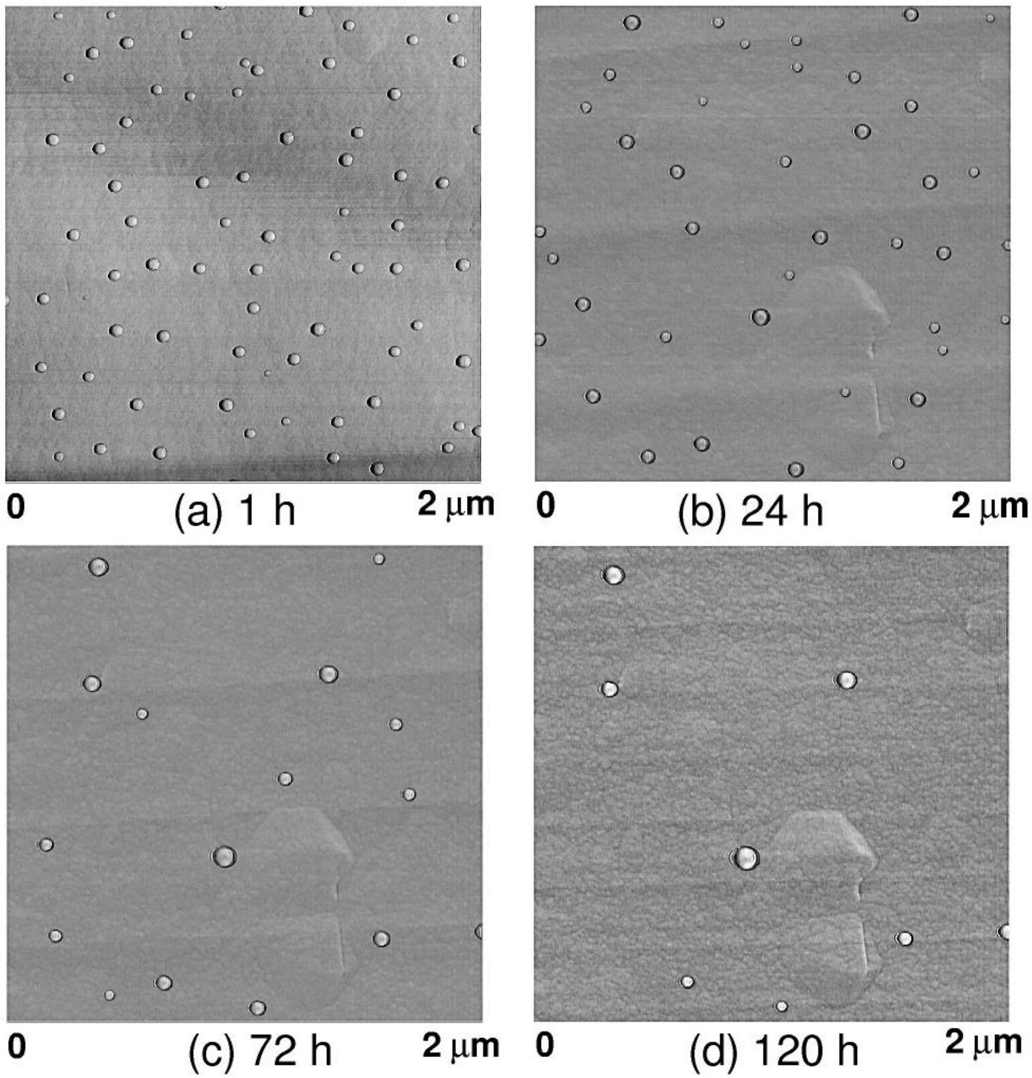
Ref. D. Litvinov et al.
APL 81, 640 (2002)

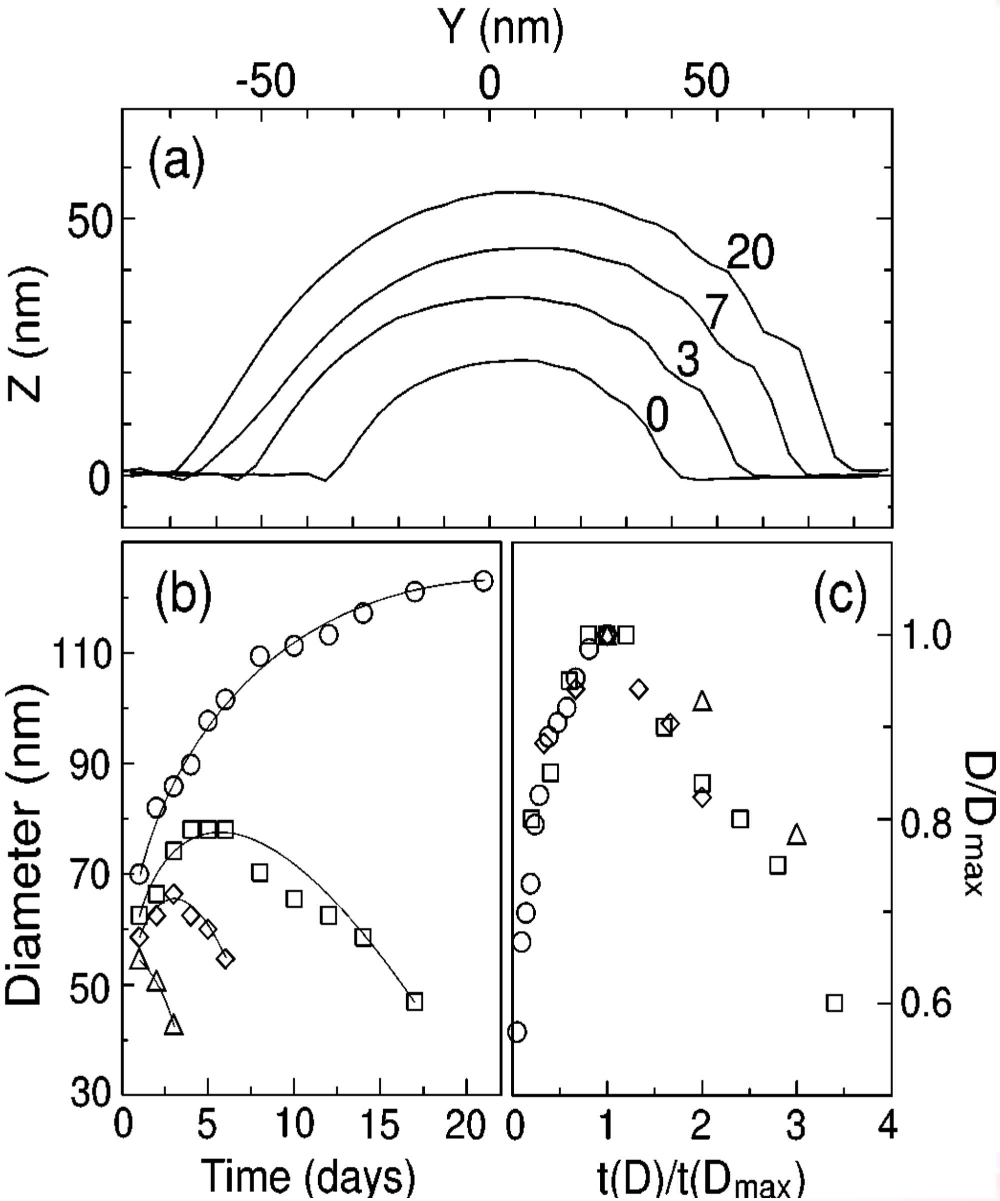


Dynamics of Ripening of Self-Assembled II-VI Semiconductor Quantum Dots



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



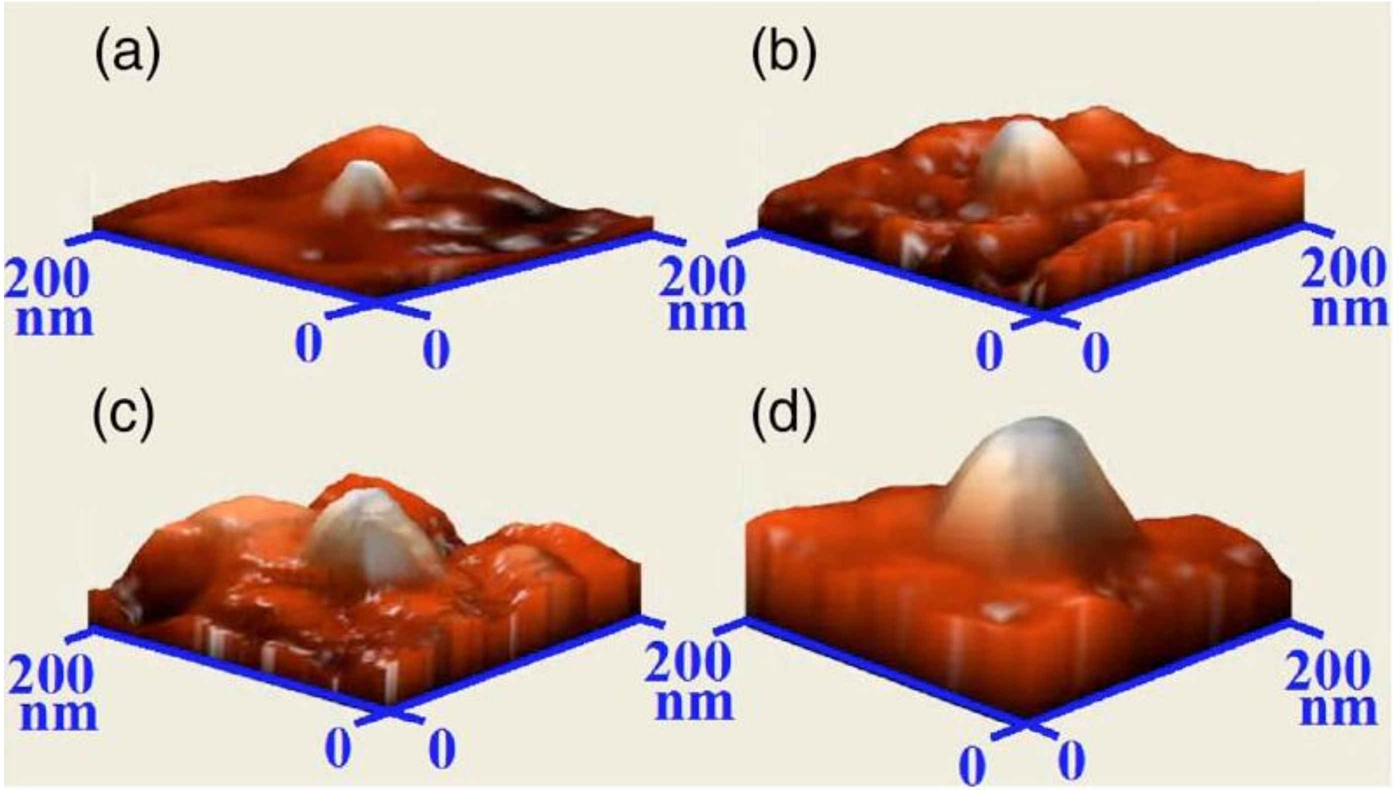


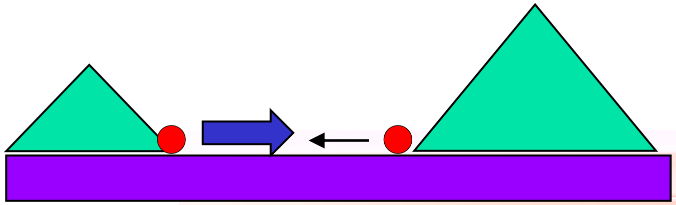
Ref. S.Lee et al., Phys. Rev. Lett. 81, 3479 (1998)

Self-similarity

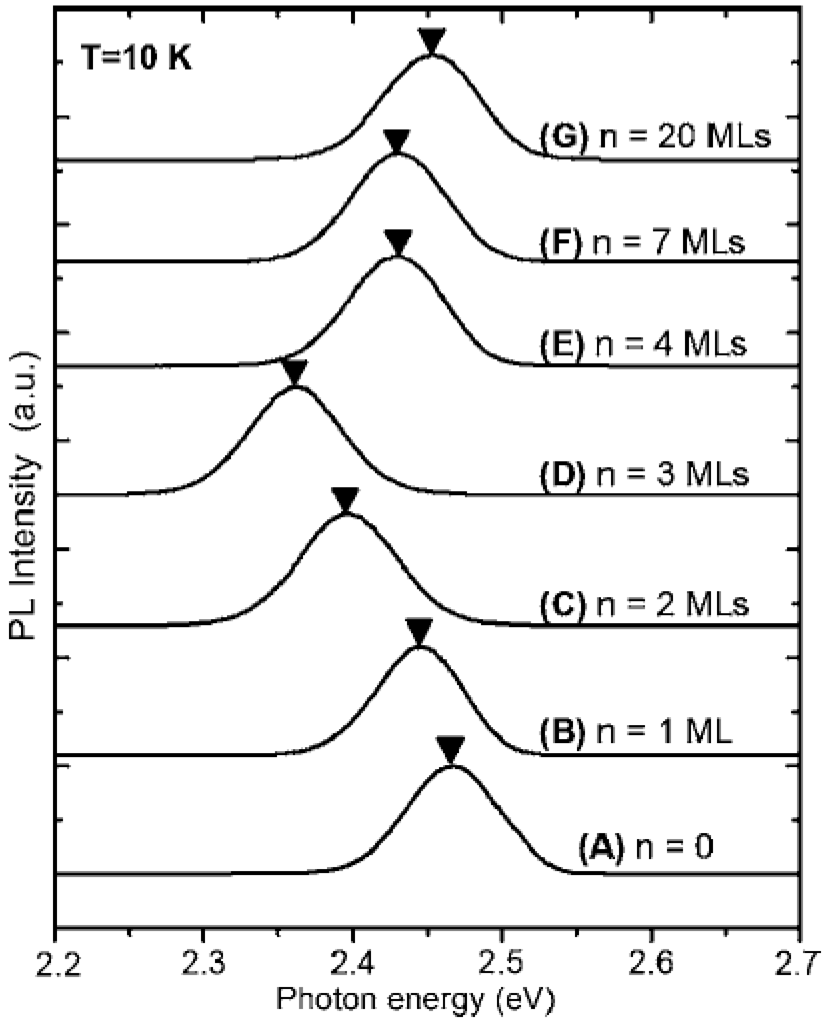
APPLIED PHYSICS LETTERS **90, 083116 2007**

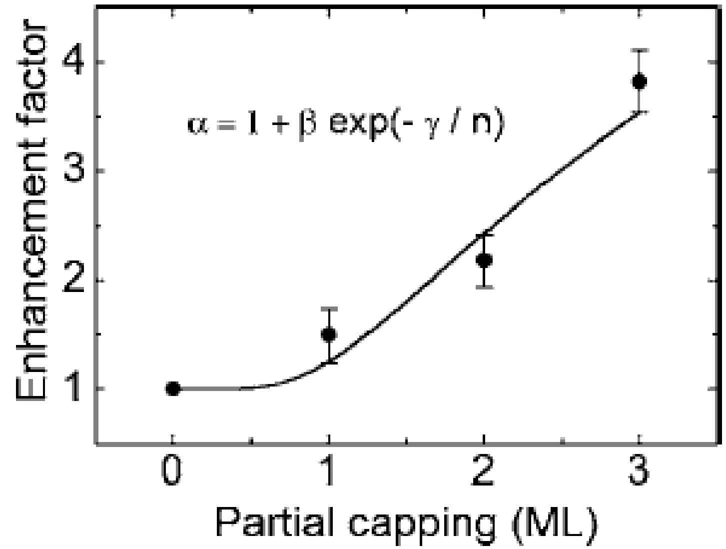
Effect of ZnSe partial capping on the ripening dynamics of CdSe quantum dots





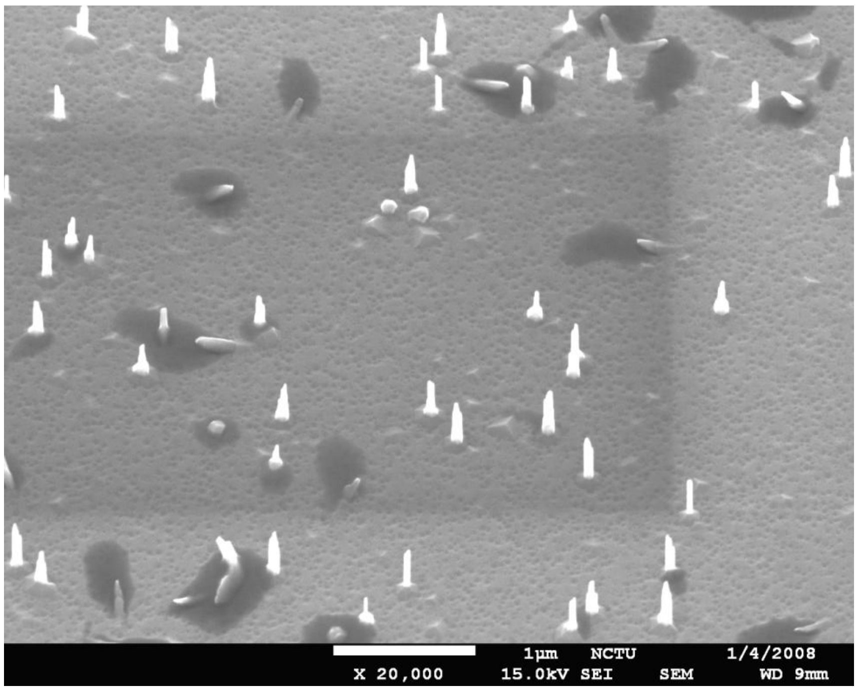
Effect of ZnSe partial capping on the ripening dynamics of CdSe quantum dots

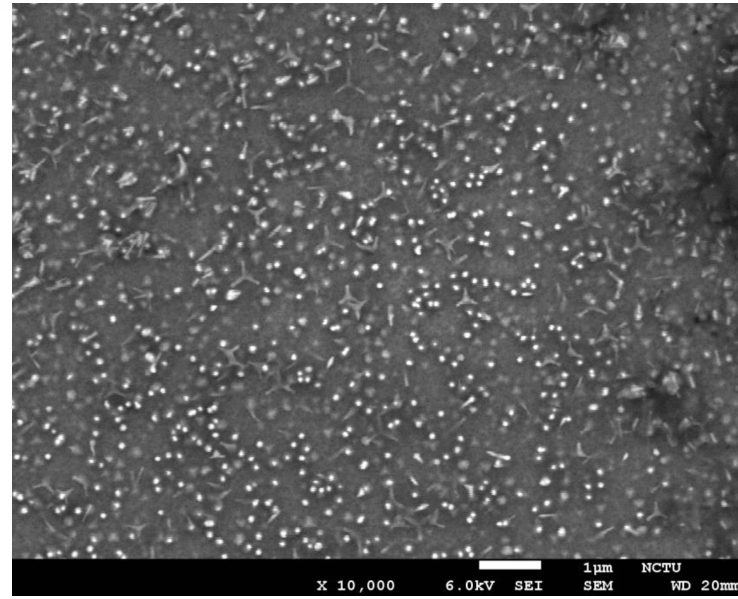


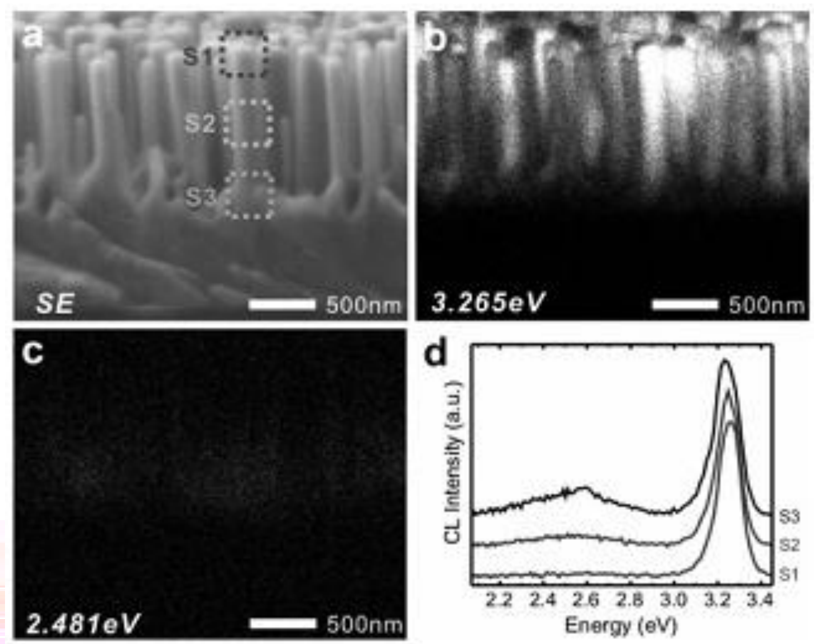


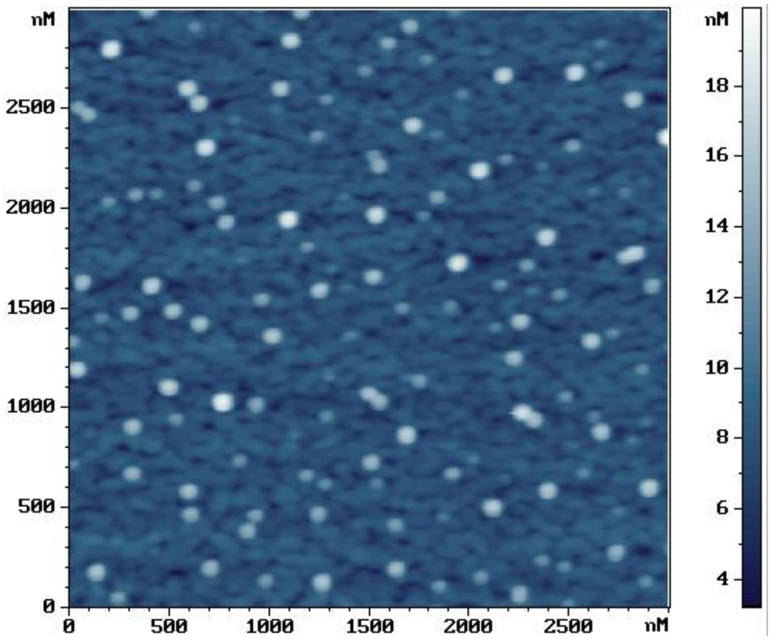
APPLIED PHYSICS LETTERS **90, 083116 2007**

ZnO nano-tip


1μm NCTU 1/4/2008
X 20,000 15.0kV SEI SEM WD 9mm

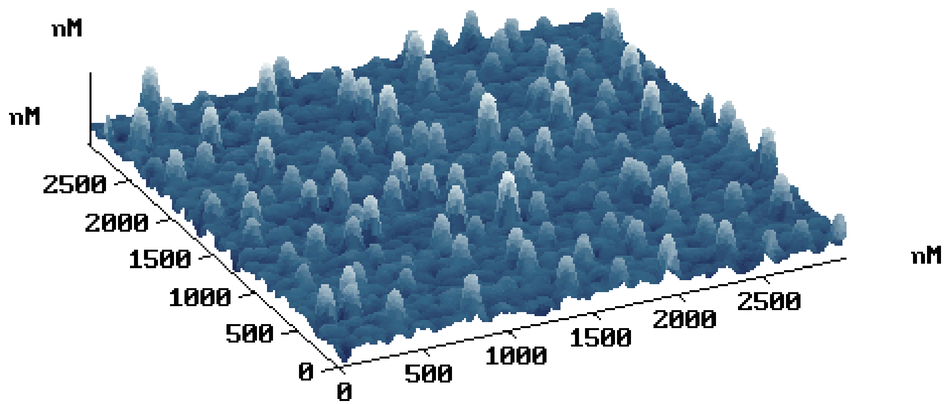

1μm NCTU
X 10,000 6.0kV SEI SEM WD 20mm


a
S1
S2
S3
SE
500nm
b
3.265eV
500nm
c
2.481eV
500nm
d
CL Intensity (a.u.)
Energy (eV)
2.2 2.4 2.6 2.8 3.0 3.2 3.4
S3
S2
S1



CdSe (3.0 MLs)/ZnSe/GaAs

Issue of size distribution



Competing of strain and surface energy.

Issues of size distribution.

Issues of ripening.