



清華大學物理系 奈米物理特論 2011/04/07 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

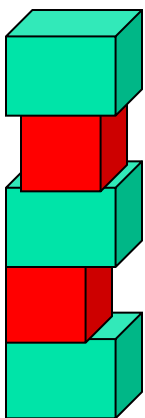
Part II: 半導體奈米結構光電特性---Photoluminescence

Part III: 半磁性半導體奈米結構之自旋磁光特性

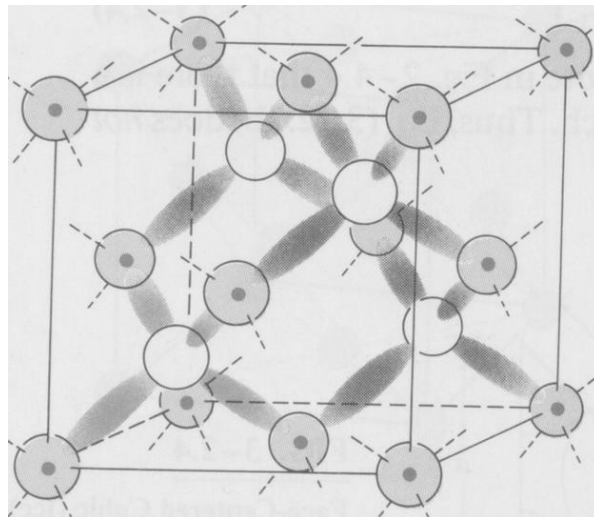
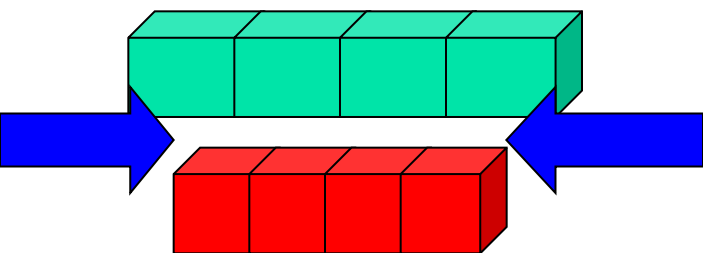




Hetero-structure epitaxy 異質結構磊晶



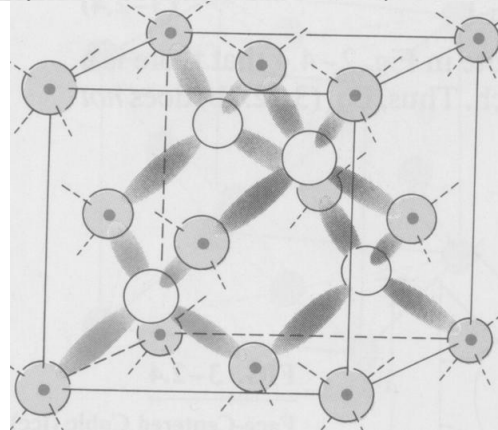
Compressive strain 壓縮應變



● Zn

○ Te

$E_g = 2.4 \text{ V}$



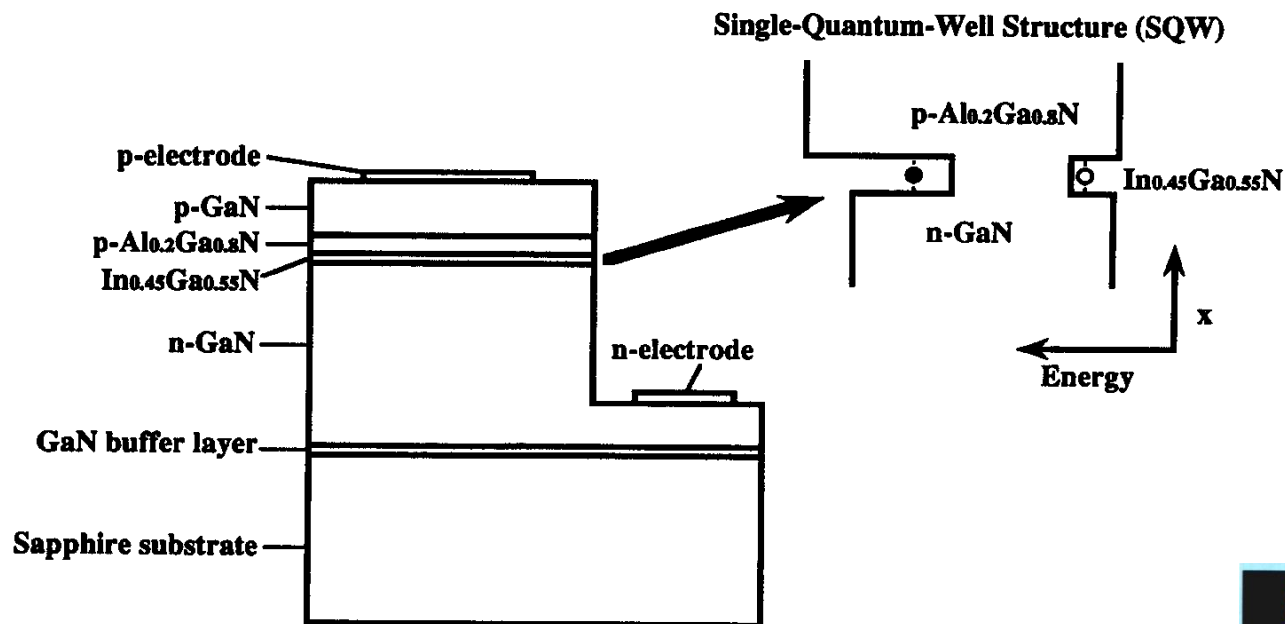
● Zn

○ Se

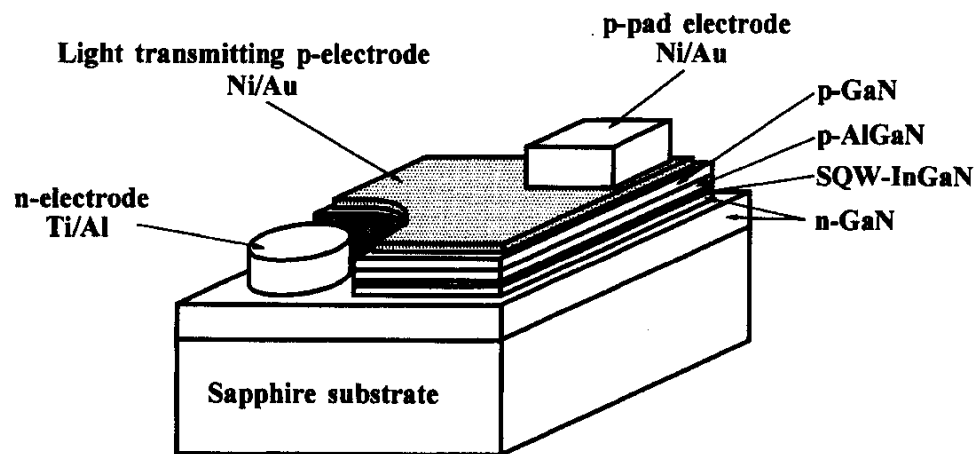
$E_g = 2.8 \text{ V}$

原子排列與堆疊 魔術師:操控晶格常數 能隙等

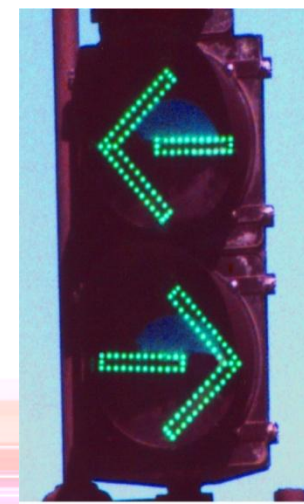
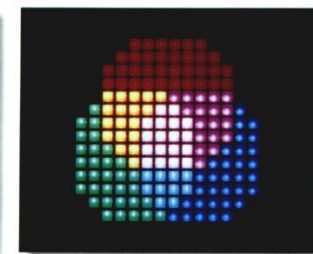
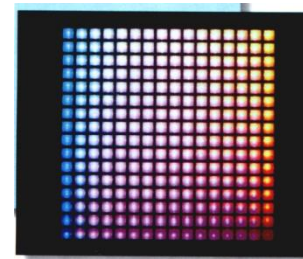
InGaN green SQW LEDs



The structure of a green SQW LED



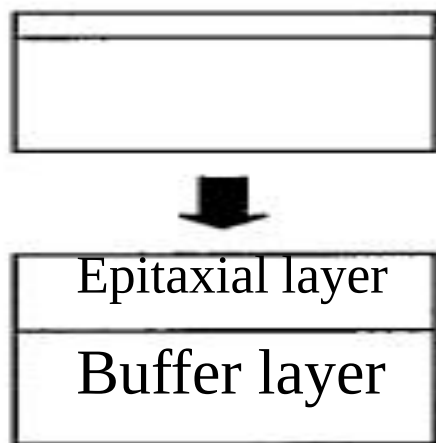
Schematic drawing of the SQW LED



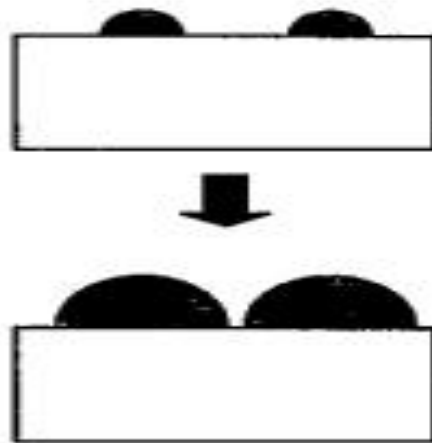


Self-assembled nanostructures, Self-organized quantum dots (QDs)

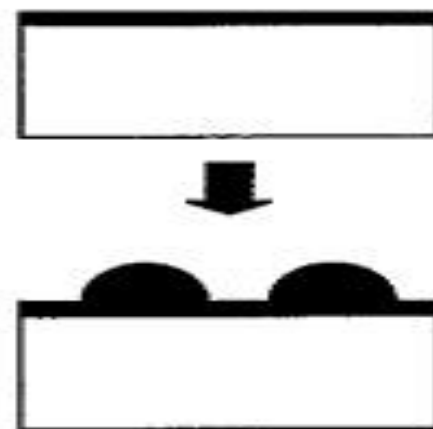
自聚性量子點



F-vdM



V-W



S-K

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)

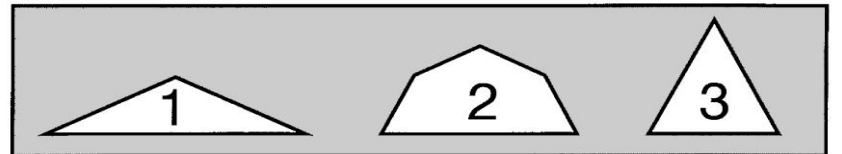
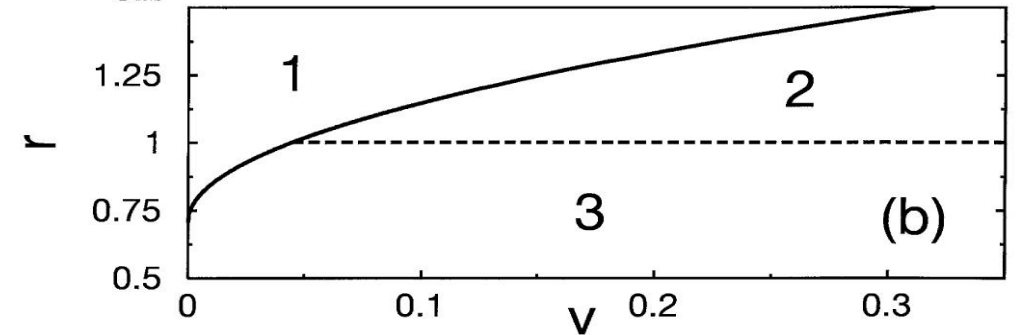
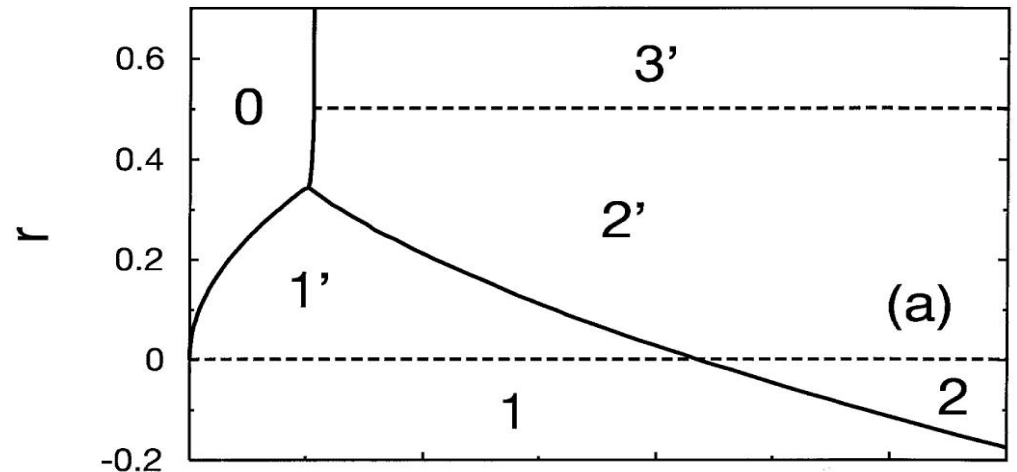
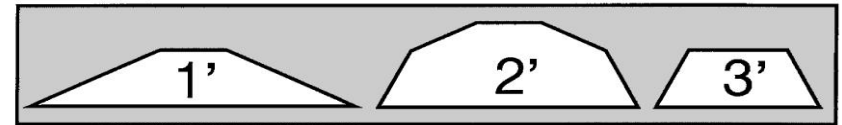
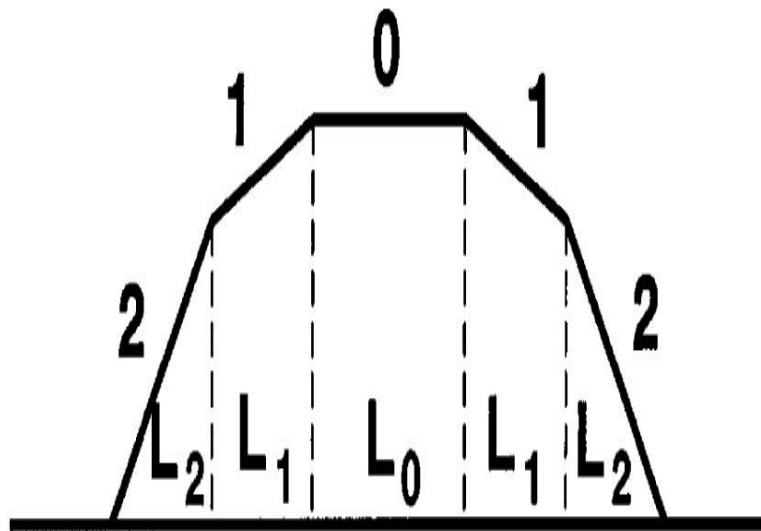
$$u(H, n_1, n_2, \varepsilon) = E_{\text{ml}}(n_1) + n_2 E_{\text{isl}} + (H - n_1 - n_2) E_{\text{rip}}$$

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

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

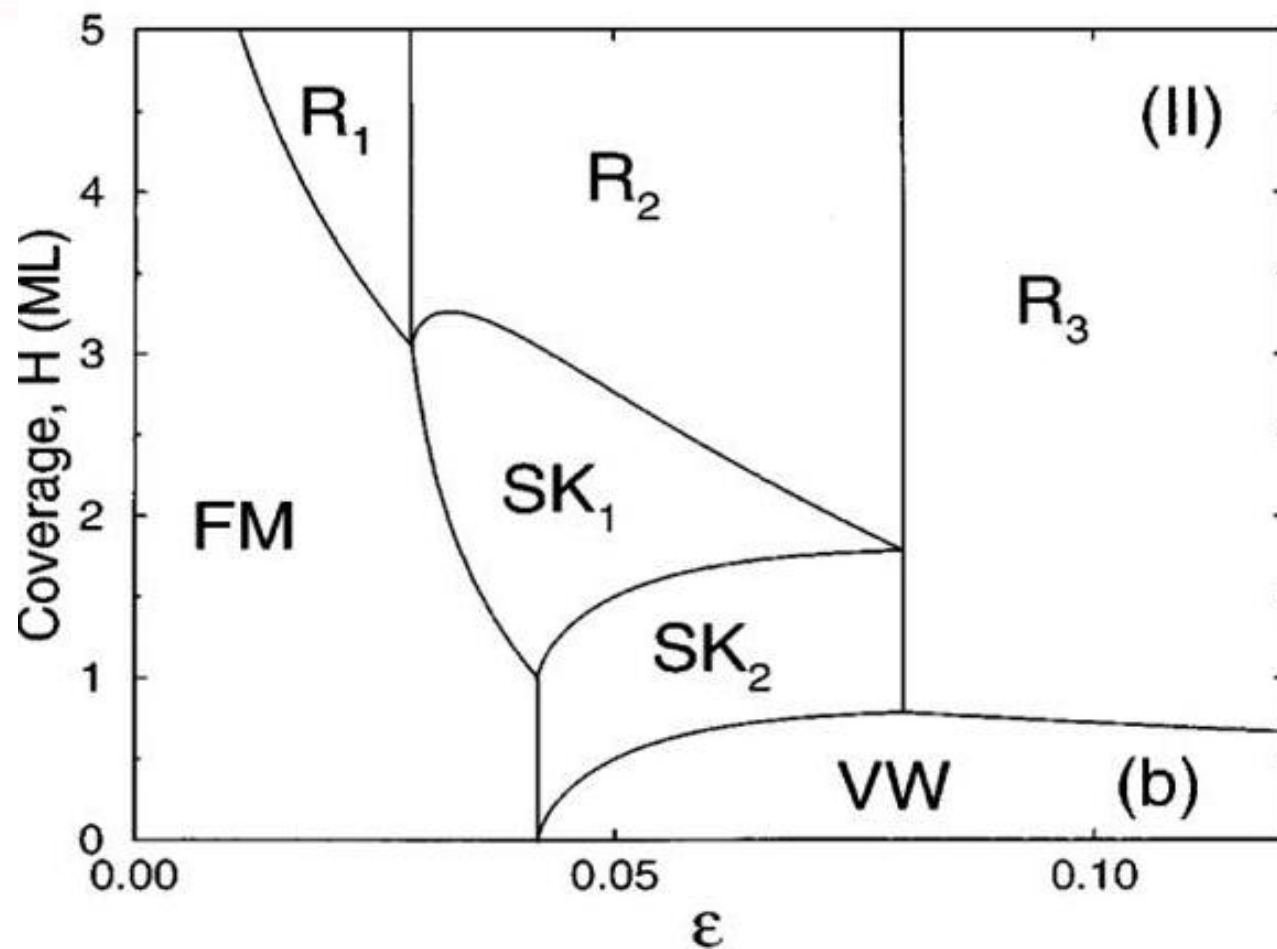
$$E_{\text{rip}} = E_{\text{isl}} (x \rightarrow \infty) = gC\varepsilon^2 - \Phi_{\text{AA}}$$

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



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)



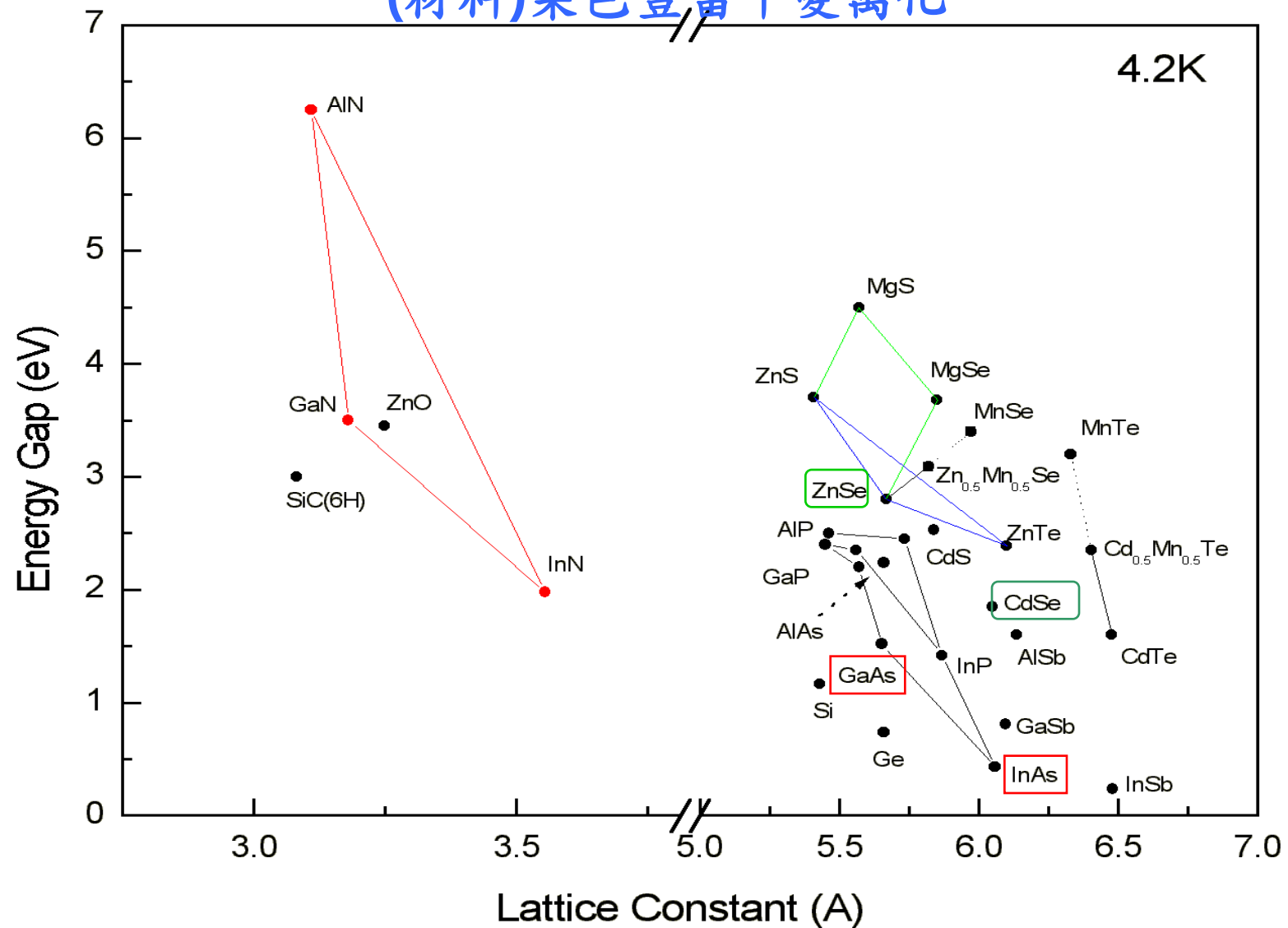
$$u(H, n_1, n_2, \epsilon) = E_{ml}(n_1) + n_2 E_{isl} + (H - n_1 - n_2)E_{rip}$$

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



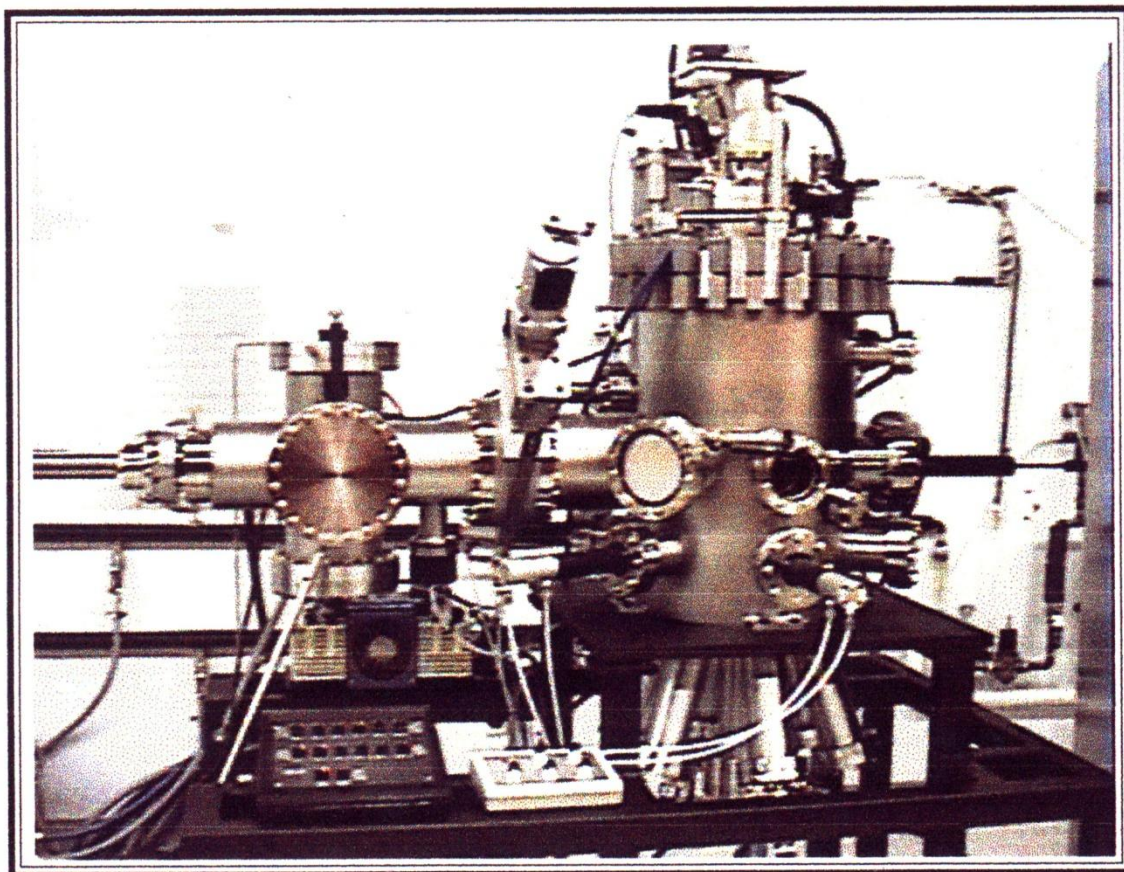
Energy Gap vs Lattice Constant

(材料) 菜色豐富 千變萬化





EPI Model 620 Molecular Beam Epitaxy System

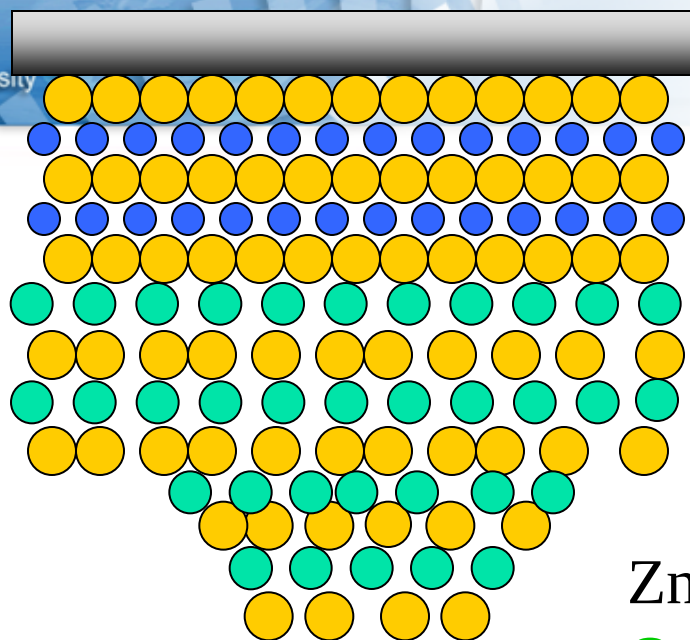


Rev Date: 11/96

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

Alternating supply MBE

Atomic Layer Epitaxy
(ALE)



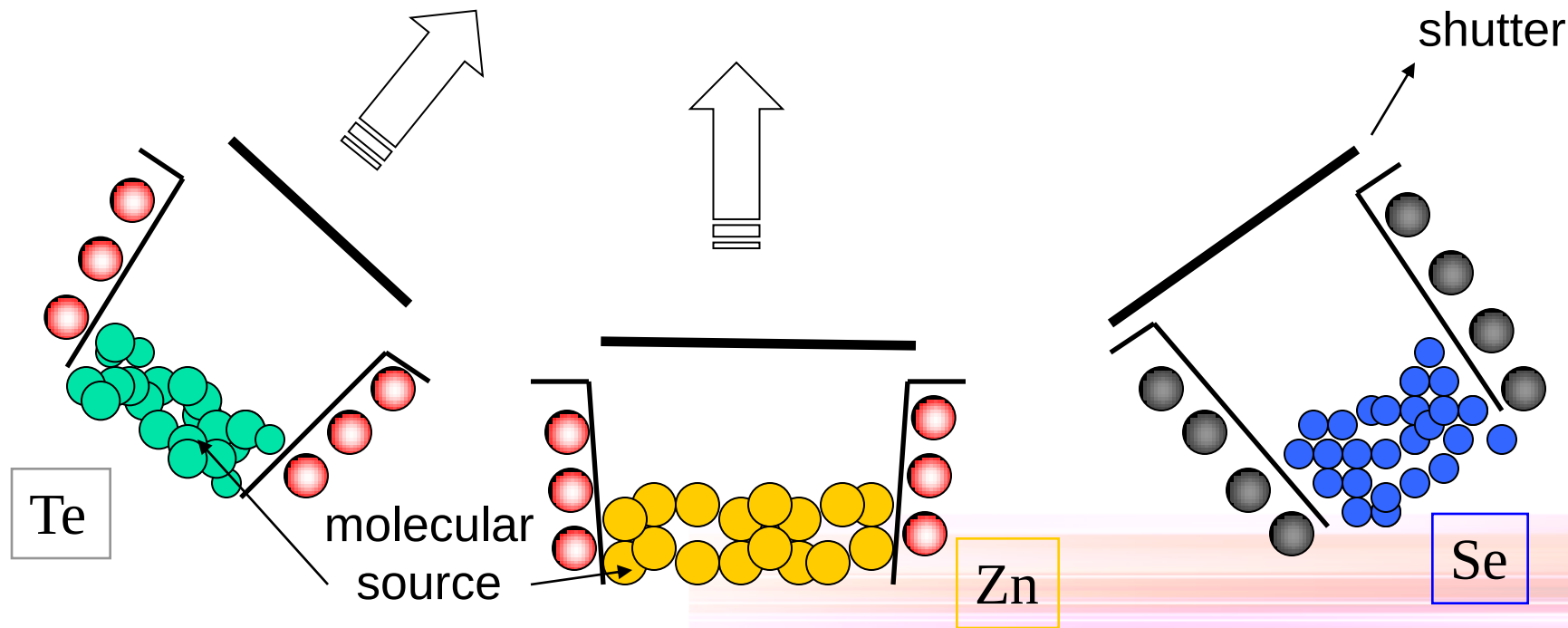
substrate

buffer **ZnSe**

strain

ZnTe or CdSe
Wetting layer

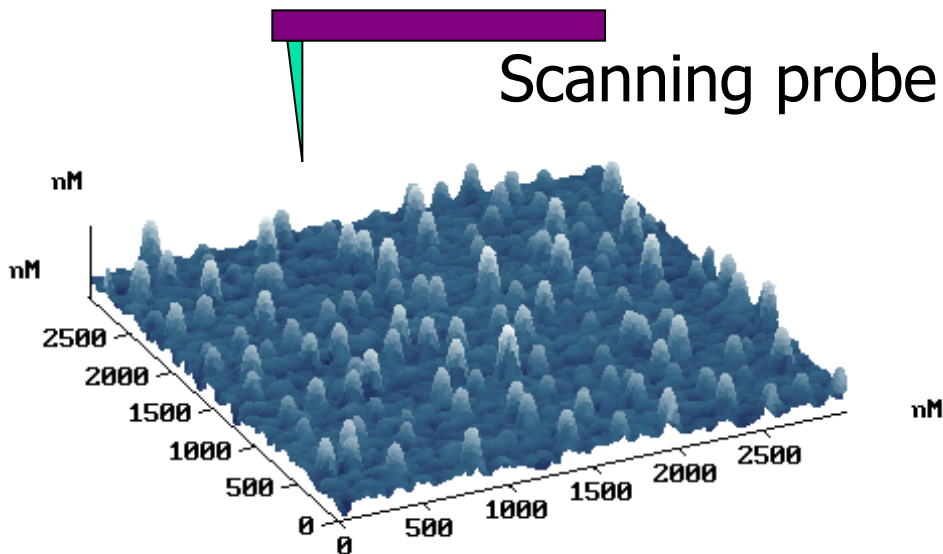
ZnTe or CdSe
Quantum Dot





Atomic force microscopy, AFM

Scanning probe microscopy



1982 IBM 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)。1986 G. 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

The Nobel Prize in Physics 1986

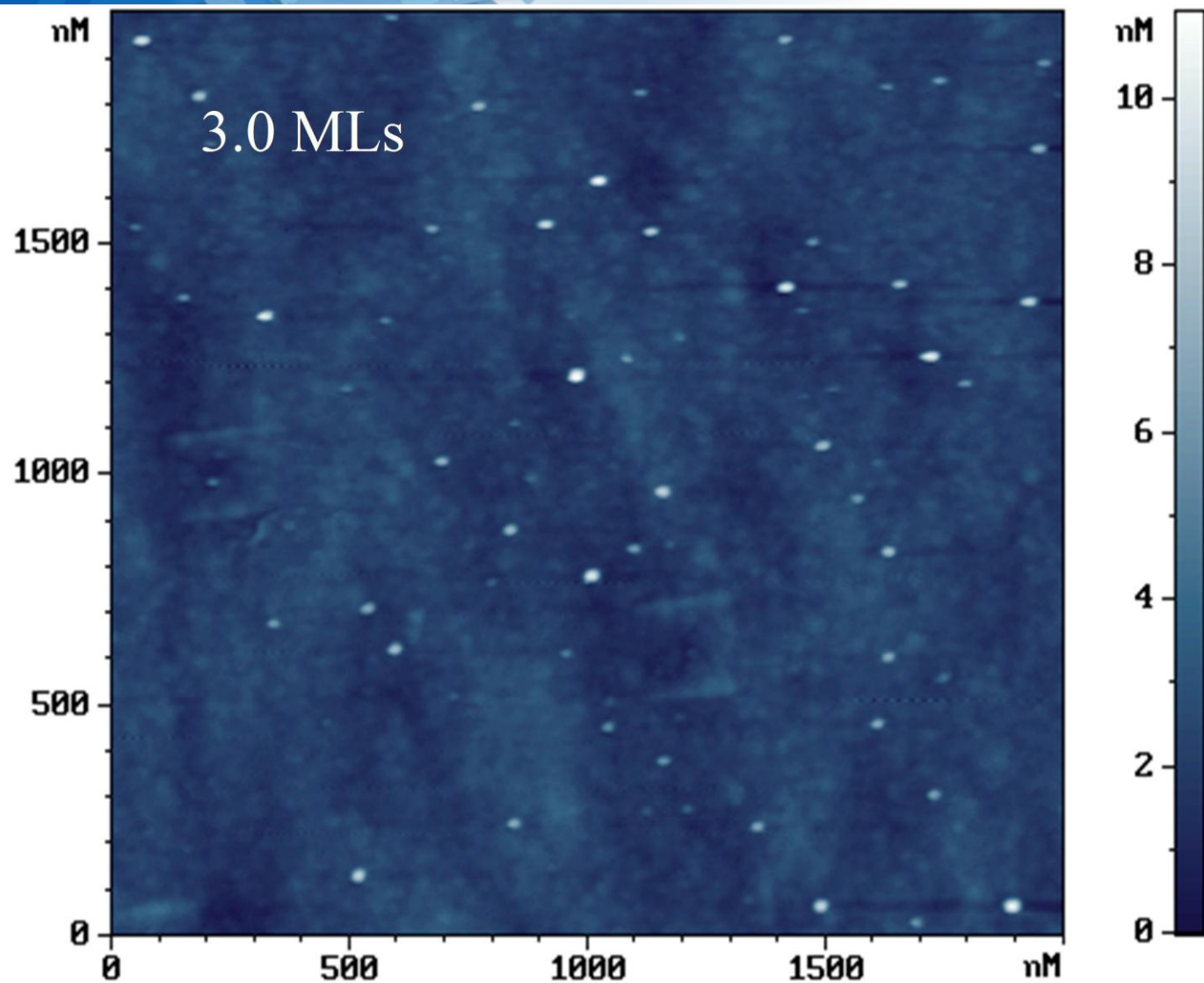
"for their design of the scanning tunneling microscope"

Gerd Binnig



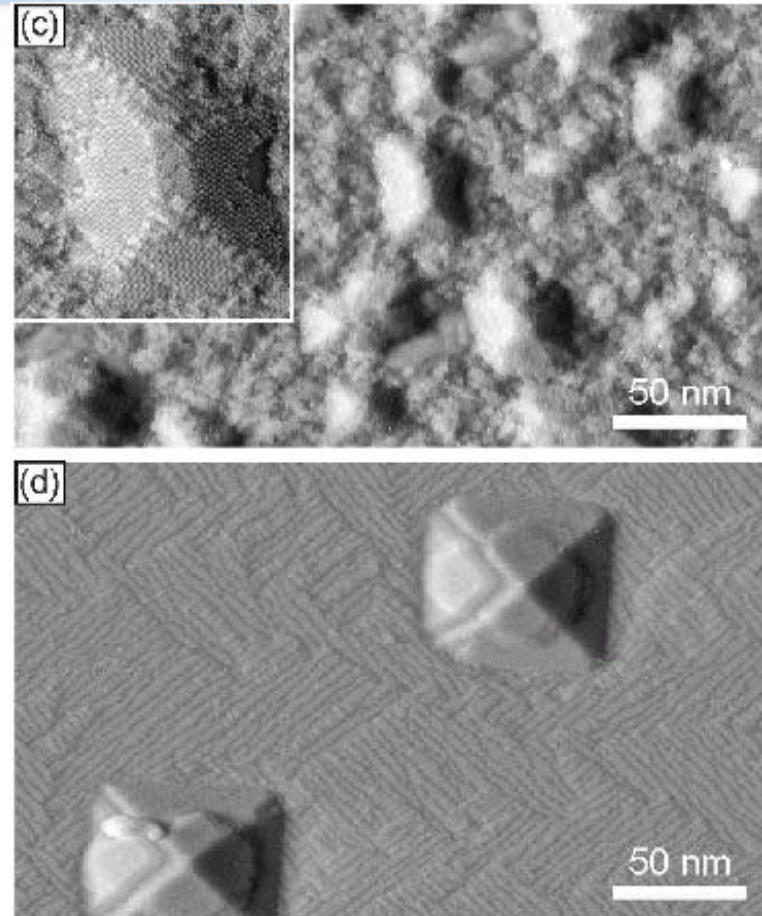
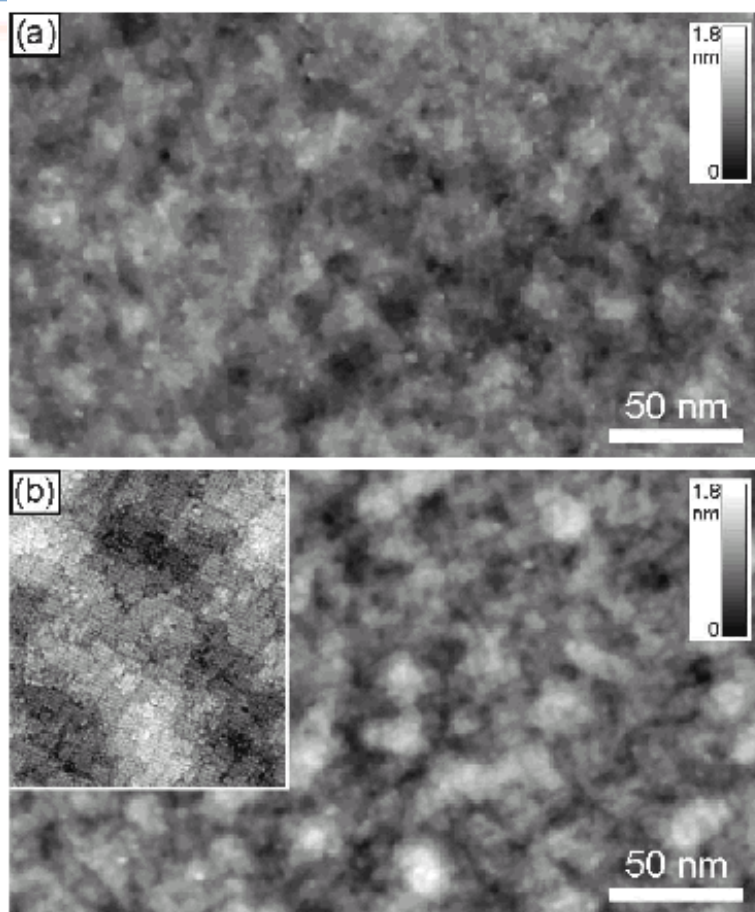
Heinrich Rohrer





碲化鋅量子點之表面高低(明暗)形貌直徑約10-30奈米

AFM

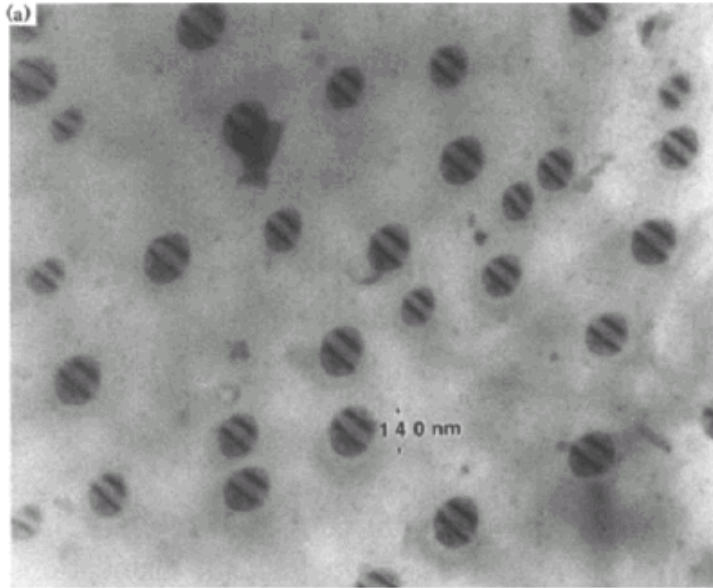


***In situ* scanning tunneling microscopy study of C-induced Ge quantum dot formation on Si(100)**

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

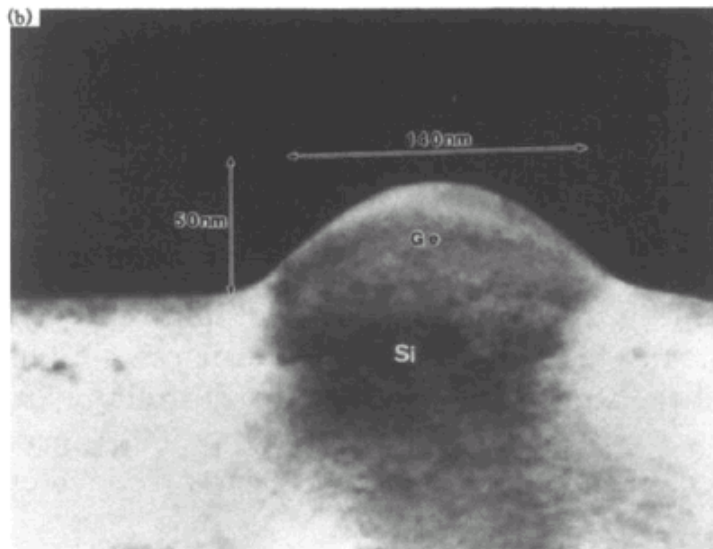


Dislocation-Free Stranski-Krastanow Growth of Ge on Si(100)



D. J. Eaglesham and M. Cerullo

PRL64, 1943 (1990)

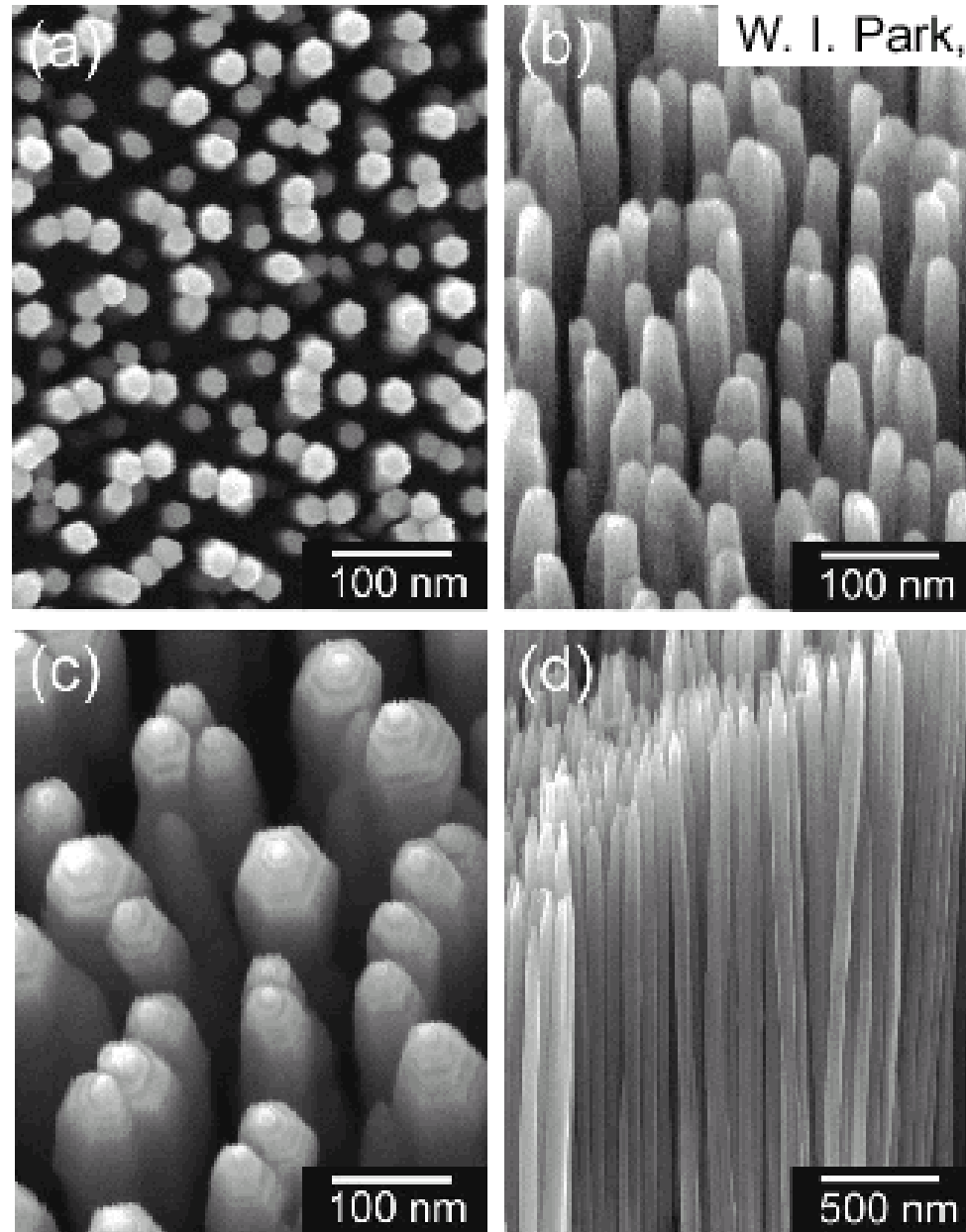


dome-shaped

半導體奈米結構之形狀

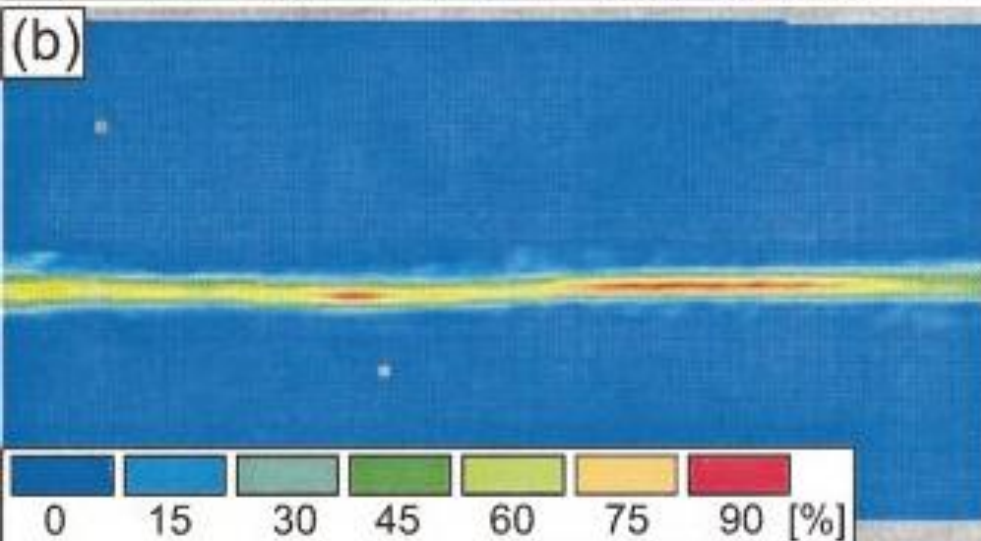
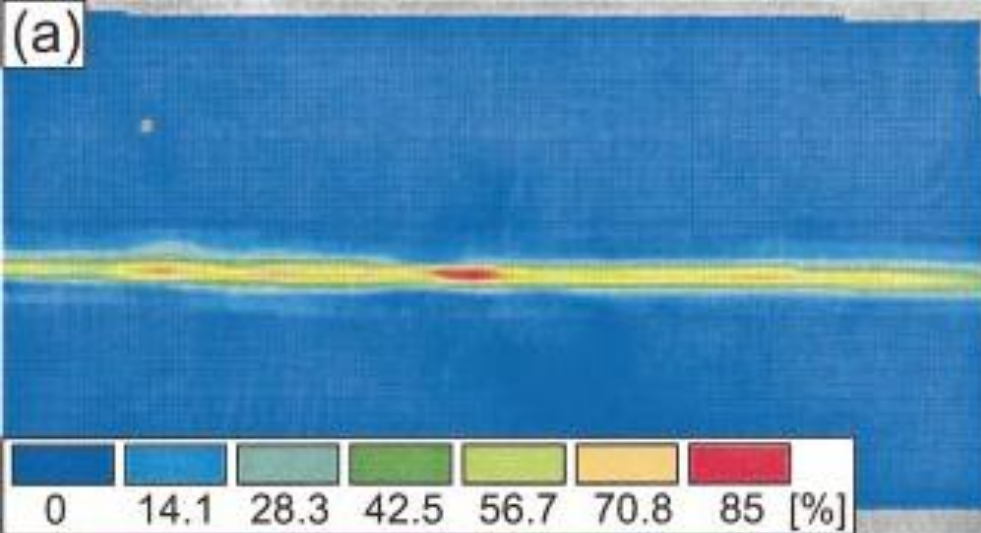
Metalorganic vapor-phase epitaxial growth of vertically well-aligned ZnO nanorods

W. I. Park, D. H. Kim, S.-W. Jung, and Gyu-Chul Yi^{a)}

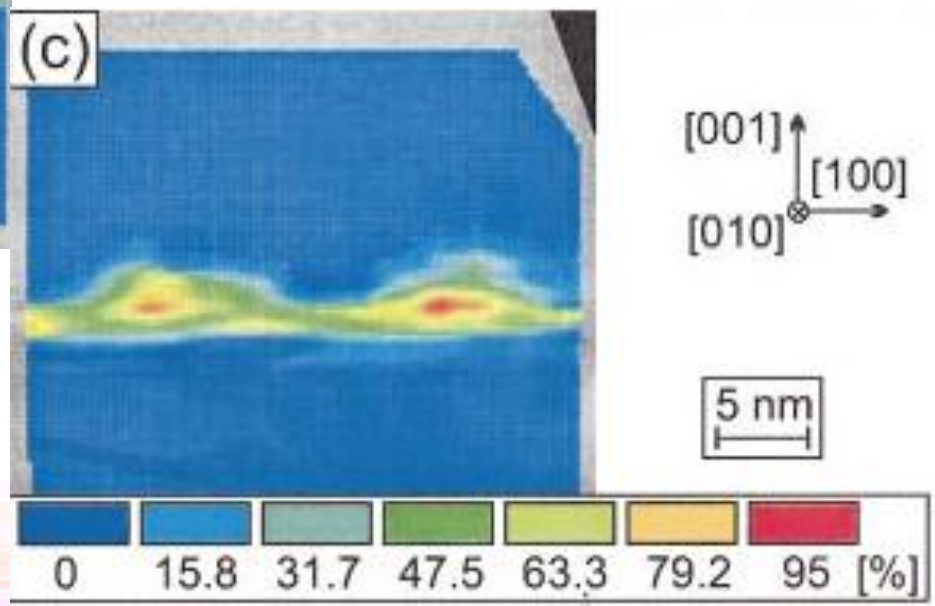


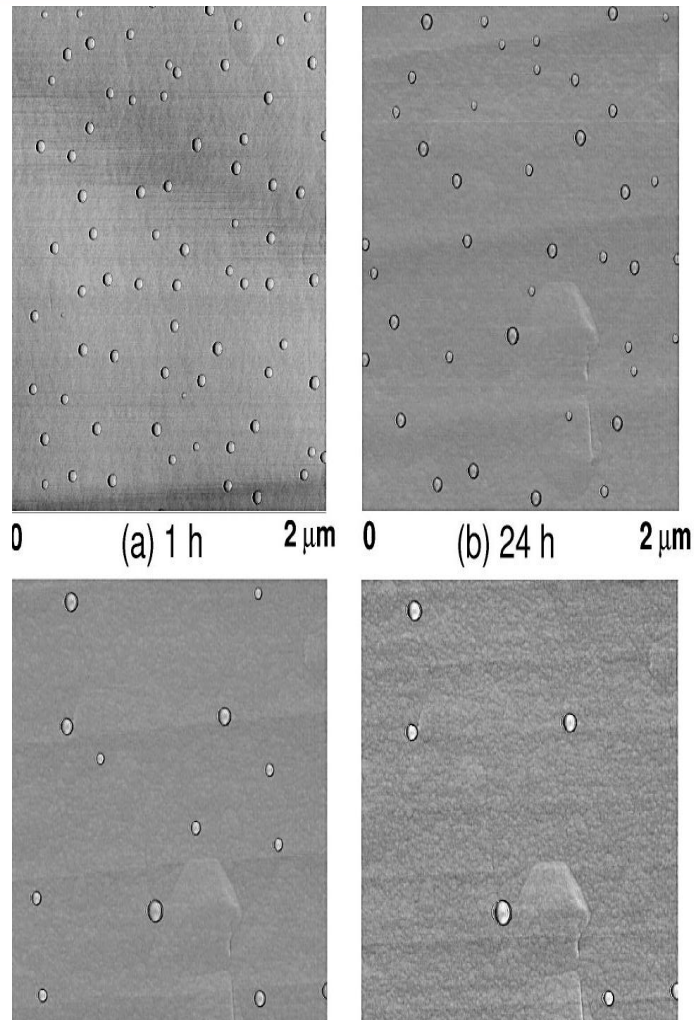
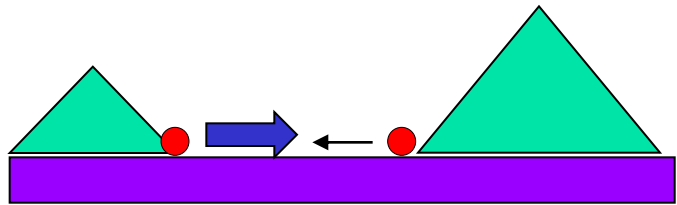
APL80, 4232 (2002)

半導體奈米結構之形狀

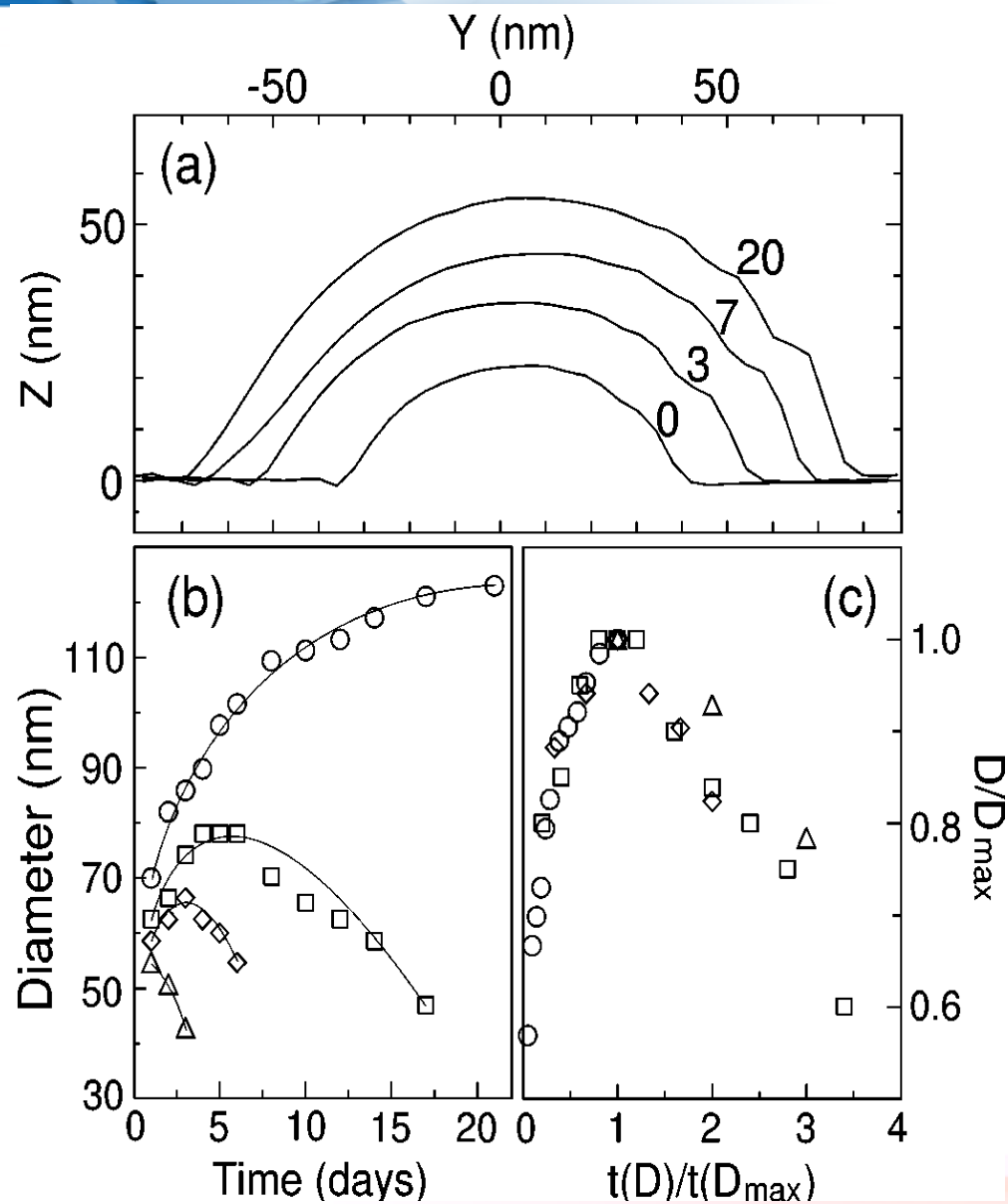


Ref. D. Litvinov et al.
APL 81, 640 (2002)



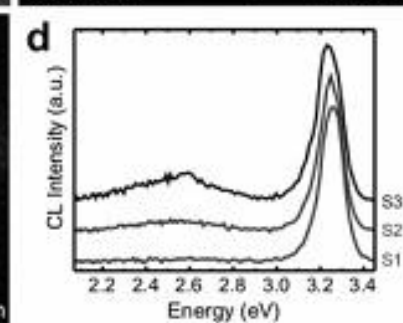
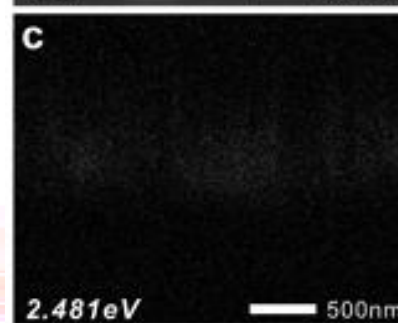
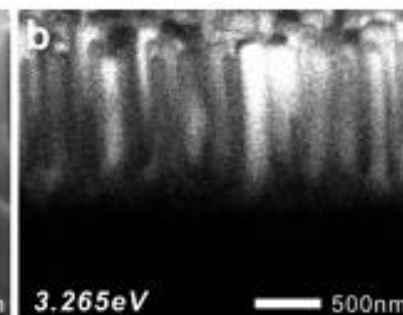
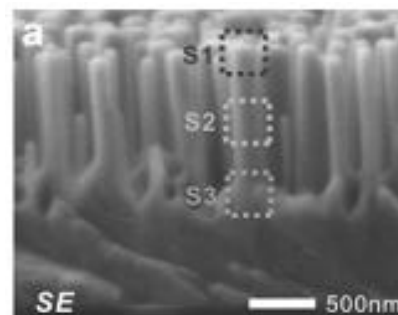
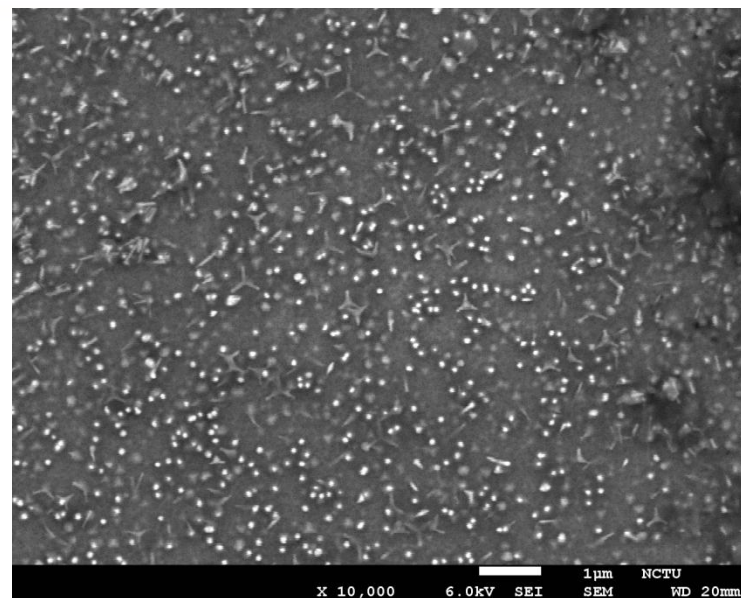
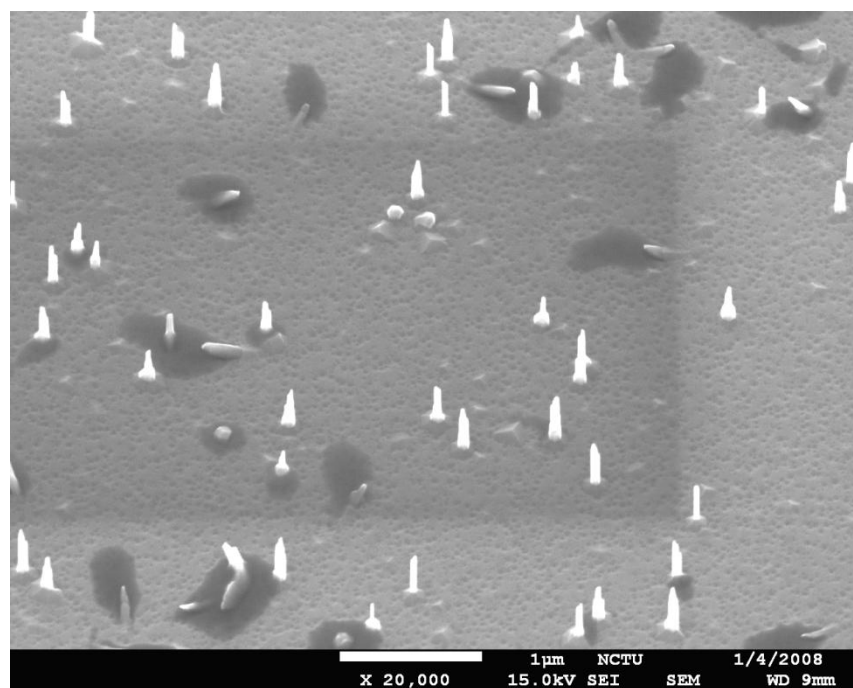


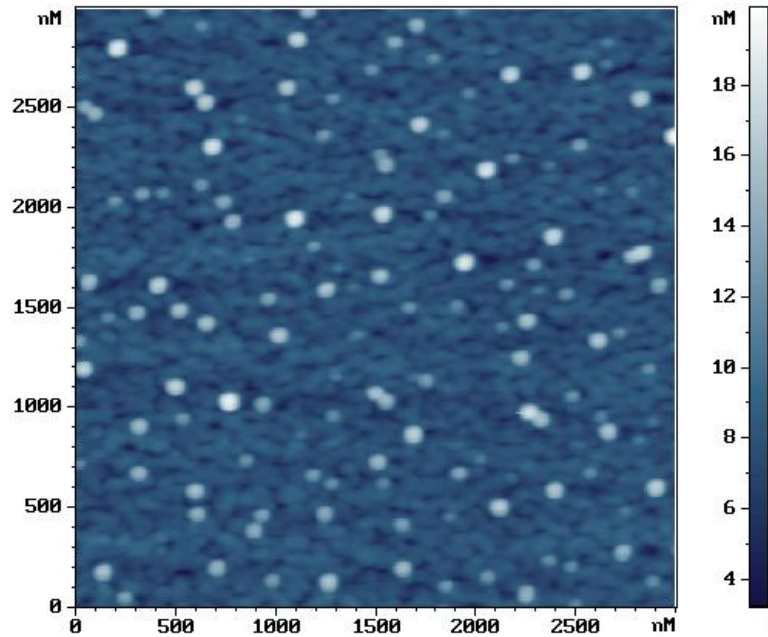
Ref. S.Lee et al., Phys. Rev. Lett. 81, 3479 (1998)





ZnO nano-tip





CdSe (3.0 MLs)/ZnSe/GaAs

Issue of size distribution

