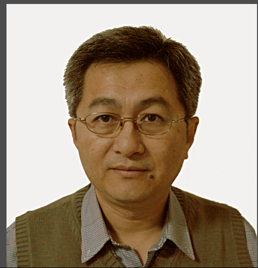
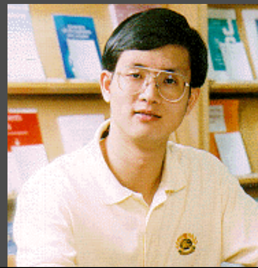
Surface and Nano Sciences Lab

(www.phys.sinica.edu.tw/~nano/)

鄭天佐(1990)
Tien T. Tsong



張嘉升(1991)
C.S. Chang



黃英碩(1994)
I.S. Hwang

蘇維彬(2001)
W.B. Su

胡恩德(2010)
A.D. Hwu

魏金明(1991)
C.M. Wei

Surface dynamics, epitaxial growth, atom manipulation
bio-imaging

FIM, SPM, TEM

Calculations and simulations

Theoretic work

UHV TEM + STM

Size-, shape-, and site-specific properties of nanomatrerials

Nanoscience

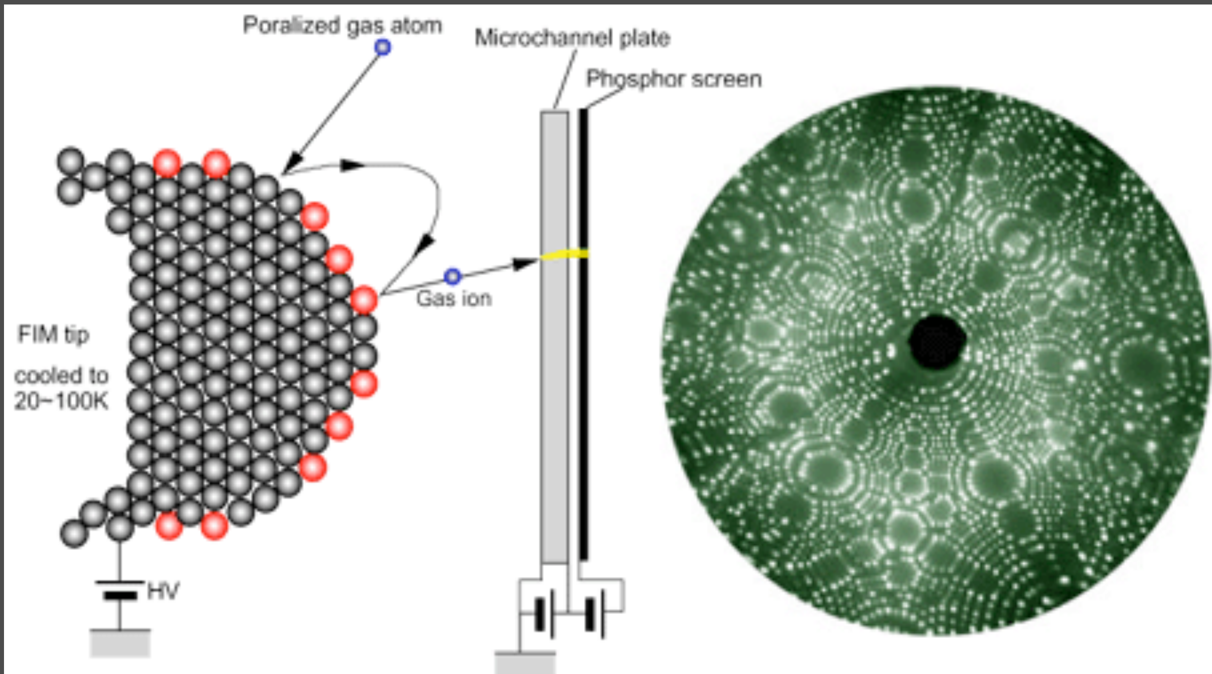
LT STM + magnet

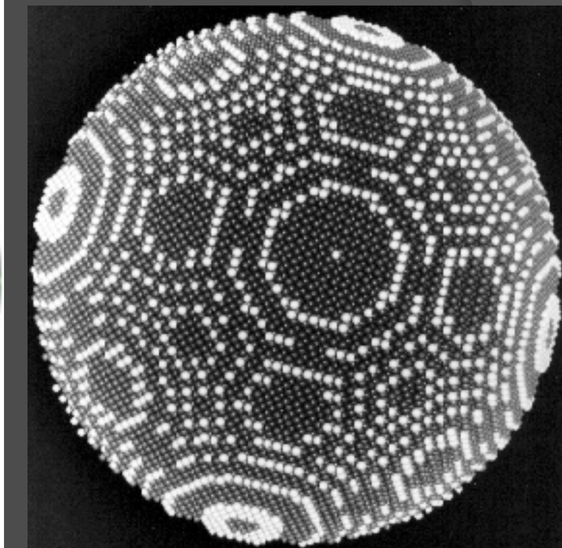
Single spin detection, quantum phenomena in nanostructures

Nanotechnology

New tools, new instruments, new methods

Field Ion Microscopy

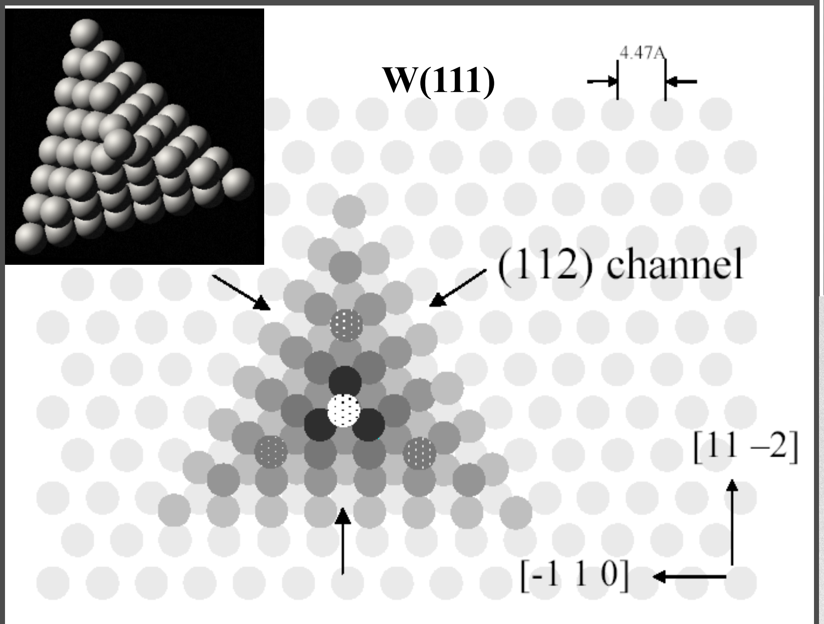


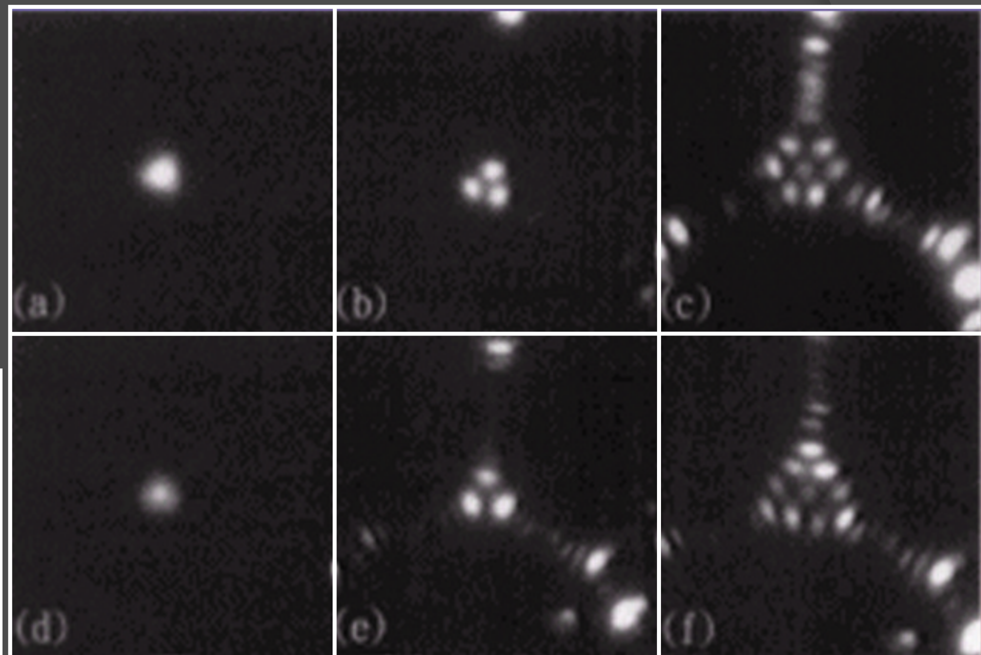


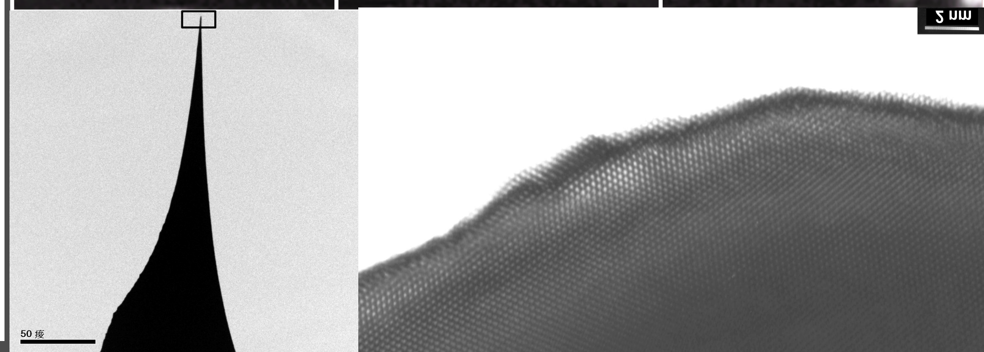
The image gas atoms in the vicinity of the specimen are polarized because of the high field and then attracted to the apex region of the specimen. After a series of collisions with the specimen during which the image gas atoms lose part of their kinetic energy, these image gas atoms become thermally accommodated to the cryogenic temperature of the specimen. If the field is sufficiently high, these image gas atoms are field ionized by a quantum-mechanical tunneling process. The ions produced are then radially repelled from the surface of the specimen towards the microchannel plate and screen assembly. A microchannel plate image intensifier positioned immediately in front of the phosphor screen produces between 10^3 and 10^4 electrons for each input ion. These electrons are accelerated towards the phosphor screen where they produce a visible image. The field-ion microscope was invented by Erwin Müller in 1951 at Pennsylvania State University.

Single atom tip

1) STM probing
2) Coherent e$^-$ beam
3) Point ion source

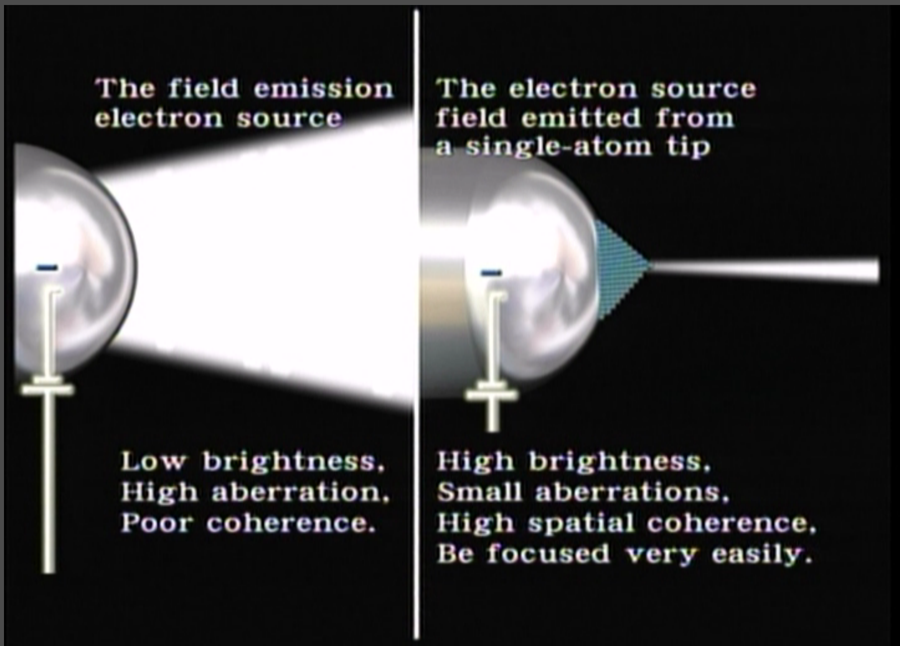


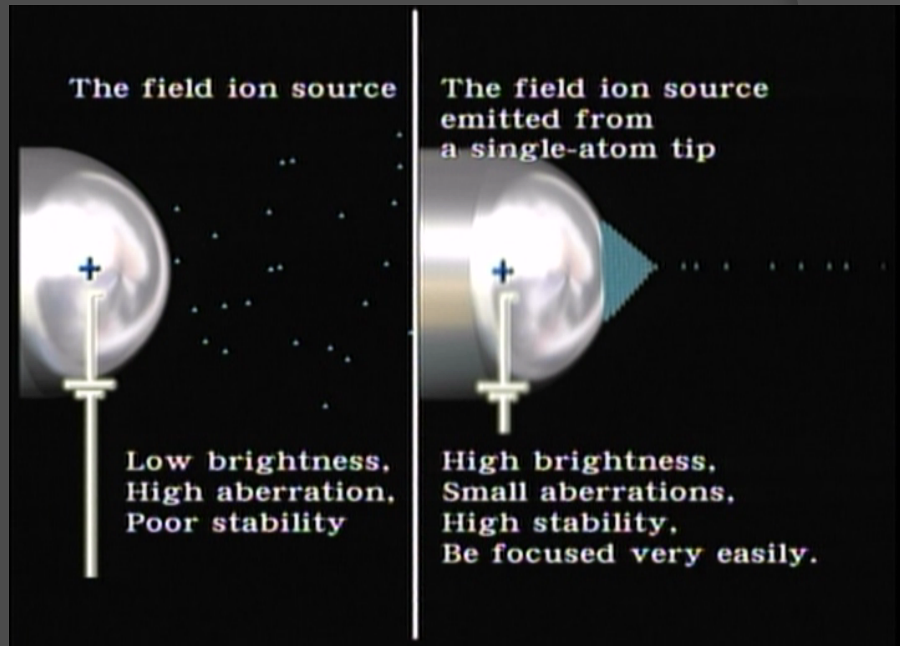




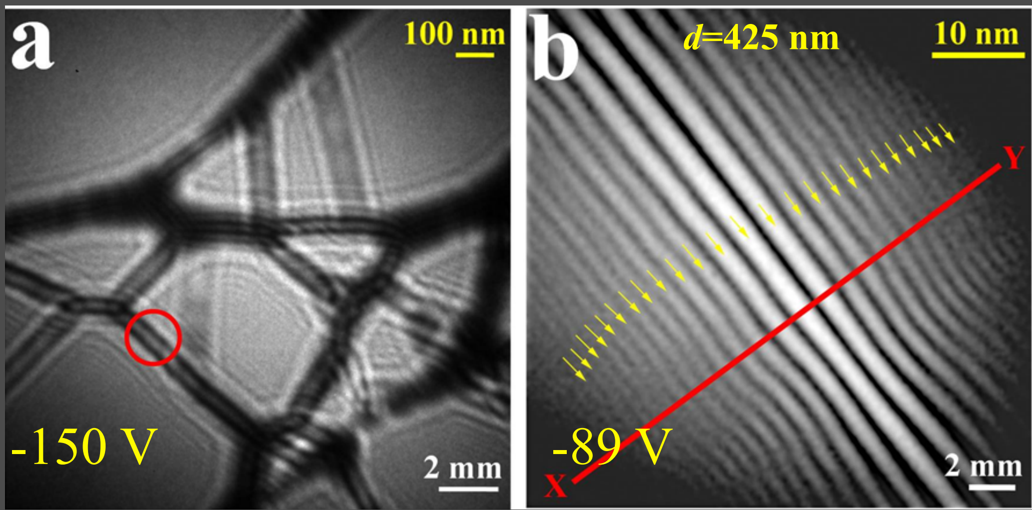
E-beam and ion beam sources

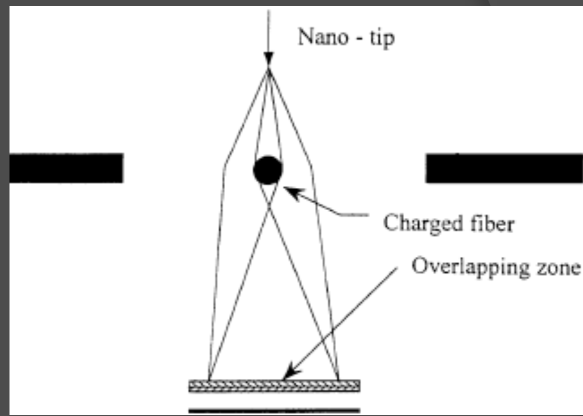
Traditional | Ideal electron point source | Traditional | Ideal ion point source





High degree of spatial coherence

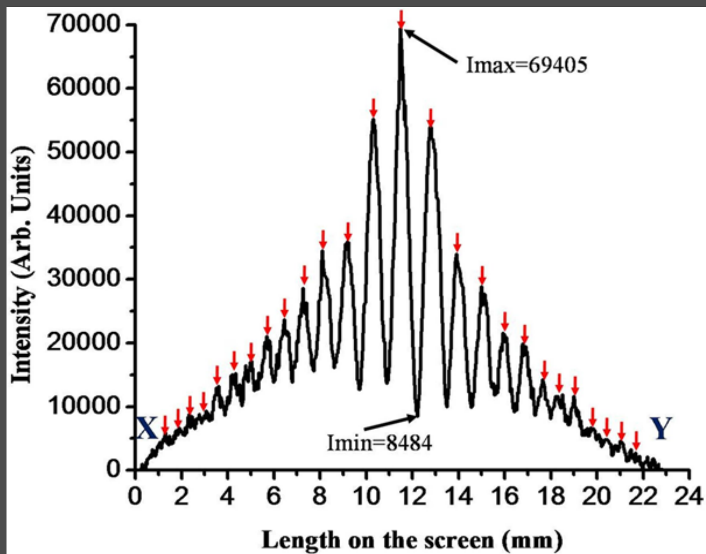




Electron Biprism

Visibility

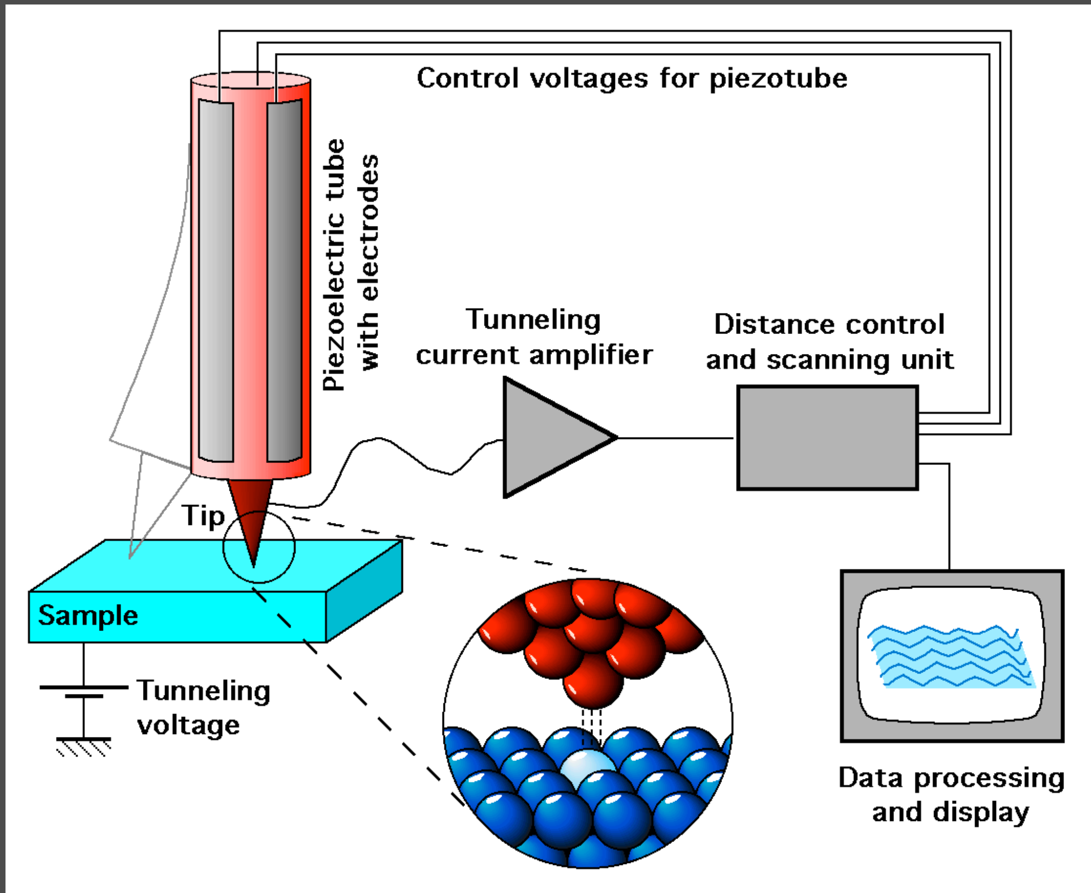
$$V = \frac{(I_{max} - I_{min})}{(I_{max} + I_{min})} = 0.78$$



SWNT bundle can act as a nanoprism, which splits the wavefront of an incoming electron wave into two coherent partial waves, which are deflected by the electric fields around the nanoprism in opposite directions and meet on the screen.

Nanotechnology **20**, 115401 (2009)

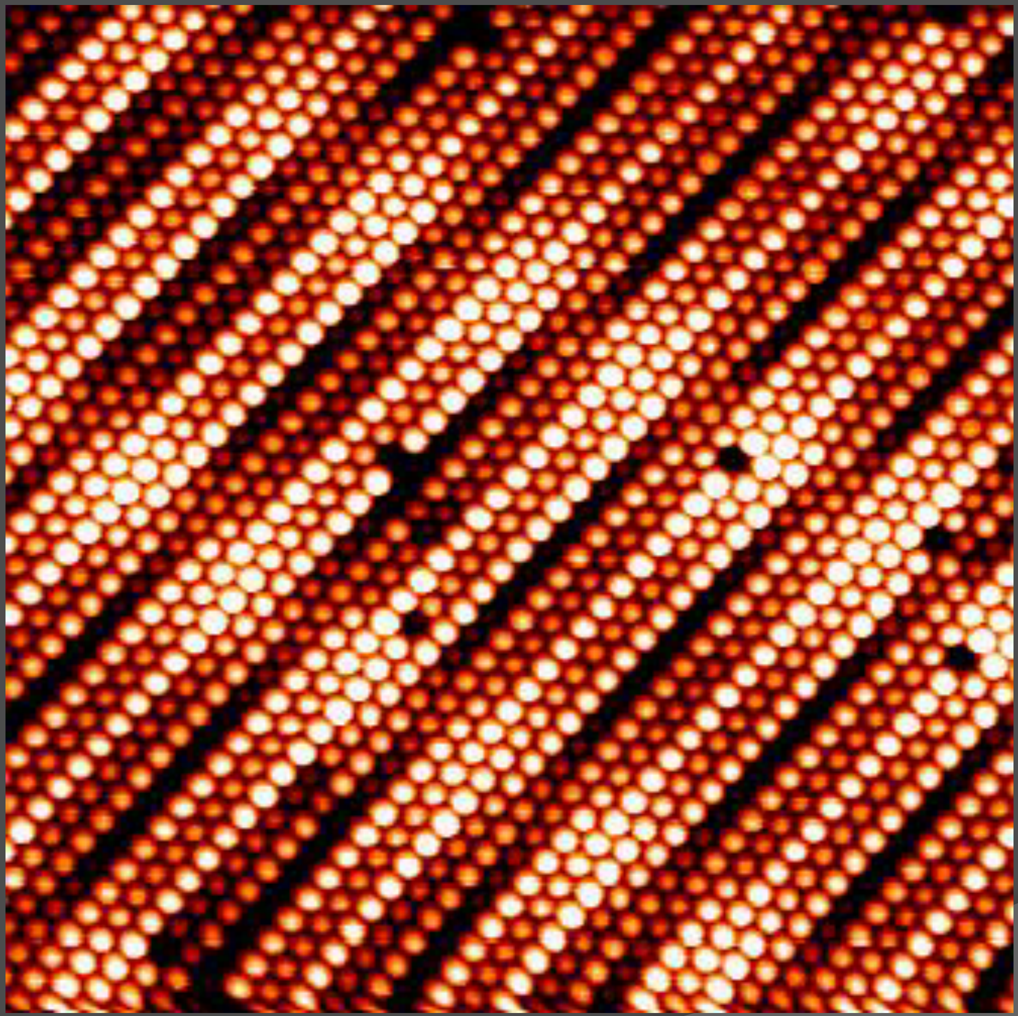
Scanning Tunneling Microscopy



References:

1. G. Binnig, H. Rohrer, C. Gerber, and Weibel, Phys. Rev. Lett. **49**, 57 (1982); and ibid **50**, 120 (1983).
2. J. Chen, *Introduction to Scanning Tunneling Microscopy*, New York, Oxford Univ. Press (1993).

Pt(001) reconstructed Surface



Surface Science **306**, 10 (1994)

Surface and interface properties of ultrathin metal films on Si and Cu substrates

Jason Chang, Wei-Bin Su, and Tien T. Tsong

Institute of Physics, Academia Sinica

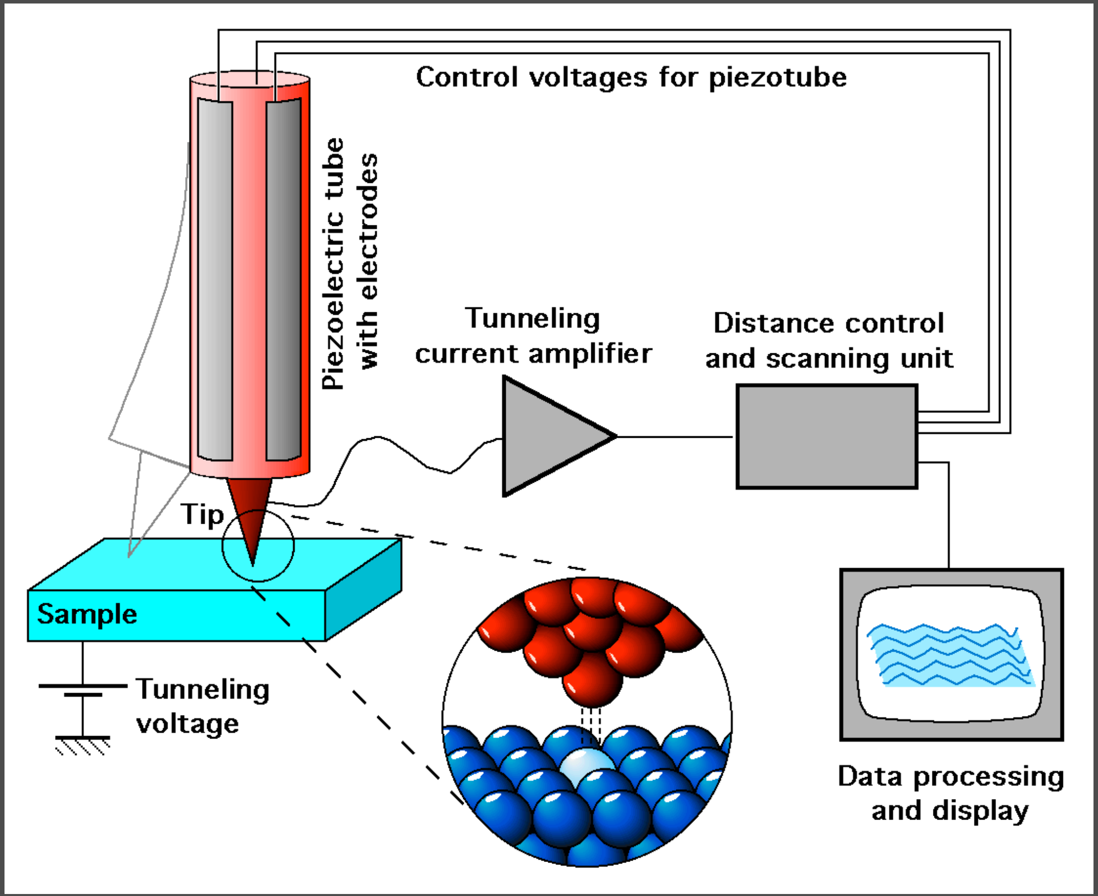
Taipei, Taiwan

Supported by the National Program for Nanoscience and Technology, NSC, Taiwan

Outline

- Quantum well states in ultrathin Pb films
  - Manifestation of interfacial potential
  - Effect of image potential
- Gundlach osillations in STM configuration
  - Work function measurements
- Transmission resonance through thin films
  - Determination of film thickness

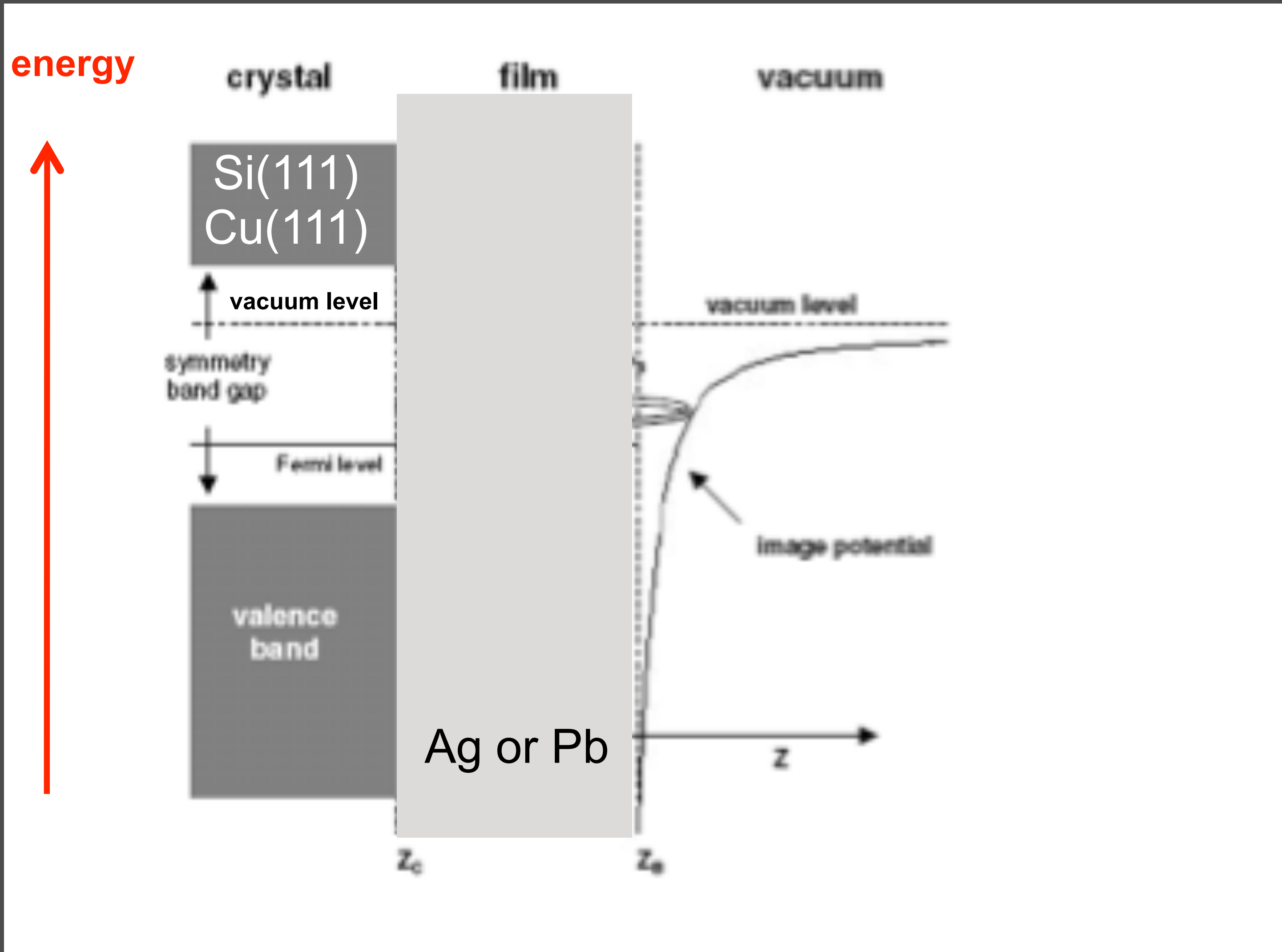
Scanning Tunneling Microscopy



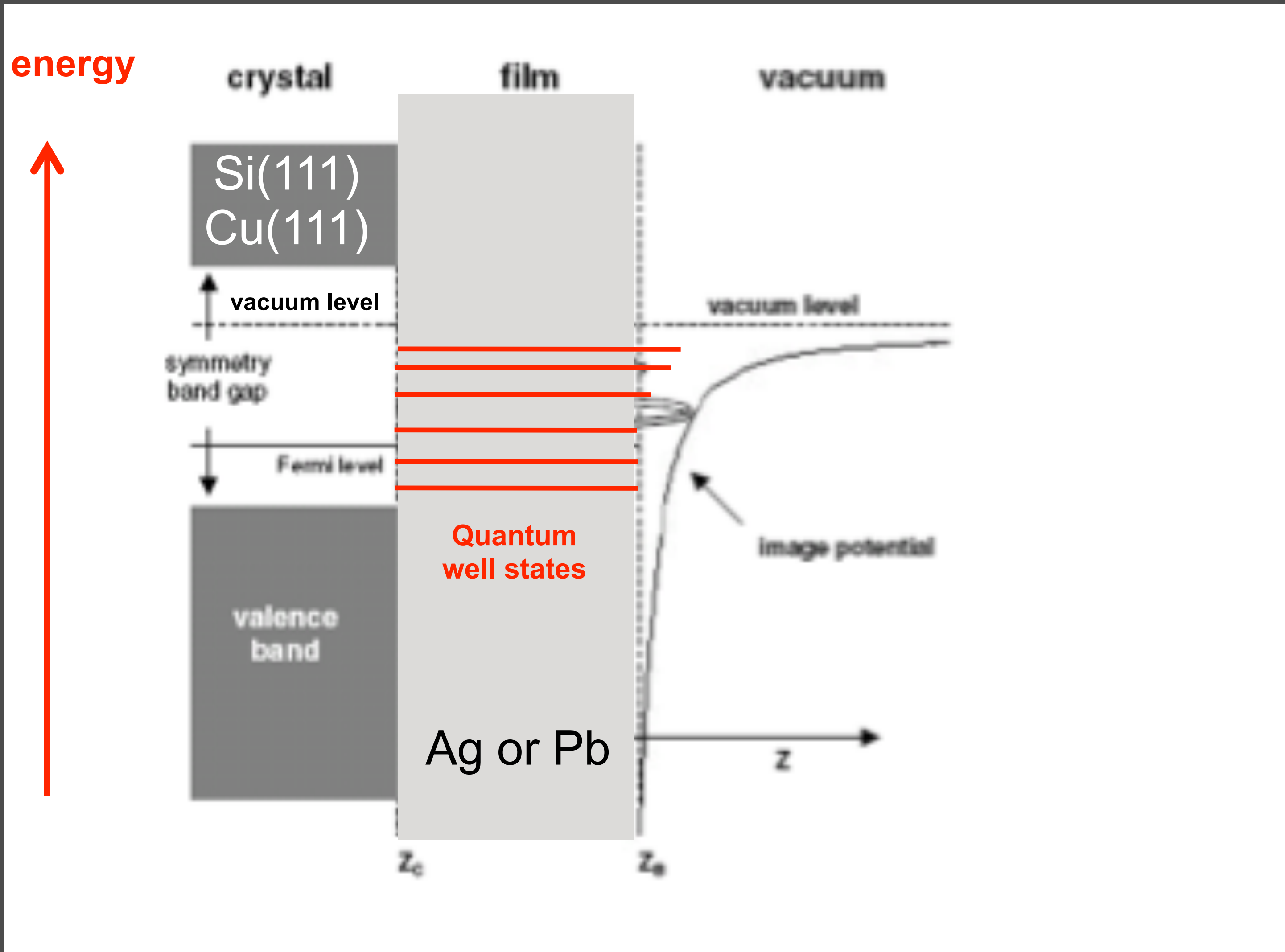
References:

1. G. Binnig, H. Rohrer, C. Gerber, and Weibel, Phys. Rev. Lett. **49**, 57 (1982); and ibid **50**, 120 (1983).
2. J. Chen, *Introduction to Scanning Tunneling Microscopy*, New York, Oxford Univ. Press (1993).

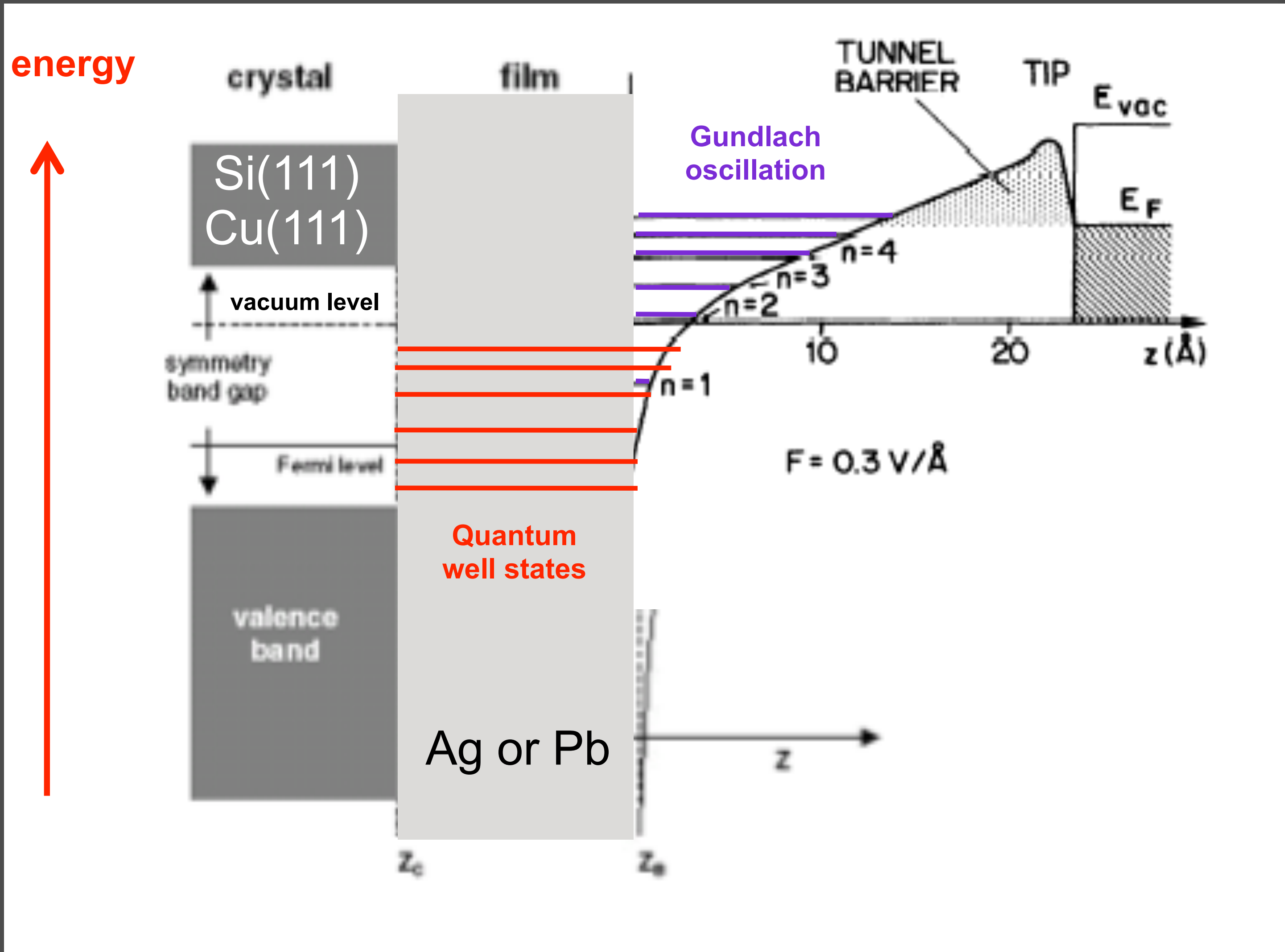
Various quantum phenomena



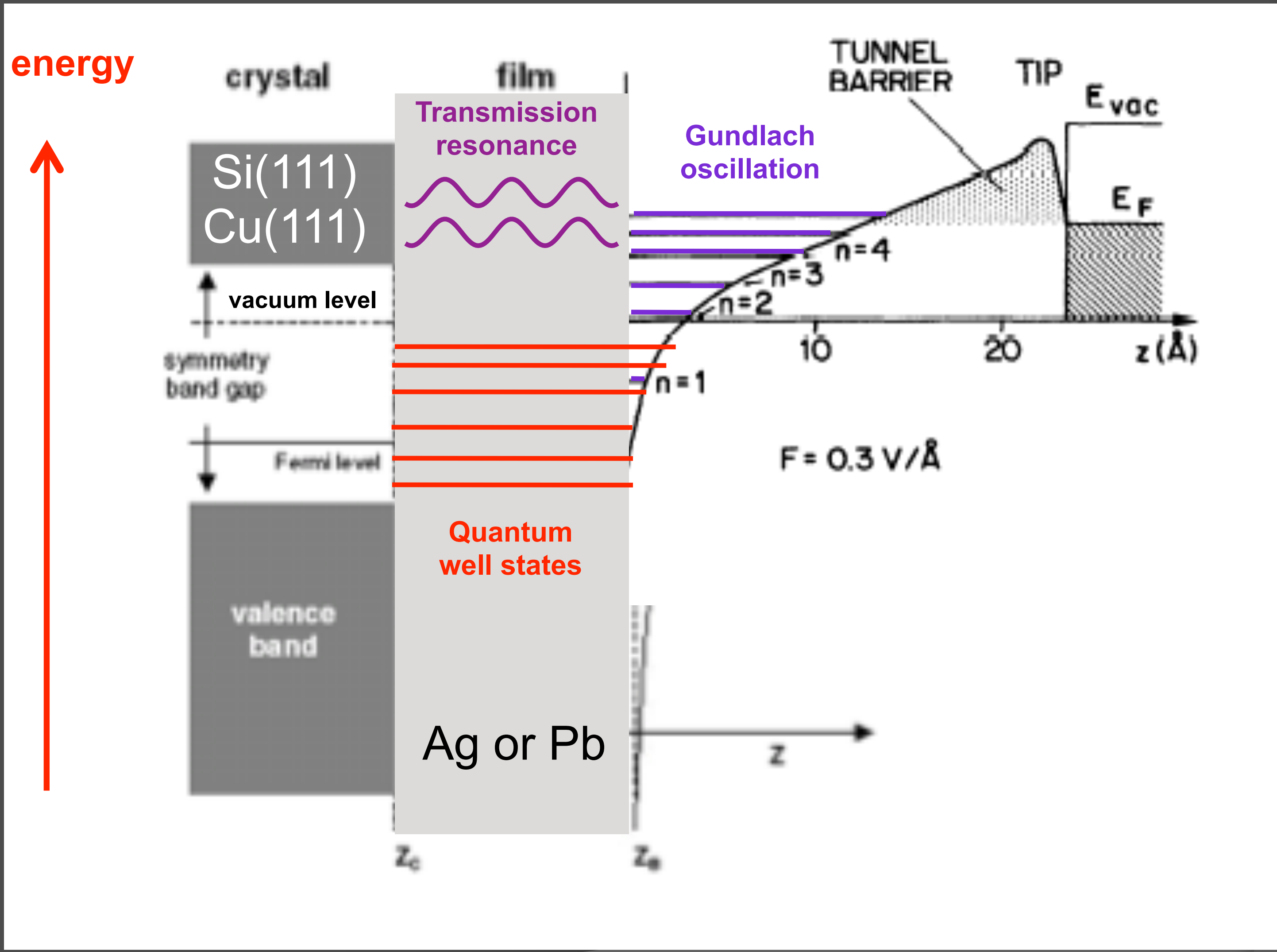
Various quantum phenomena



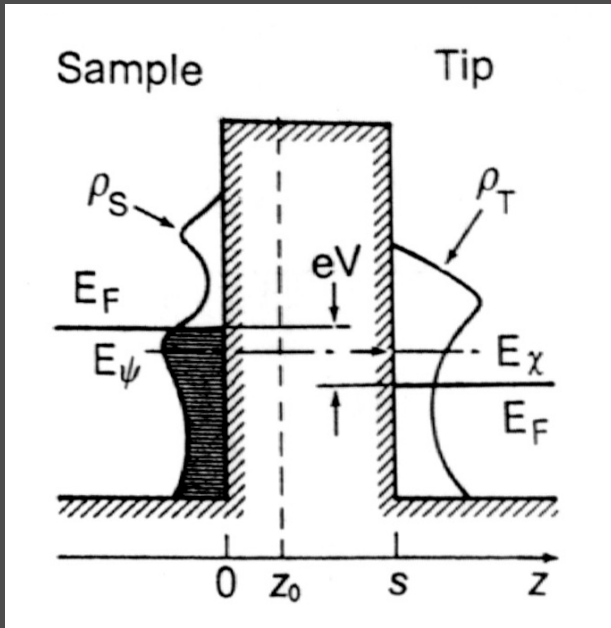
Various quantum phenomena



Various quantum phenomena

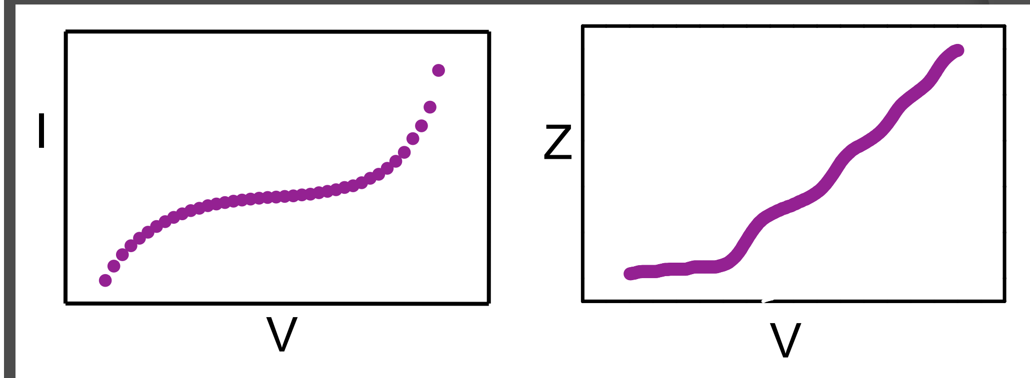


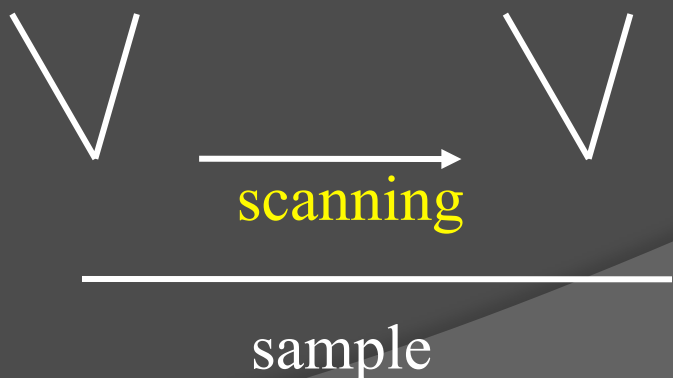
Scanning Tunneling Spectroscopy



(feedback off)
I-V spectrum

(feedback on)
Z-V spectrum

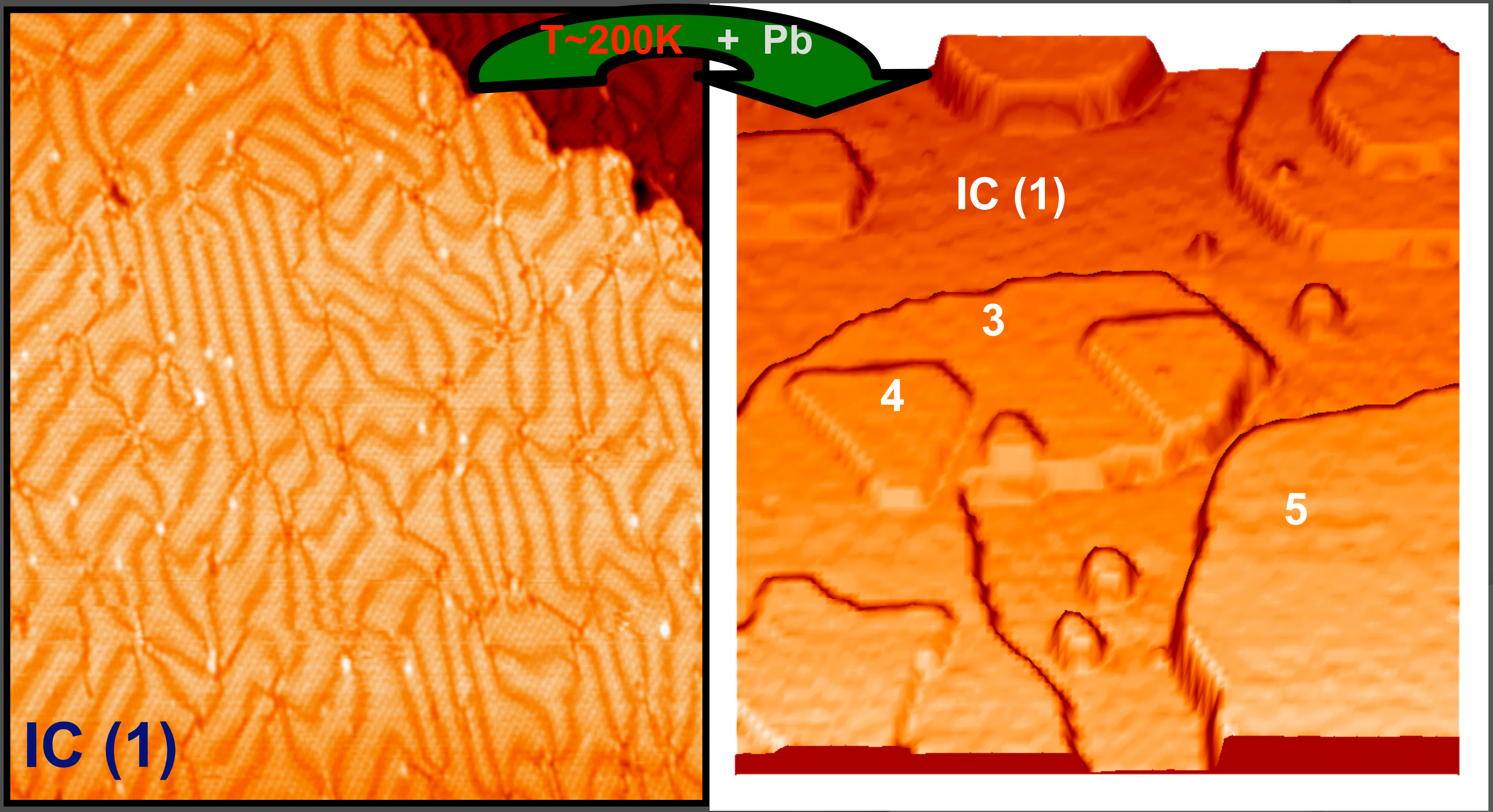




$$I \propto \int_0^{eV} \rho_s(E_F-eV+\varepsilon)\ \rho_T(E_F+\varepsilon)d\ \varepsilon$$

ρ_T is constant $\Rightarrow dI/dV \propto \rho_s(E_F-eV)$

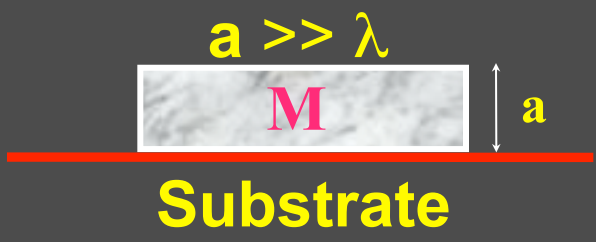
Pb islands on the IC Pb/Si(111)

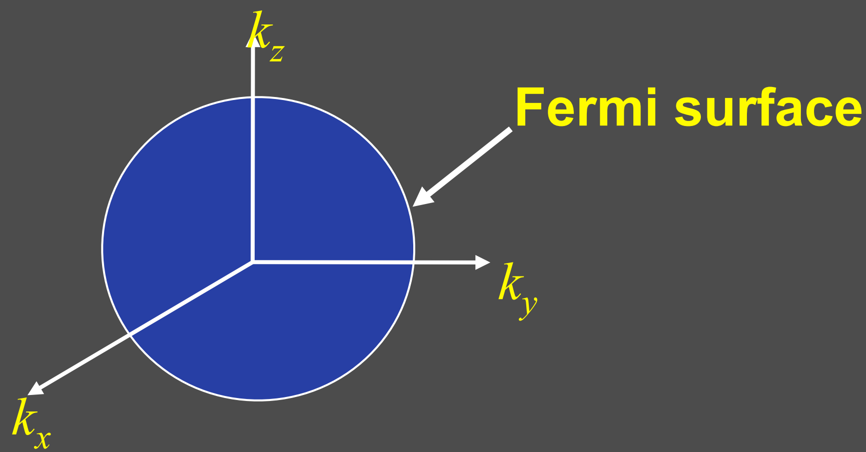


Quantum size effect

λ = de Broglie wavelength of electron

a = thickness of metal film





Quantum size effect

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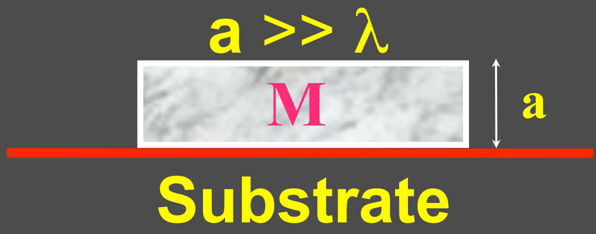
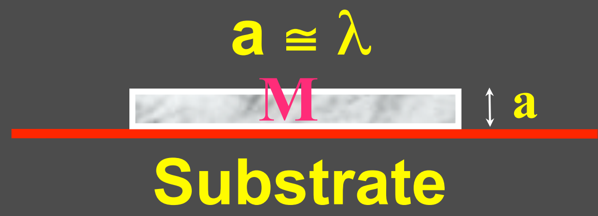
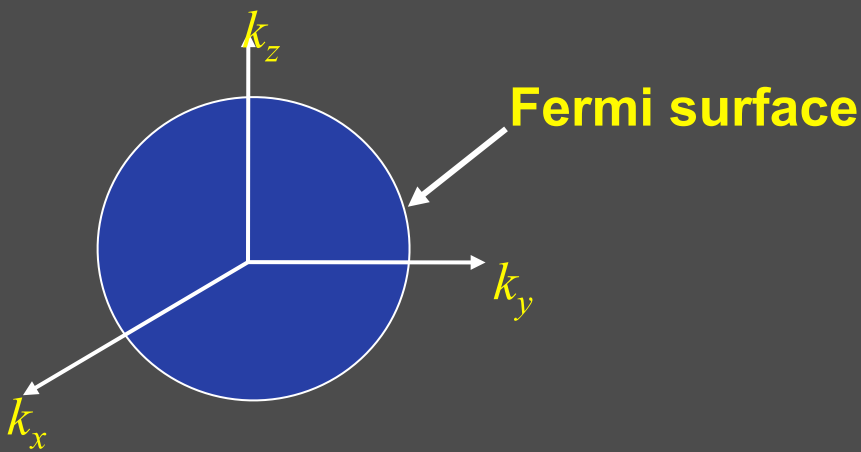
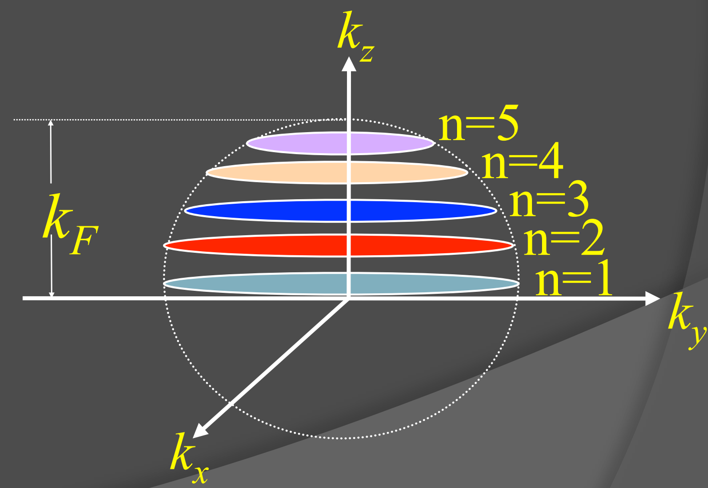
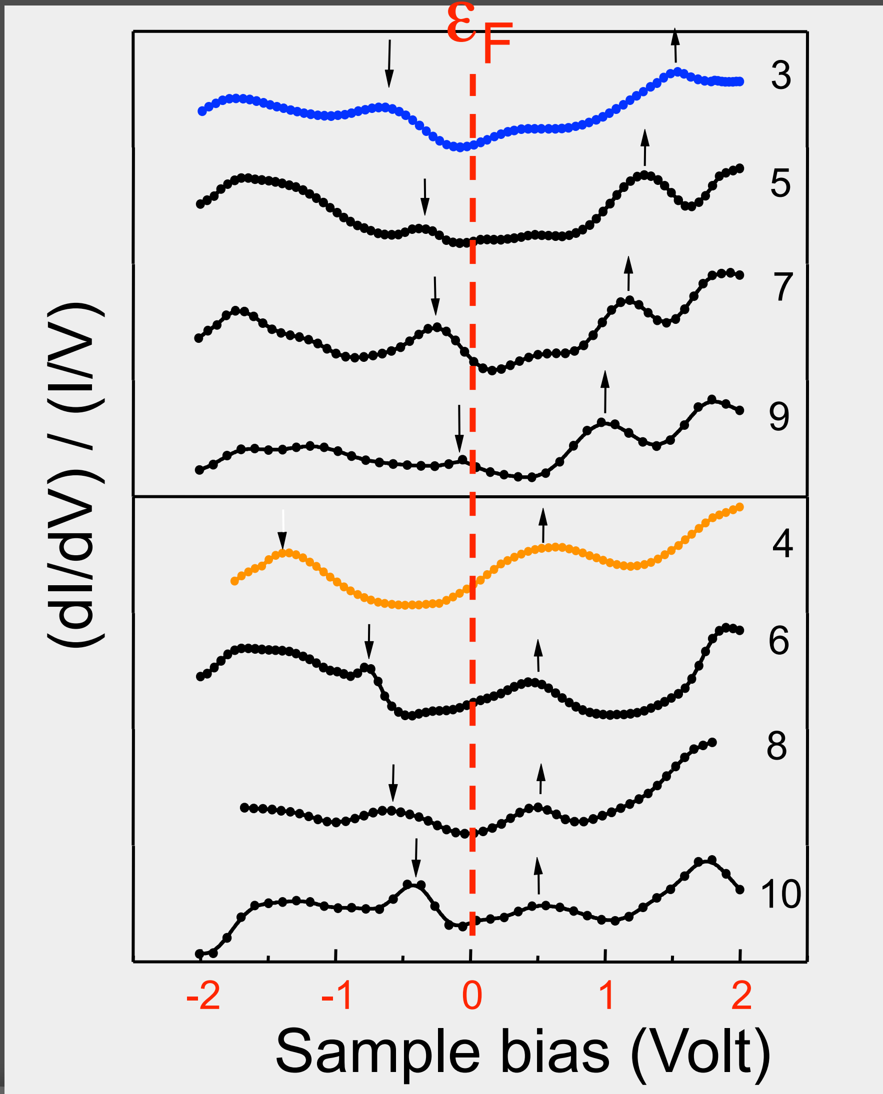


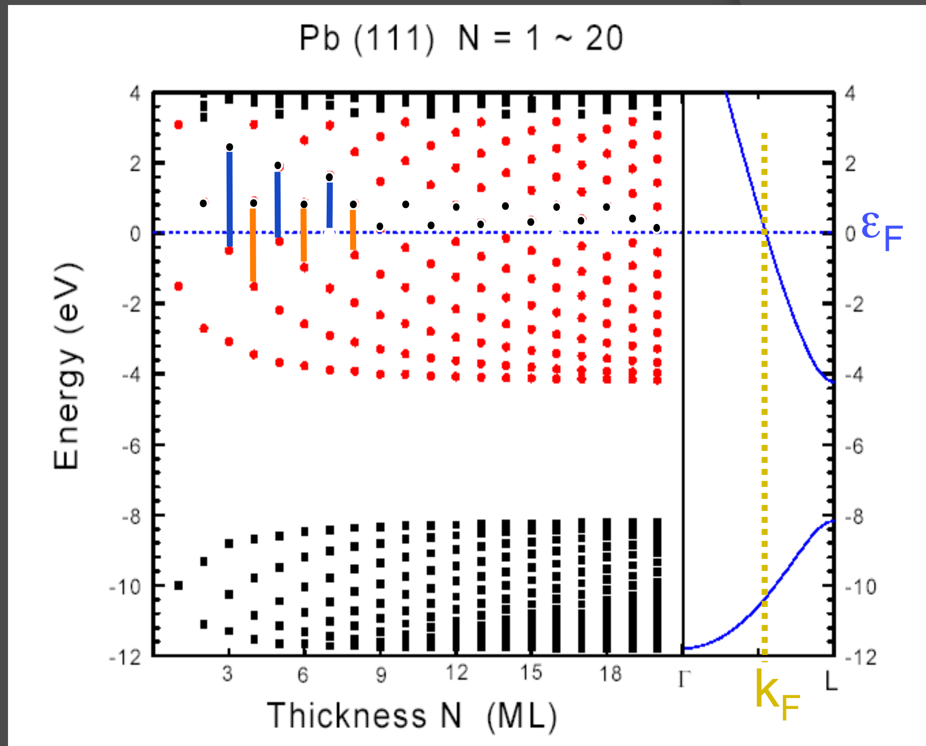






Spectra for Pb Films



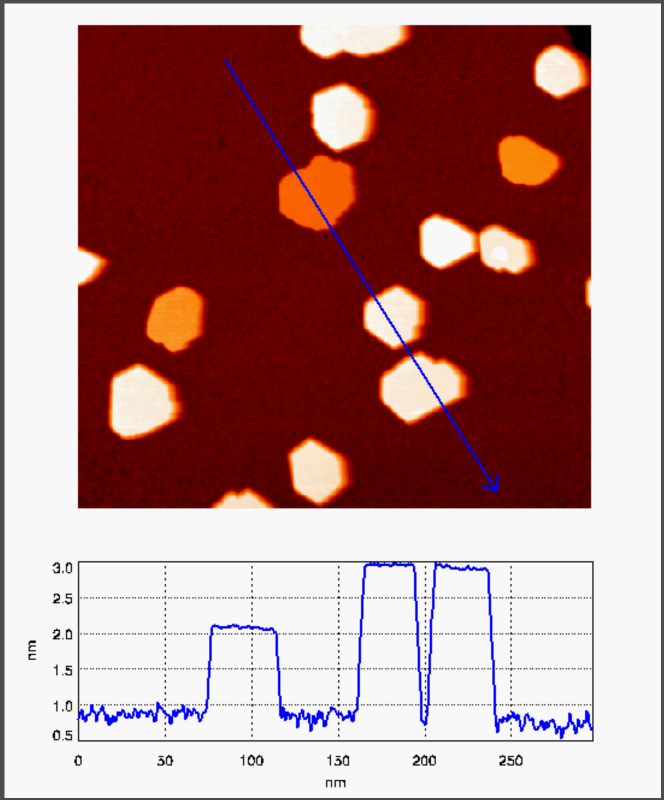


C.M. Wei and M.Y. Chou

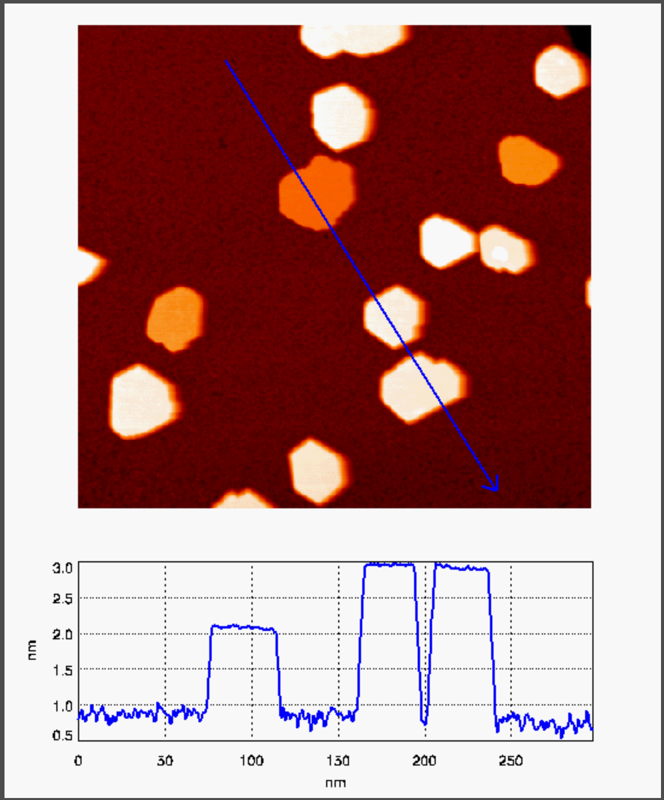
d_0 = 2.85 Å λ_F = 3.94 Å

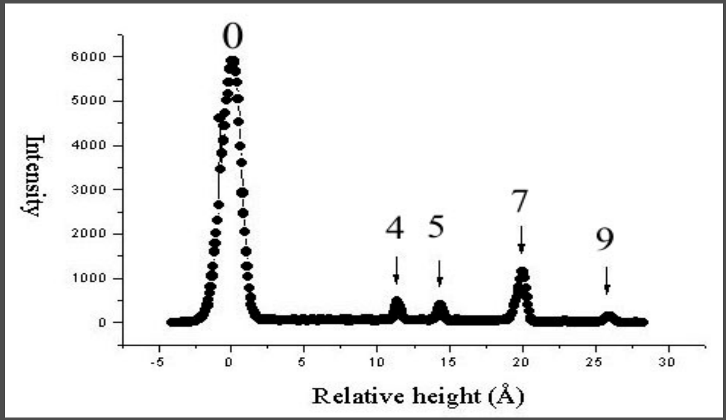
$2d_0 \approx 3(\lambda_F/2)$

Apparent island heights

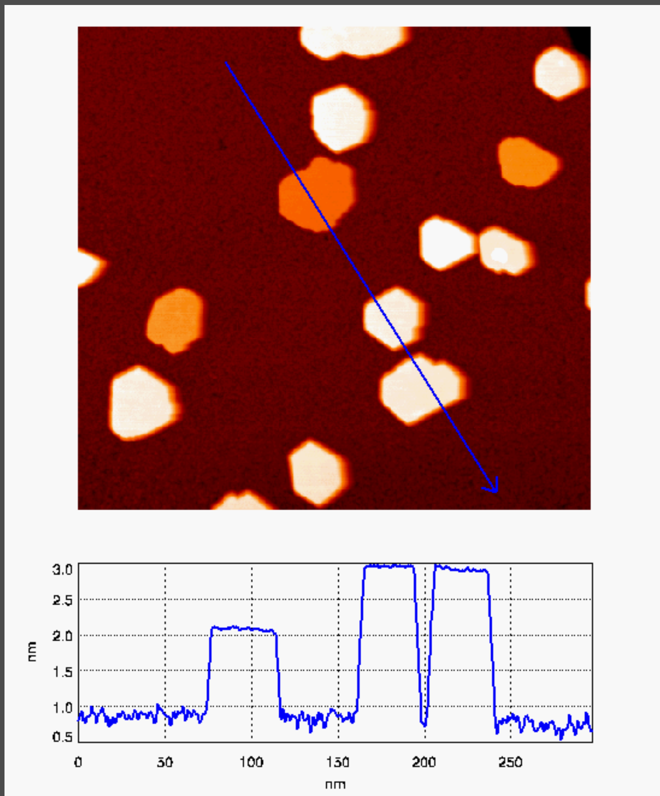


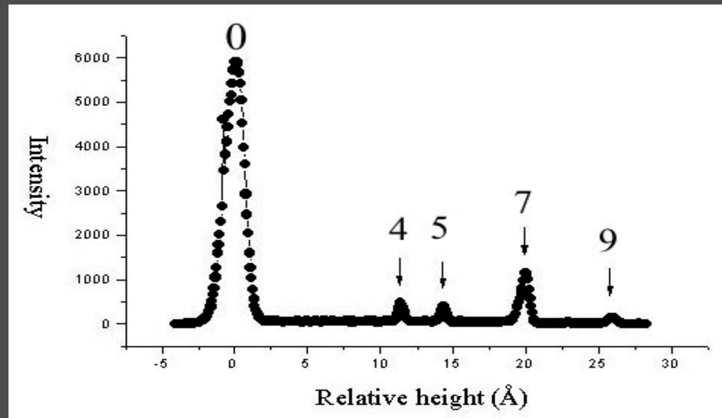
Apparent island heights

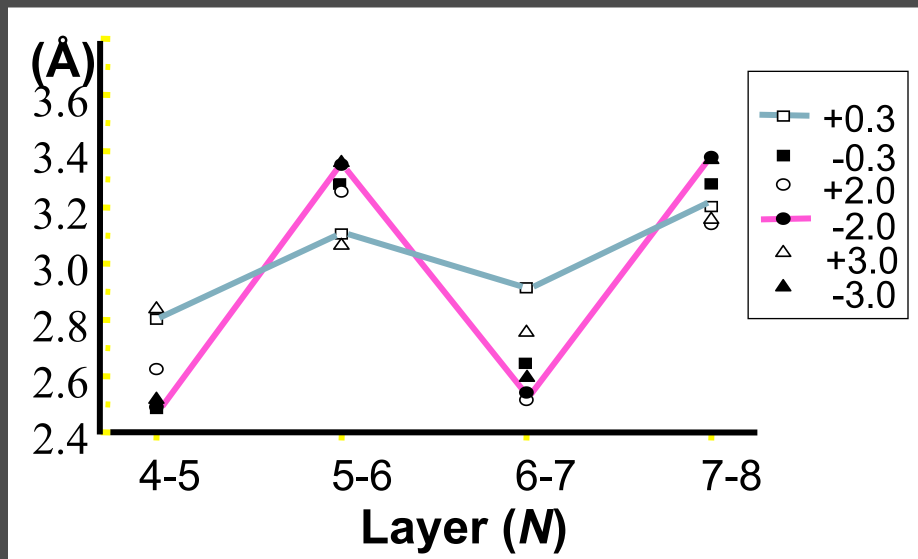




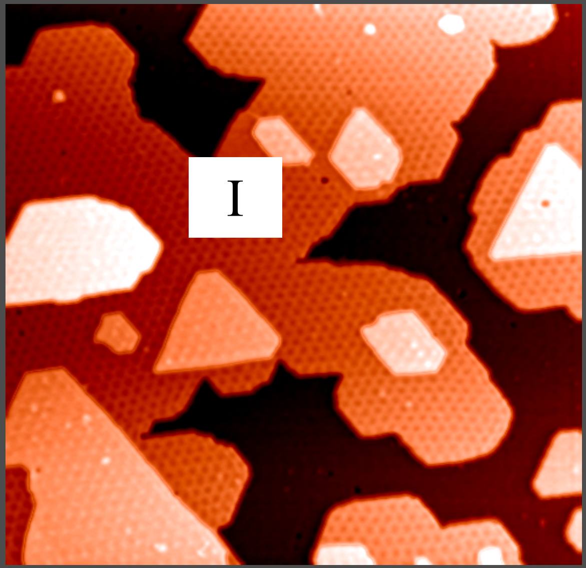
Apparent island heights

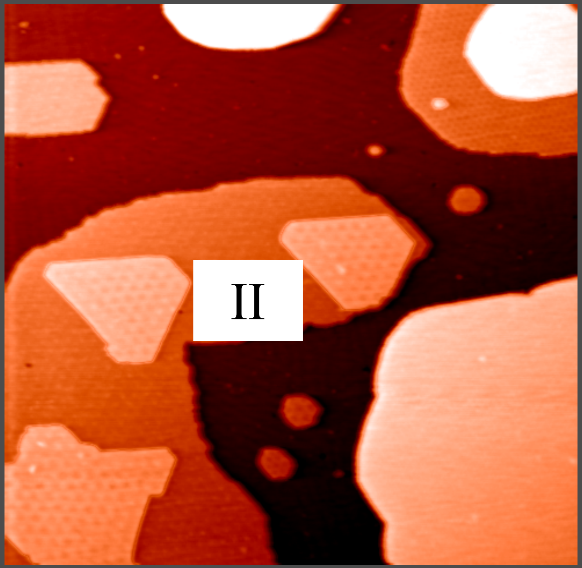




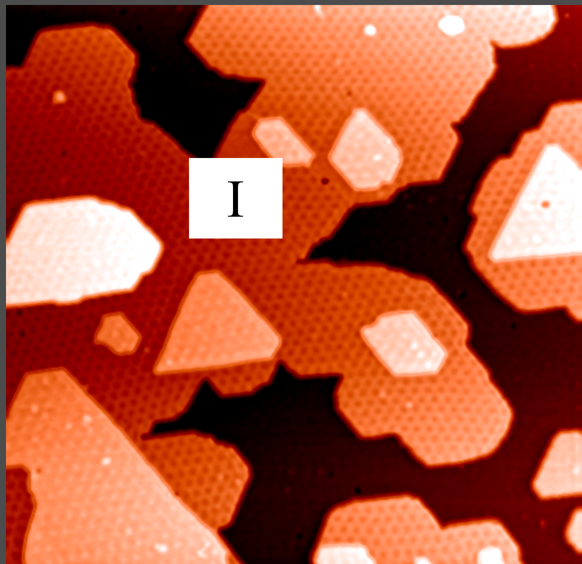


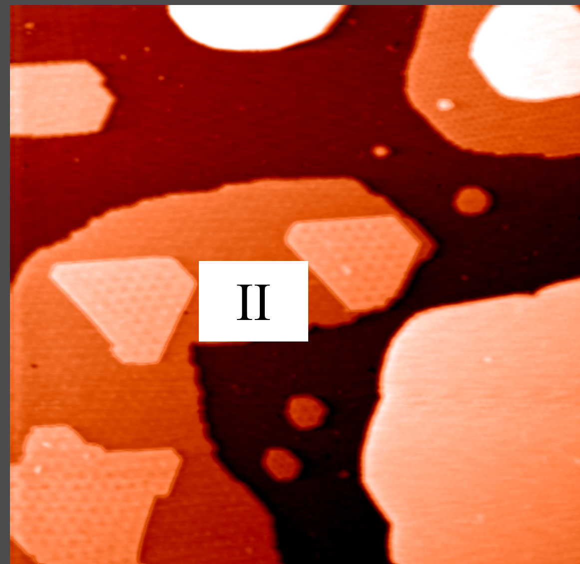
Difference in layer stacking

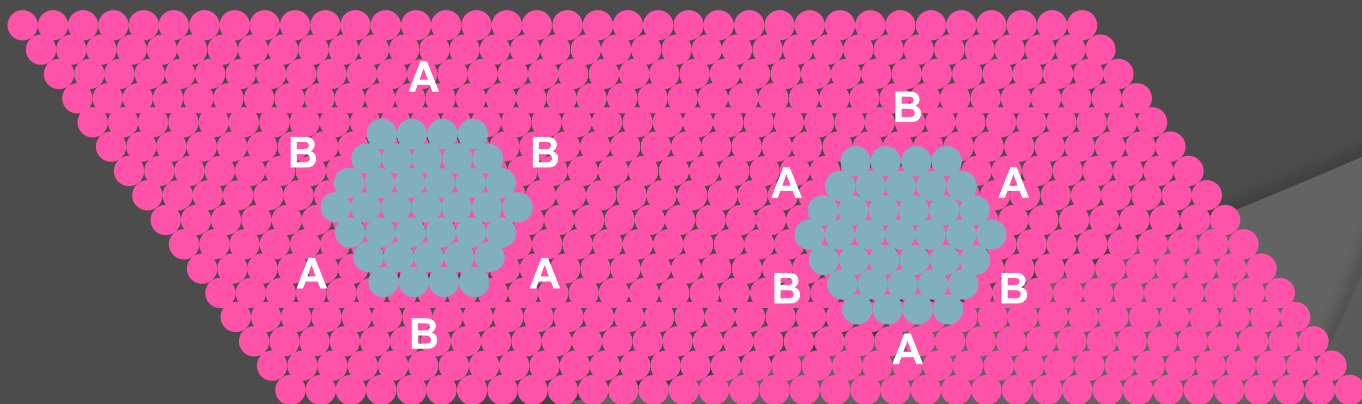




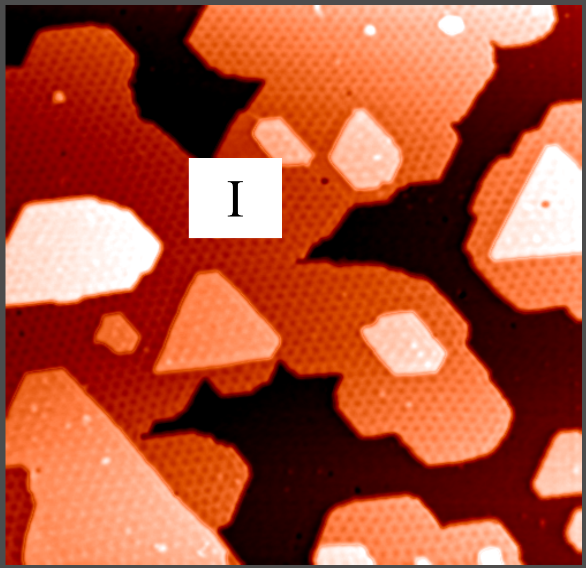
Difference in layer stacking

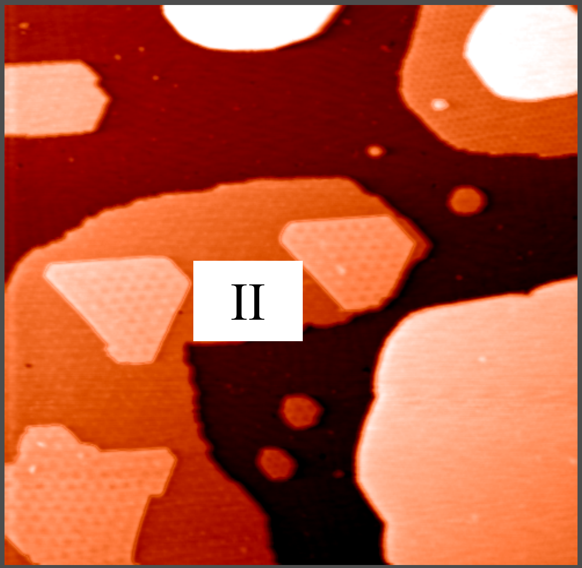


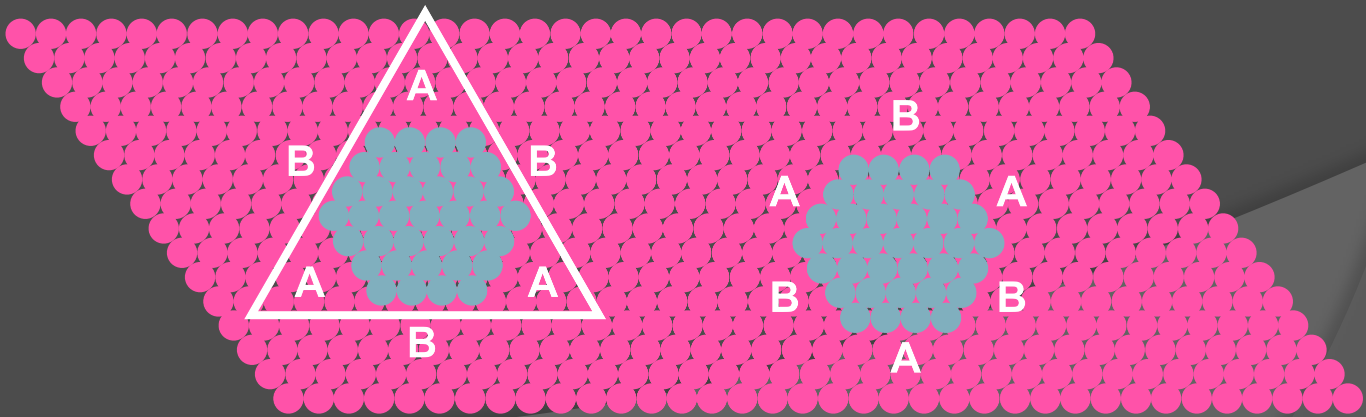




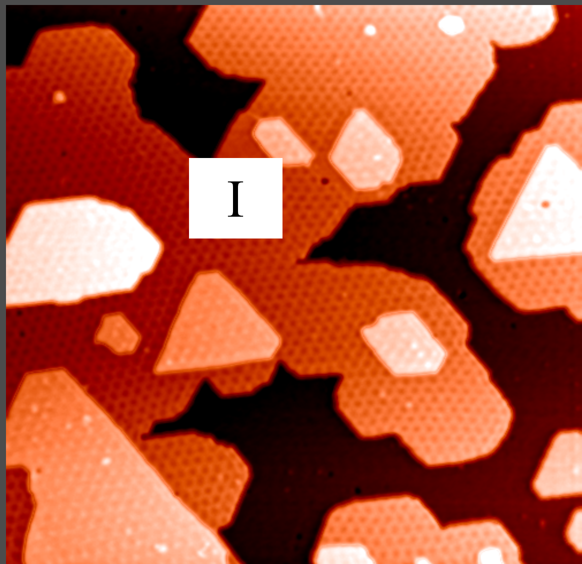
Difference in layer stacking

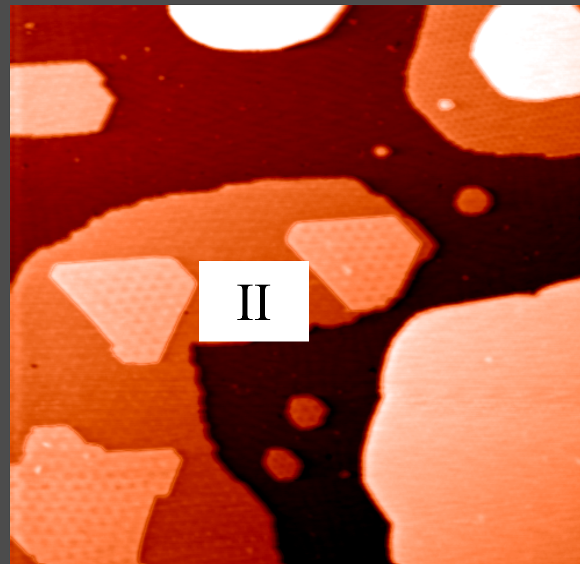


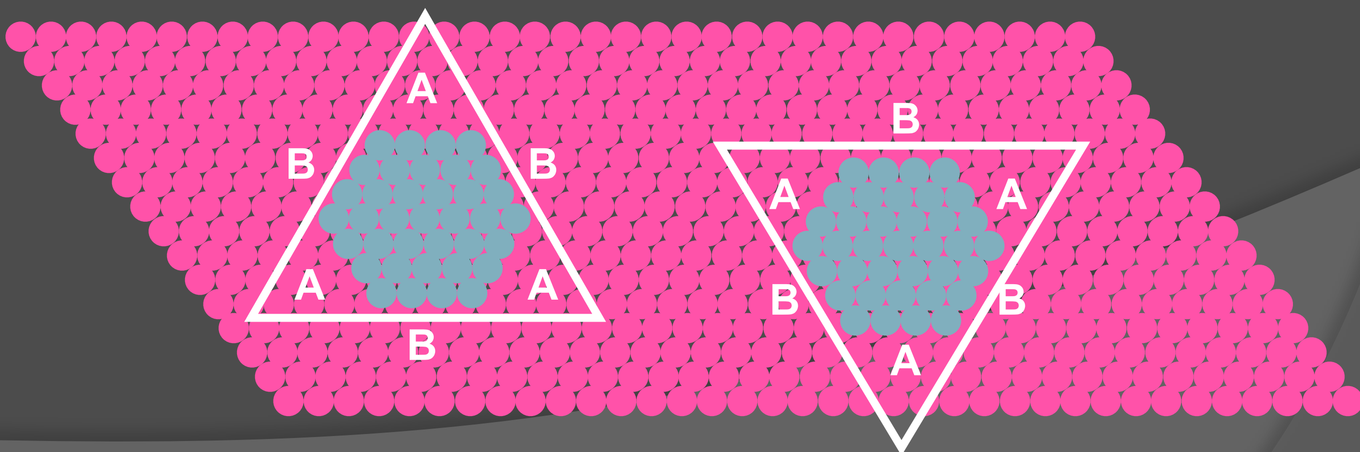




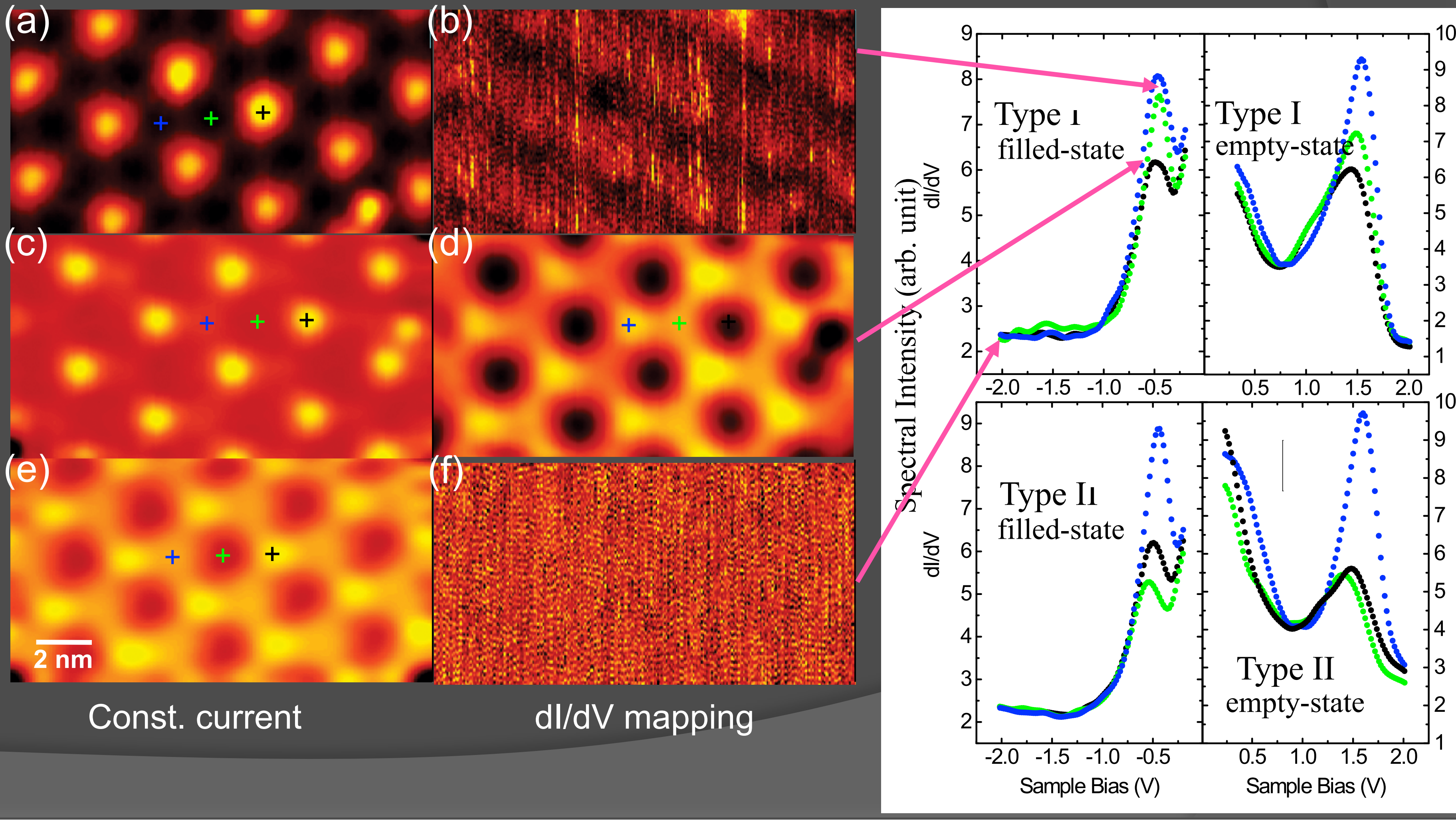
Difference in layer stacking



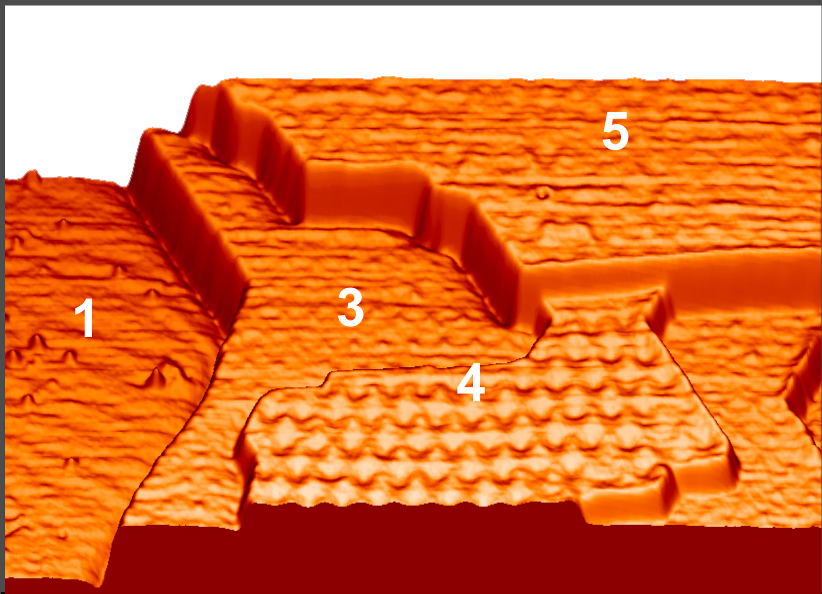




Characteristics of Pb islands---Bias-dependent imaging contrast



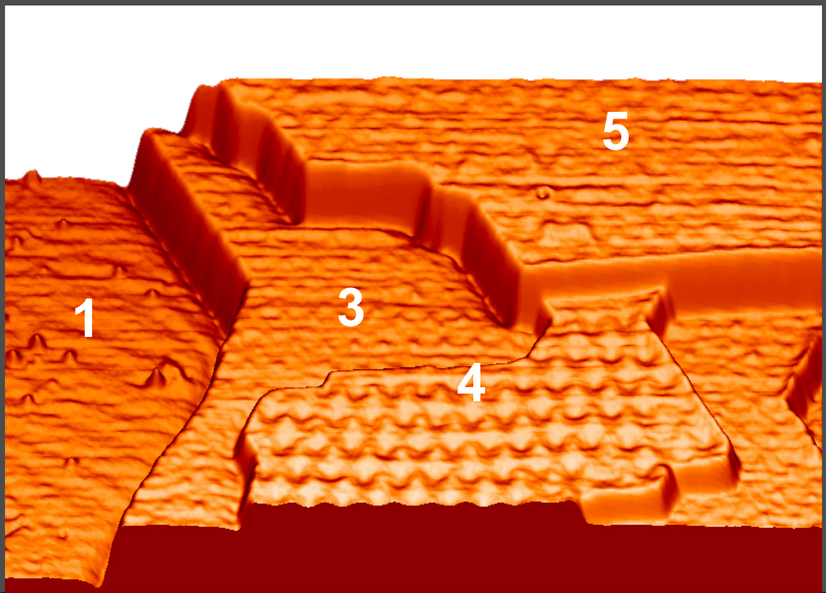
Characteristics of Pb island: oscillatory and complementary contrast



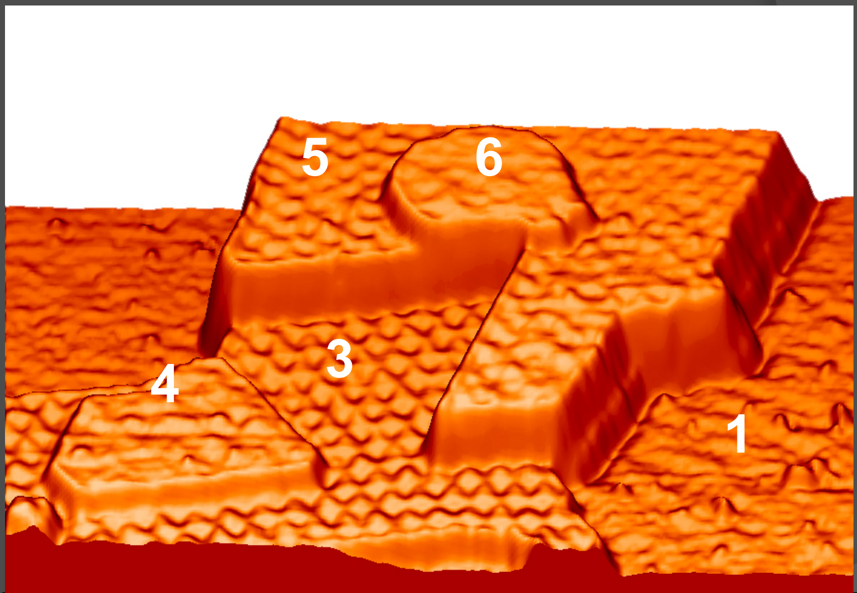
Type II

W.B. Jian *et al*., Phys. Rev. Lett. **90**, 196603 (2003)

Characteristics of Pb island: oscillatory and complementary contrast



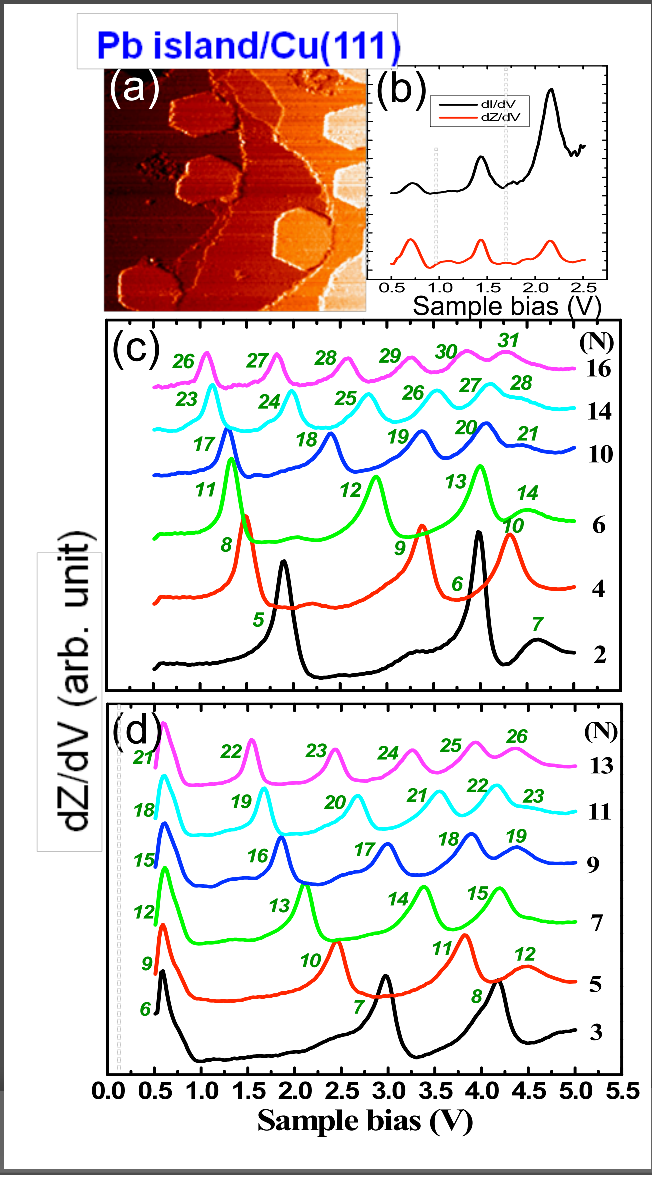
Type II



Type I

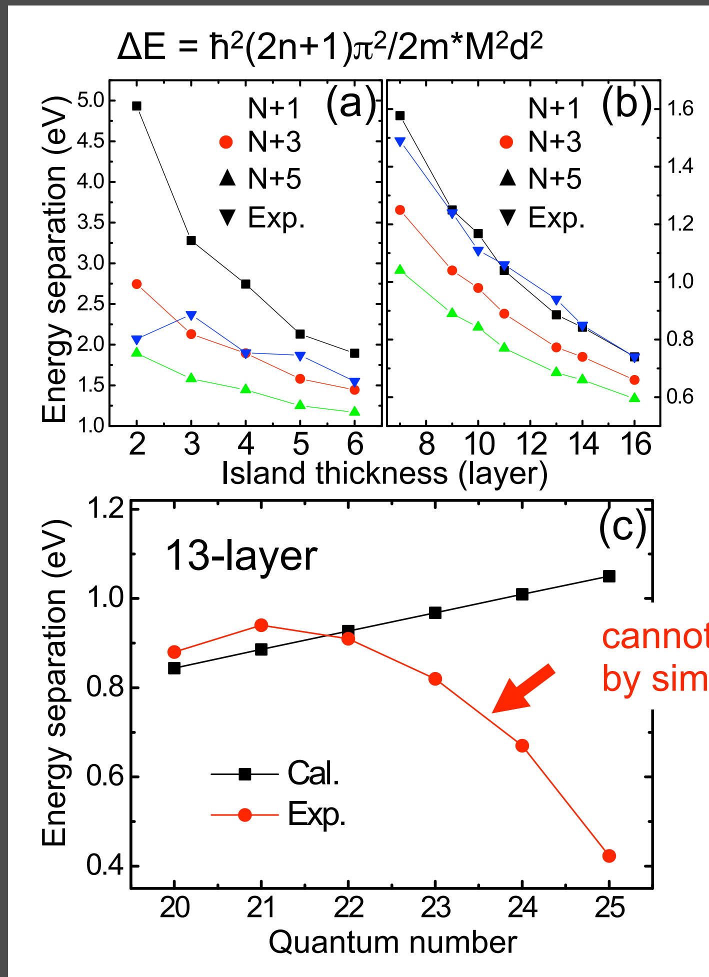
W.B. Jian *et al*., Phys. Rev. Lett. **90**, 196603 (2003)

Effect of image potential on quantum well states



even

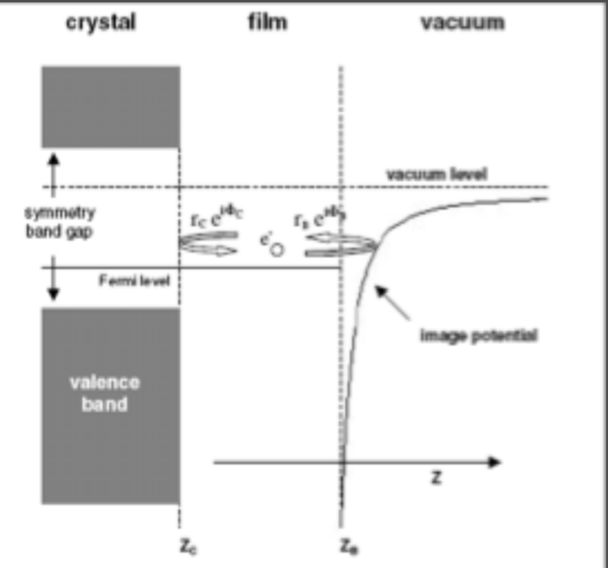
odd

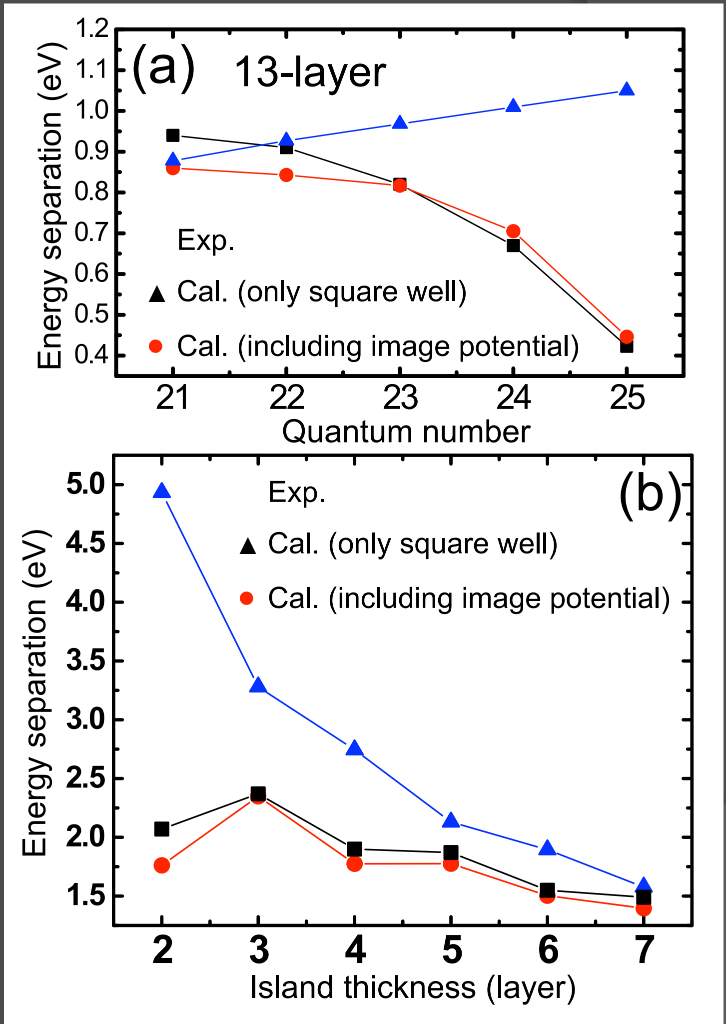


cannot be explained by simple square well

Phys. Rev. Lett. **102**, 196102 (2009)

Phase contribution of image potential





Phase accumulation (PA) model: total phase=2nπ

For simple square well:

$$2k(N+1)d=2n\pi$$

Including phase ϕ_B contributed from image potential

$$2k(N+1)d+\phi_B=2n\pi$$

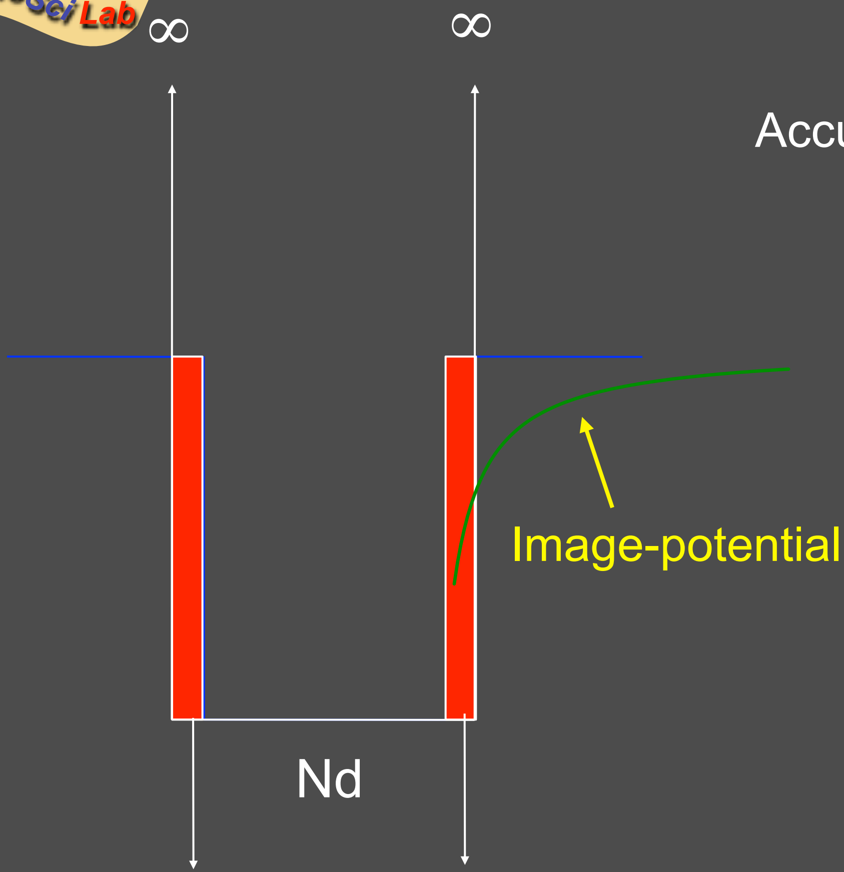
and $\phi_B/\pi=[3.4\ eV/(E_V-E)]^{1/2}-1$

E: energy of quantum well state

E_V: Vacuum level

E_V=4.6 eV above E_F

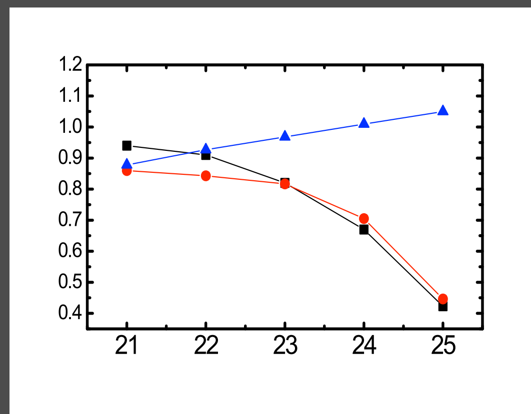
Accumulative phase model



Penetration depth: d/2

Accumulative phase for quantization:

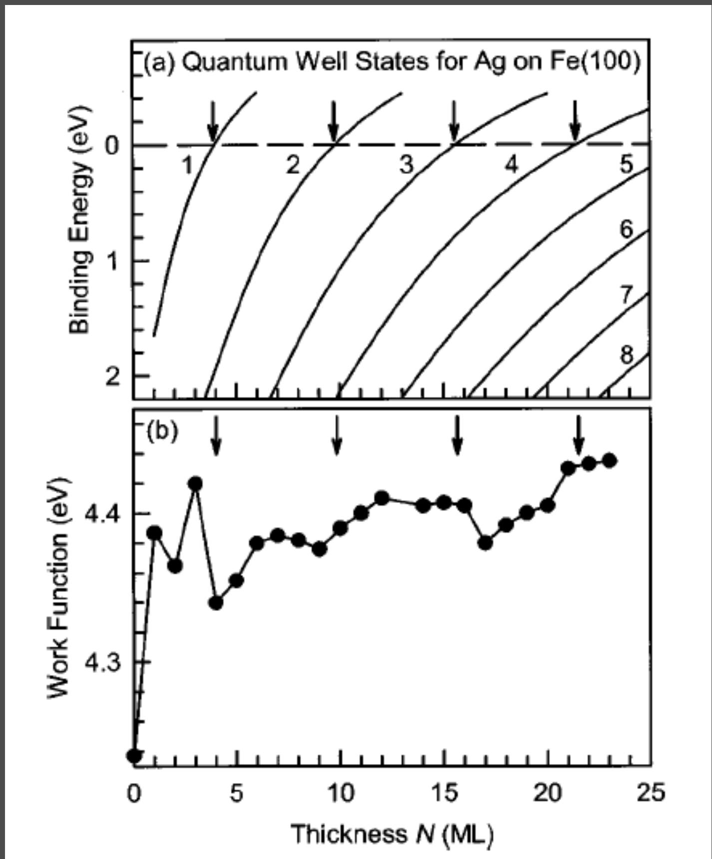
$$2k(N+1)d + \phi_B = 2n\pi$$



Finite square well with width Nd is approximated by infinite square well with width (N+1)d (M=N+1/2+1/2)

Work function of ultrathin films

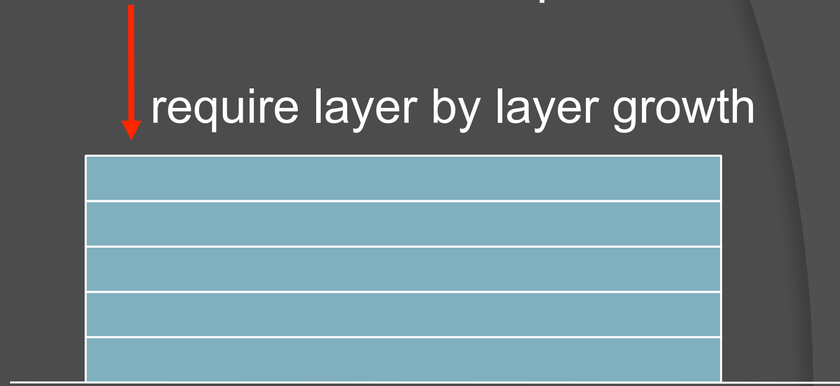
work function measurement for thin film using photo-emission spectroscopy



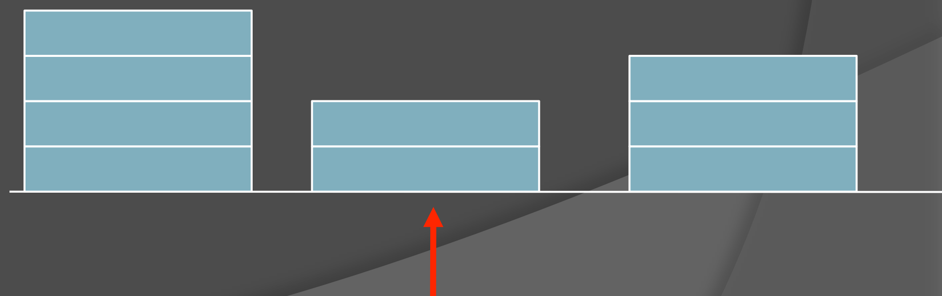
J. J. Paggel et al. 66, Phys. Rev. B (2002) 233403.

Broad beam technique

require layer by layer growth



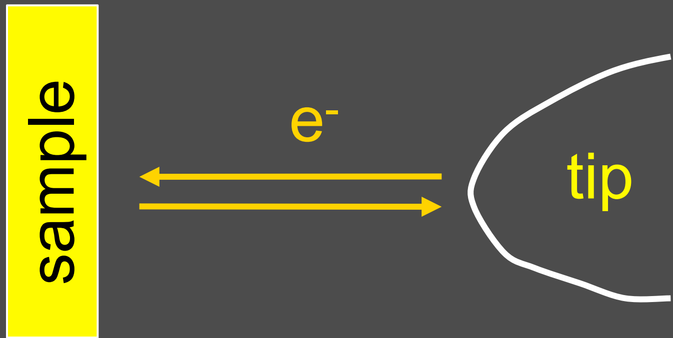
Average work function of various thickness

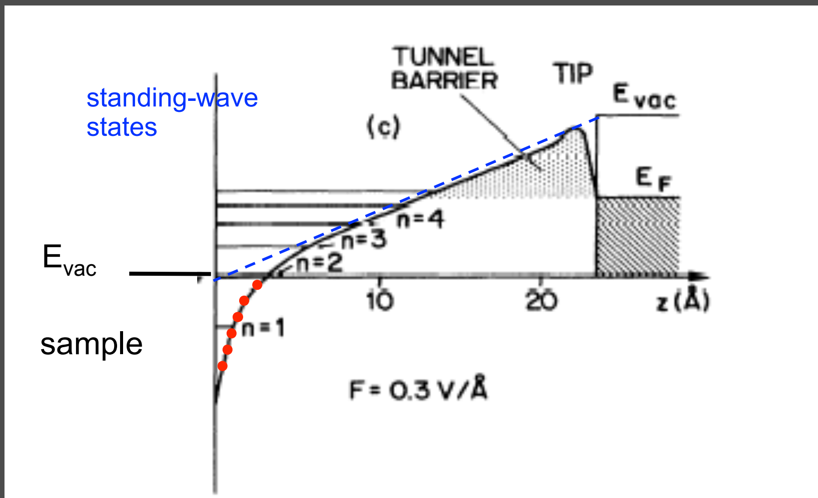


Local probe technique, e.g. STM

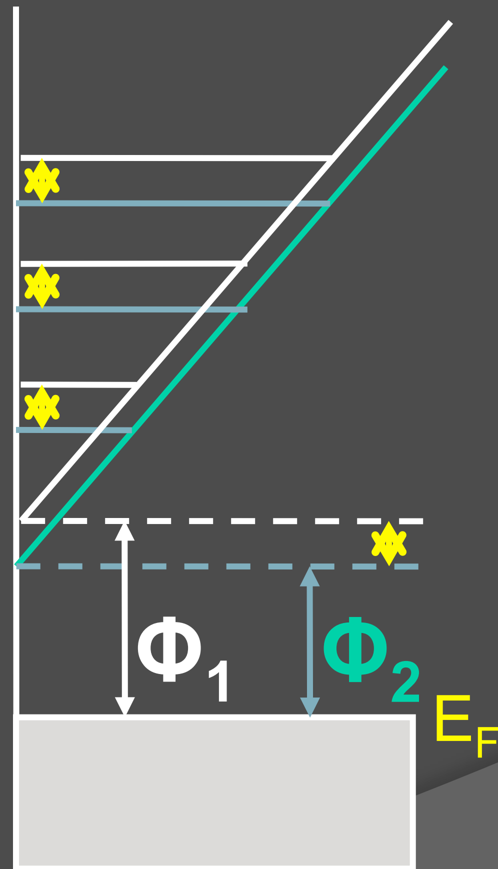
2011年6月20日星期一

Gundlach oscillation



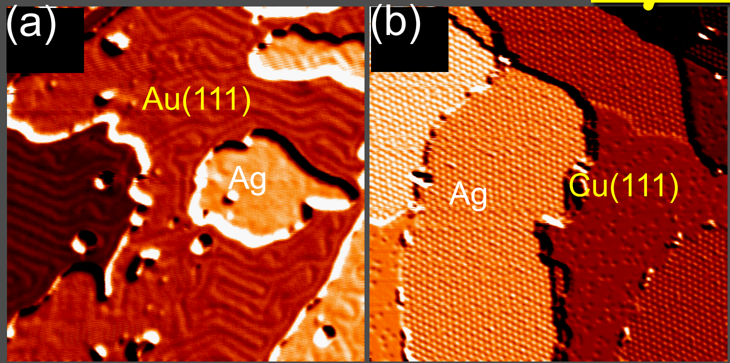


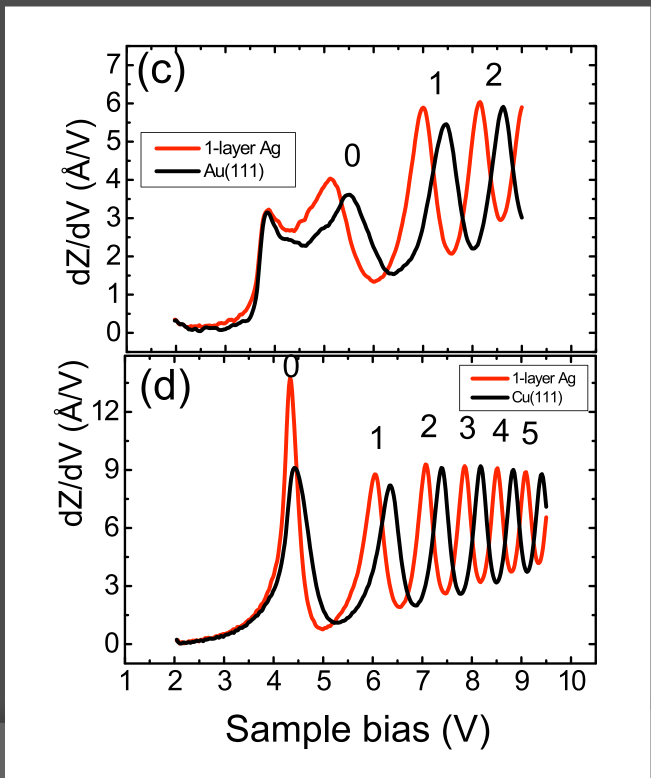
Superposition of image potential
and applied potential

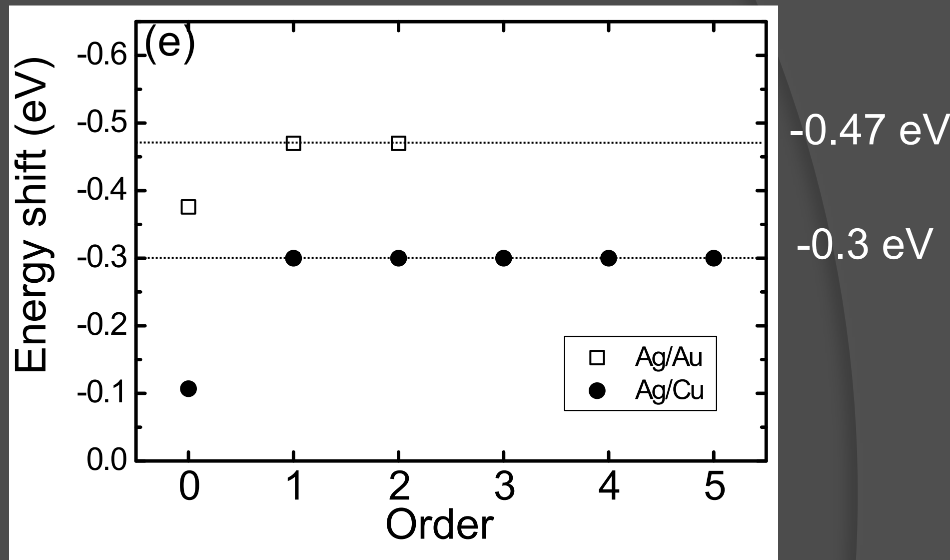


Constant energy separation = Work function difference

Work function measurements by Gundlach oscillation





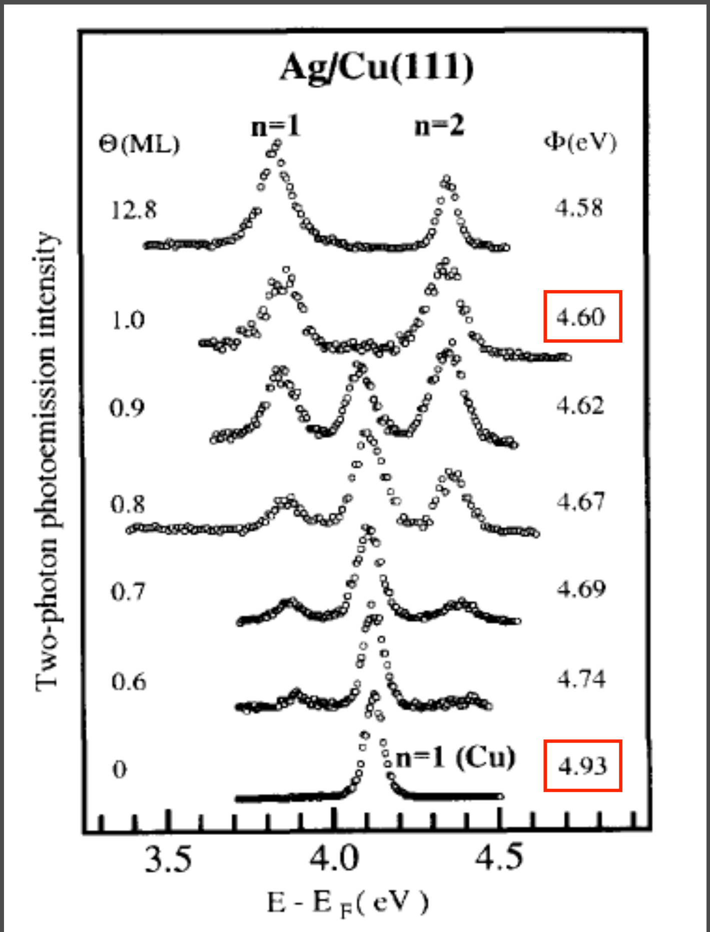


Bulk Materials	Φ(eV)
Au(111)	5.31
Ag(111)	4.74
Cu(111)	4.98

Lin et al., Phys. Rev. Lett. 99, 216103 (2007)

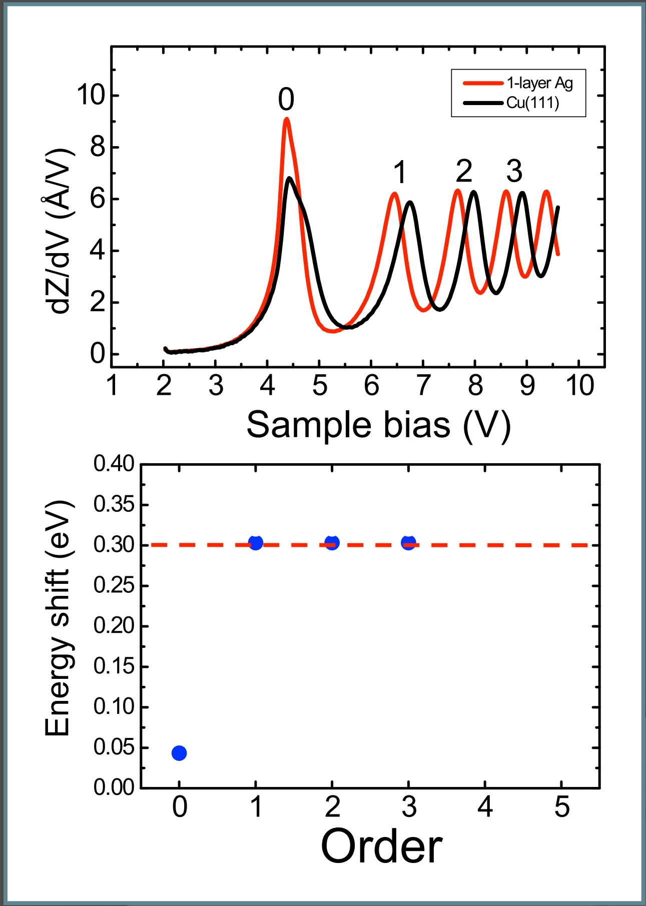
Comparison with PES measurement

Photoemission (-0.33 eV)

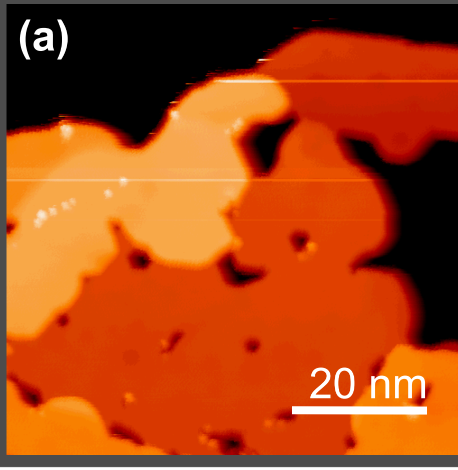


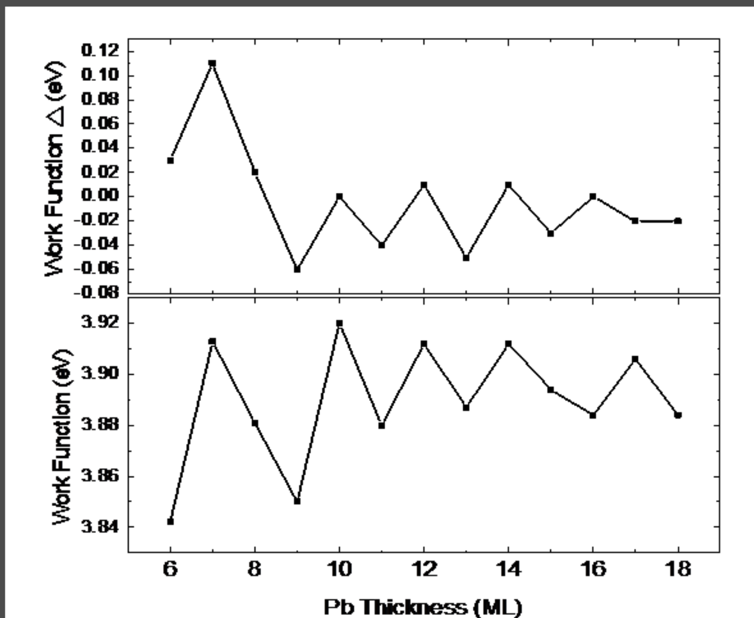
Wallauer et al., Surf. Sci 331, 731 (1995)

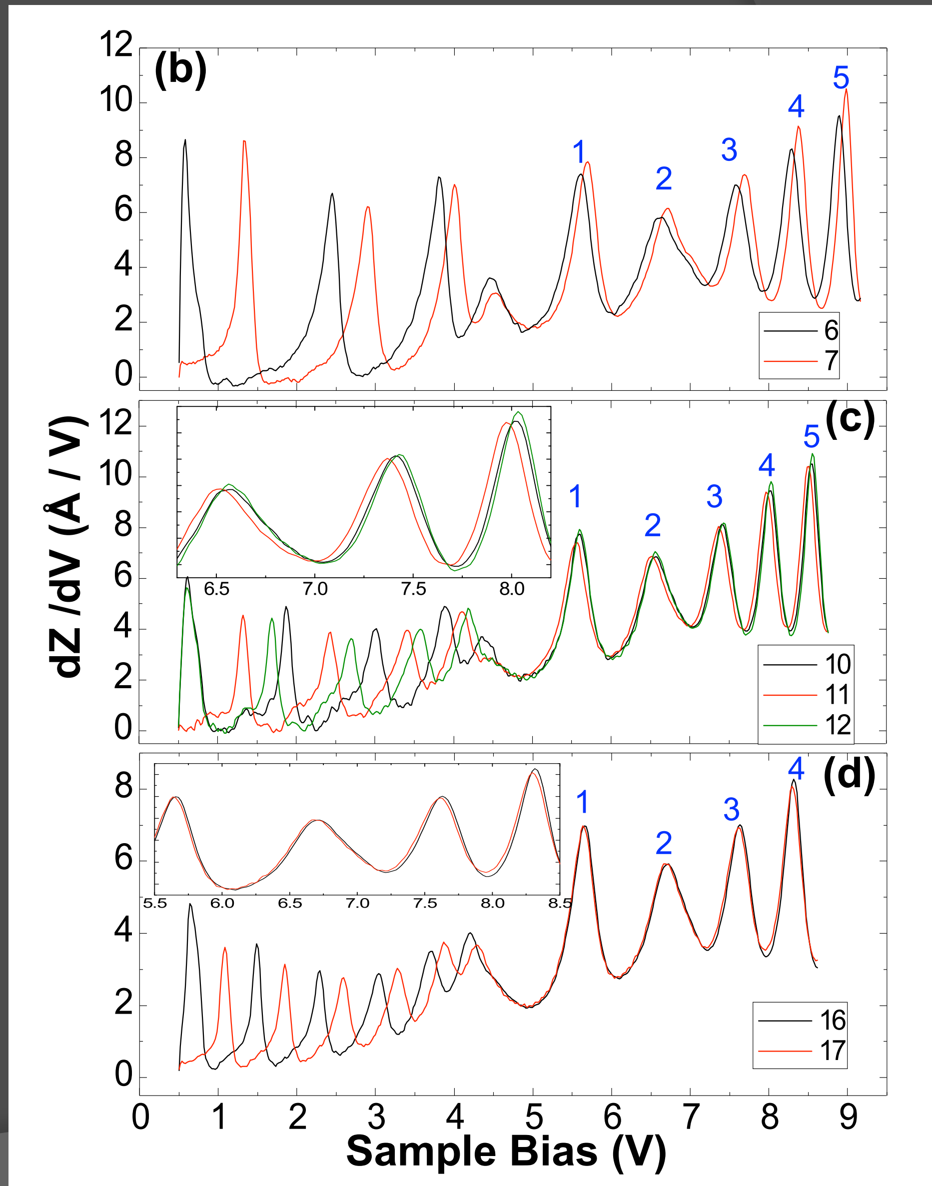
Gundlach oscillation (-0.3 eV)



Work function differences on Pb films



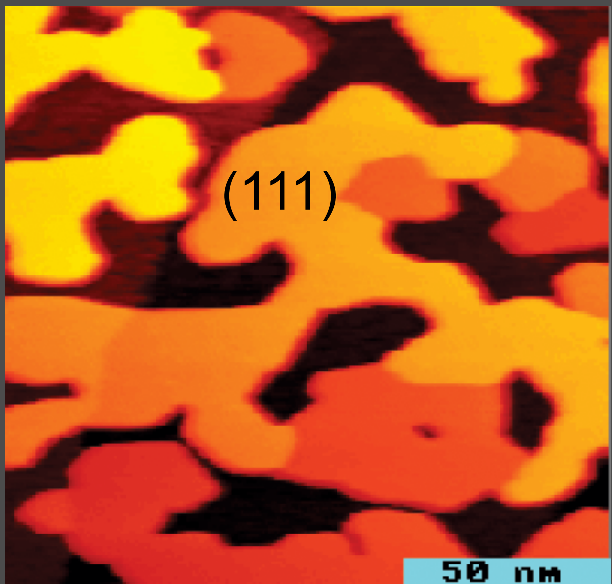


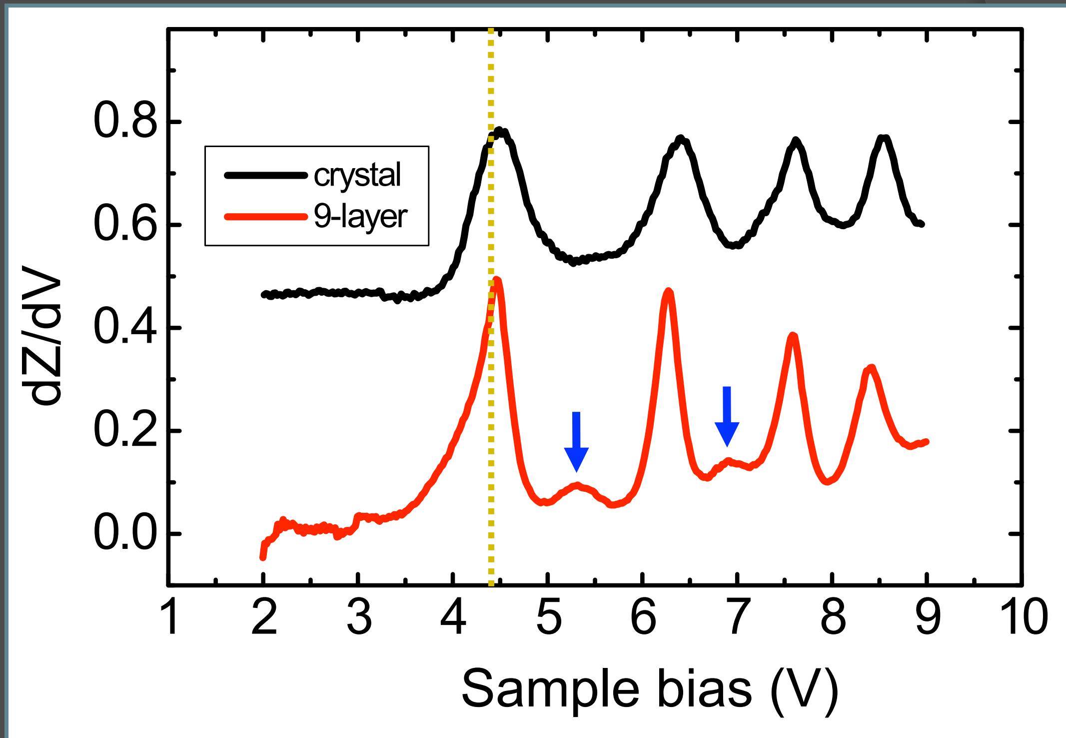


Yu Jia *et al*., Phys. Rev. B 74, 035433 (2006)

Transmission Resonance in Ag Films on Si(111)

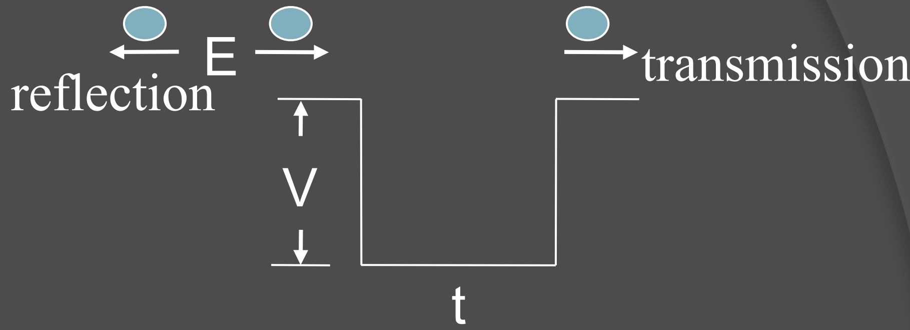
Ag film on Si(111) at RT





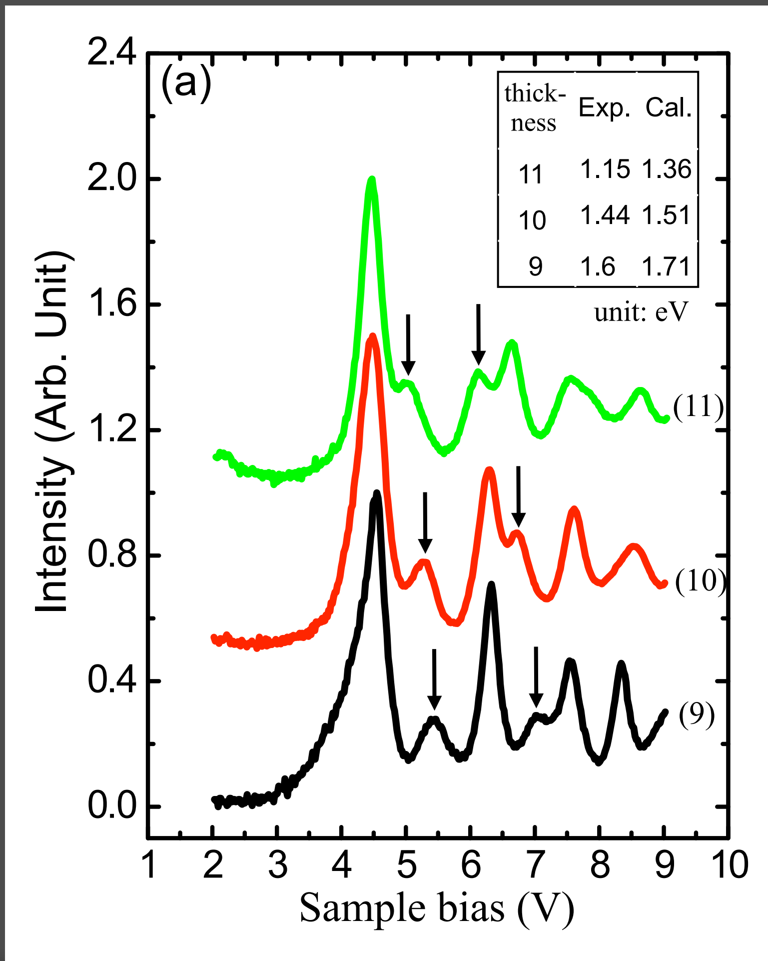
Work function of Ag/Si(111) = 4.41 eV

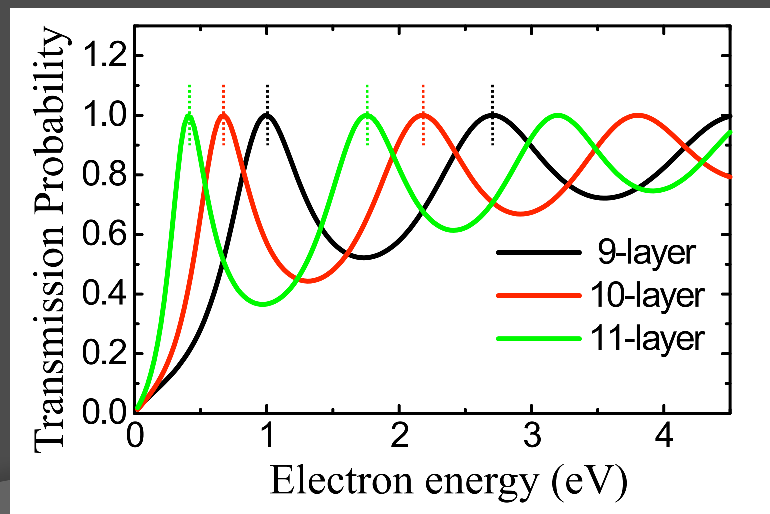
Quantum Size Effect above Vacuum Level



$$\frac{1}{T} = 1+\frac{1}{4}\frac{V^2}{E(E+V)}\sin^2(kt); R=1-T; \frac{\hbar^2k^2}{2m} = E+V$$

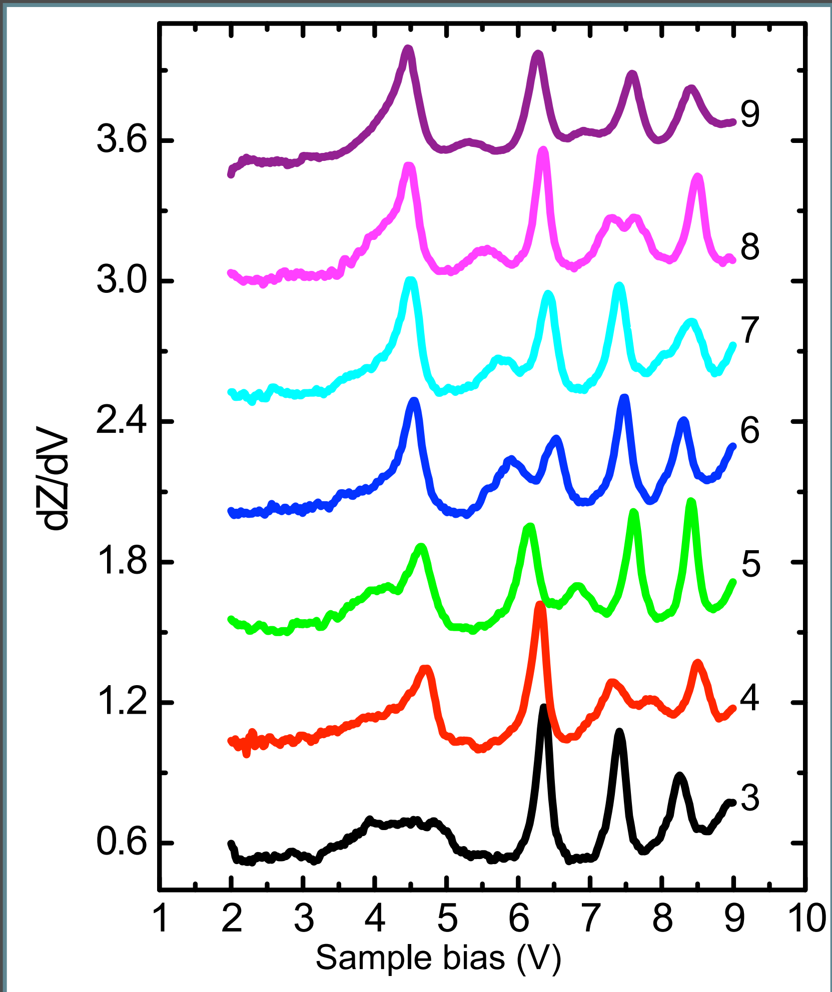
$kt=n\pi \longrightarrow T=1$ transmission resonance

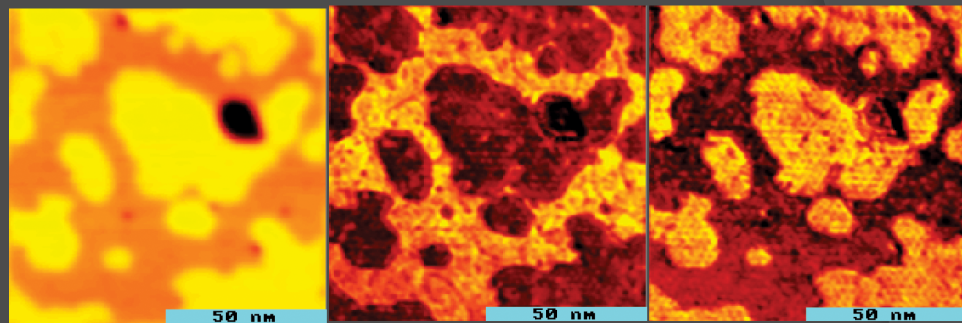


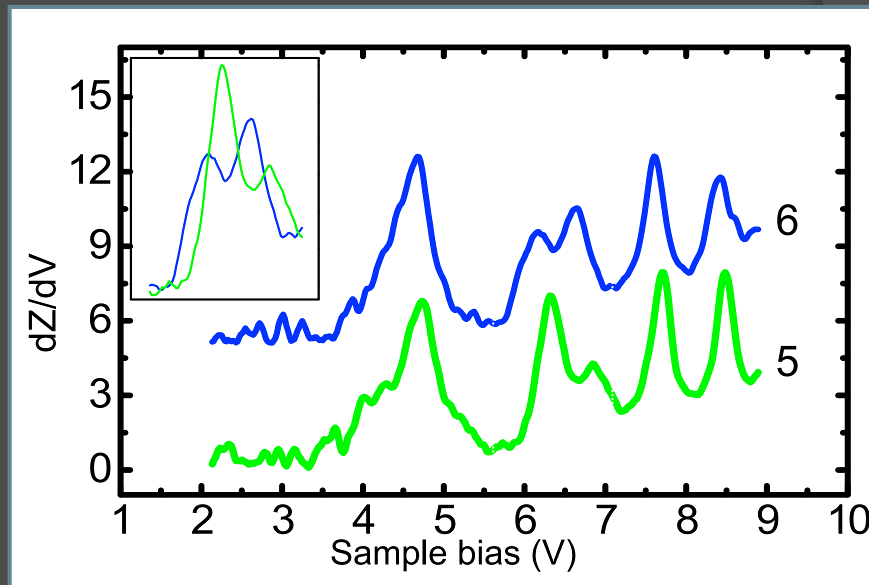


"Finger print" of film thickness

Low temperature deposition followed annealing to room temperature







Summary

- Quantum well states are measured with STS in the Pb films of varied thickness on the Si(111) surface.
- The lattice mismatch at the interface produces a periodic potential variation, which manifests in a vertical charge oscillation at the surface, and the subtle phenomena of the complementary and alternating contrast reversals through two types of islands with different stacking are observed.
- The QW states in the energy range of 2 - 5 eV above the Fermi level are affected by the image potential, which causes the shrinking in energy separations with the quantum number.

Summary

- *A general phenomenon of the constant energy shift is observed in high order Gundlach oscillation.*

  The work function of a thin metal film can be measured with the constant energy shift better than 0.02 eV, comparable to the photoemission results.

- *Quantum transmission resonance can be observed with STS in Ag films on the Si(111) surface.*

  Positions of the transmission resonance measured with STS can serve as finger prints for the Ag films of varied thickness.

Acknowledgment

C. L. Lin, S. M. Lu, M.C. Yang, H.Y. Chou,
W.B. Jian, H.Y. Lin, Y.P. Chiu, and C.M. Wei

Thank you for your attention