# 前沿奈米科學與技術

## 小 就是美

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# 時代雜誌 二十世紀風雲人物

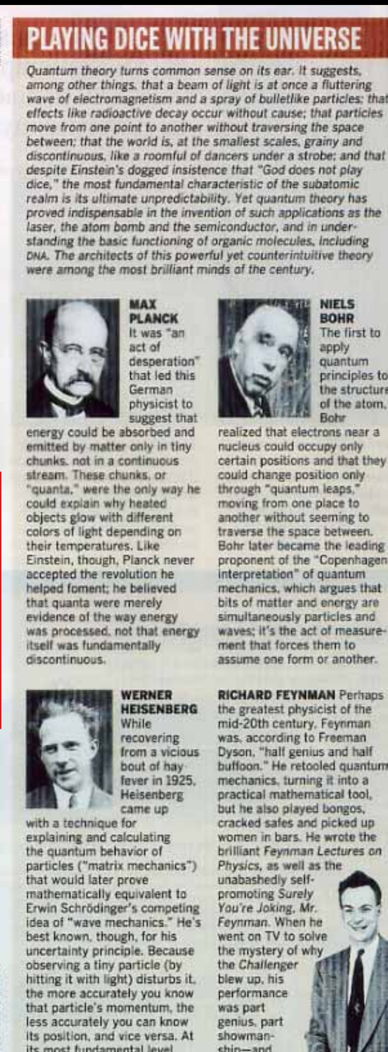

A NAZI REFUGEE AND ZIONIST, HE WELCOMES JEWISH CHILDREN TO THE U.S.

mystery of life's eternity and with a knowledge, a sense, of the marvelous structure of existence."

In embracing Einstein, our century took leave of a prior universe and an erstwhile God. The new versions were not so rigid and deterministic as the old Newtonian world. Einstein's God was no clockmaker, but he was the embodiment of reason in nature—"subtle but malicious he is not."

THE MAN WHO PROVED

**愛因斯坦**
**奇蹟年1905**
**百週年紀念**



## PLAYING DICE WITH THE UNIVERSE

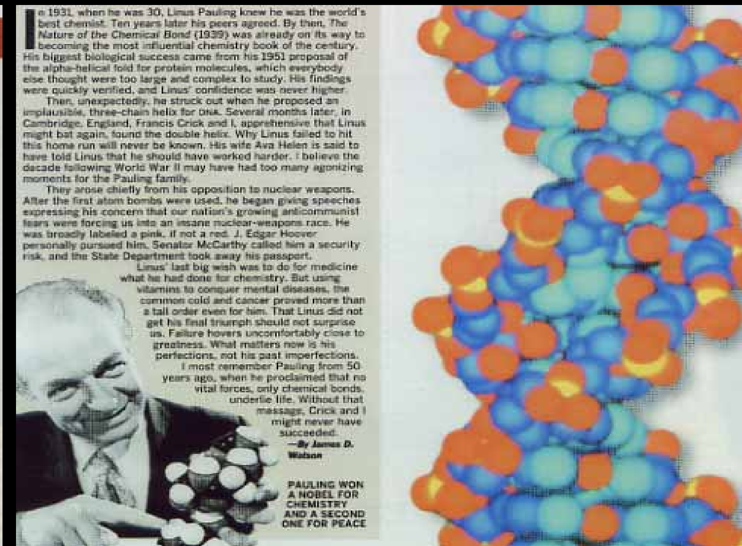
*Quantum theory turns common sense on its ear. It suggests, among other things, that a beam of light is at once a fluttering wave of electromagnetism and a spray of bulletlike particles; that effects like radioactive decay occur without cause; that particles move from one point to another without traversing the space between; that the world is, at the smallest scales, grainy and discontinuous, like a roomful of dancers under a strobe; and that despite Einstein's dogged insistence that "God does not play dice," the most fundamental characteristic of the subatomic realm is its ultimate unpredictability. Yet quantum theory has proved indispensable in the invention of such applications as the laser, the atom bomb and the semiconductor, and in understanding the basic functioning of organic molecules, including DNA. The architects of this powerful yet counterintuitive theory were among the most brilliant minds of the century.*

**MAX PLANCK** It was "an act of desperation" that led this German physicist to suggest that energy could be absorbed and emitted by matter only in tiny chunks, not in a continuous stream. These chunks, or "quanta," were the only way he could explain why heated objects glow with different colors of light depending on their temperatures. Like Einstein, though, Planck never accepted the revolution he helped foment; he believed that quanta were merely evidence of the way energy was processed, not that energy itself was fundamentally discontinuous.

**NIELS BOHR** The first to apply quantum principles to the structure of the atom, Bohr realized that electrons near a nucleus could occupy only certain positions and that they could change position only through "quantum leaps," moving from one place to another without seeming to traverse the space between. Bohr later became the leading proponent of the "Copenhagen interpretation" of quantum mechanics, which argues that bits of matter and energy are simultaneously particles and waves; it's the act of measurement that forces them to assume one form or another.

**WERNER HEISENBERG** While recovering from a vicious bout of hay fever in 1925, Heisenberg came up with a technique for explaining and calculating the quantum behavior of particles ("matrix mechanics") that would later prove mathematically equivalent to Erwin Schrödinger's competing idea of "wave mechanics." He's best known, though, for his uncertainty principle. Because observing a tiny particle (by hitting it with light) disturbs it, the more accurately you know that particle's momentum, the less accurately you can know its position, and vice versa. At its most fundamental level,

**RICHARD FEYNMAN** Perhaps the greatest physicist of the mid-20th century, Feynman was, according to Freeman Dyson, "half genius and half buffoon." He retooled quantum mechanics, turning it into a practical mathematical tool, but he also played bongos, cracked safes and picked up women in bars. He wrote the brilliant *Feynman Lectures on Physics*, as well as the unabashedly self-promoting *Surely You're Joking, Mr. Feynman*. When he went on TV to solve the mystery of why the *Challenger* blew up, his performance was part genius, part showmanship—and



In 1931, when he was 30, Linus Pauling knew he was the world's best chemist. Ten years later his peers agreed. By then, *The Nature of the Chemical Bond* (1939) was already on its way to becoming the most influential chemistry book of the century. His biggest biological success came from his 1951 proposal of the alpha-helical fold for protein molecules, which everybody else thought were too large and complex to study. His findings were quickly verified, and Linus' confidence was never higher.

Then, unexpectedly, he struck out when he proposed an implausible, three-chain helix for DNA. Several months later, in Cambridge, England, Francis Crick and I, apprehensive that Linus might bat again, found the double helix. Why Linus failed to hit this home run will never be known. His wife Ava Helen is said to have told Linus that he should have worked harder. I believe the decade following World War II may have had too many agonizing moments for the Pauling family.

They arose chiefly from his opposition to nuclear weapons. After the first atom bombs were used, he began giving speeches expressing his concern that our nation's growing anticommunist fears were forcing us into an insane nuclear-weapons race. He was broadly labeled a pink, if not a red. J. Edgar Hoover personally pursued him. Senator McCarthy called him a security risk, and the State Department took away his passport.

Linus' last big wish was to do for medicine what he had done for chemistry. But using vitamins to conquer mental diseases, the common cold and cancer proved more than a tall order even for him. That Linus did not get his final triumph should not surprise us. Failure hovers uncomfortably close to greatness. What matters now is his perfections, not his past imperfections.

I most remember Pauling from 50 years ago, when he proclaimed that no vital forces, only chemical bonds, underlie life. Without that message, Crick and I might never have succeeded.

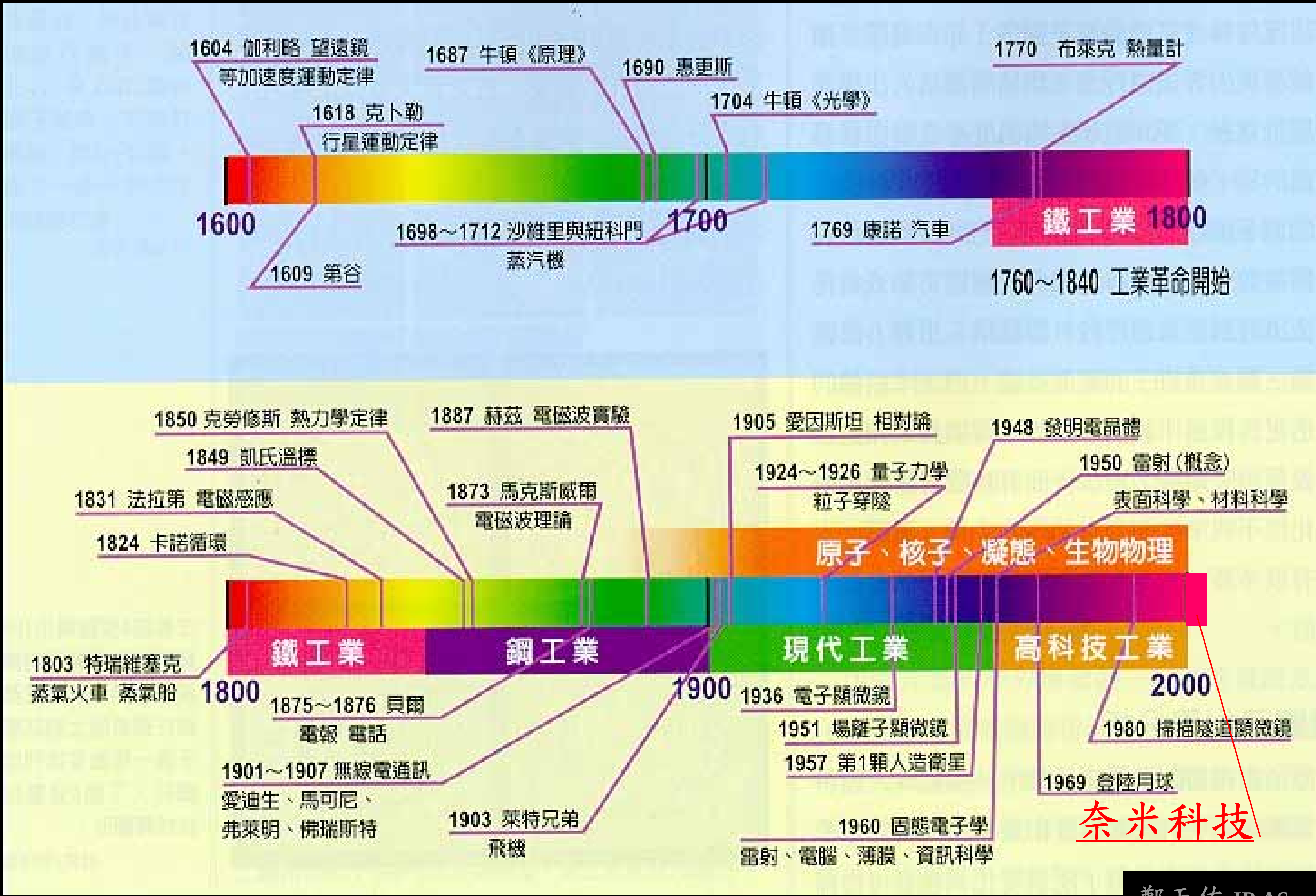
—By James D. Watson

PAULING WON A NOBEL FOR CHEMISTRY AND A SECOND ONE FOR PEACE

物理促進了其他科學和工業的發展，徹底改變了人類的生活和思維方式。 二十世紀科學風雲人物

鄭天佐 IPAS

# 科學與工業的發展史的時光譜線

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# 近代物理 與 科學與技術

1) 電磁波

1831: 法拉第，場與感應

1873: 馬克斯威爾，電磁波

2) 相對論，愛因斯坦

1905: 狹義相對論，時與空和質量與能量的相等性

1915: 廣義相對論，重力與加速度的相等性

3) 量子力學

1900: 普朗克，能量量子化

1905: 愛因斯坦，光子

1913: 波爾，氫原子模型、量子物理的應用

1924: de Broglie，物質波

1925: 海森堡，量子力學

1926: 薛丁格，Schroedinger equation

原子分子物理: 雷射、

Optical Trap、BE-Condens.

凝聚態物理:

半導體電子元件和科技

電腦及資訊科技

化學: 化學鍵

化學與製藥工業

生物: DNA 雙螺旋結構

生物科技

表面物理: 薄膜

電子材料及觸媒劑

材料科學: 跨科技的材料工業

奈米科學與技術：

跨領域科技

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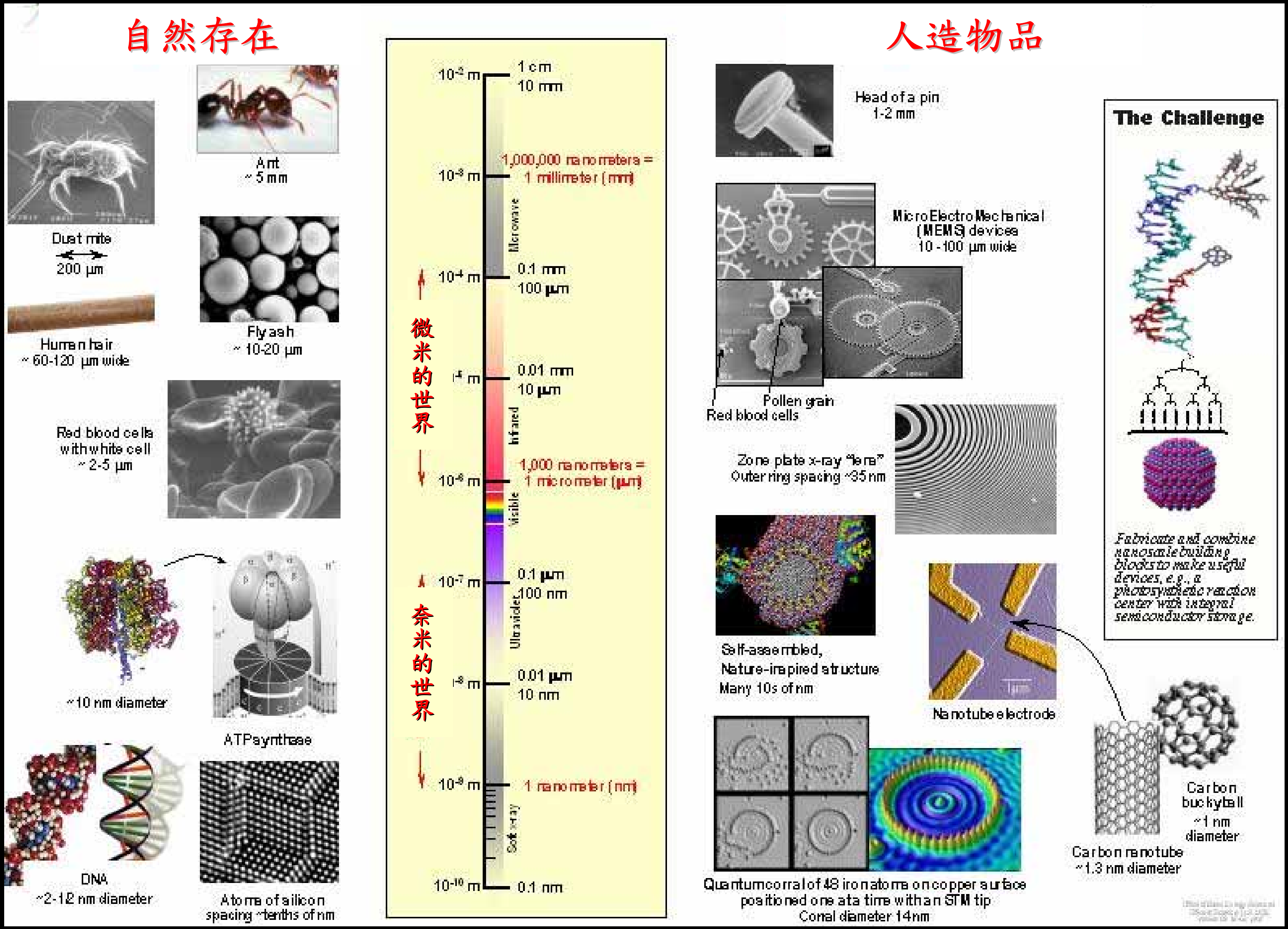
# 東西的尺寸：奈米科技乃是 1 奈米至100 奈米的科技

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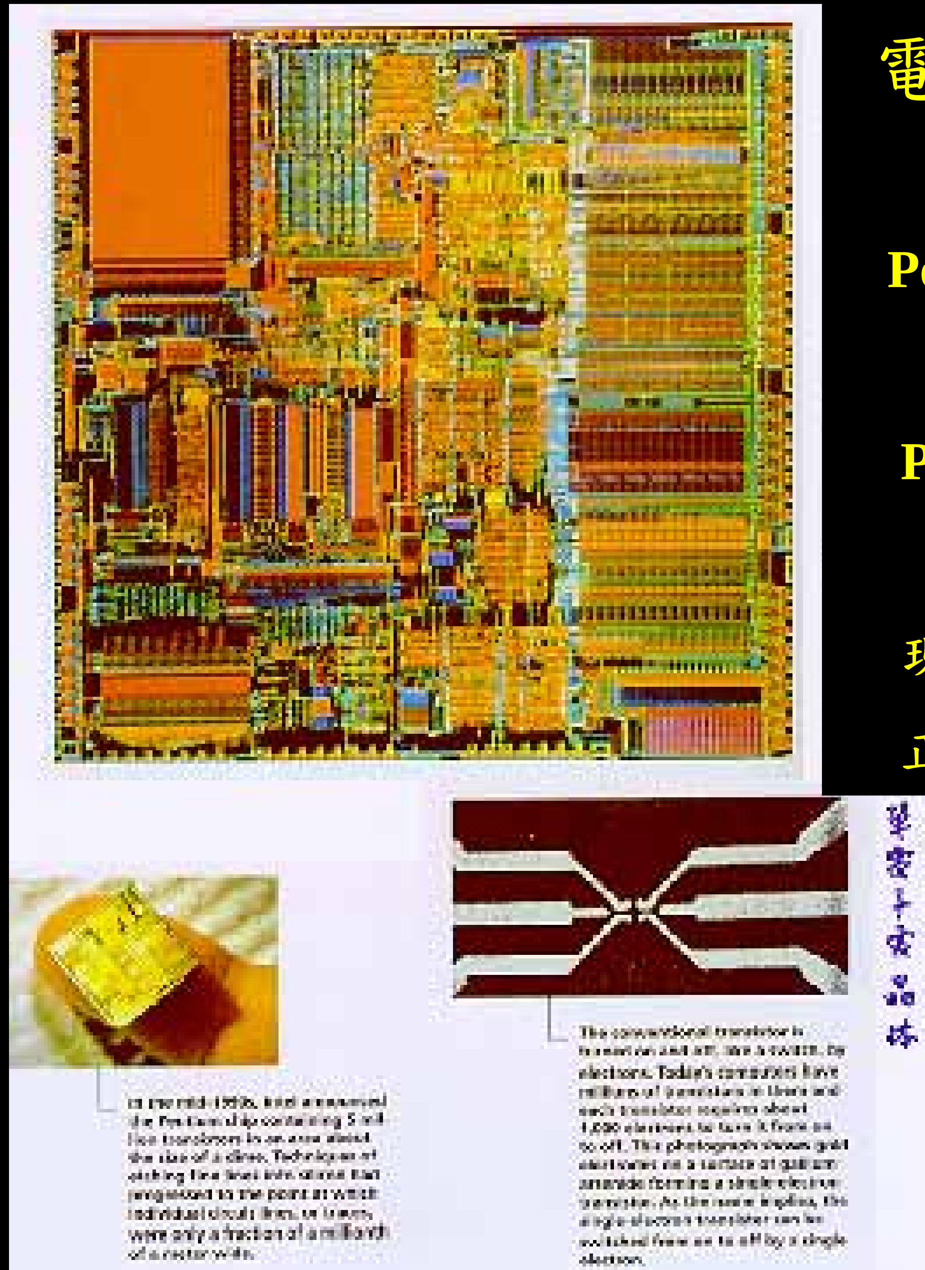
# 奈米電子元件



**電腦中心處理器:**

**<1.5x1.5 cm$^2$**

**Pentium II**

**~14 M, 電晶體, 180 nm**

**Pentium IV, Centrino**

**~42 M, 電晶體, 130 nm**

**現在前端製程: ~90 nm**

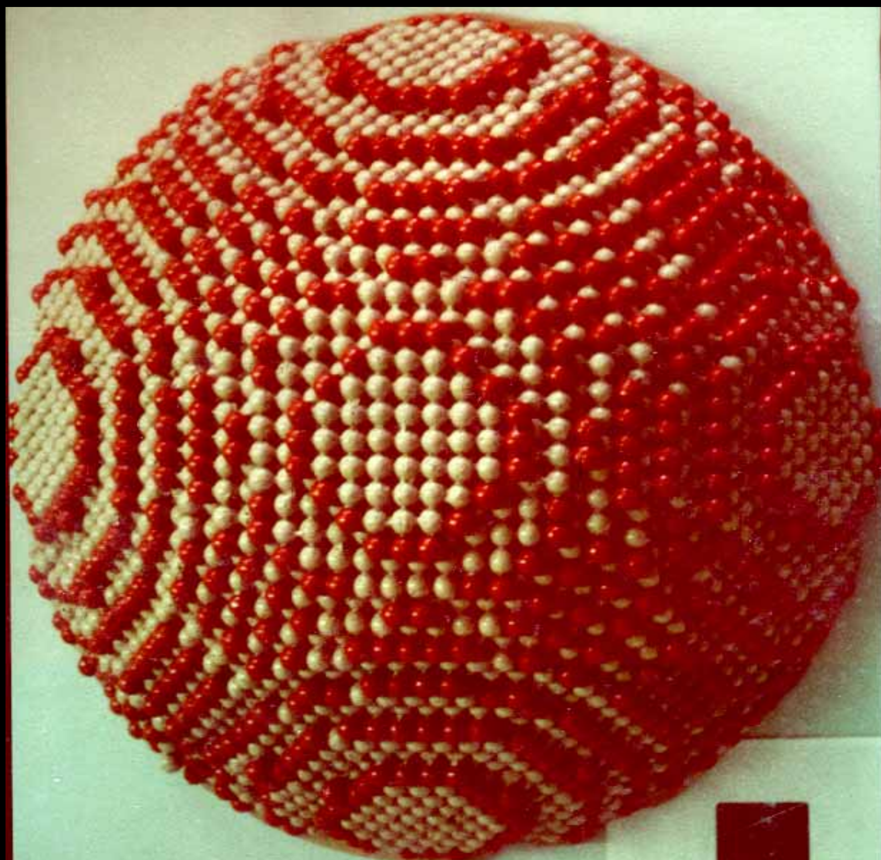
**正在開發 35 nm 製程**

**摩爾定律:**

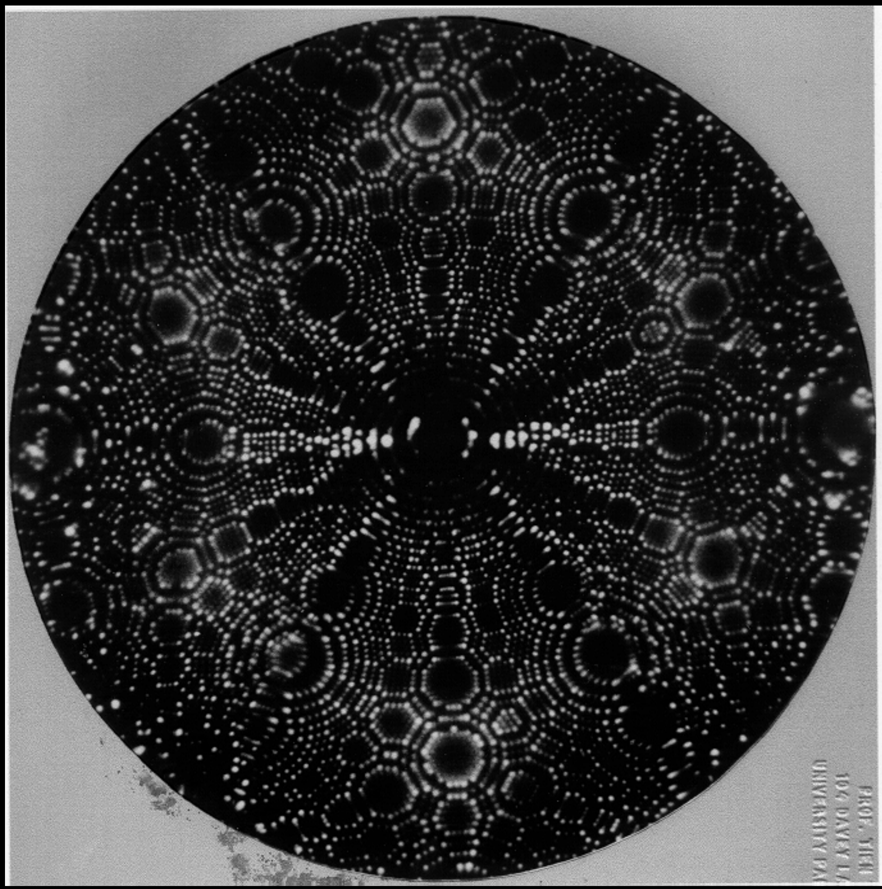
**密度每十八個月增加一倍**

**尺寸相對應縮小**

場離子顯微鏡針狀樣品模型
半徑： 十奈米



鎢針頭原子排列的影像
二十五奈米



E. W. Müller & T. T. Tsong, *Field Ion Microscopy*, Elsevier 1969

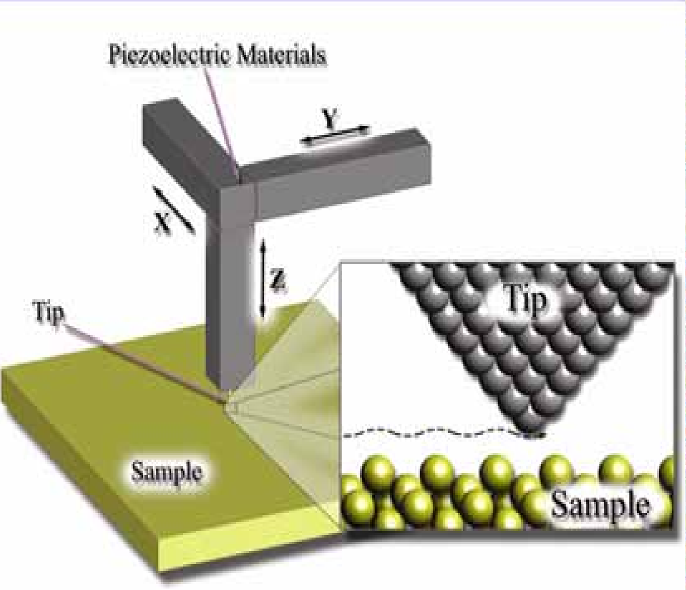
T. T. Tsong, *Atom-Probe Field Ion Microscopy*, Cambridge Univ. Press, 1990

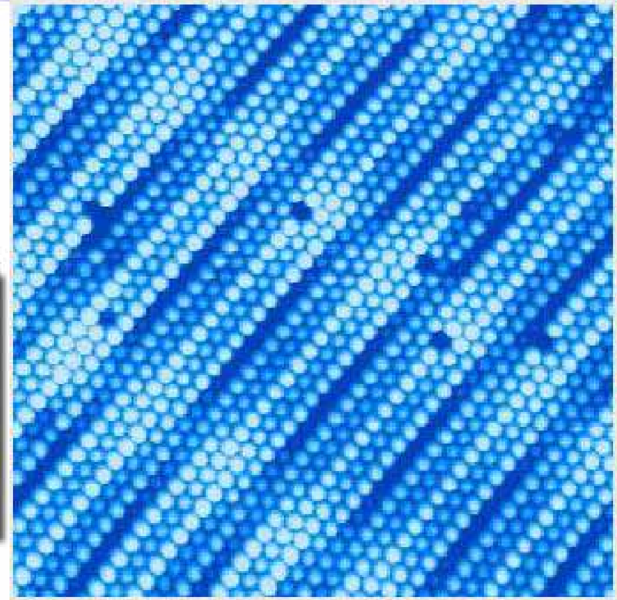
# 50th Years of Seeing Atoms: E. W. Müller

# 掃瞄隧道顯微鏡 (STM)

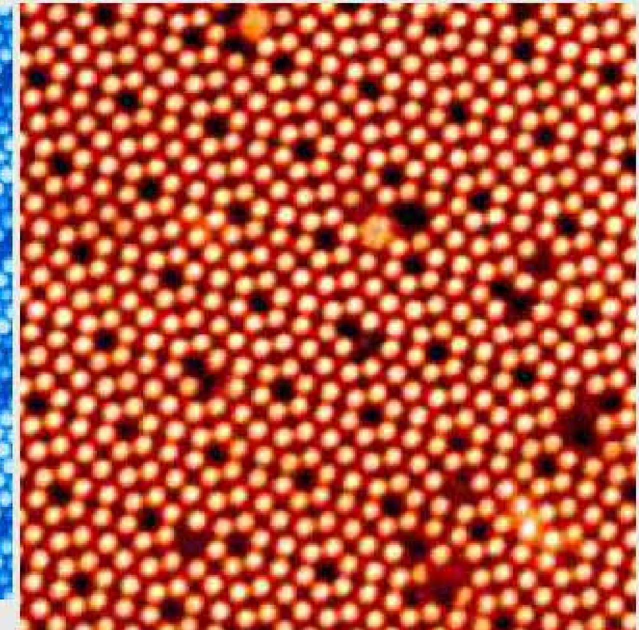
**Binnig & Rohrer et al. 1981**

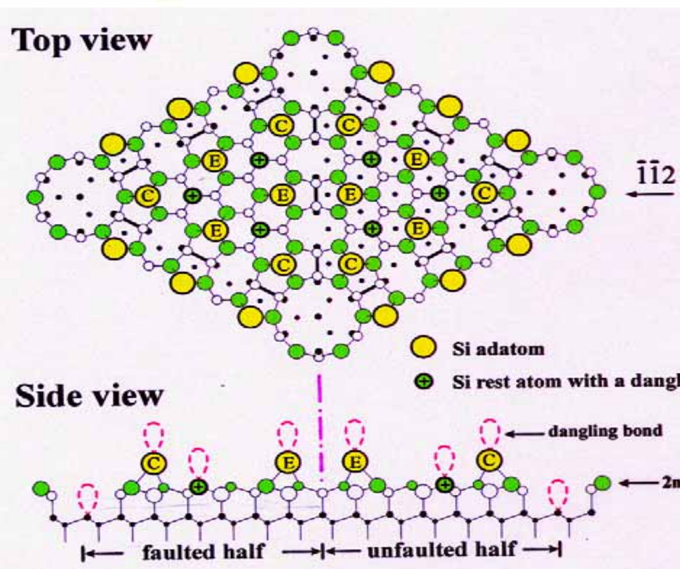
## 掃瞄隧道顯微鏡影像：矽表面原子排列，可見到台階和奈米缺陷與魔數原子團

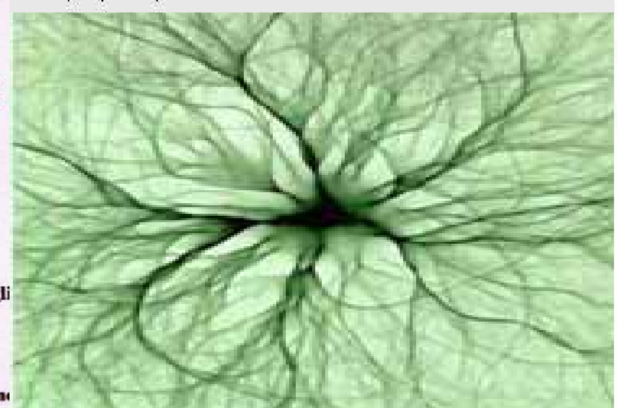


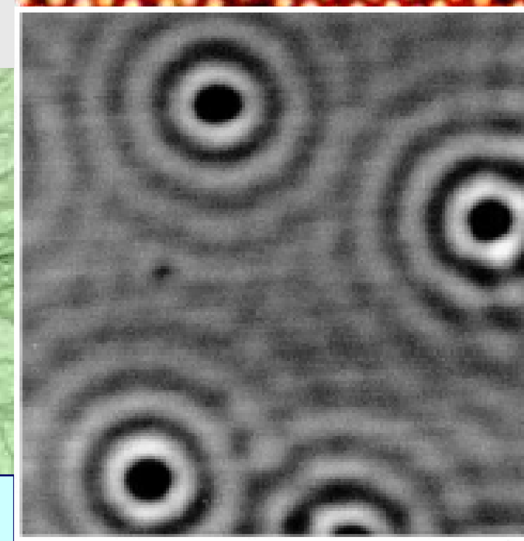
Atomic Resolution on Pt(100)
E. Bergene, Trondheim, Norway; *Published in Surf. Sci.* *306 1/2 (1994) 10-22*



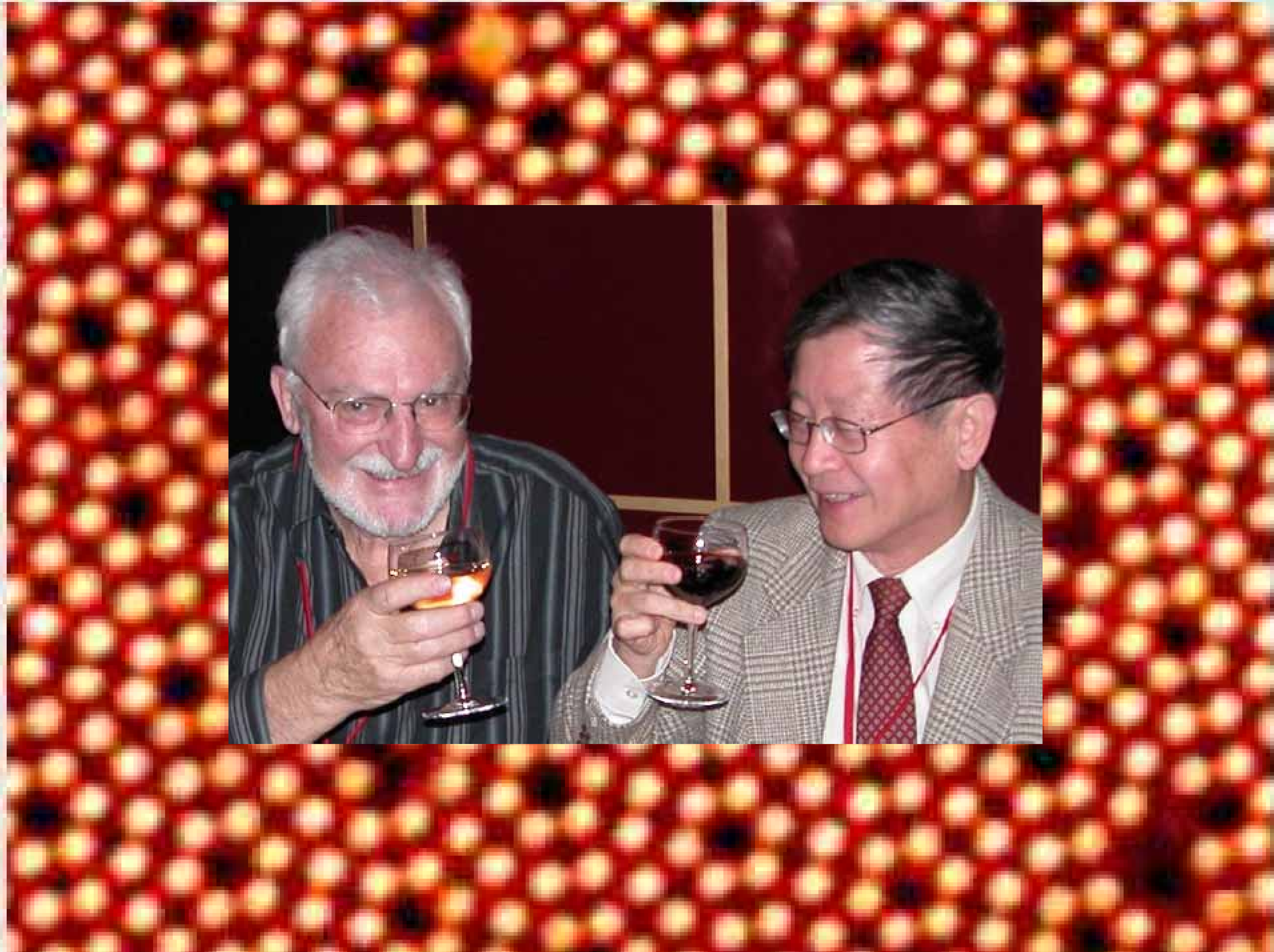


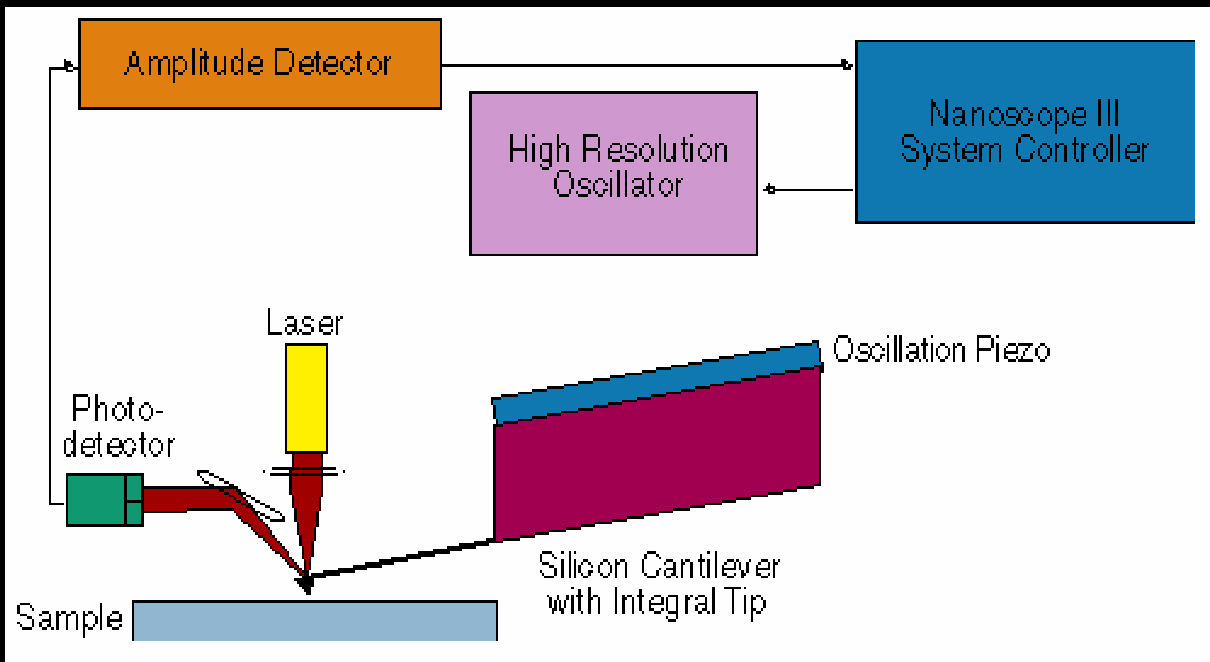
電子流動密度圖 R. Westervelt

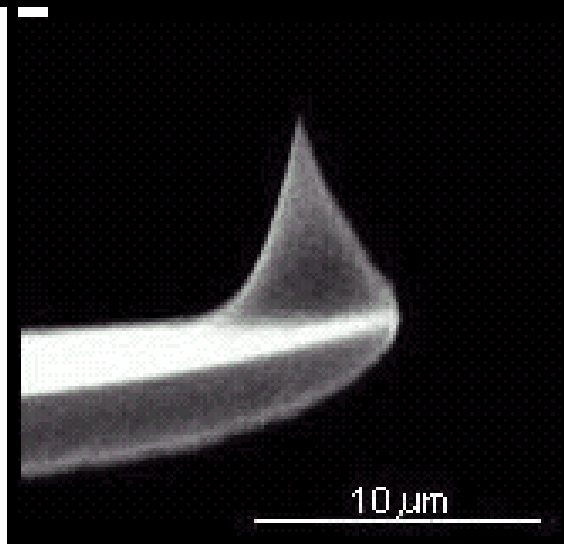


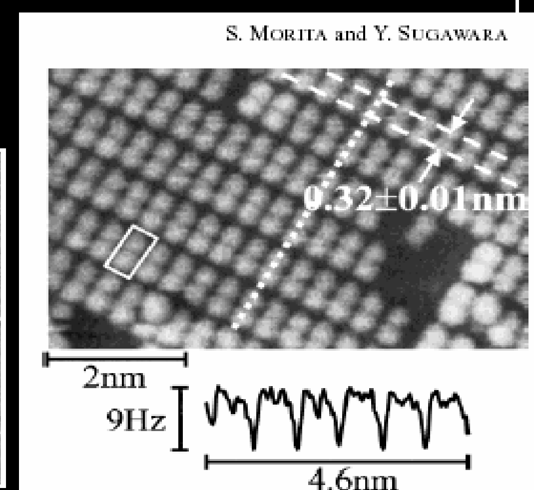
電子波干涉波紋

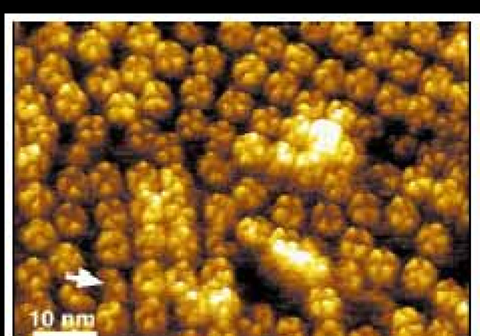


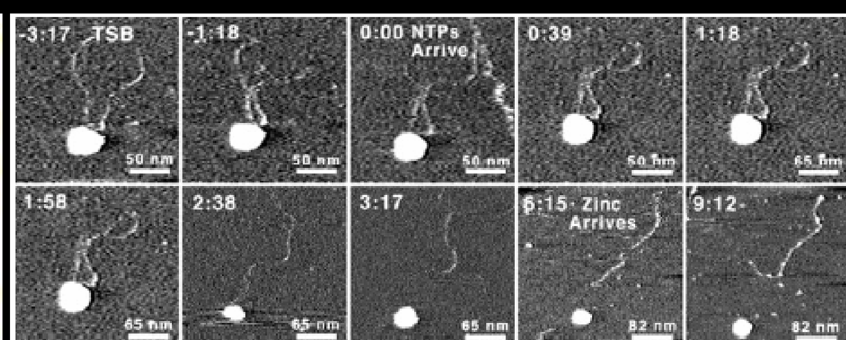
# 原子力顯微儀 (Atomic Force Microscopy)
# 已經達到原子解析度




**蛋白質分子 (MIP)**　　**Polymerase DNA 分子動態**　　**矽(100)-2x1重構**

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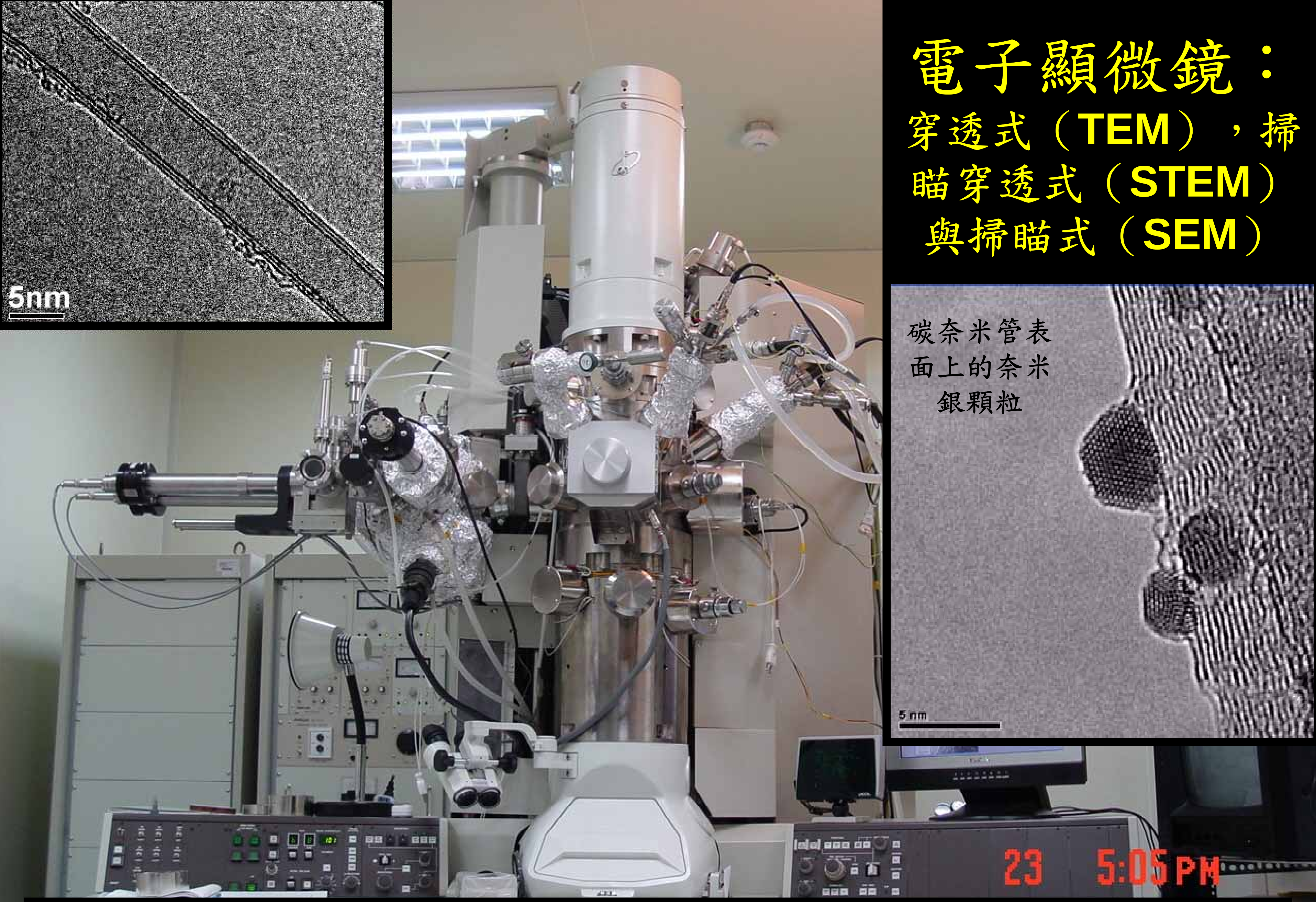
# 電子顯微鏡：

穿透式（TEM），掃瞄穿透式（STEM）與掃瞄式（SEM）




中研院物理所奈米科學研究群高真空 TEM

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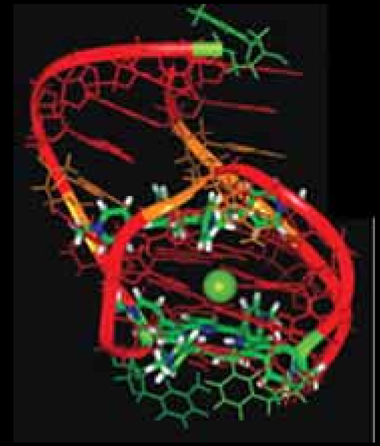
# 生命和生物機能來自生物分子動態行為

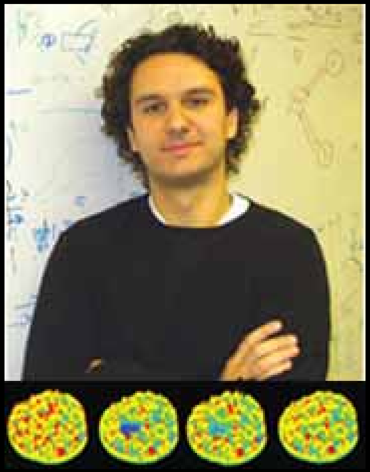
**Science 選為 2003 年十大科學重要成就：**

**單分子技術，如以QD螢光追蹤單分子動態**



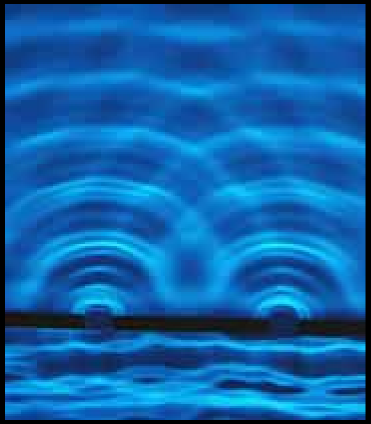
這個特別的 **DNA** 結構（紅色）可能會防禦癌症基因的形成

© H. Vankayalapati / Univ. Arizona

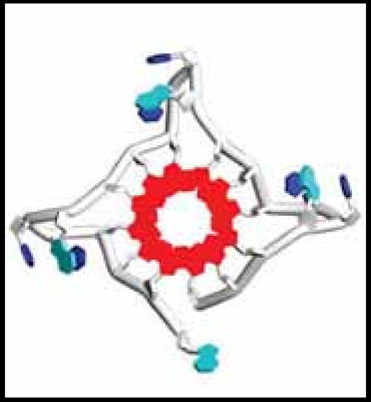


細胞核中蛋白質的動態

© T. Misteli / NCI/NIH

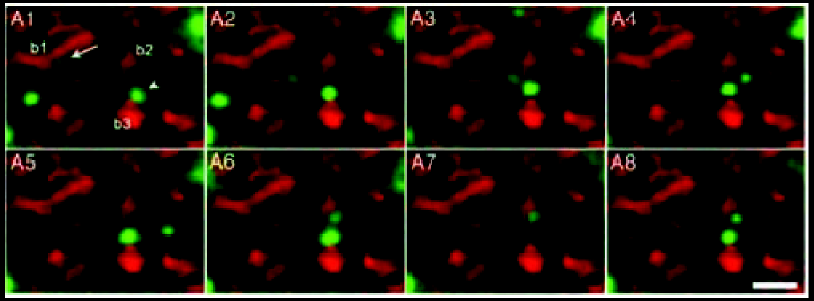


牛津大學科學家認為生命來自生物分子內電子的的波動性質



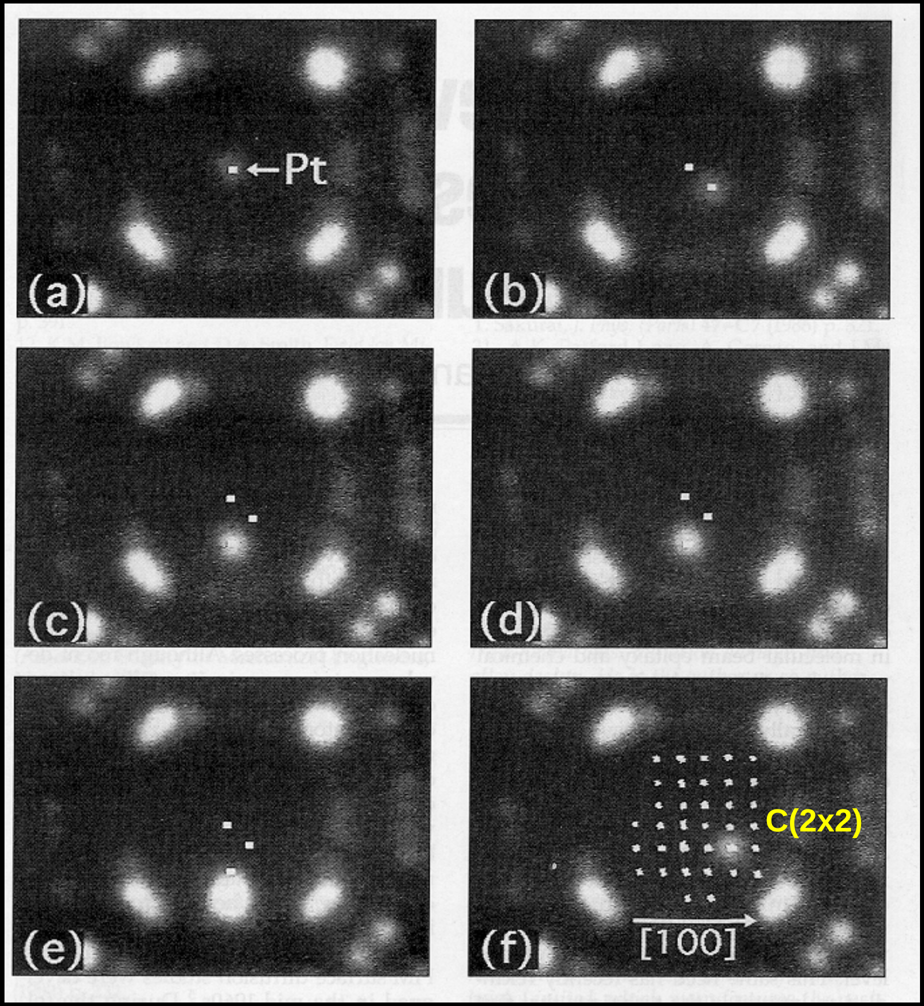
羅旋槳形狀的分子結構必有動態的目的

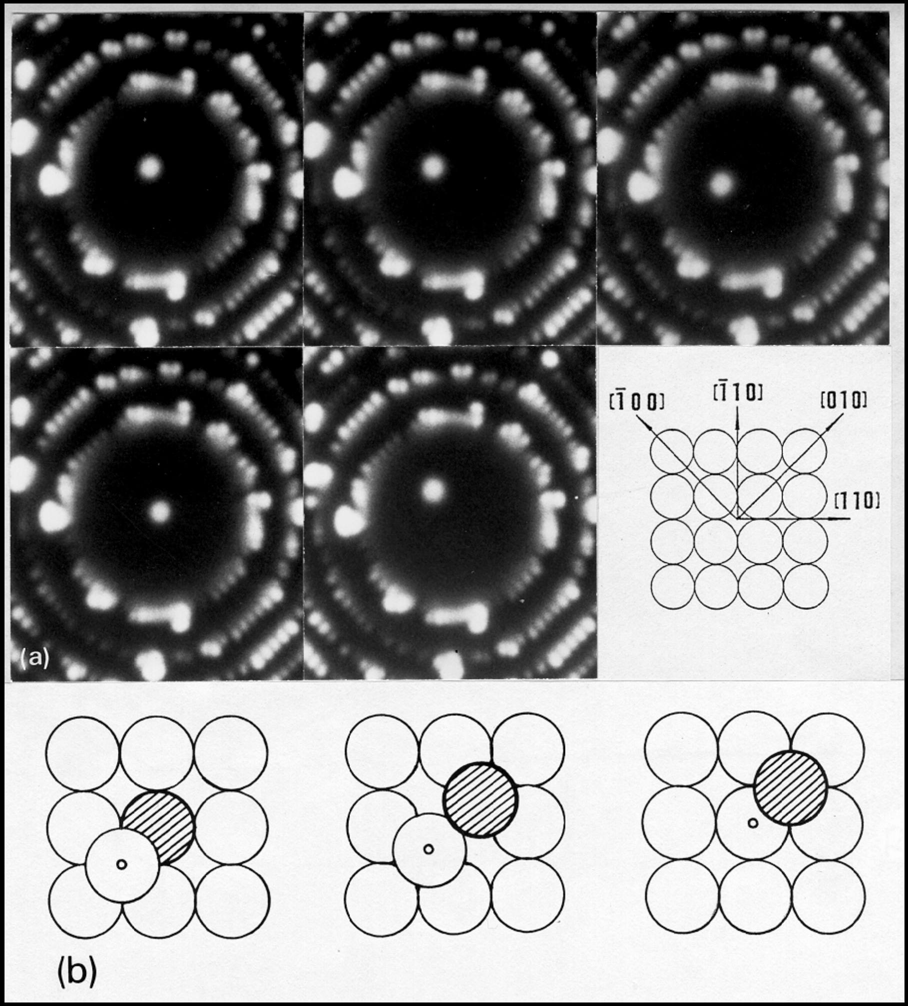
© S. Neidle




以量子點螢光追蹤 **Glycine Receptors** 的擴散動態, **Triller et al. Science '03**

# 原子取代跳動機制 Ir/Ir(001)




**Tracking the movement of one surface atom**

**Chen & Tsong, PRL' 90, Nature' 91**

**Kellogg & Feibelman, PRL'90**

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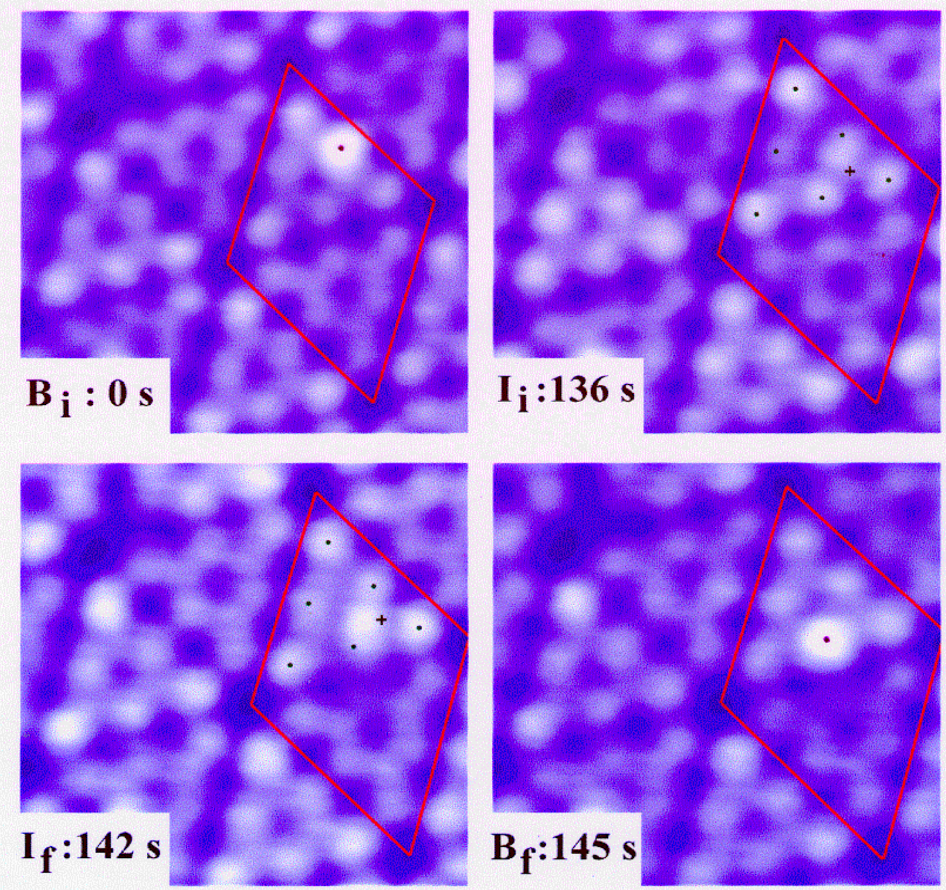
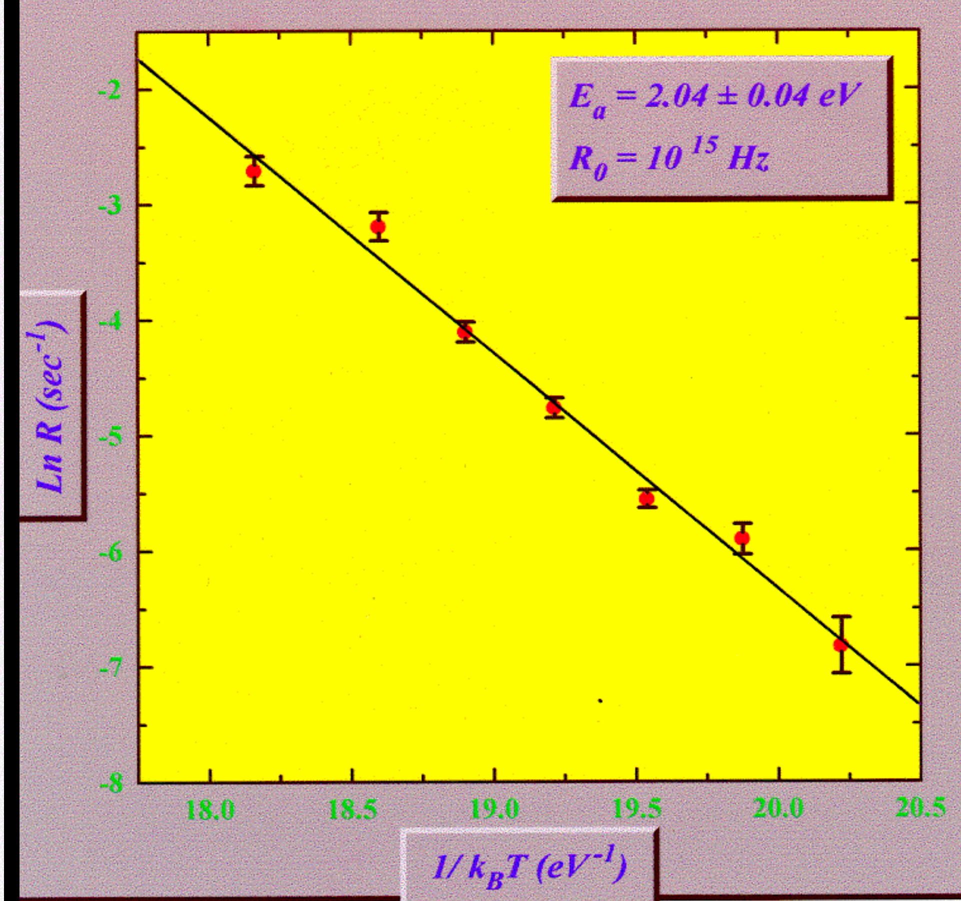
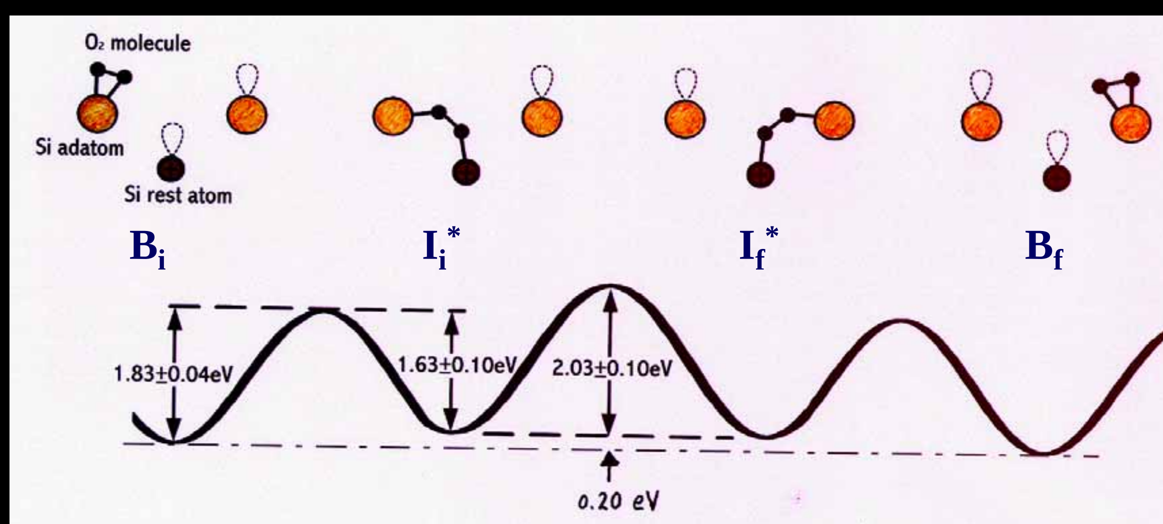



$O_2$/Si(111)-7x7, 300 C
Hwang et al. '97

一個氧分子在矽表面上的翻跟斗跳動機制

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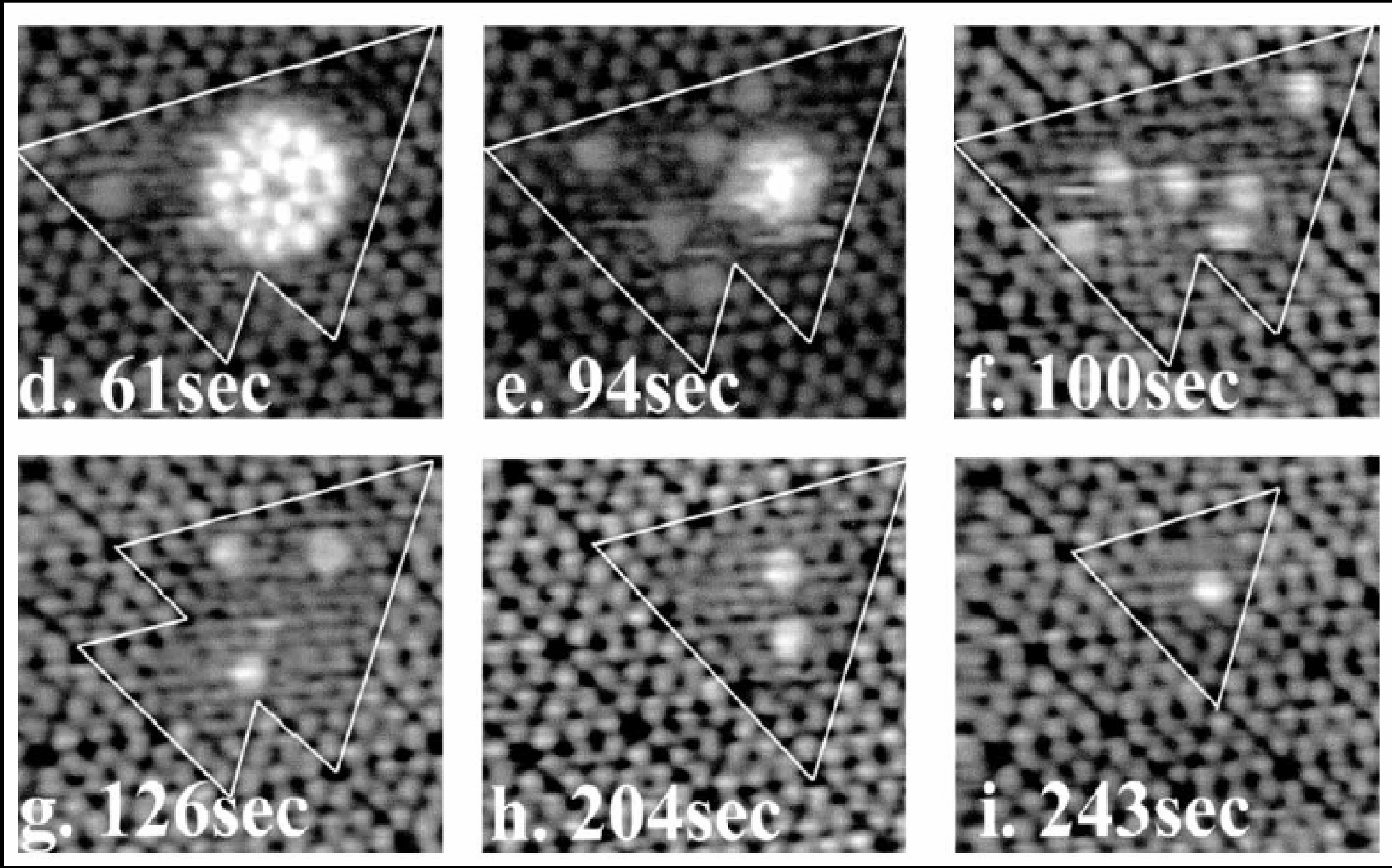
# 矽「魔數(或奇異)原子團（表面分子）」在矽表面上的動態



# 奈米材料結構的特殊物理性質

表面效應顯著: 表面原子份量增加，表面效應愈加顯著

量子物理性質顯著

量子點： 人造原子，離散能階

量子線: Ballistic Regime，電導量子化，無電阻，不發熱！

電阻是錯誤的概念，會導致 1+1=1 和 ax1=1 的邏輯錯誤

量子波動效應: 電子波干涉和量子侷限現象

粒子穿隧效應: 絕緣性質的消失，..

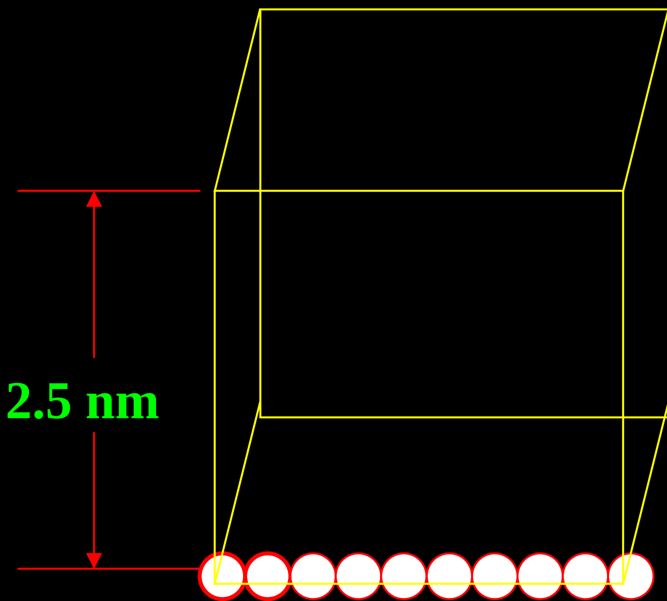
電子自旋效應: 電子元件中的磁阻，巨磁阻，自旋流

原子分子動態: 奈米結構的成長，穩定性

成長現象的電子效應，原子動態現象，尺寸和原子數的變動

庫倫障礙: 奈米顆粒電容小 (< 0.1 fF)，單電子電子元件

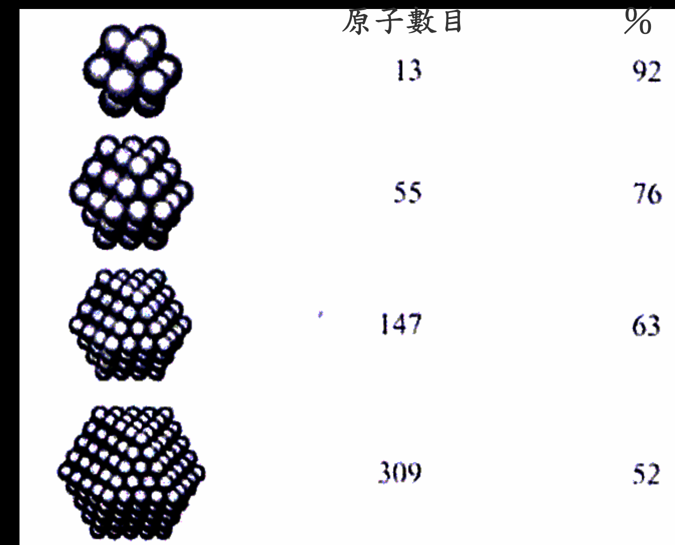
化學穩定性: 抗氧化和抗腐蝕材料



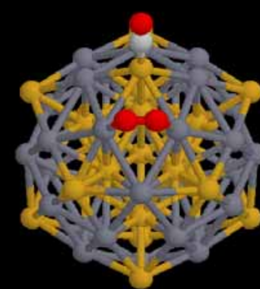

表面原子安排多樣，物化性質多元

# 表面效應:

| 尺寸 | 1 nm | 2.5 nm |
|---|---|---|
| 總共 | 64 | 1000 |
| 表面 | 56 | 488 |
| 比值 | 87.5% | 48.8% |

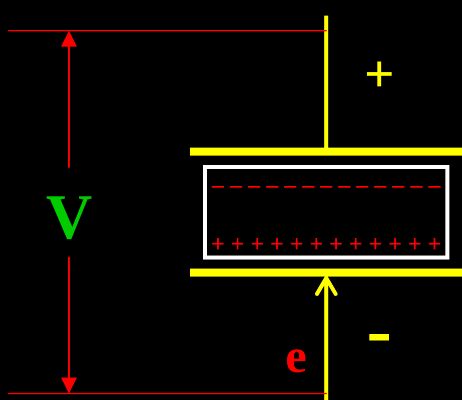


| | 原子數目 | % |
|---|---|---|
| | 13 | 92 |
| | 55 | 76 |
| | 147 | 63 |
| | 309 | 52 |



$Au_{25}Ag_{30}$

C. M. Wei et al




## 單電子效應：

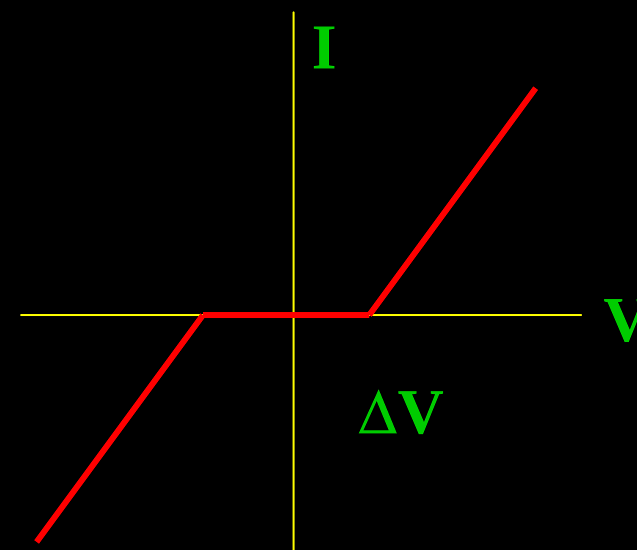
庫倫障礙

電壓 ＝電荷/電容

$V = Q/C$

$\Delta V = \Delta Q/C = e/C$

$>> kT/e$

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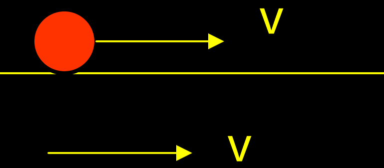
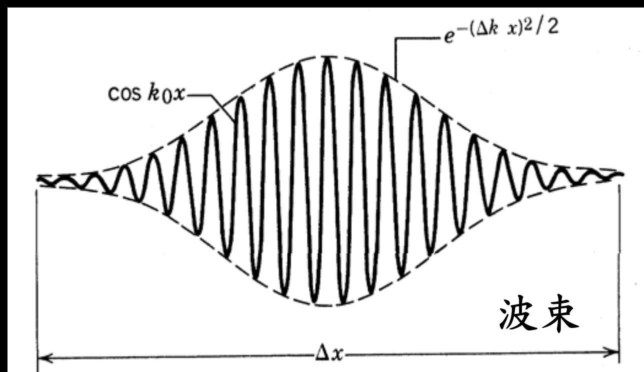
# 量子力學特性

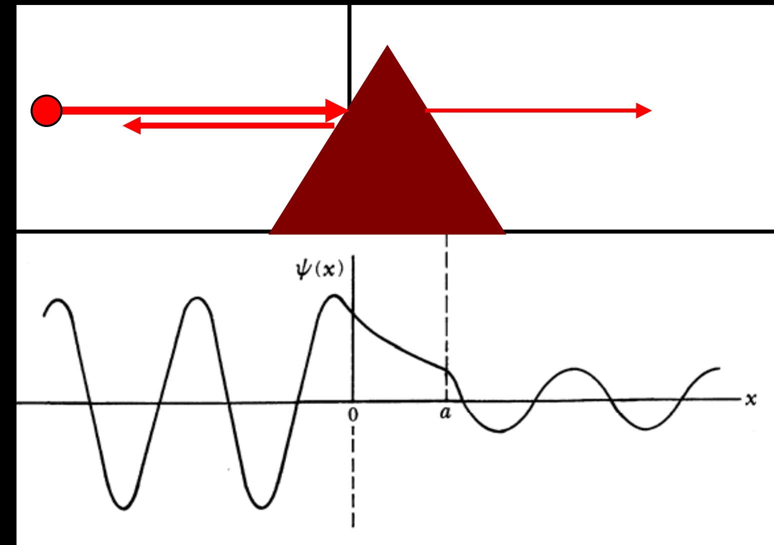
## 1 物質波

$\lambda = h/p$



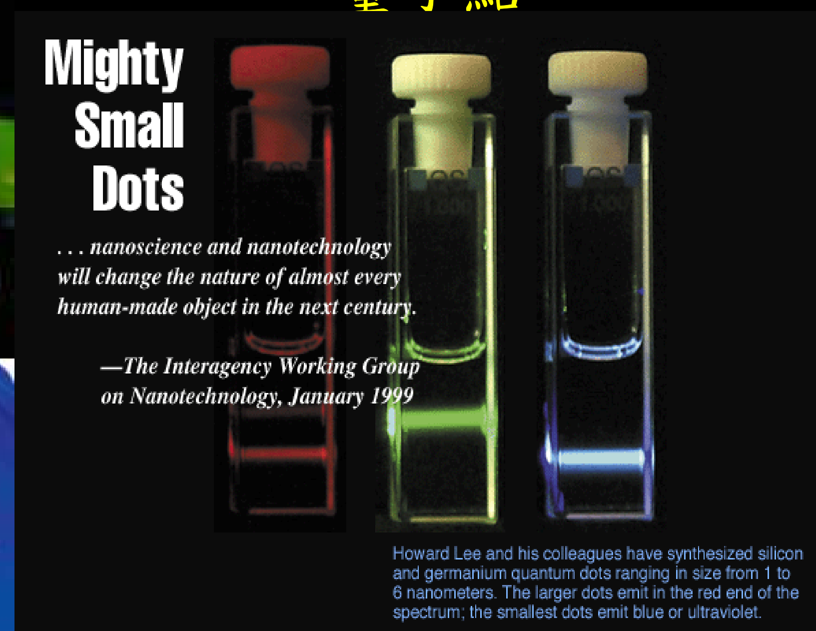




## 2 粒子穿隧效應




## 3 能量量子化

量子點




量子點大小→量子能階→量子點螢光色彩

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# The end of the road for silicon?

Max Schulz

Computer chips continue to shrink. But the discovery that a layer of silicon dioxide must be at least four to five atoms thick to function as an insulator suggests that silicon-based microchips will reach the physical limits of miniaturization early next century.

## Nature 1999

因為電子穿隧效應，氧化矽層太薄就不絕緣，現用電晶體失效！

矽工業快到窮途末路?

...icon atoms, current will penetrate through the gate oxide causing the chip to fail.

In 1925, Lilienfeld patented[2] the first field-effect device (one where current flow is modified by applying an electric field) based on silicon, but he probably never got it to work. It wasn't until 1960 that Kahng and Atalla[3] demonstrated the first metal-oxide semiconductor field-effect transistor

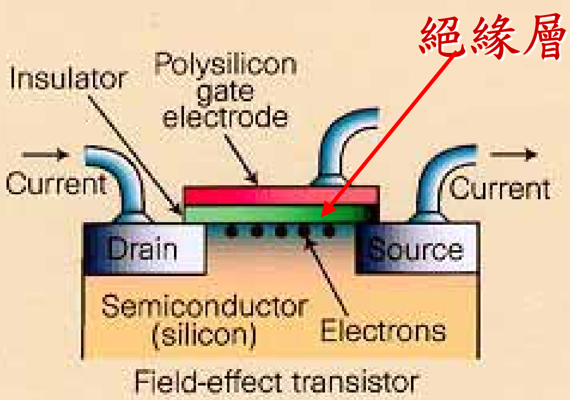
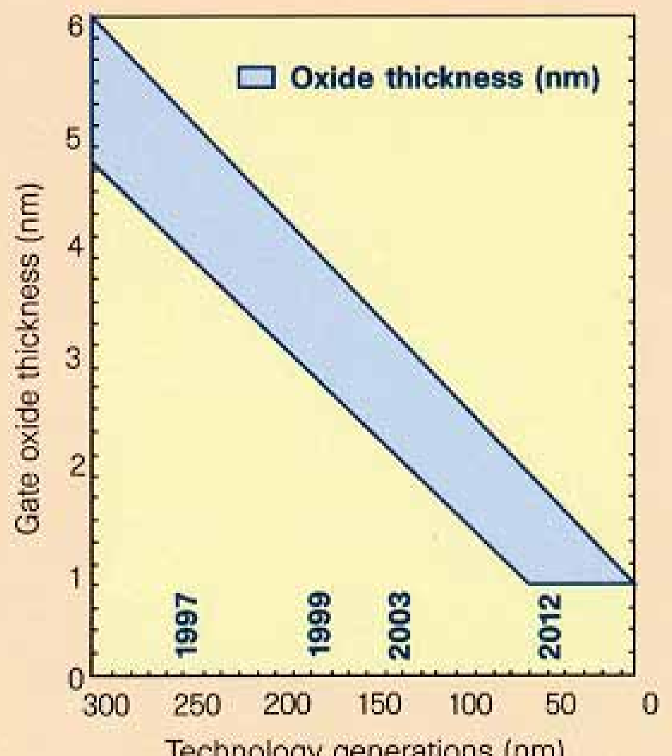
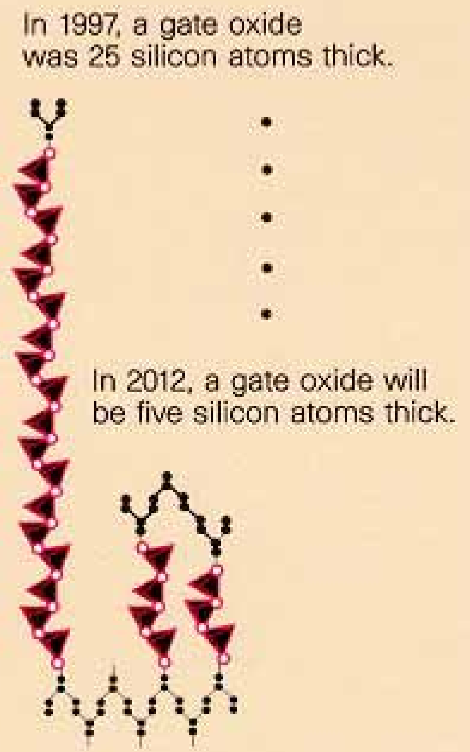
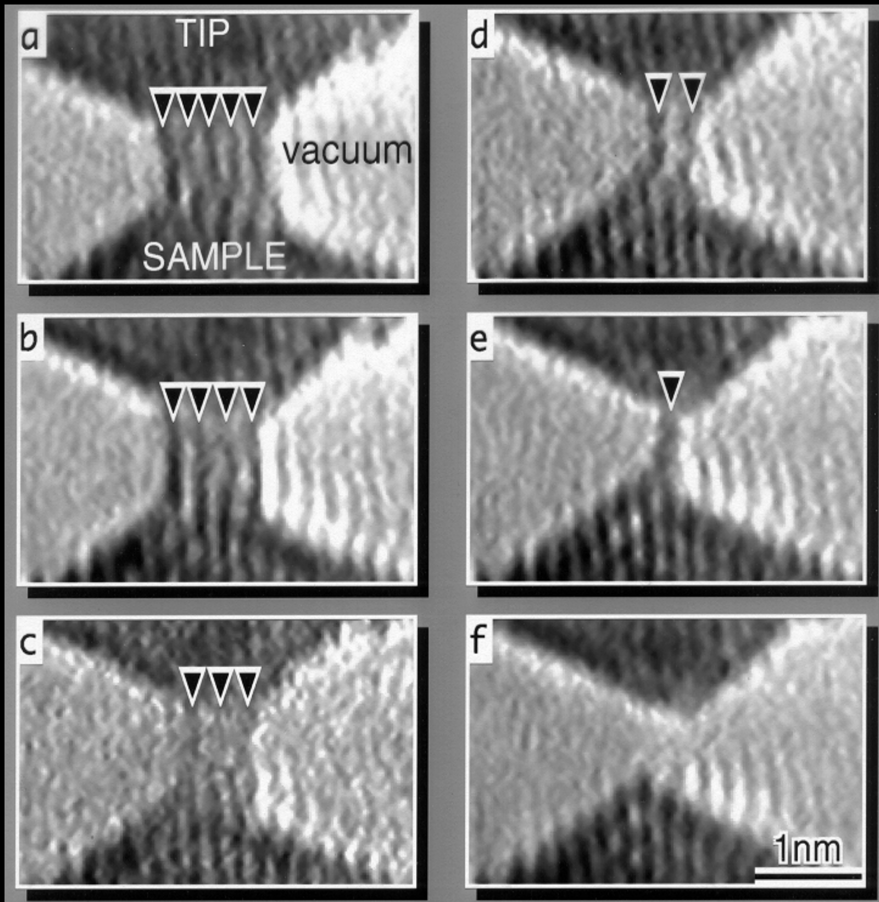


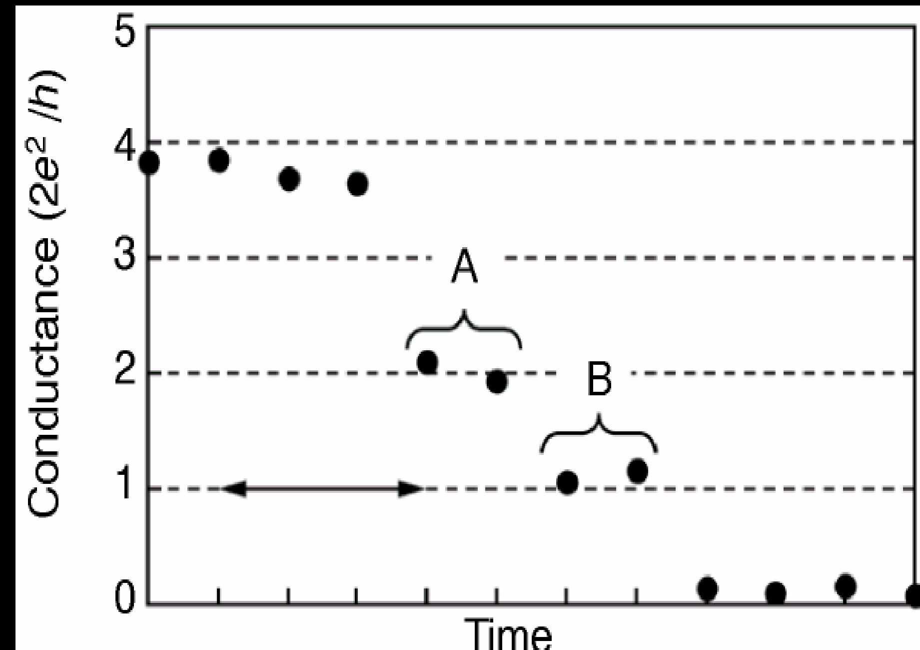

Figure 1 A field effect transistor (FET), such as

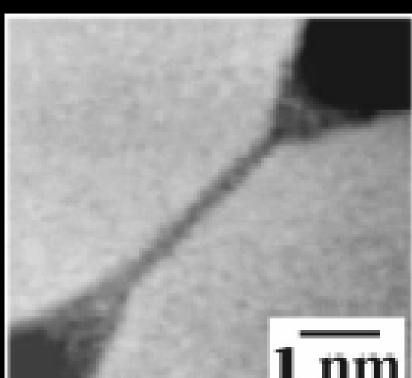


# 量子線：電導量子化

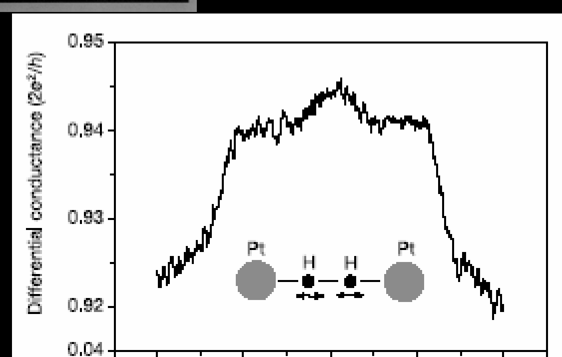


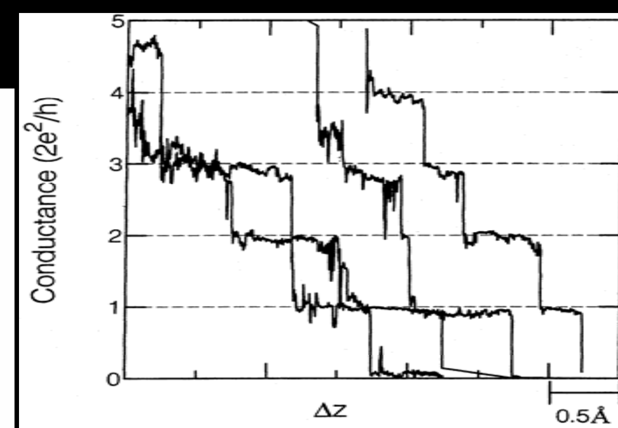




TEM images, Takayanagi et al.

11-atom gold chain

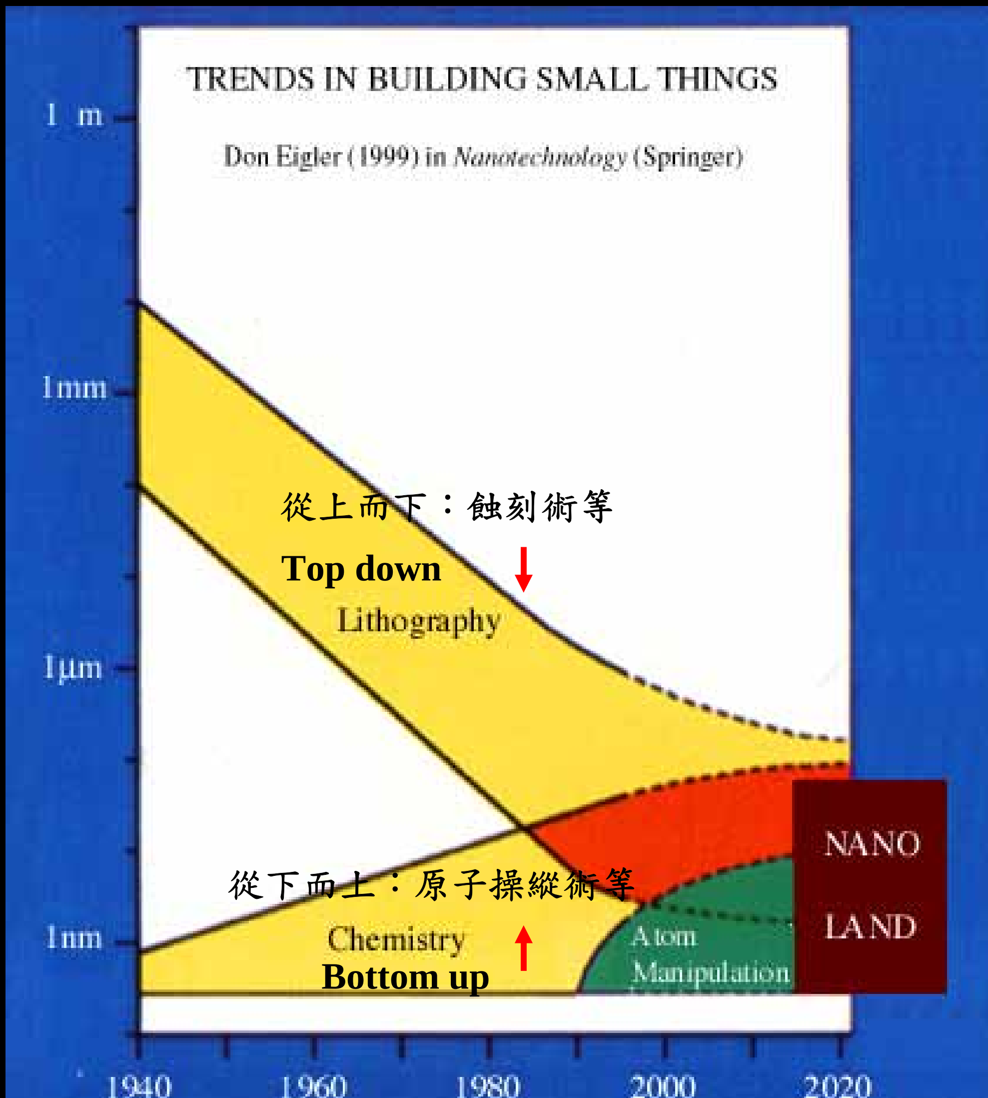



J. M. van Ruitenbeek*




Jian et al.

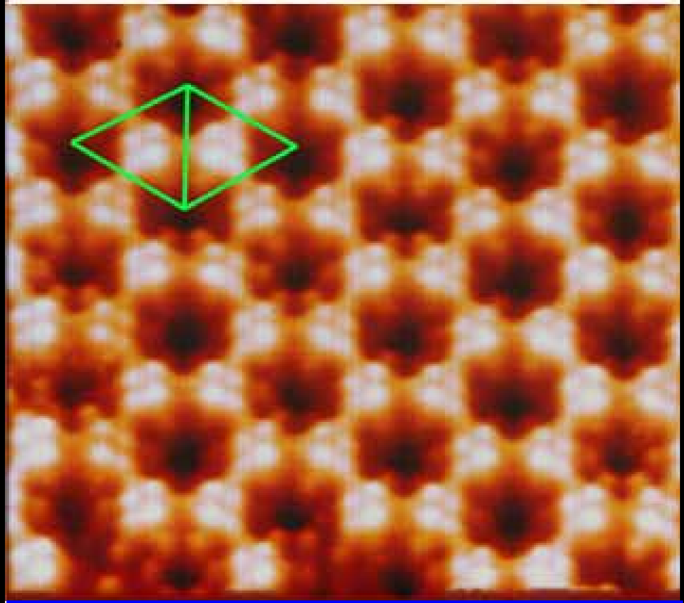
# 奈米科技 Nanotechnology




- 奈米尺寸的移動材料，製造奈米結構
- 量測並瞭解奈米結構的物化性質
- 利用這些性質製造奈米尺寸元件和器件

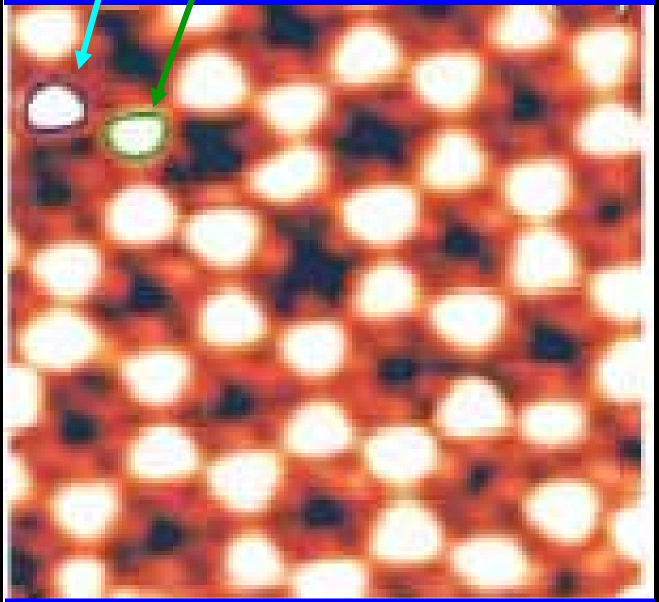
# Reconstructions as templates
## *for self-organized growth*

Ga/Si(111)7x7



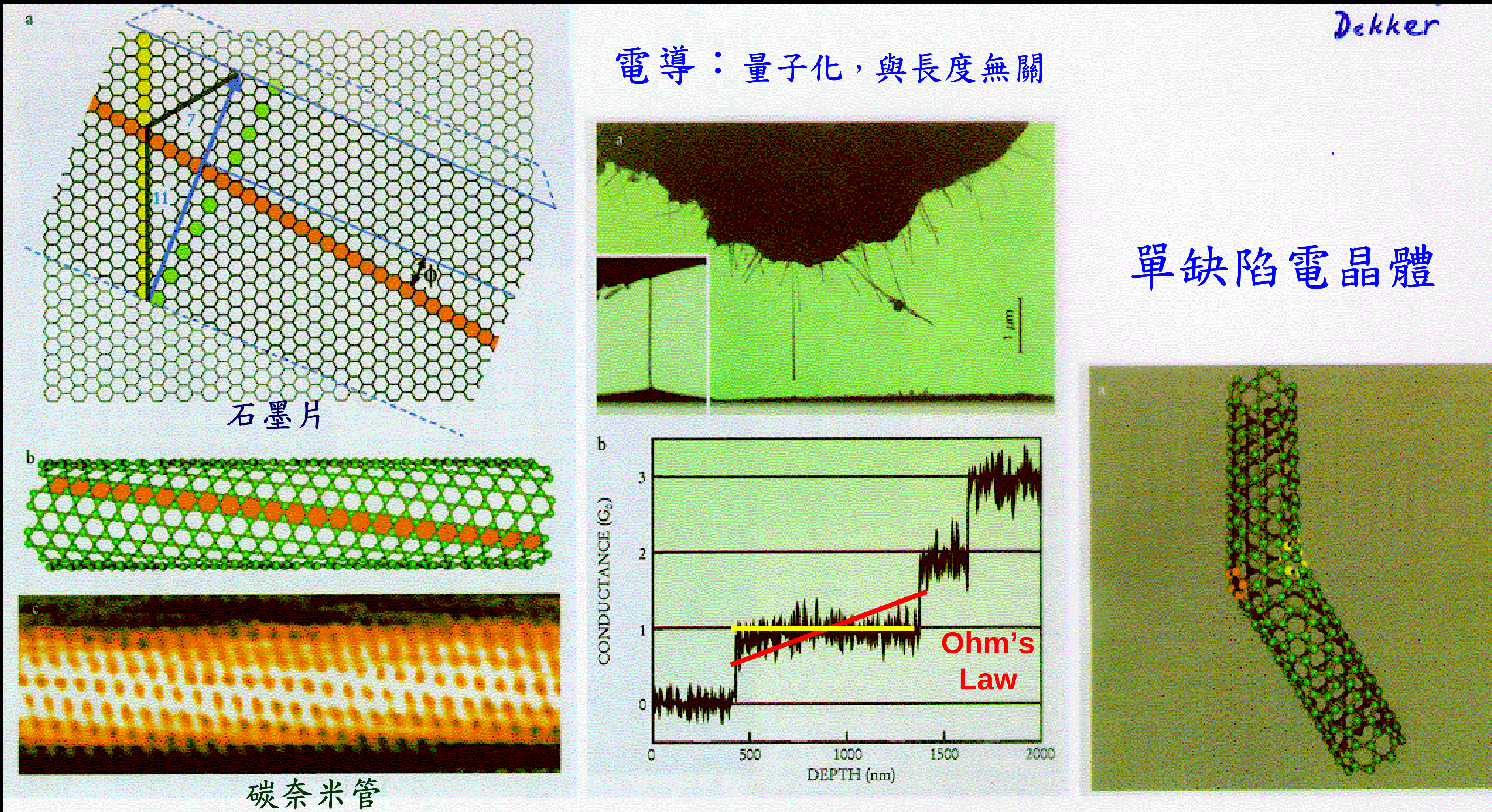
M.Y. Lai and Y. L. Wang
Phys. Rev. Lett. 81 (1998) 164

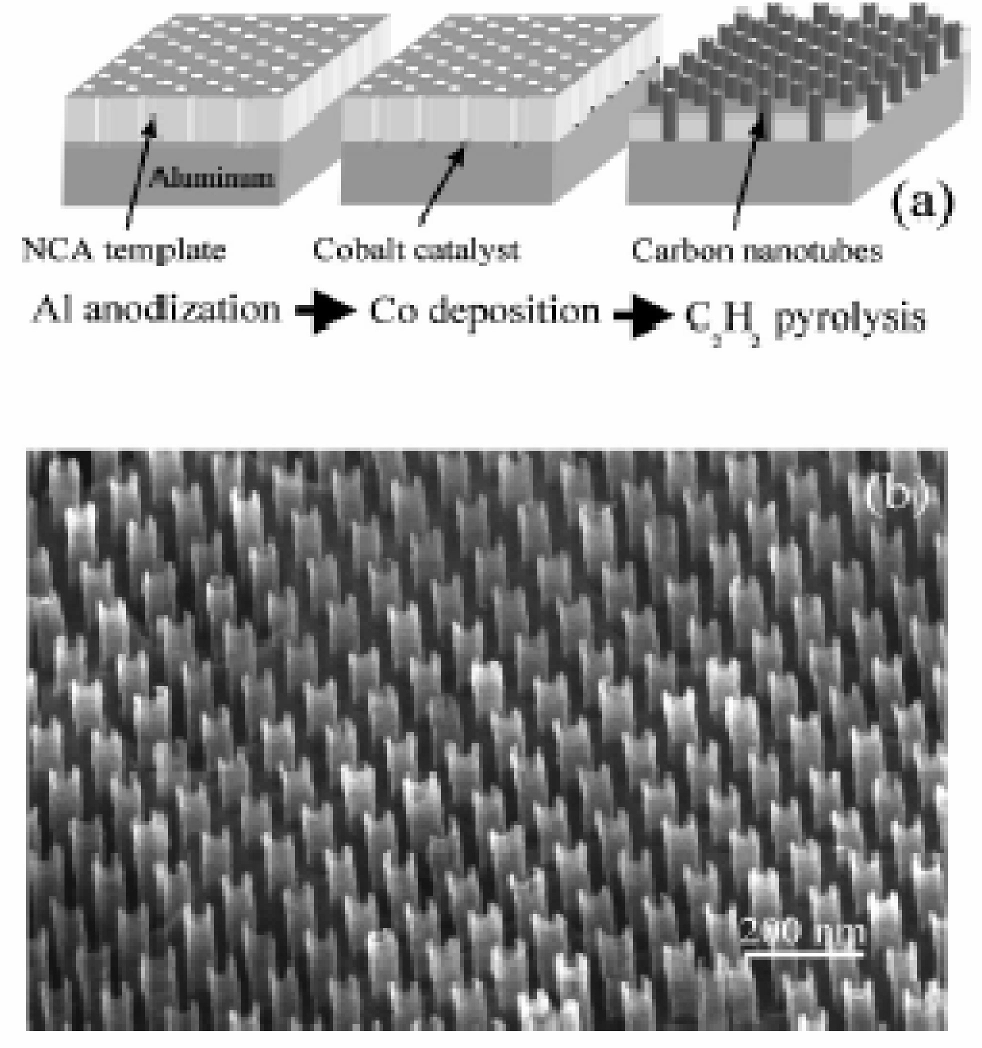
In+Mn/Si(111)7x7



Jian-Long Li *et al.*
Phys. Rev. Lett. 88 (2002) 066101

# By Chemical Synthesis & Growth: Single Wall Carbon Nanotube

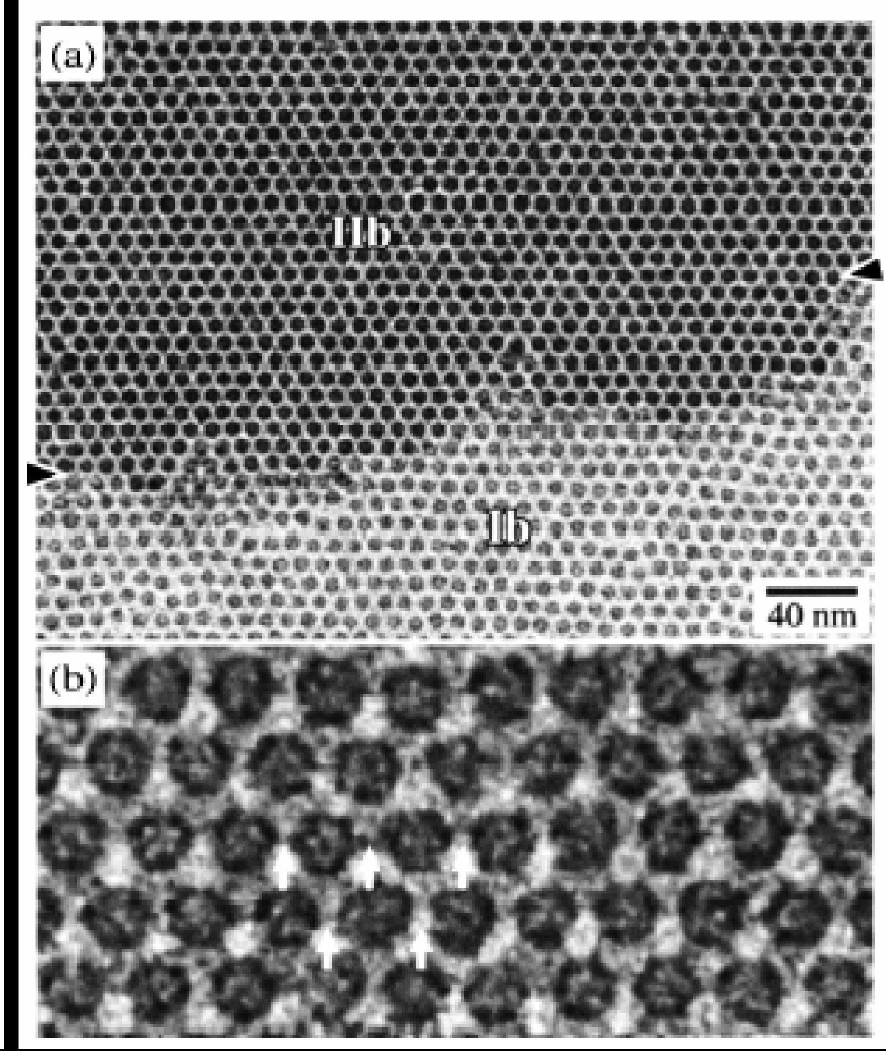





**Highly-ordered carbon nanotube arrays for electronics & FEFPD applications**

J. M. Xu et al., APL **75**, 367 (99)

U. Toronto

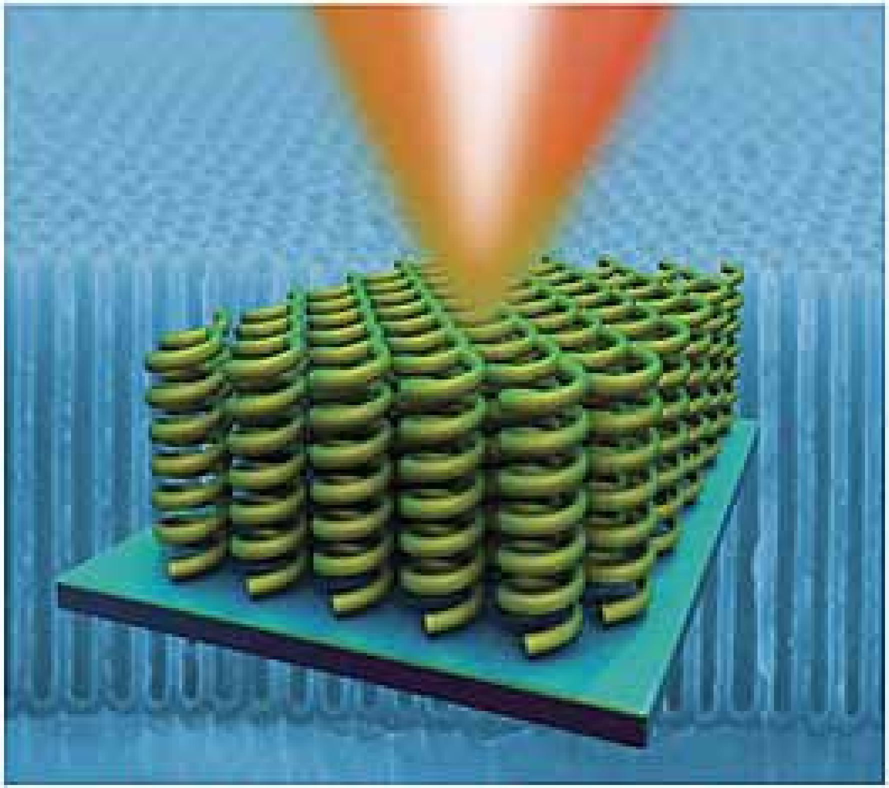



**TEM image of a film of 7.0 nm size Fe nanoparticles (coated with surfactant).**

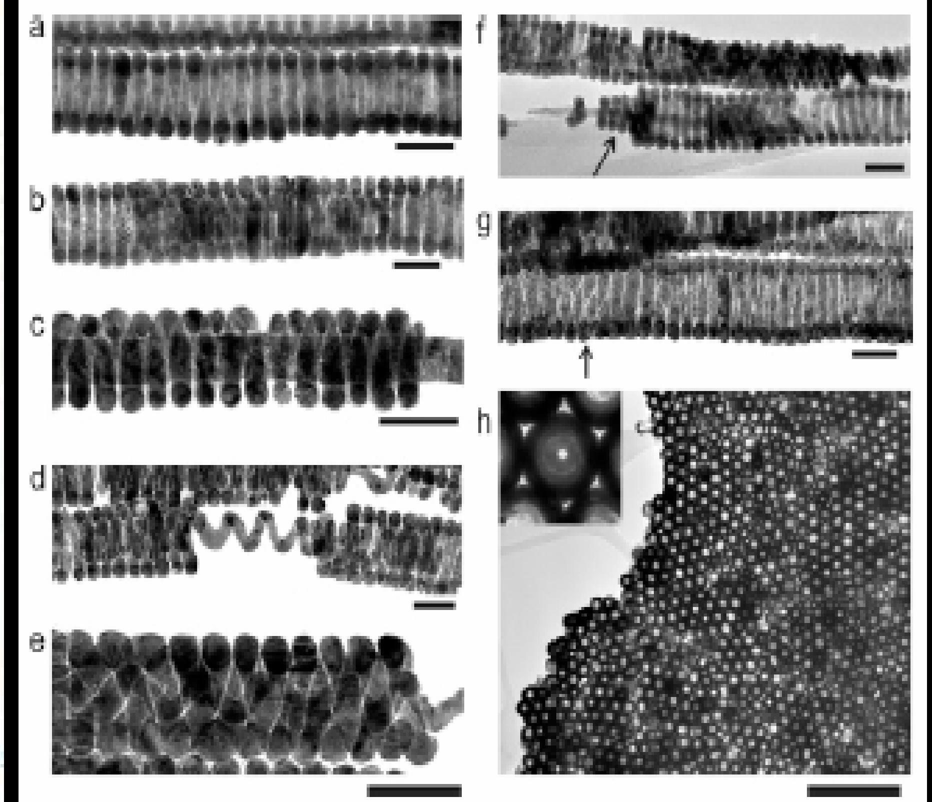
A. Majetich et al., PRB **65**, 224431 (02)

Case-Western U.

鄭天佐 IP AS



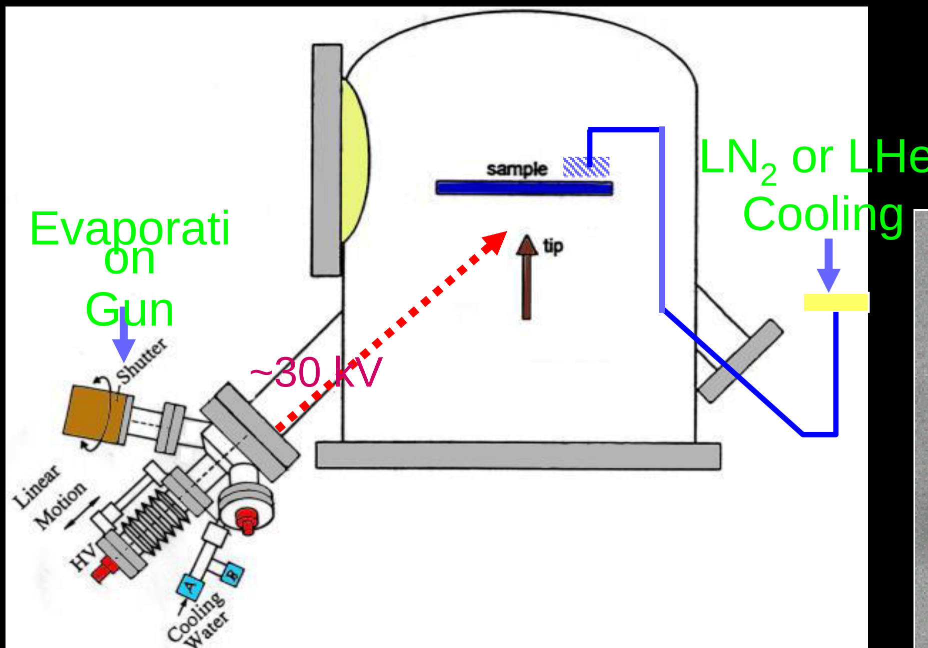
Helical Mesostructured Nanowire Arrays



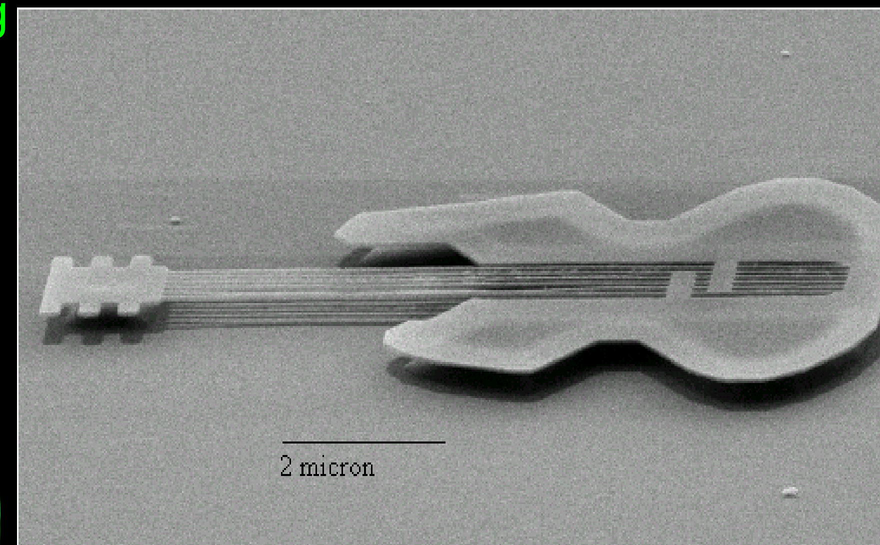

A general methodology that utilizes confined mesoporous silica as template for preparing highly ordered mesostructured nanowires and nanowire arrays is developed. The prepared Ag, Ni, and $Cu_2O$ nanowires, with unprecedented mesostructures of coaxially multilayered helical, and stacked-donut structures, have the unique features of hierarchical organization, modulated surface morphology, high surface area, and chirality. Surface-enhanced Raman spectra from a silver mesostructured-nanowire bundle are presented.

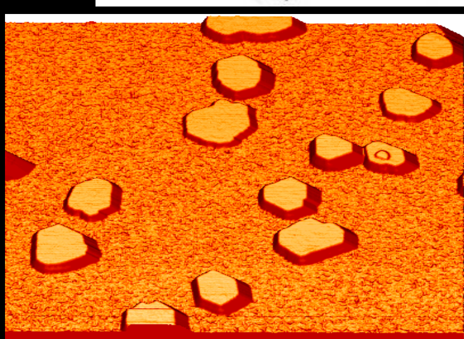
Y. Wu et al. Nano Lett. '04

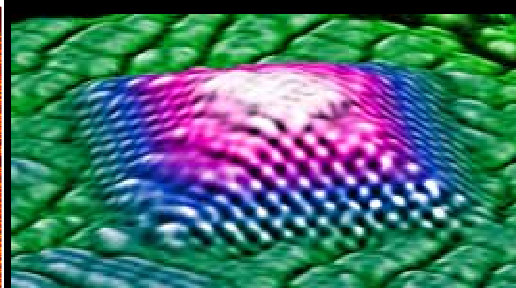
# 奈米材料結構的製造方法




以蝕刻法作成的奈米吉他



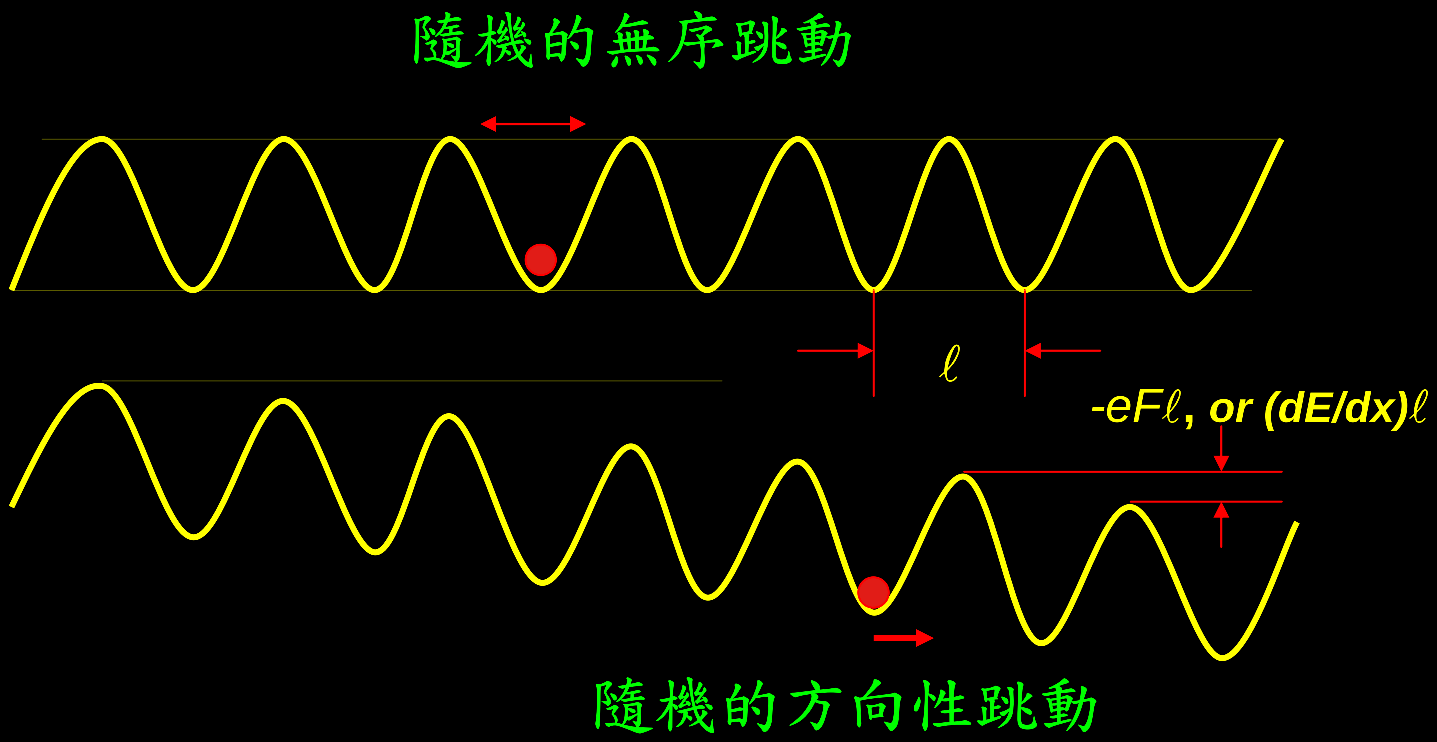





量子島：蒸鍍法

蘇維彬、張嘉升等人 ‘00

世界上最小的吉他，全長**10μm**。
含六根絃，每根**50nm**寬。
需要微米青春偶像機械人來演奏奈米音樂
猜猜機械人聽得到的音調！



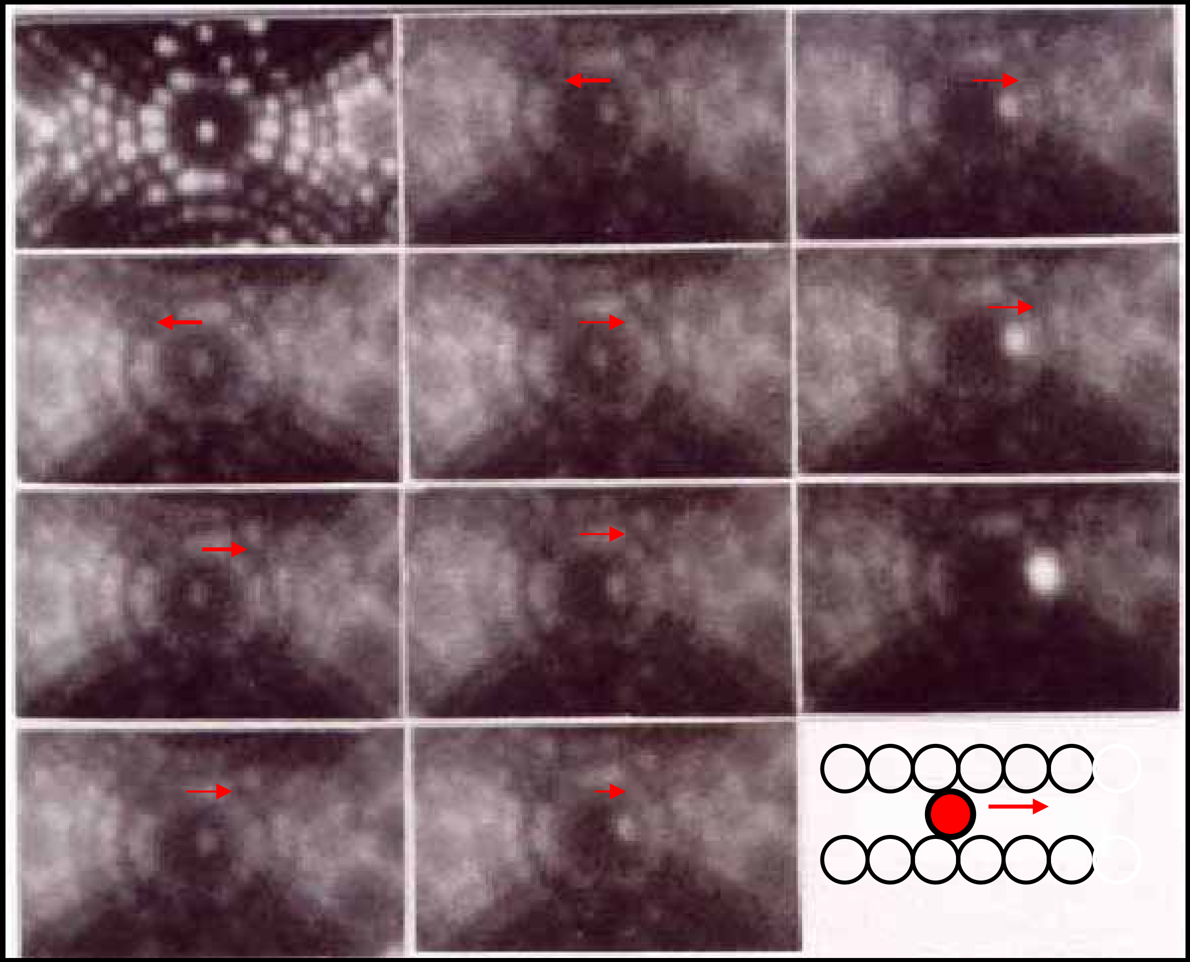

# 化學勢能梯度引發隨機的方向性跳動

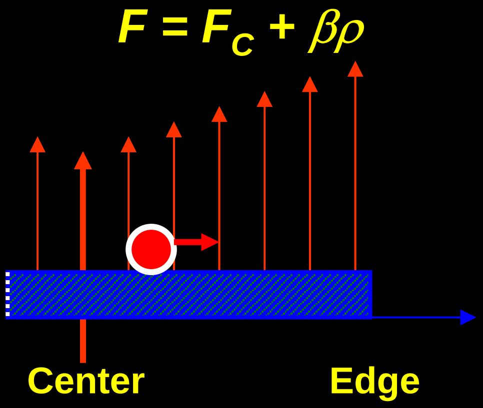
化學勢能梯度：電場梯度，粒子密度及溫度梯度，原子間作用

非平衡熱力學效應， **Kinetic Effects**

# Directional Walk of W on W(112)

## Produced by Chemical Potential Gradient (Field Gradient)

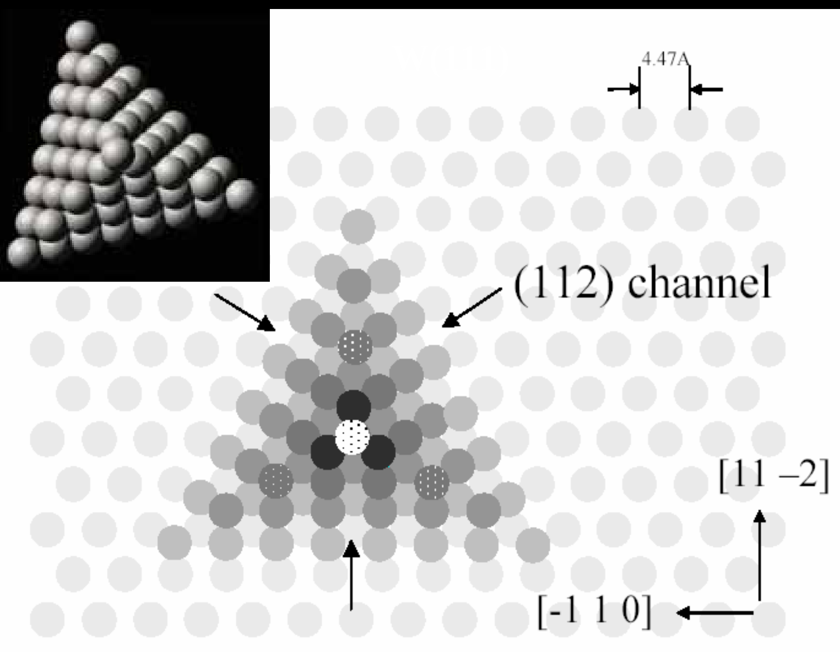





Tsong, Walko, Kellogg, Wang ‘72, ’75 ‘82

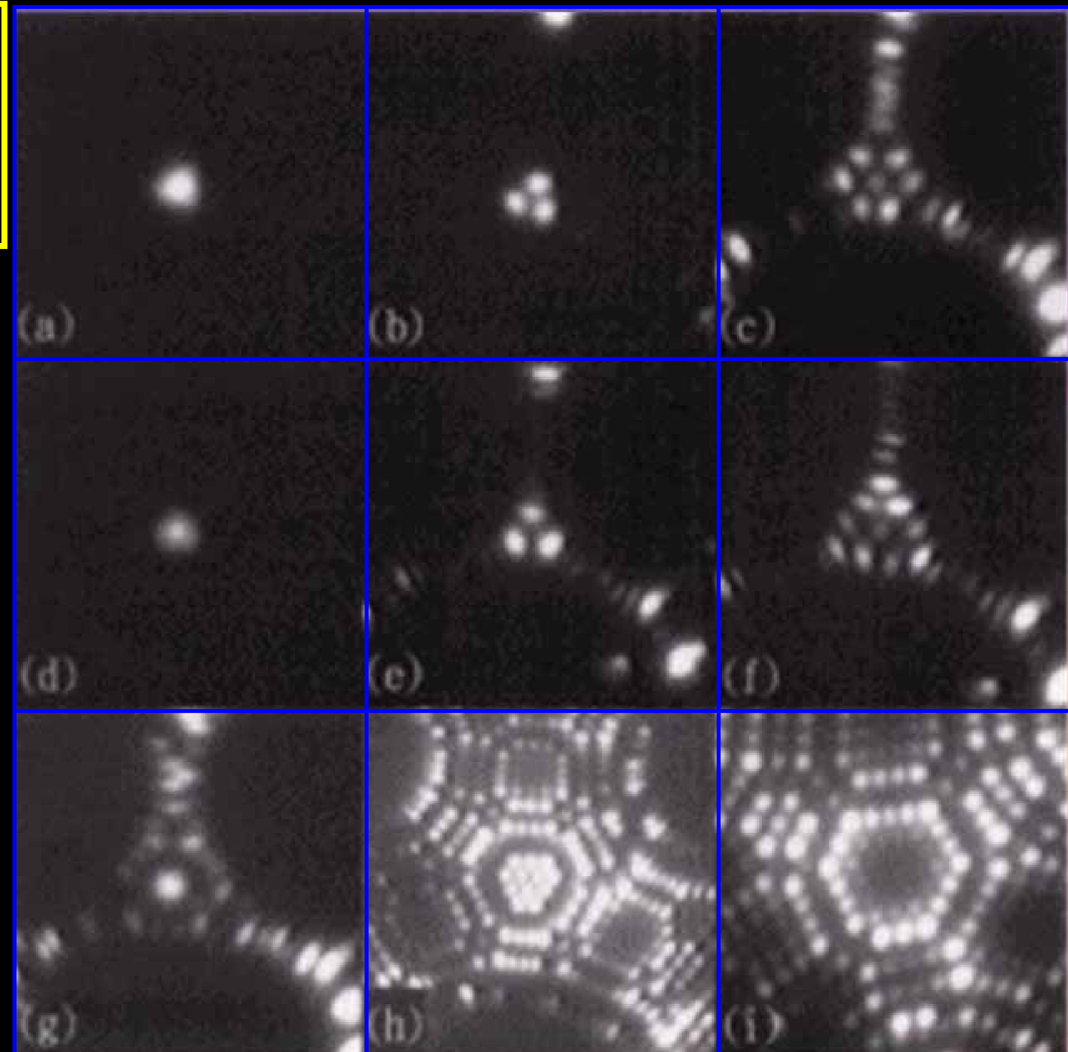
# 以原子堆砌的世界最小金字塔：約 1.4 nm 高

1) 用為 STM 探針
2) 全像術所需同相位電子源
3) 點電子與離子源




T. Madey et al.: Formation of pyramids by two comp. systems

T-Y Fu *et al.* PRB (2001).




**Atom perfect & chemically inert Pd-covered W(111)-base pyramid. Thermally stable up to ~1000 K, h ~ 1.4 nm**

鄭天佐 IP AS

# 世界最美的建築之一 (?)


埃及金字塔，~140 m

比： 高 $10^{11}$ 體積 $10^{33}$

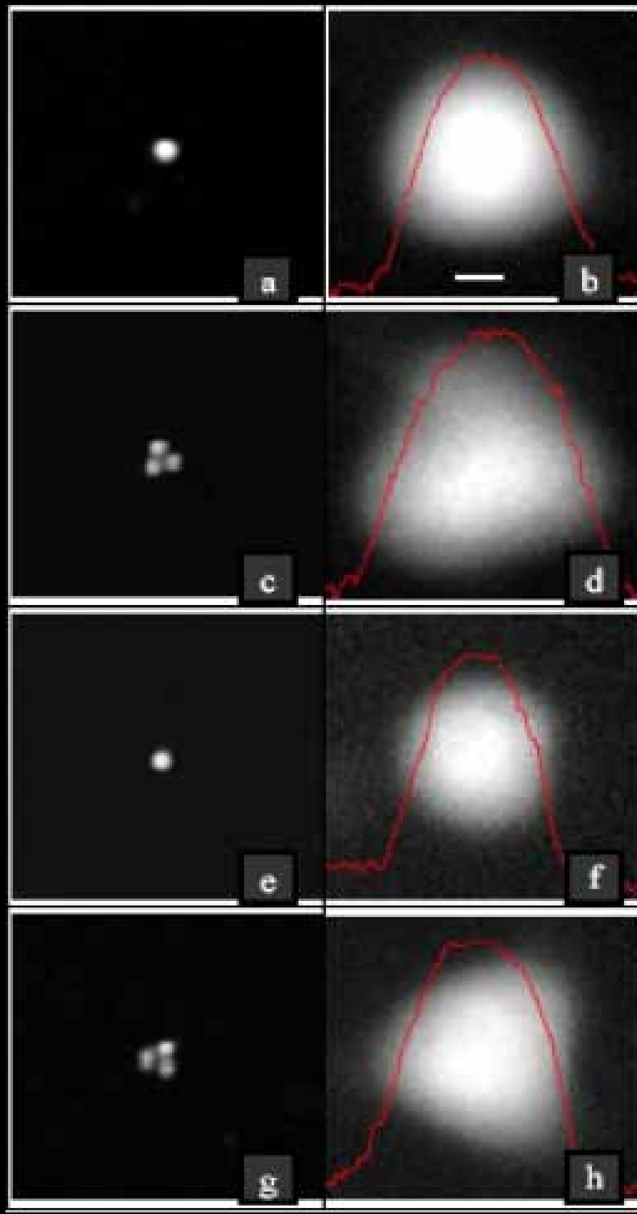

貝聿名金字塔，~14 m

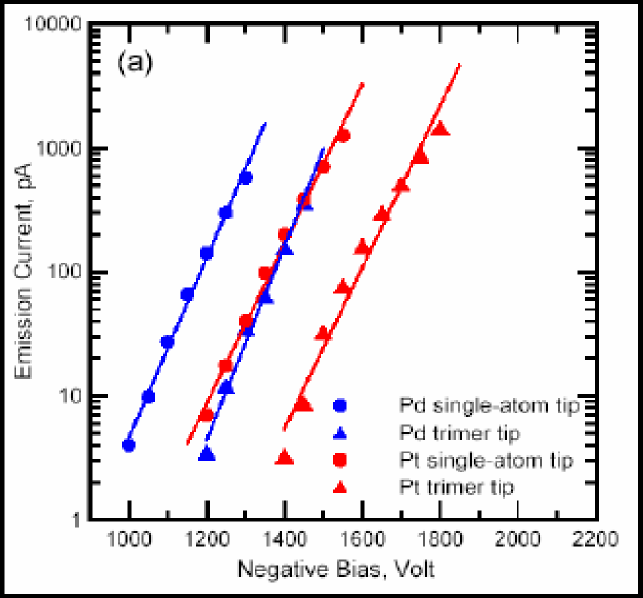
比： 高 $10^{10}$ 體積 $10^{30}$

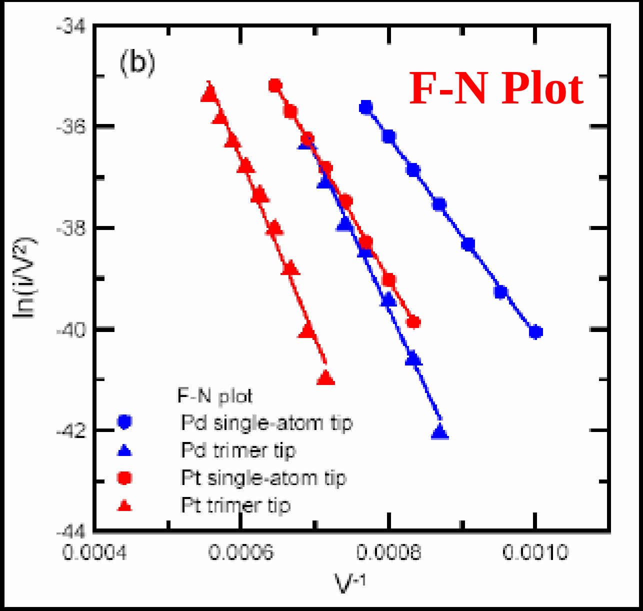
FI Source FE Source

Pd on W(111)

Pt on W(111)




**Field emission: extension angle ~ 6°**

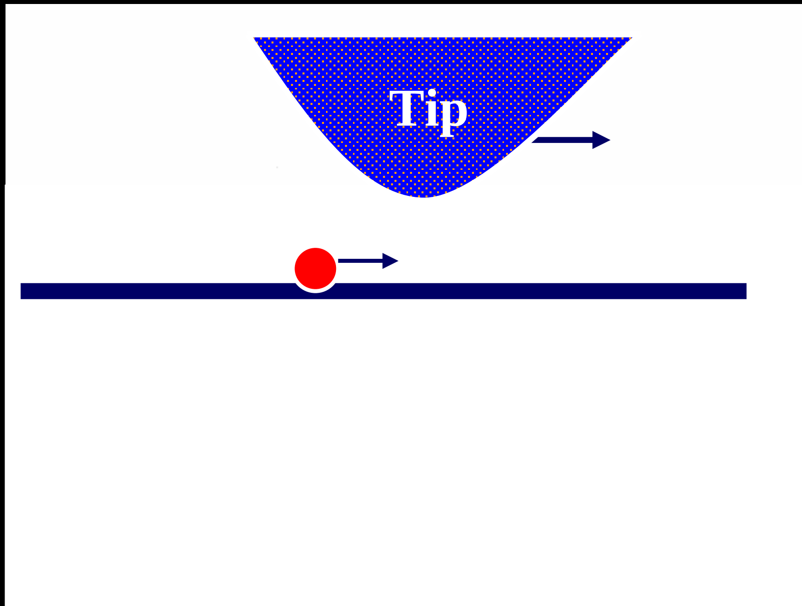
**Field ionization: extension angle ~ 0.5°**

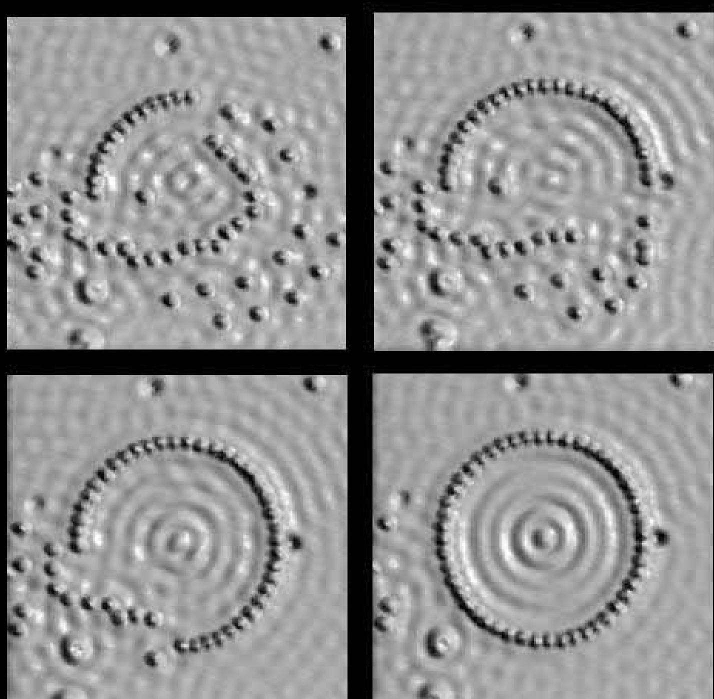
Kuo et al. NANO Lett. ’04

# STM 原子與分子操縱術

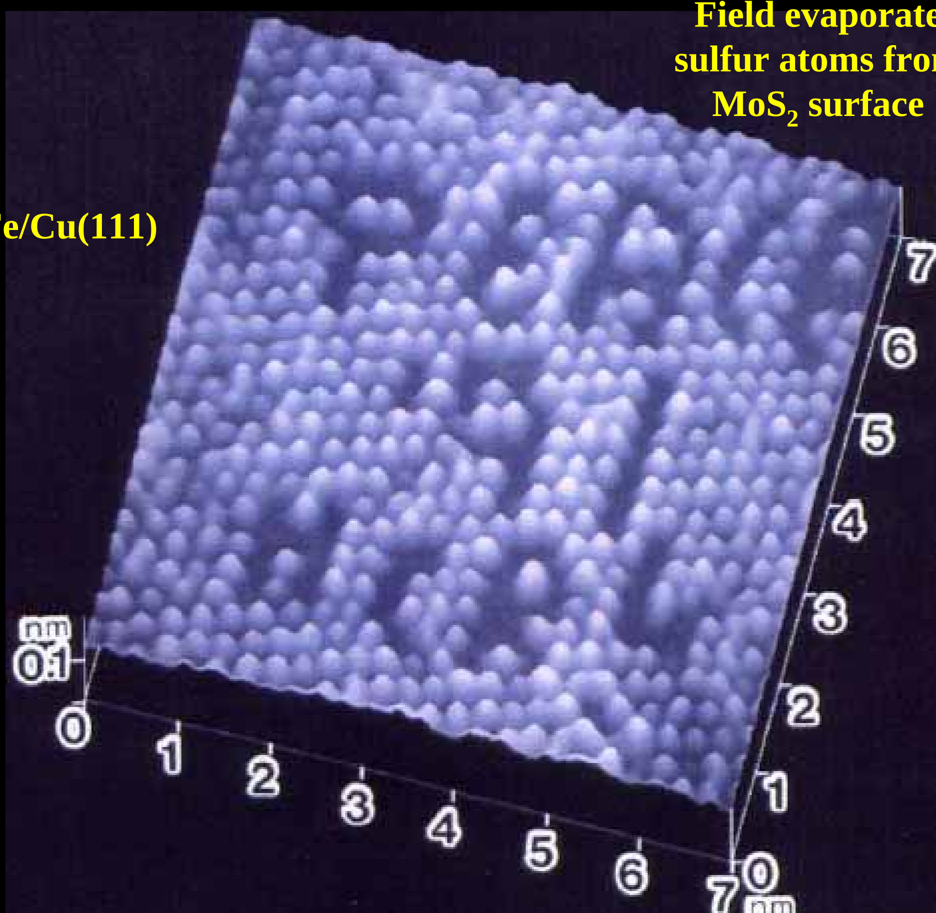
**原子相互作用: Eigler et al. '90**

**場蒸發: Hosoki et al. '91**



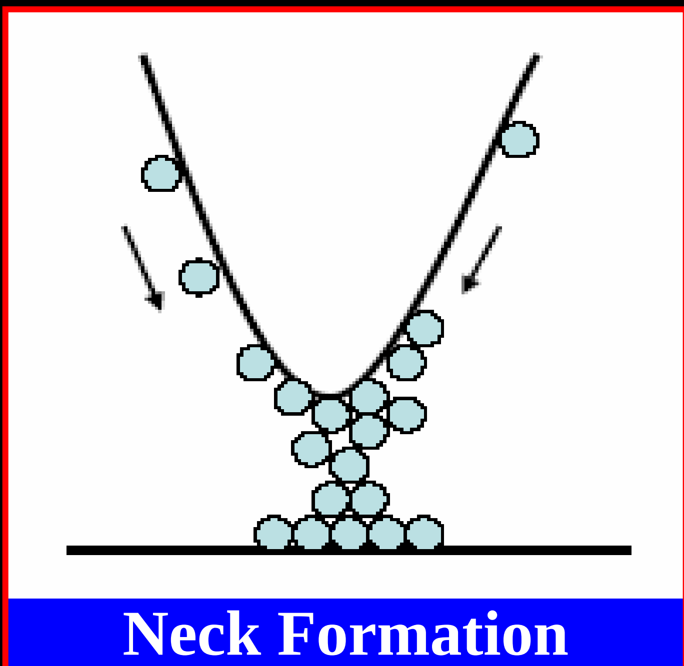



Fe/Cu(111)

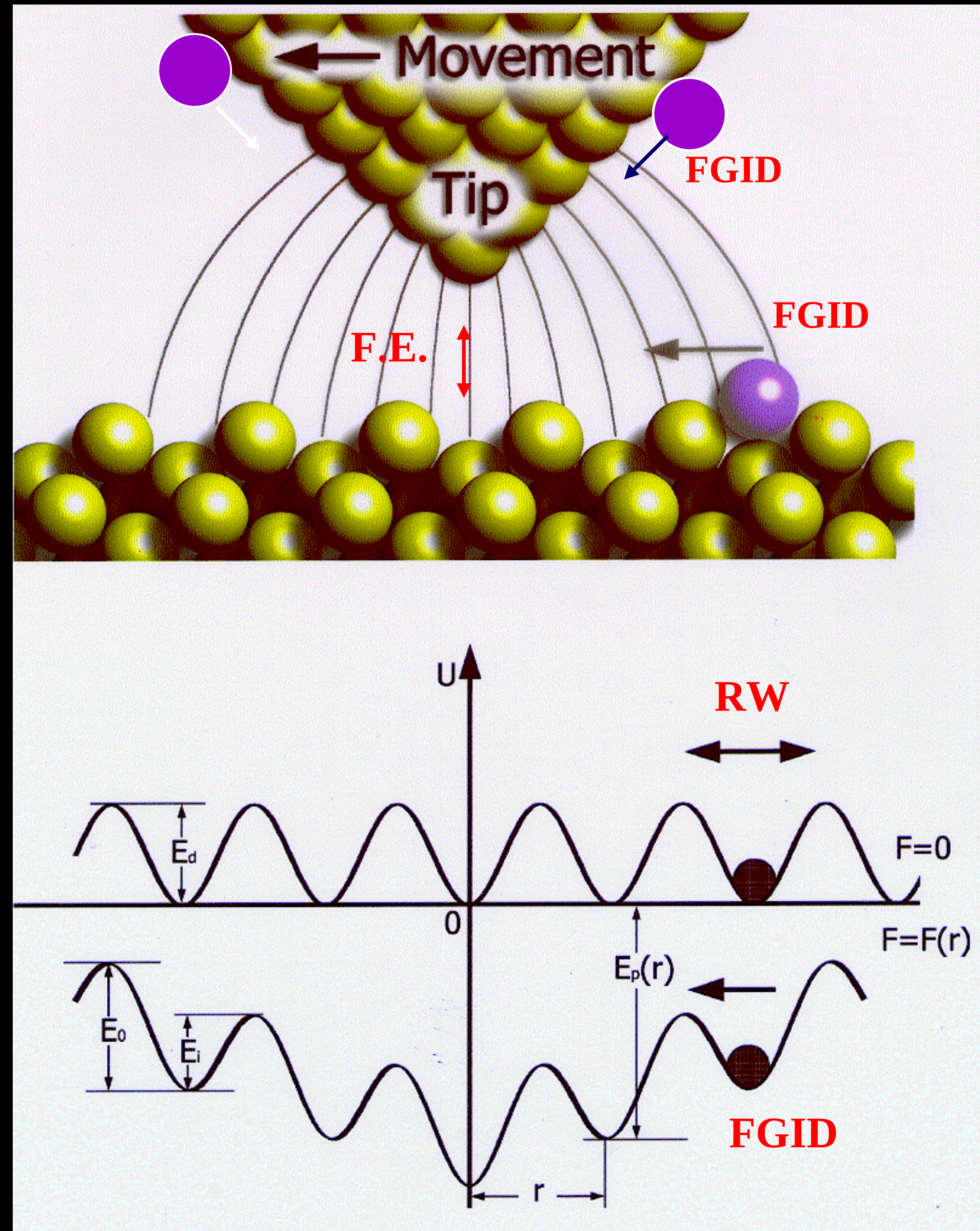


# 其他操縱法

1. Field Gradient Induced Diffusion:
   Directional walk    Neck formation
2. Field Evaporation:
   Atom transfer between tip & sample



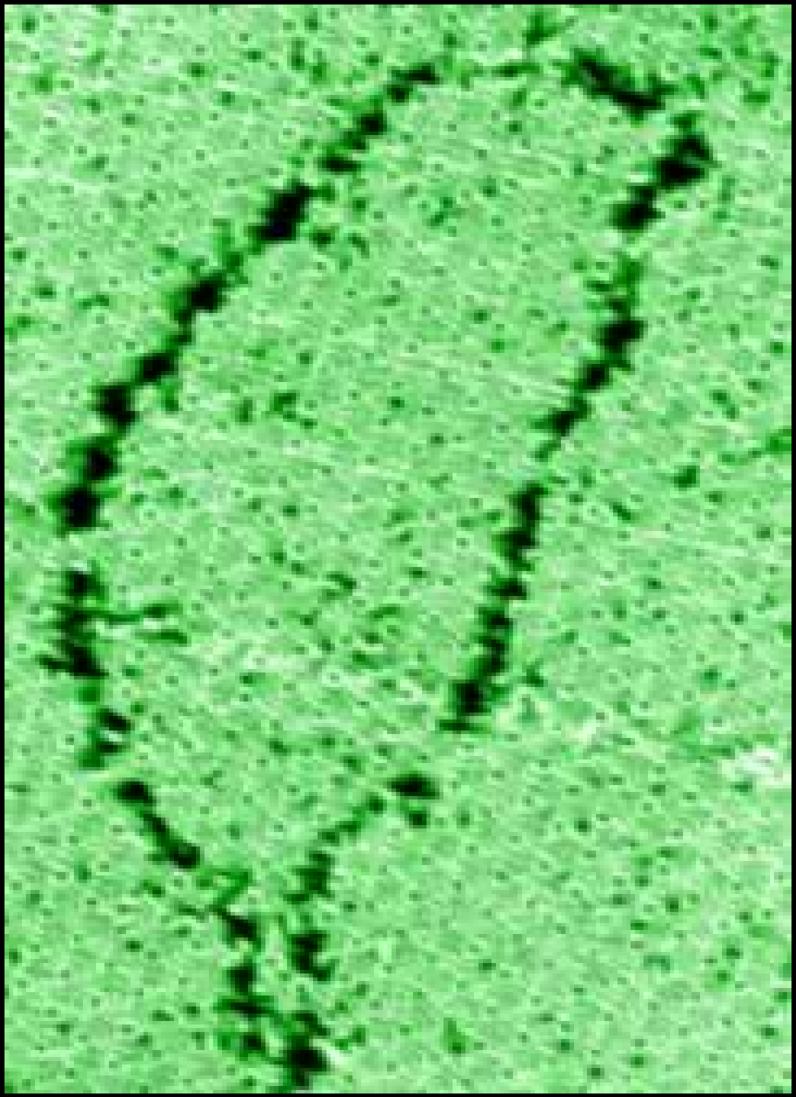

Tsong' PRB '91



# Manipulation in nanoscale

*Thermally stable at 300 K*

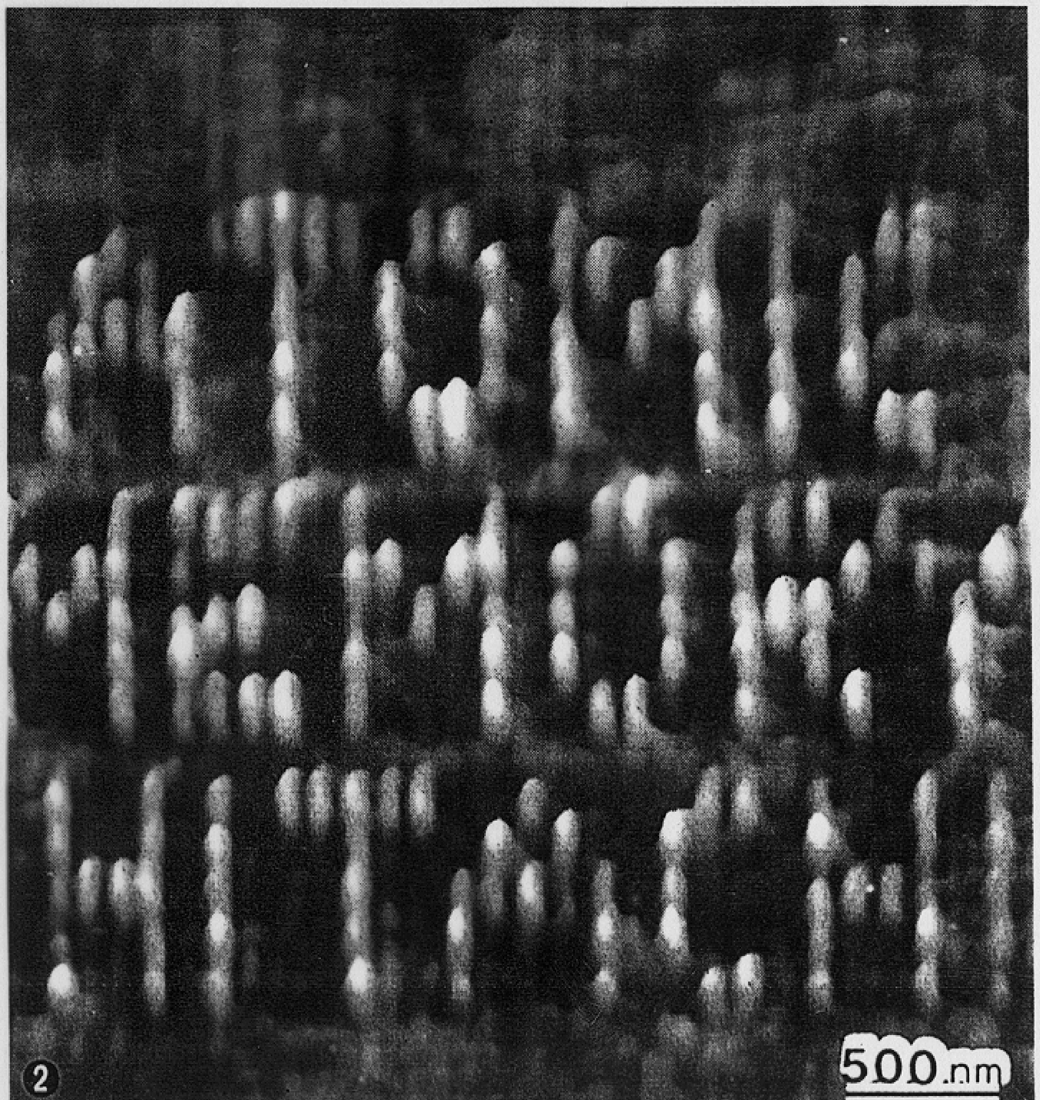
Neck Formation (700 x 1000 nm)

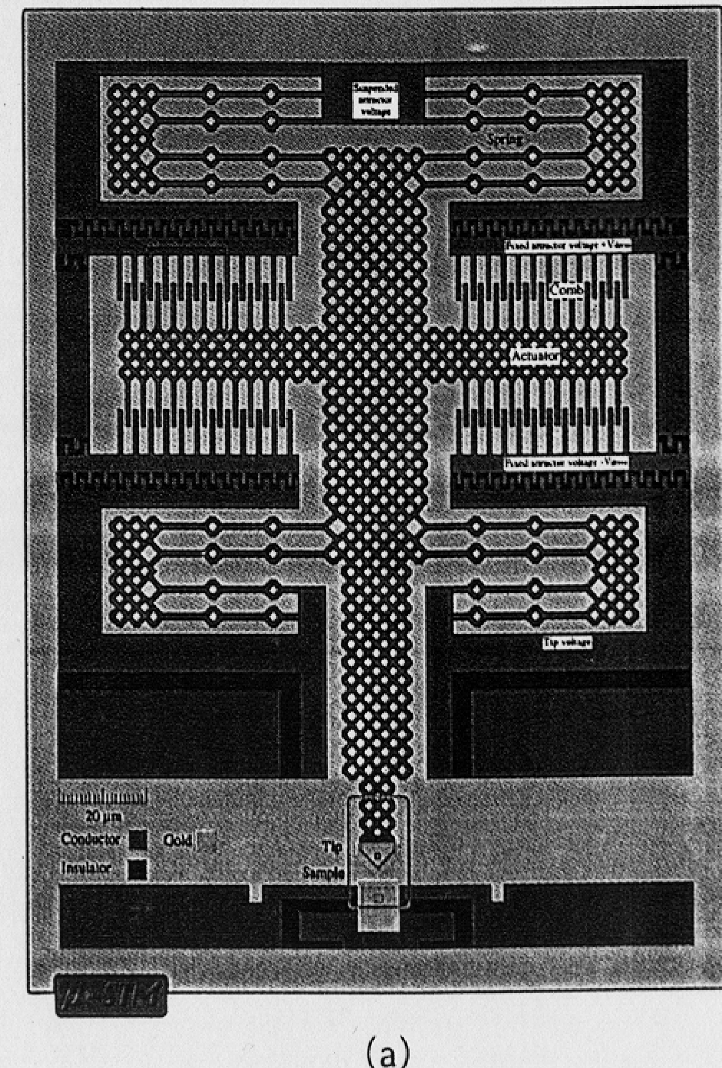


Field Evaporation (70 x 100 nm)

Tsong, IP AS

# 結合微機電和掃瞄隧道顯微術寫奈米尺寸的字



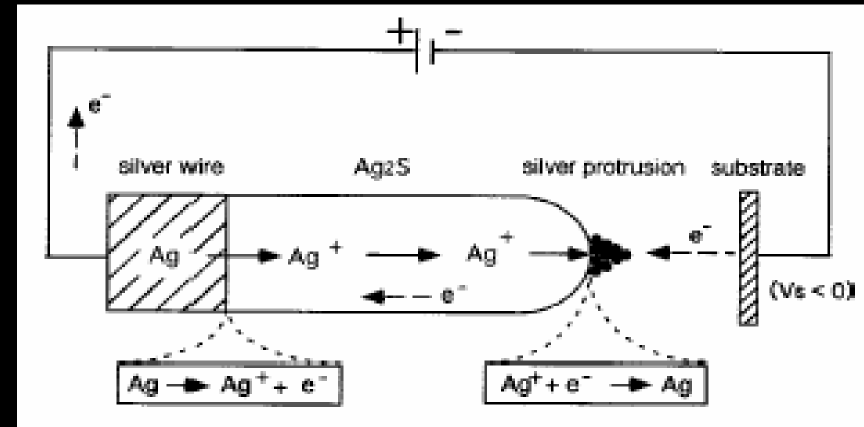



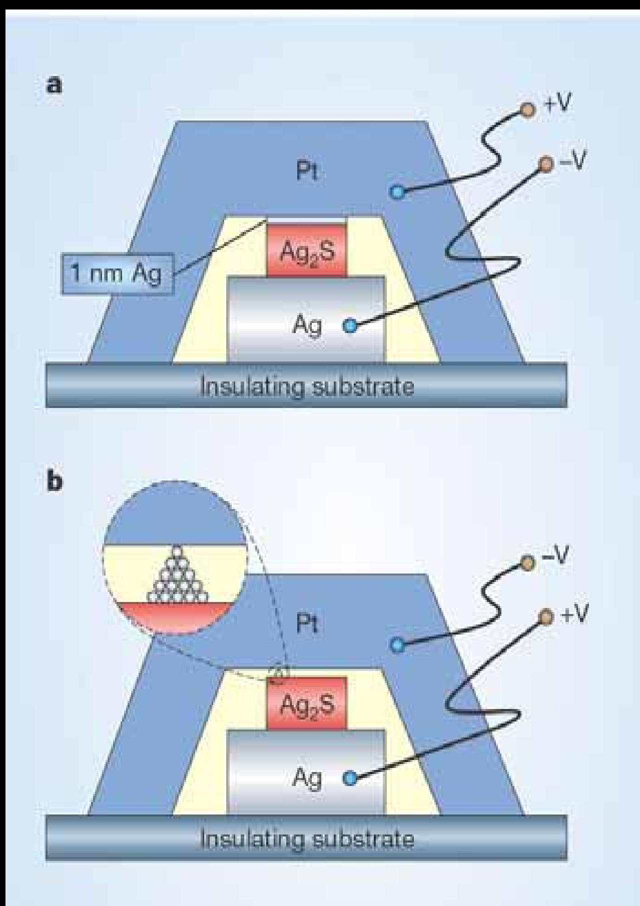

**~15 nm Tb/in$^2$**　　　　**MEMS**

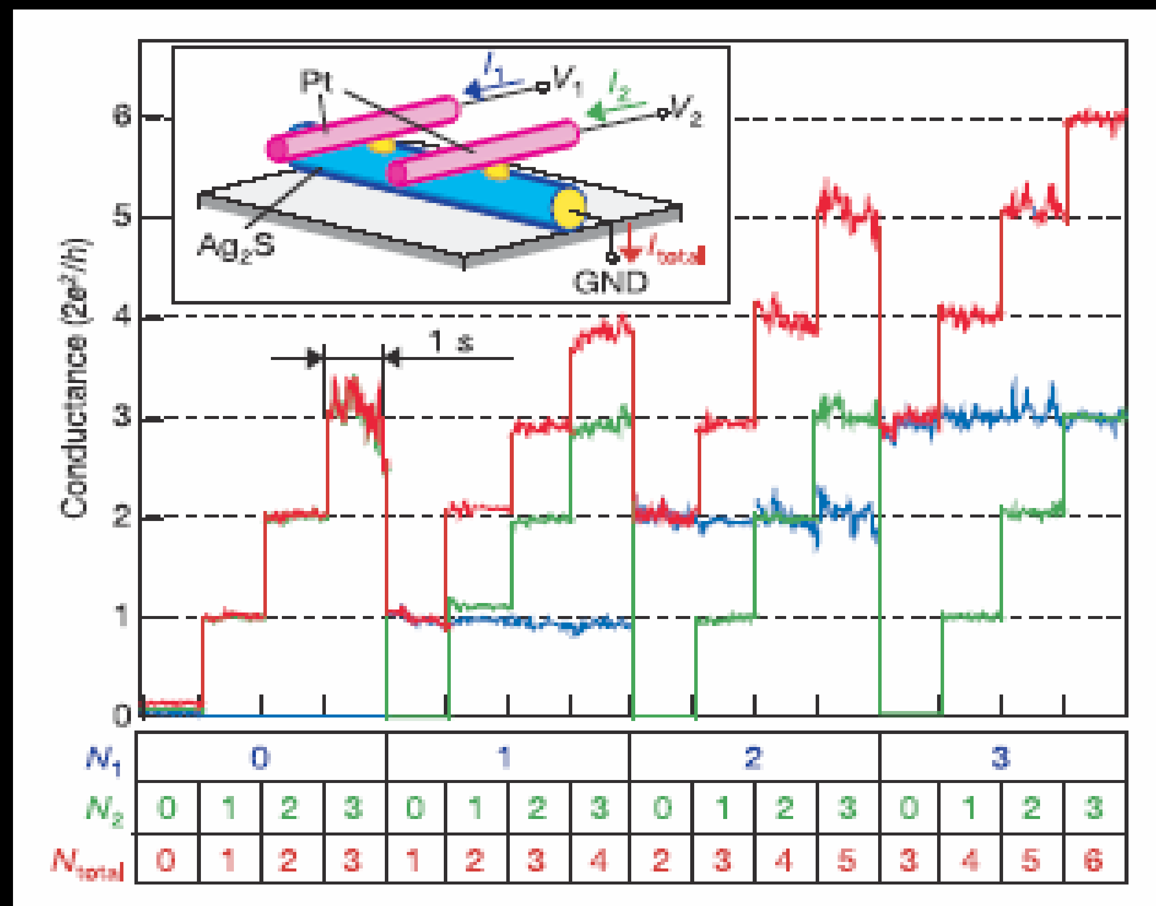
鄭天佐 IP AS

# 原子鋼筆 和 原子開關

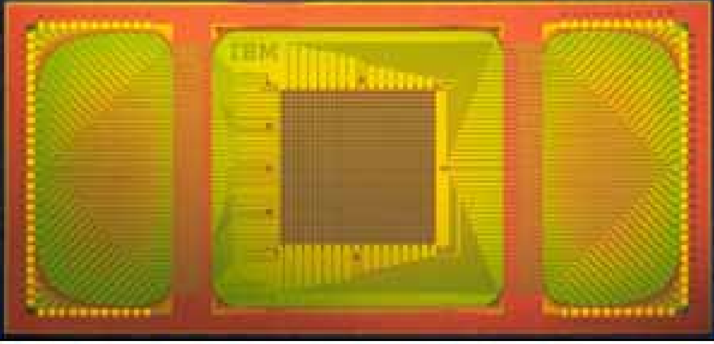
**Ag 是墨水，$Ag_2S$ 是筆，寫在矽表面上；另它或 $Cu_2S$ 針和薄膜都可用來當原子開關. Terabe et al. Nature '05**

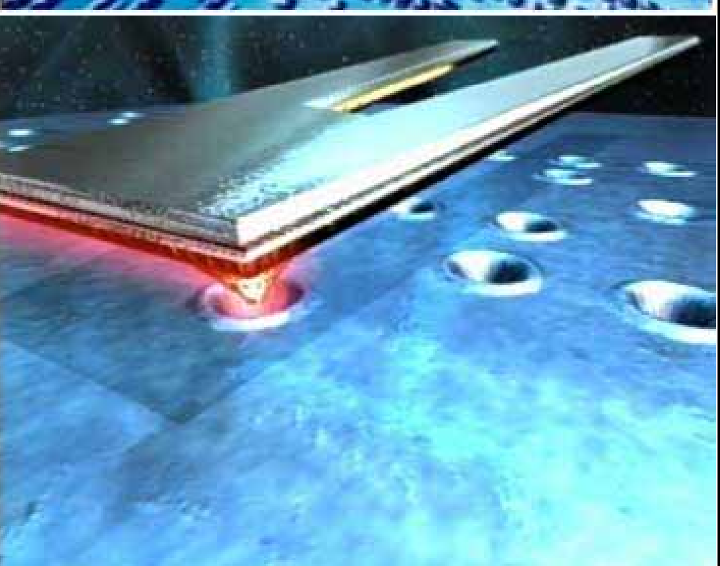
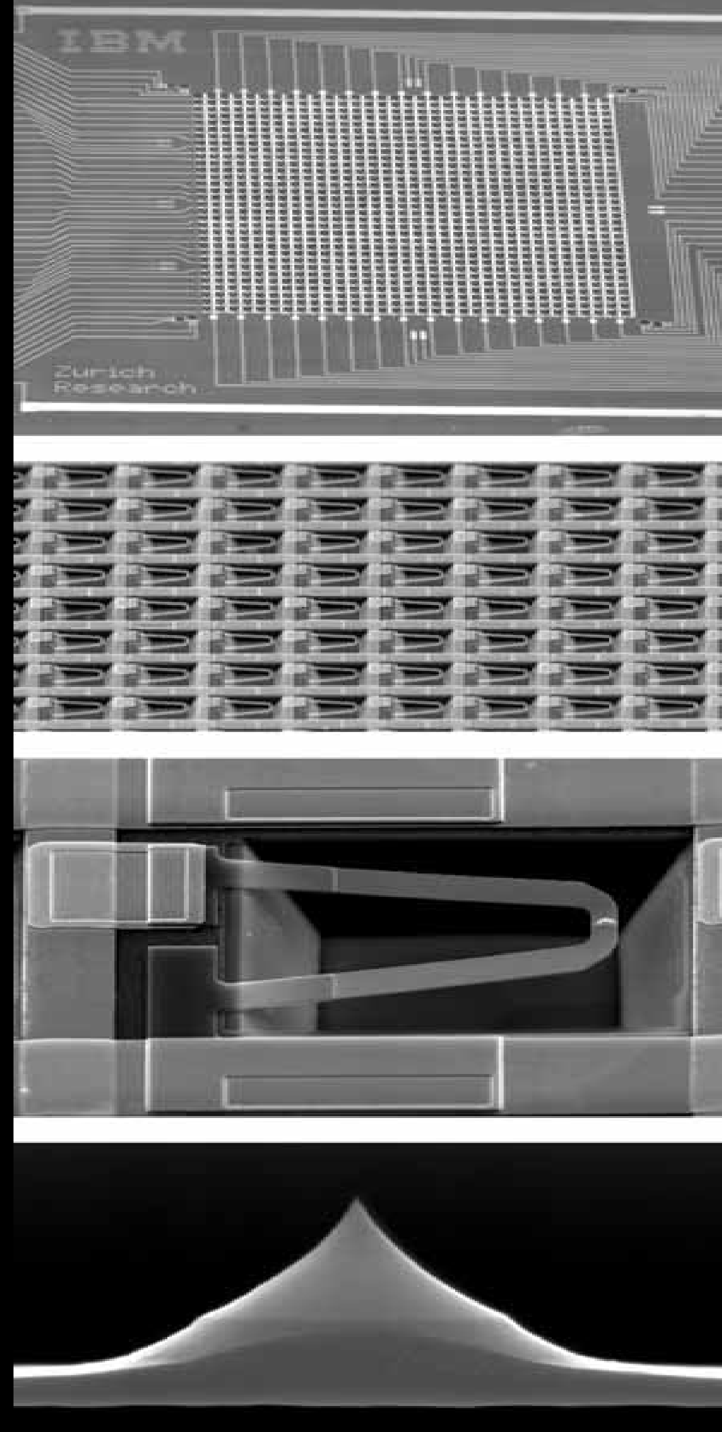



鄭天佐 IP AS




# IBM Millipede
# 千足兆位元記憶體
## 2002

0: 無洞

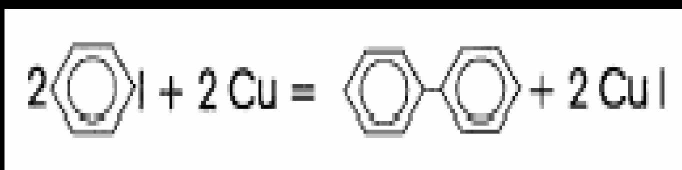
1: 有洞

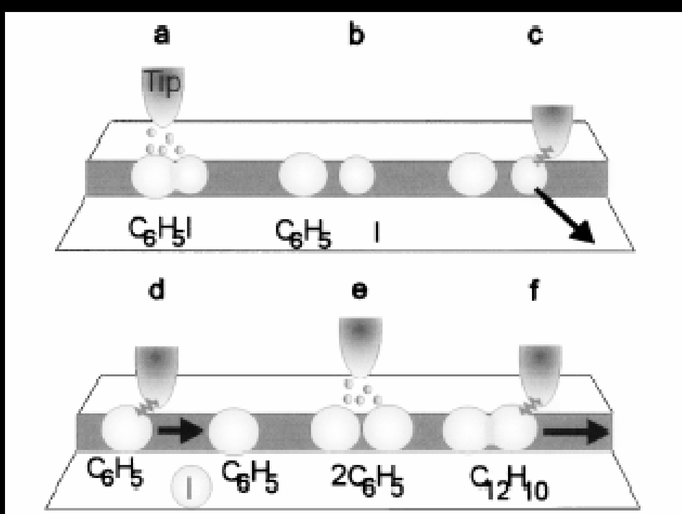
郵票大小可儲存幾十張DVD

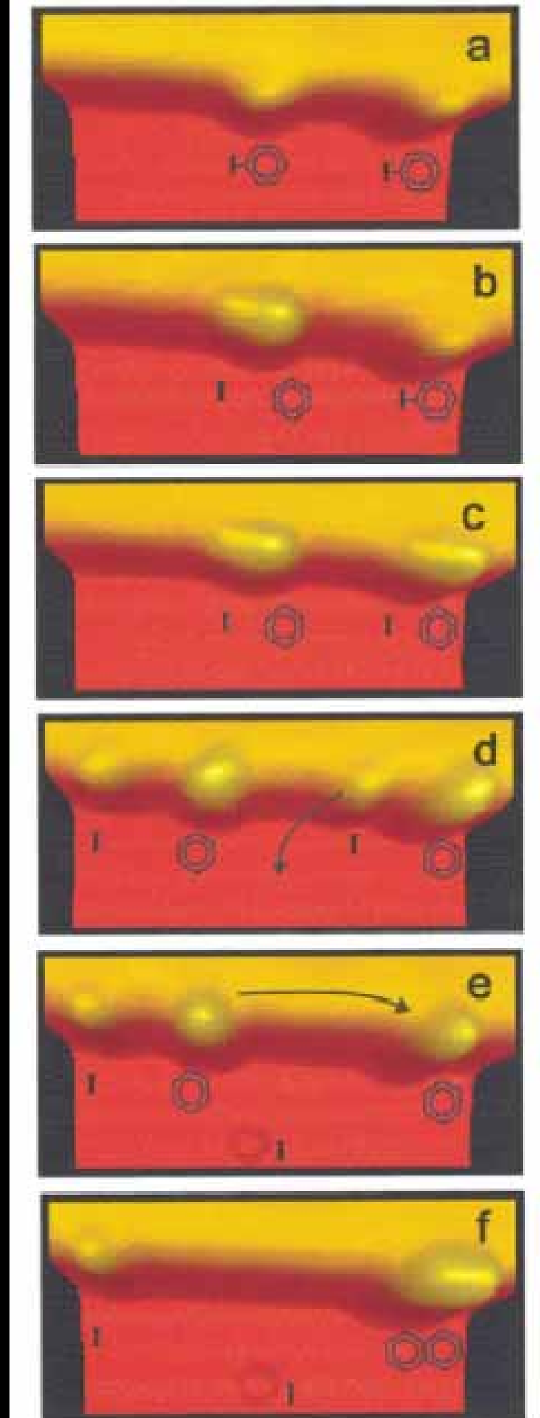
# 合成單分子工程

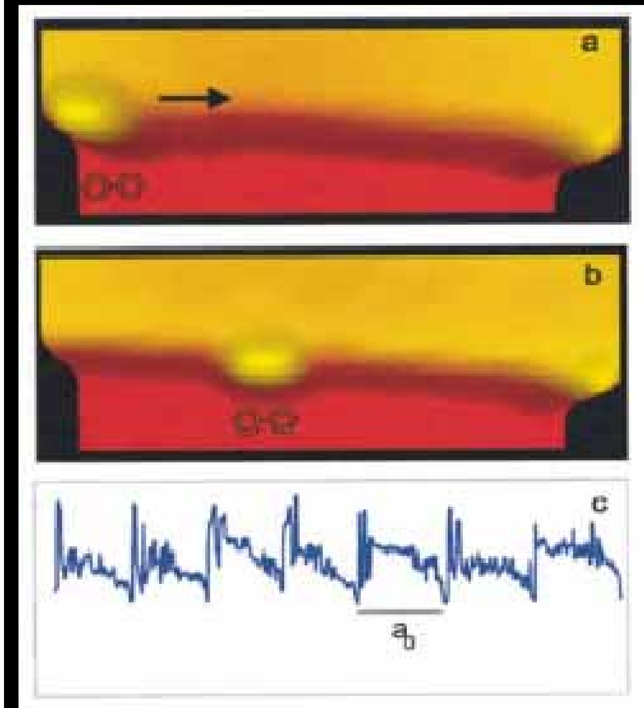
在銅表面台階處用
兩個 碘化苯 合成
一個 biphenyl

Rieder et al., PRL’00



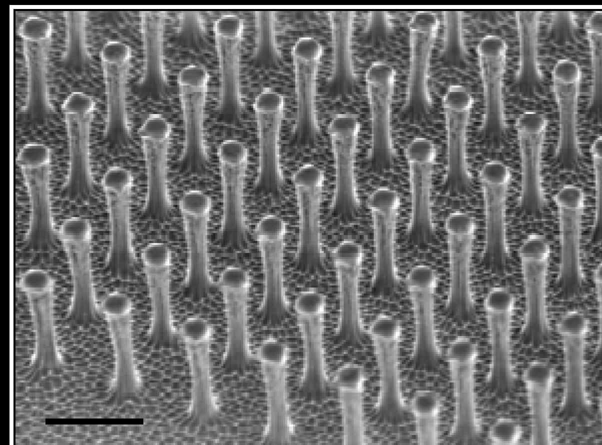



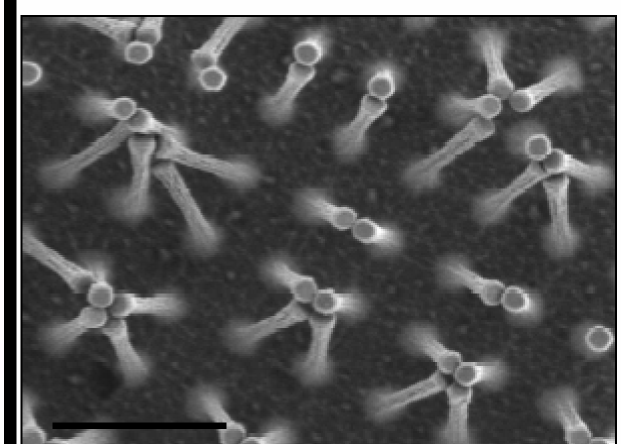



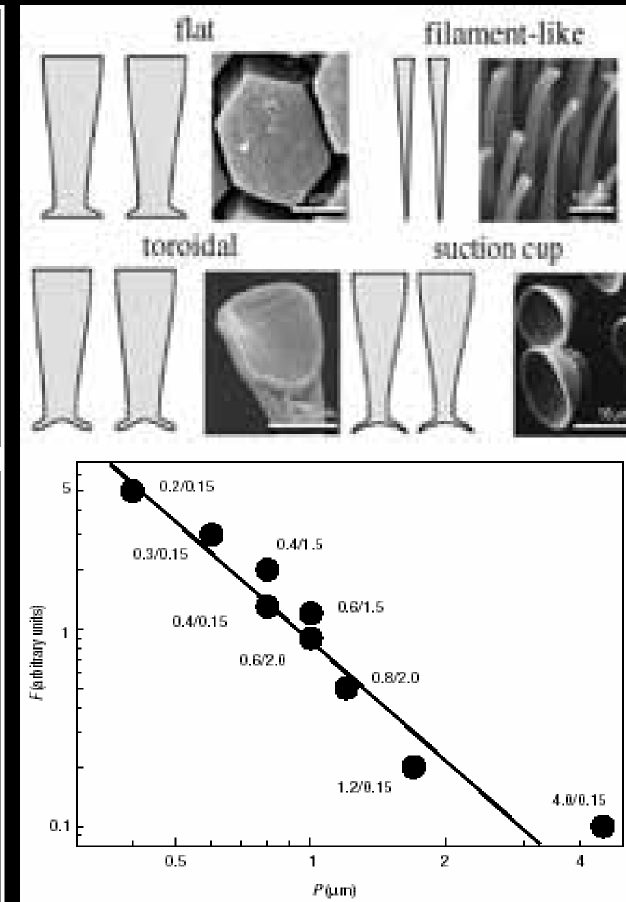



# 蛛蜘人 練成了 壁虎 (Geckos) 神工

蛛蜘人腳掌和手掌練到長出 **200** 至 **500** 奈米粗細的毛，其尖端有一層水分子以 **van der Waals** 沾在固體表面上








**Sticky reusable adhesive tapes under development**

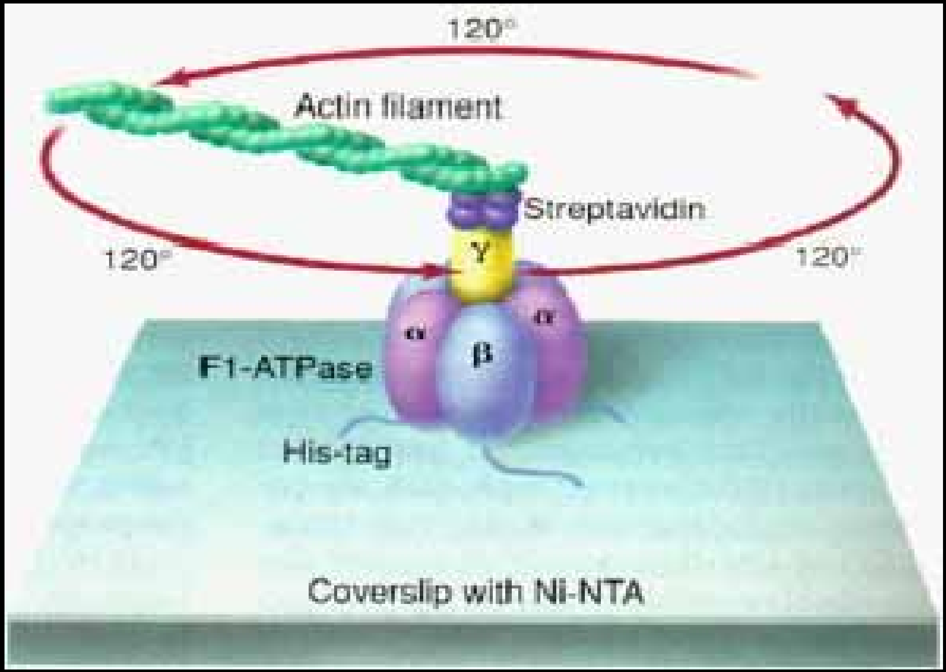
濕聚合物針頭與矽表面的沾黏力

# 生物分子馬達

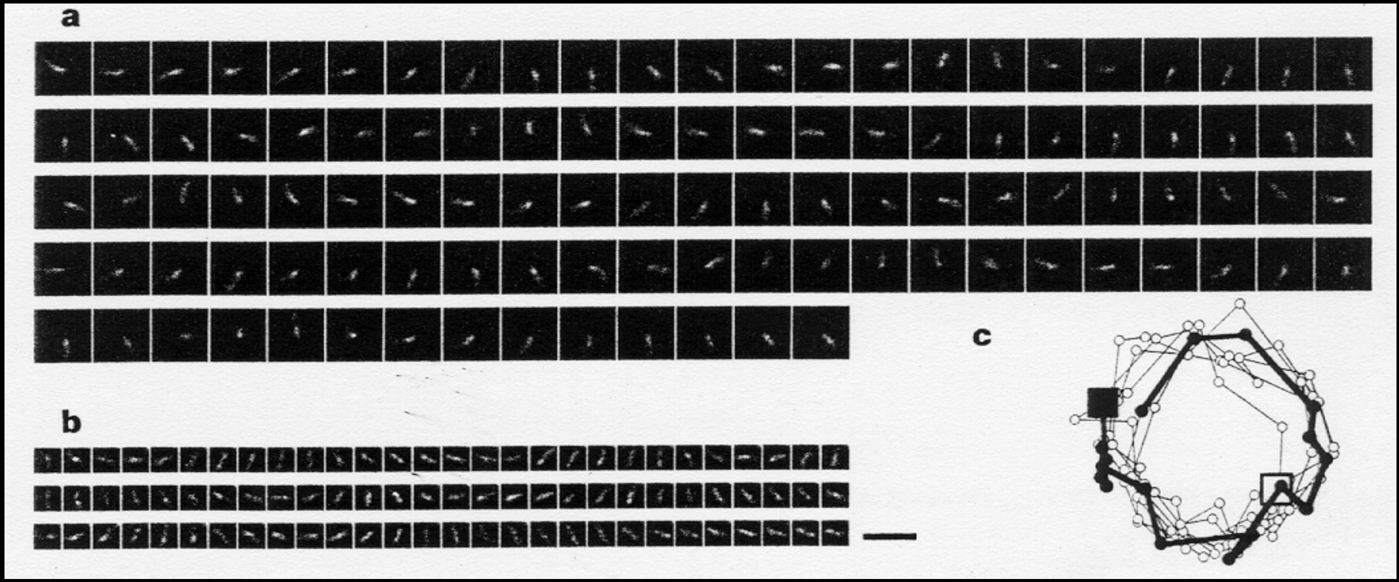
## 直接看 $F_1$-ATPase 的旋轉運動

**Noji, Yasuda, Yoshida & Kinosita**

**Nature 386, 299 (97)**



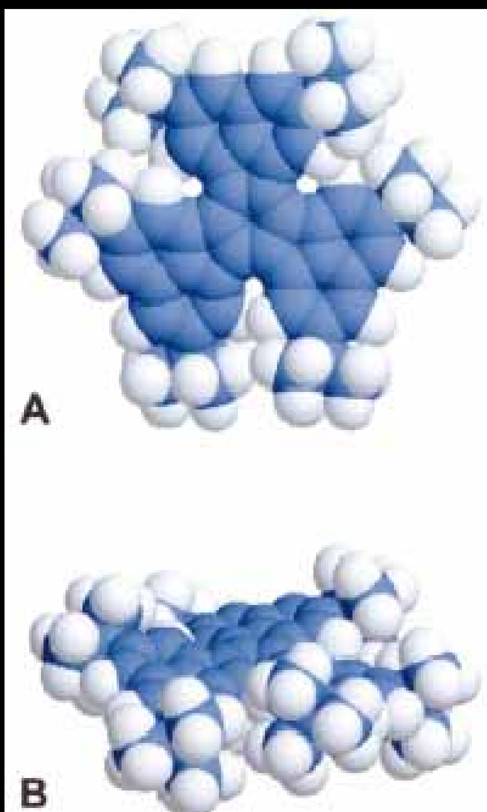


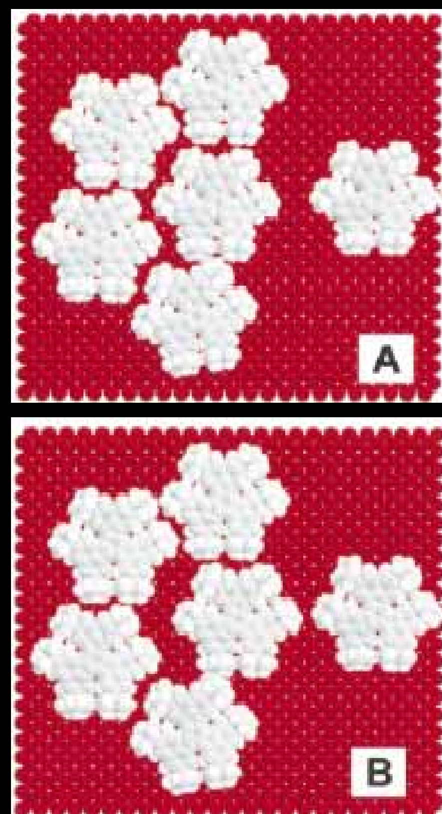


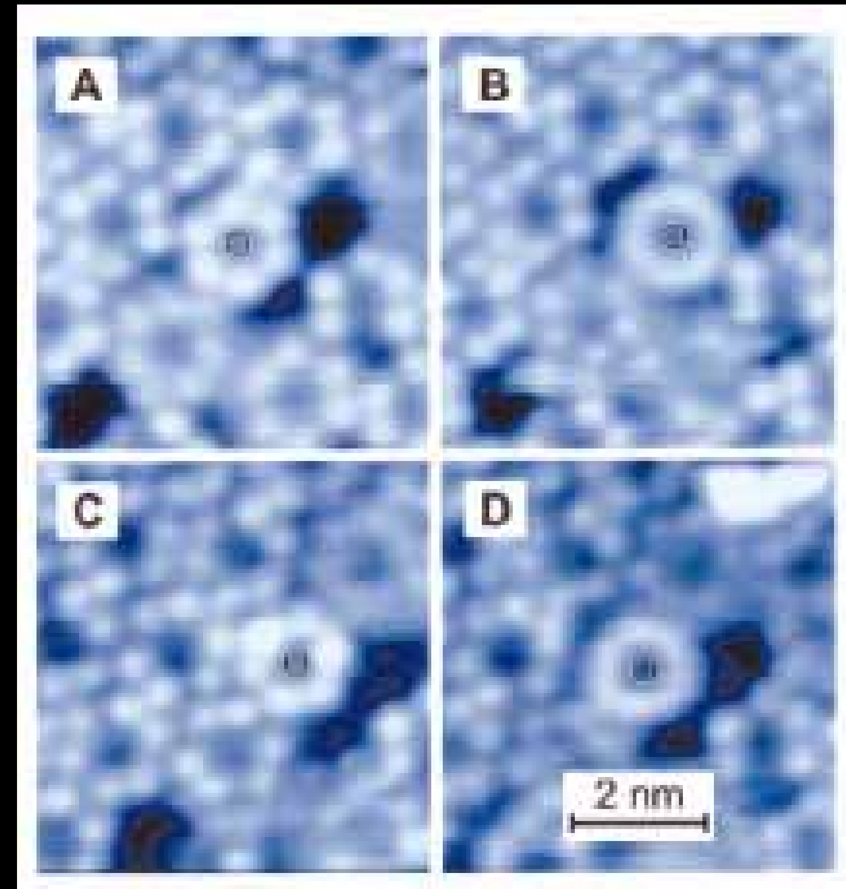
# 羅旋槳狀 HB-DC 分子吸附在銅 (001) 表面上靜態和旋轉時的 STM 影像

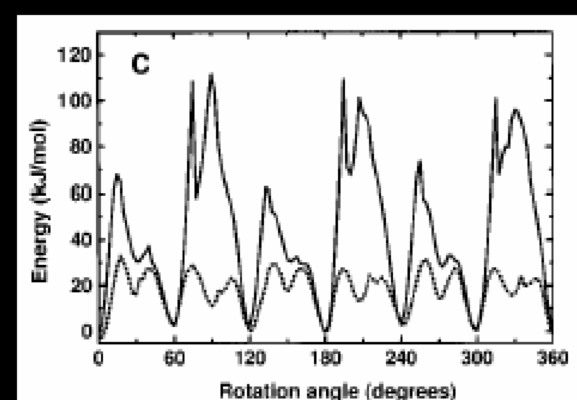
(單一分子在巨分子軸承上旋轉)

Gimzewski et al. Science 281,531 (1998)




理論計算：被卡住和不被卡住位置上旋轉時所需克服之勢壘高度

鄭天佐 IP AS

# 人造奈米機械：
## 利用生物分子馬達 來旋轉奈米棒

康乃爾奈米實驗室 **Science (2000)**

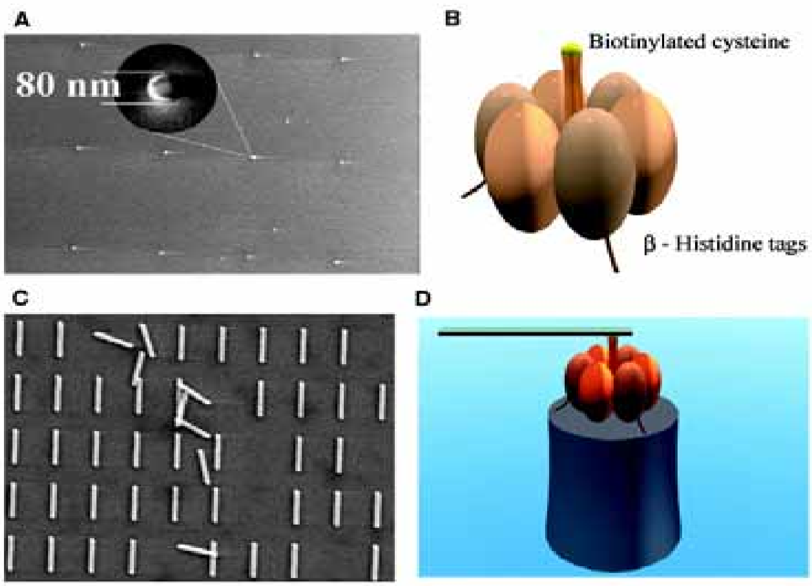
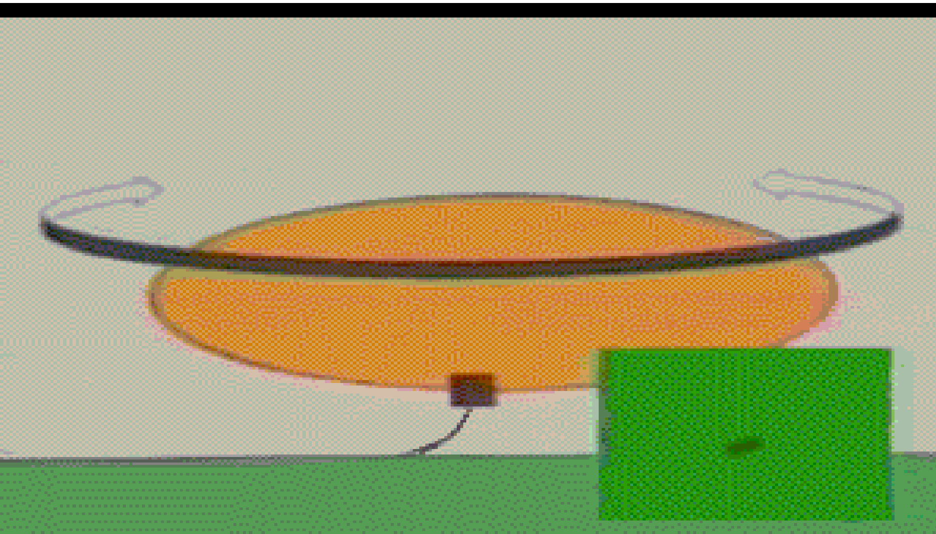



**Fig. 1.** Schematic diagram of the $F_1$-ATPase biomolecular motor–powered nanomechanical device. The device consisted of (**A**) a Ni post (height 200 nm, diameter 80 nm), (**B**) the $F_1$-ATPase biomolecular motor, and (**C**) a nanopropeller (length 750 to 1400 nm, diameter 150 nm). The device (**D**) was assembled using sequential additions of individual components and differential attachment chemistries.



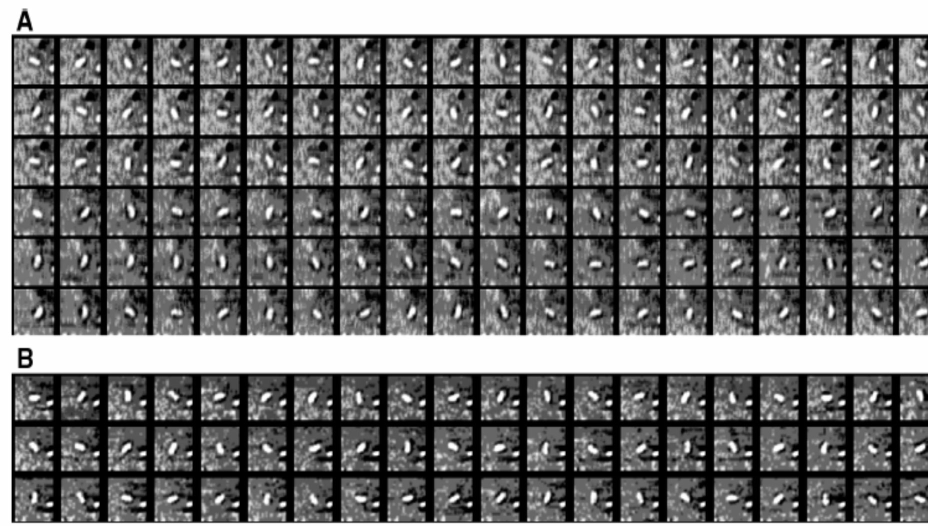


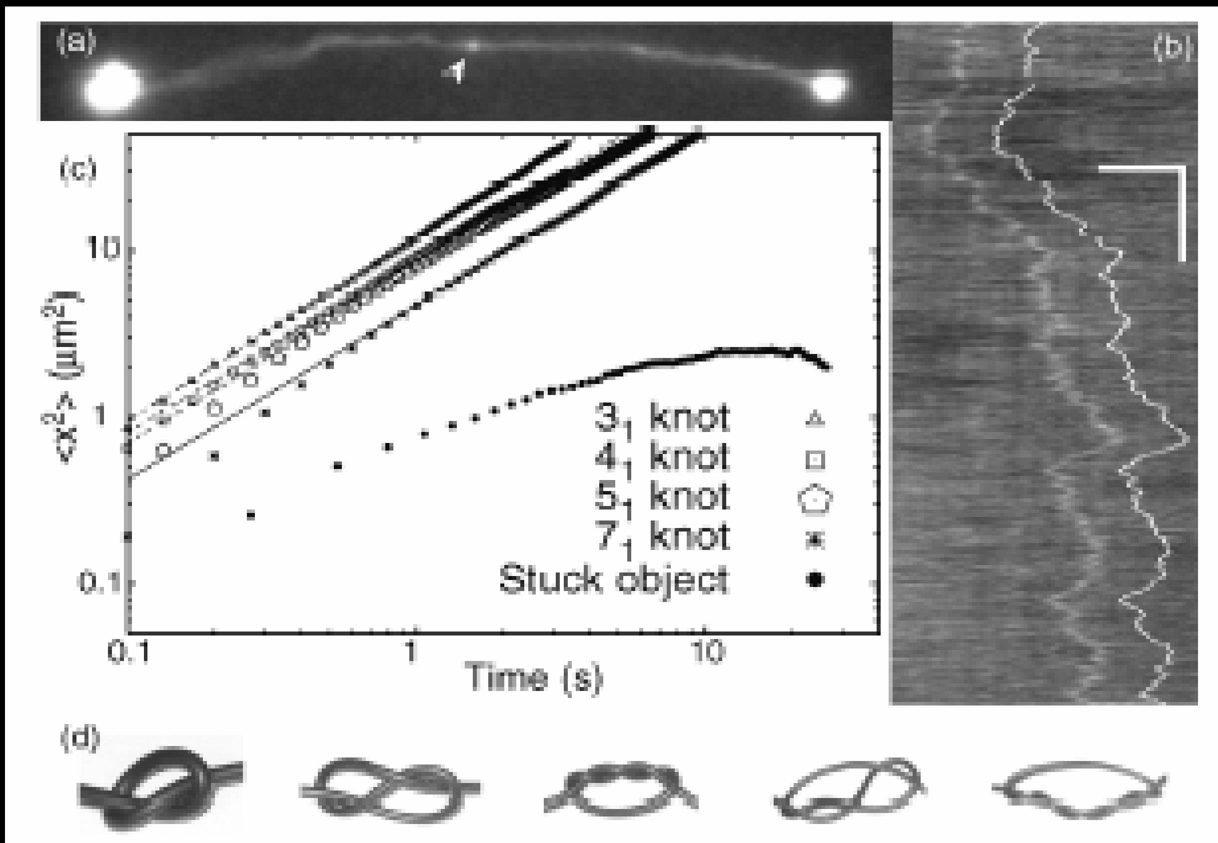

**Fig. 2.** Image sequence (viewed left to right) of nanopropellers being rotated anticlockwise at 8.3 rps (**A**) and 7.7 rps (**B**) by the $F_1$-ATPase biomolecular motor. Observations were made using 100× oil immersion or 60× water immersion and were captured with a CCD video camera (frame rate 30 Hz). The rotational velocity ranged from ~0.8 to 8.3 rps, depending on propeller length. Data were recorded for up to 30 min; however, propellers rotated for almost 2.5 hours while ATP was maintained in the flow cell. These sequences can be viewed as movies at the Nanoscale Biological Engineering and Transport Group Web site (http://falcon.aben.cornell.edu/News2.htm).

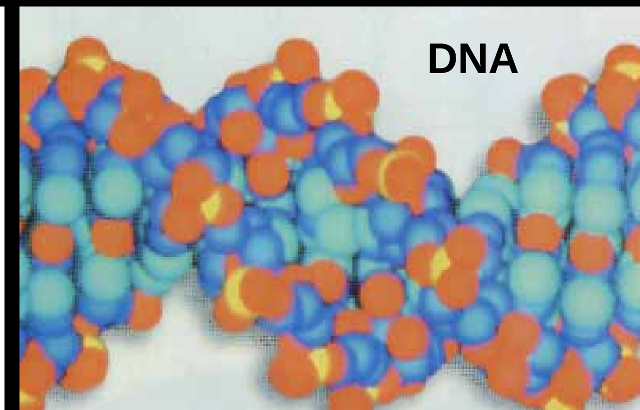
分子馬達轉動實例

**From: http://www.npn.jst.go.jp/**

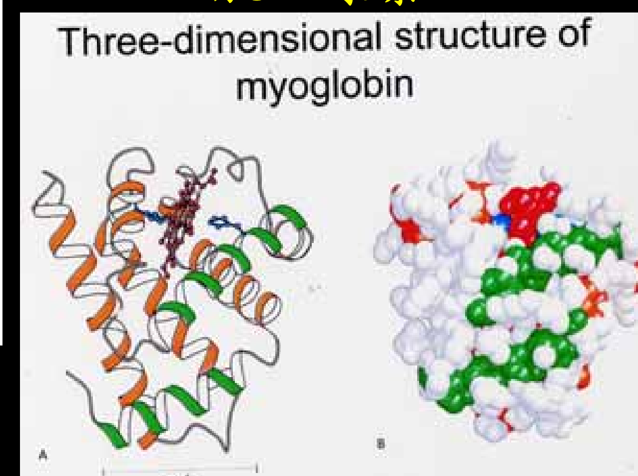
# 利用光學鉗子在 DNA 上打結

**S R Quake et al., PRL ‘03**



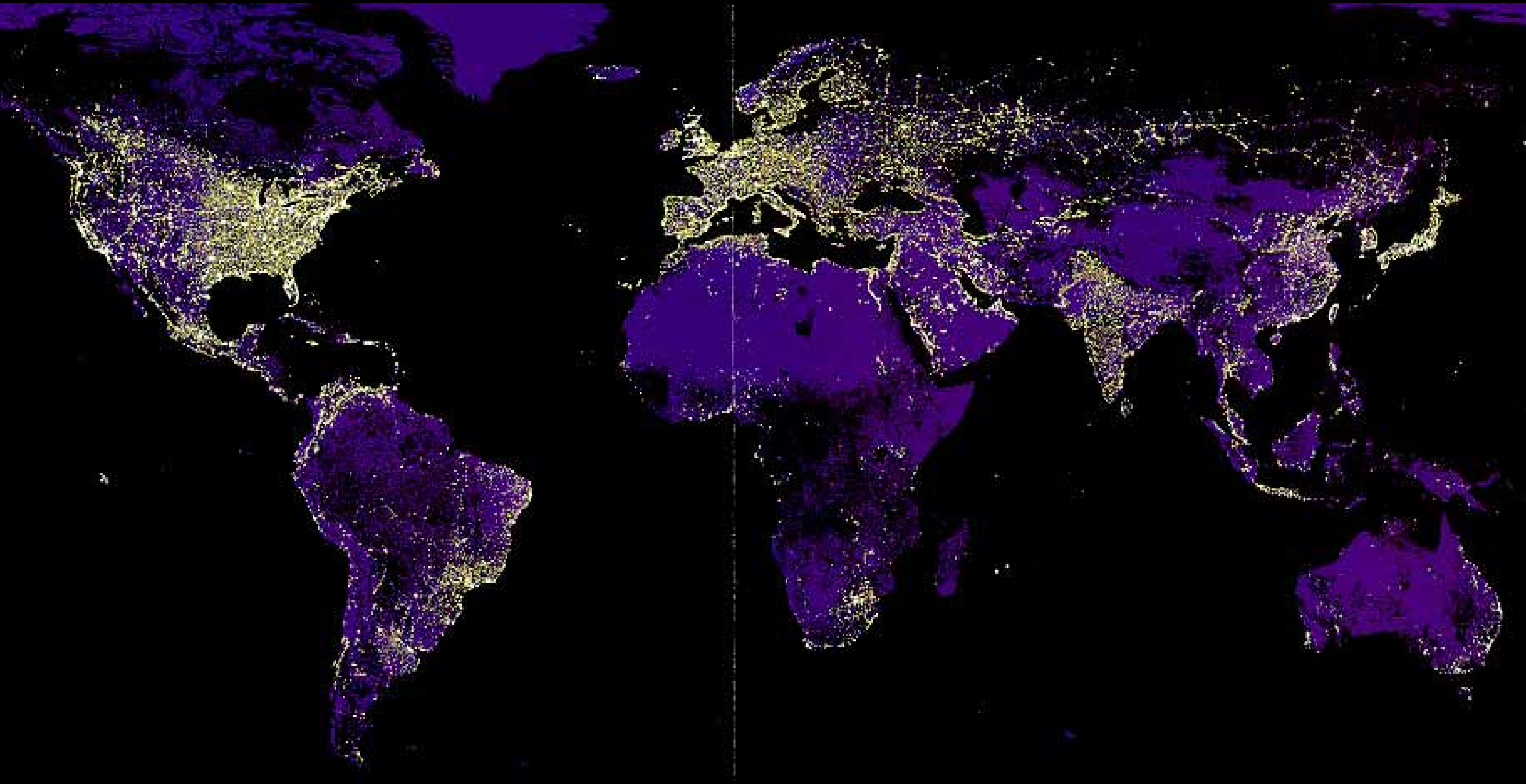




肌血球素




**Optical Tweezers: by light-dipole interaction with a dielectric particle.    A. Ashkin**

# 衛星地球夜景照片的組合



**Physics Today 4/02**

資源和能源的爭奪往往是國際紛爭的主因

鄭天佐 IP AS

# 能源科技 與 奈米科技 的 結合

## 半導體或氧化物觸媒劑直接光分解水成氫和氧

太陽可見光譜佔 60%能量，用合金和氧化物轉換，並以奈米科技增加表面積和活性度能否提高分解效率？

理論: 轉換效率應可高達50%。真的嗎？

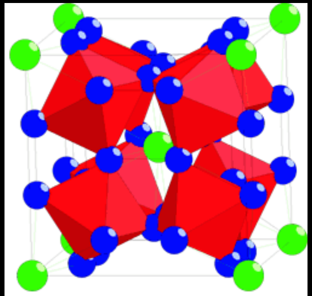
## 奈米科技 與 氫氣儲存 和 氫氣電池

鋰氮化合物儲存量～10%、奈米碳管或其他奈米顆粒和管狀物，可提高儲存量和壽命！

另可改良電池中所用隔離膜，來增加發電效率和使用壽命

## 半導體 和 塑膠薄膜太陽電池 與 電能儲存

轉換效率一般＜15%（塑膠＜10%），如何提高效率並減低成本和製造時對環境少污染和延長使用壽命是關鍵。 另錳化合物電池可能會提高儲存效率並減低環境污染。 經濟、方便、用之不竭、安全和環保是關鍵。



## 能否利用太陽熱能直接發電？

利用高電導性、高熱絕緣性、高吸熱性薄膜材料能否提高熱電效應效率？

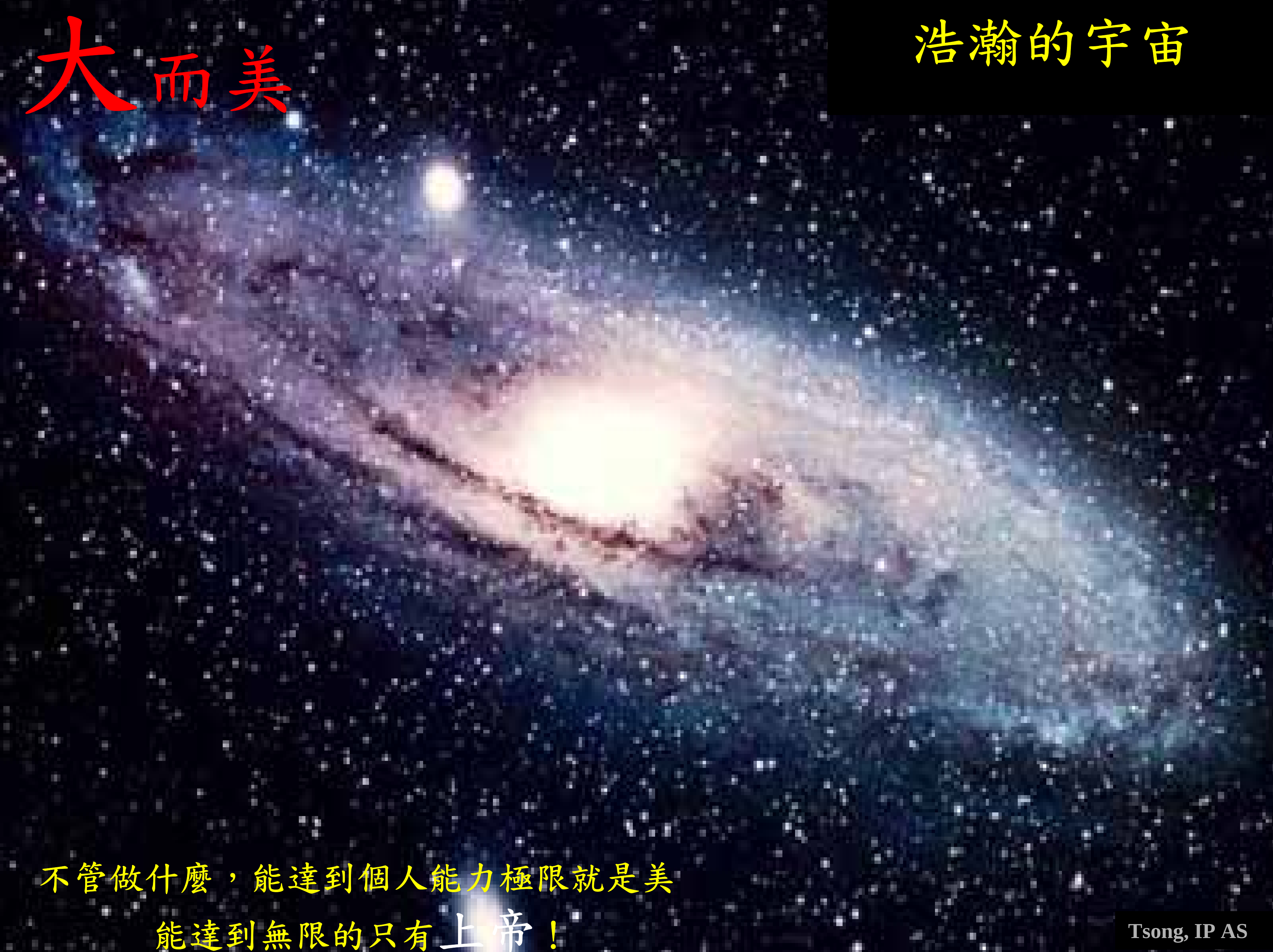
Thallium Filled Antimony Skutterudites

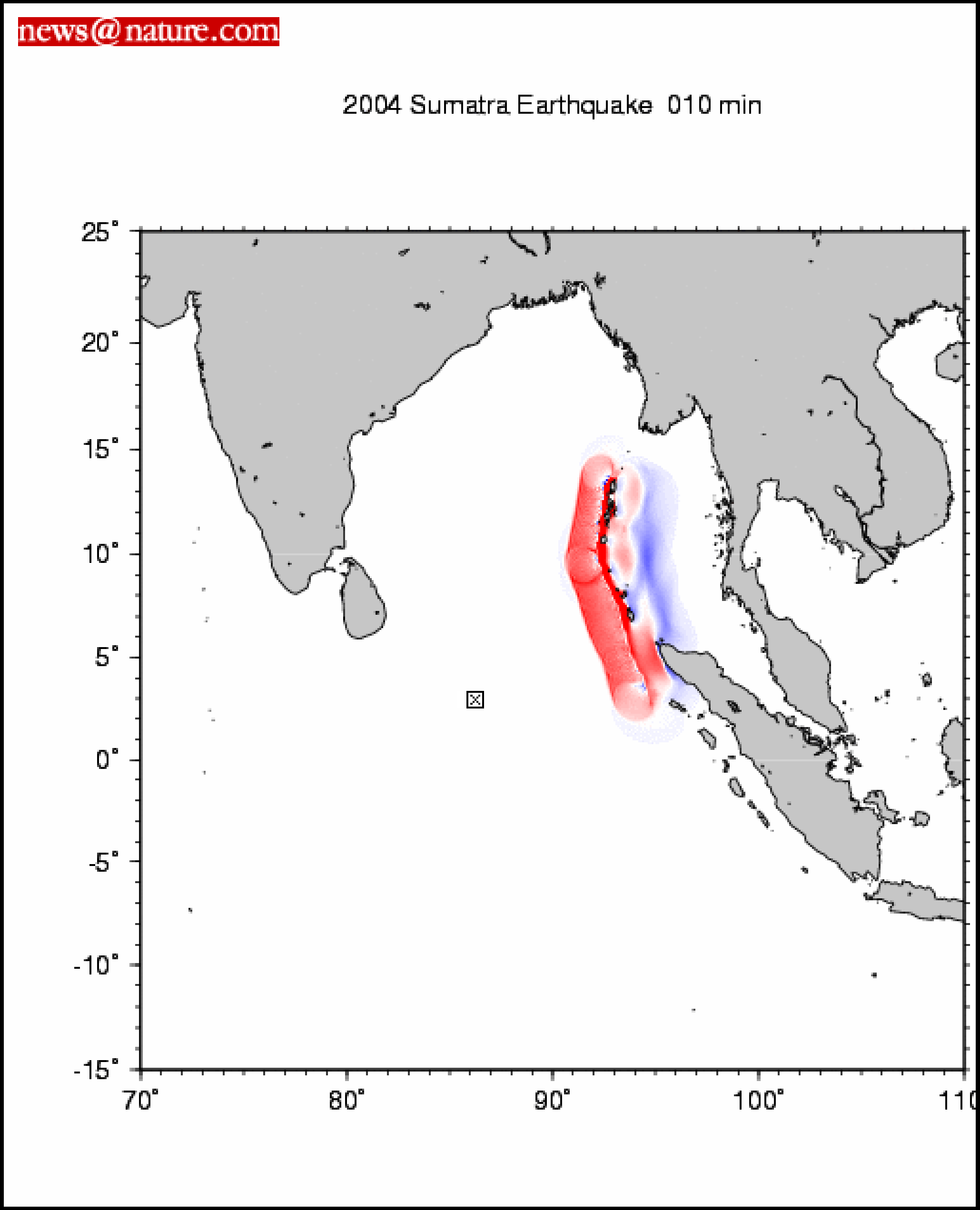
鄭天佐 IP AS

# 奈米科技－小就是美

- 1) 少費能量來製造和運轉
- 2) 奈米器件省材料， 輕便又少佔空間
- 3) 新效能、高密度、靈敏度和活性度
- 4) 在電子線路，運轉快也安全
- 5) 少破壞環境和地球生態
- 6) 有更多的人能享受科技的果實
- 7）符合人類永續發展條件，所以小就是美

- ＊ 需研究奈米材料對人體環境可能造成之傷害
- ＊ 知識和科技日新月異，我們要養成自我學習，不斷學習，和終生學習的好習慣


大而美
浩瀚的宇宙
不管做什麼，能達到個人能力極限就是美
能達到無限的只有上帝！
Tsong, IP AS

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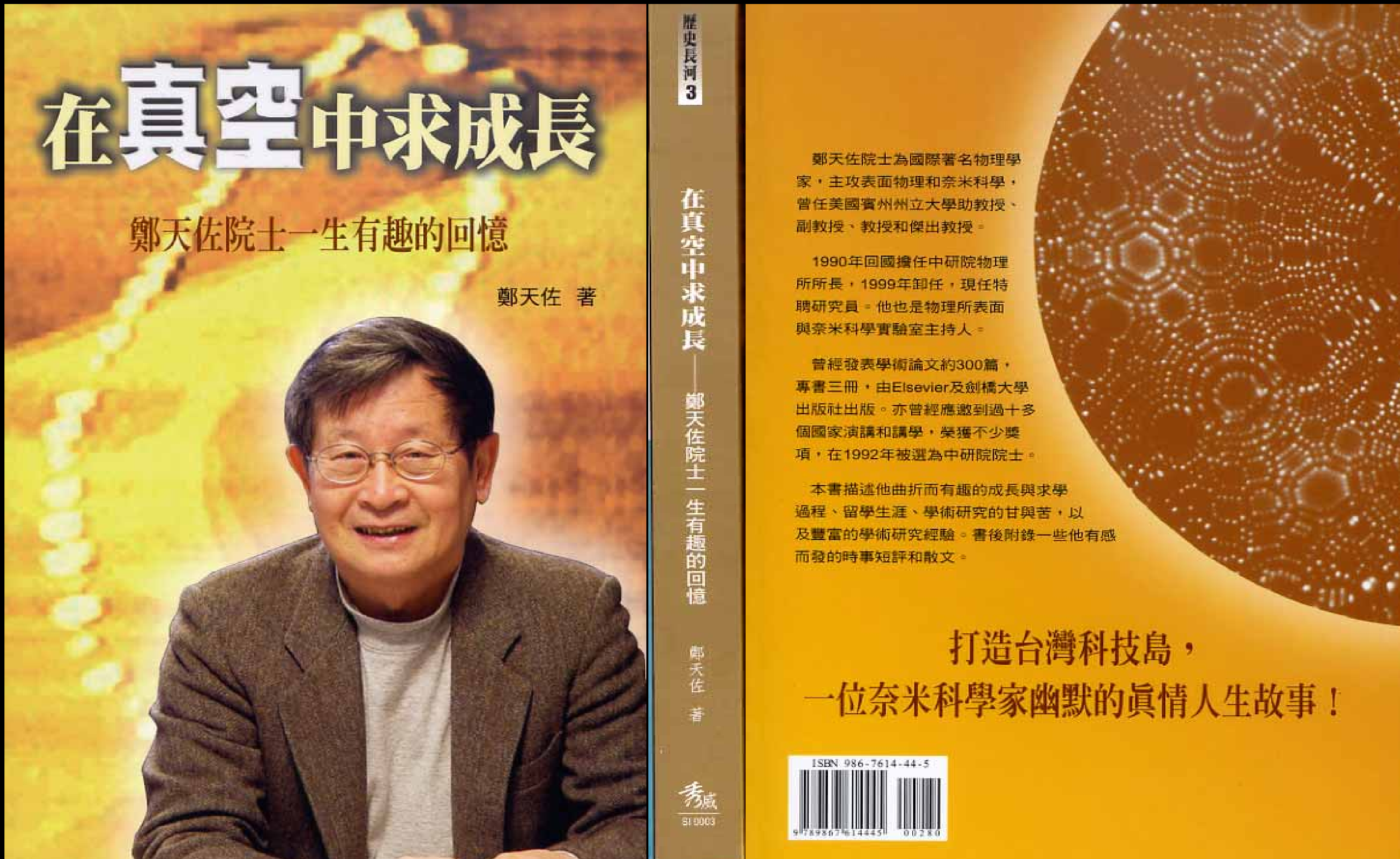
印尼

大

海嘯

動態

鄭天佐 IP AS

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