Tailoring Surface and Thin Film electronic states with Curved Surfaces

J. Enrique Ortega

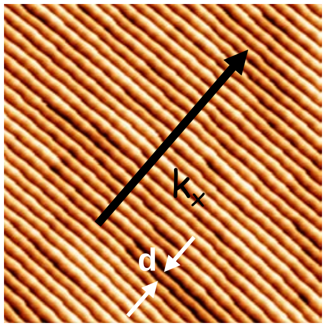
[1]Departamento de Física Aplicada I, Universidad del País Vasco
[2]Centro de Física de Materiales, Materials Physics Center CSIC-UPV/EHU
[3]Donostia International Physics Center (DIPC)

San Sebastián
Spain

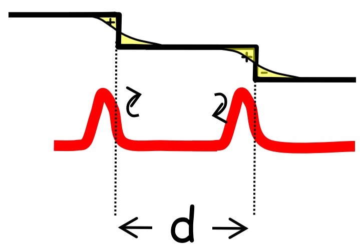
ES&ES 2013, May 21-23, Kyiv, Ukraine

Scattering at noble metal superlattices probed with ARPES

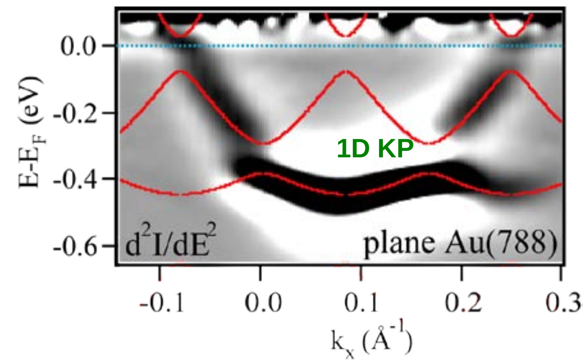
Stepped surfaces



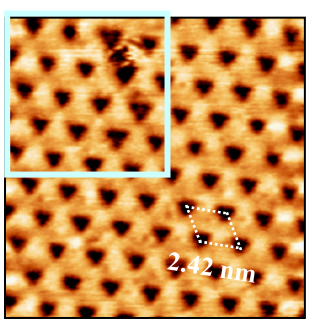
1D-lattice



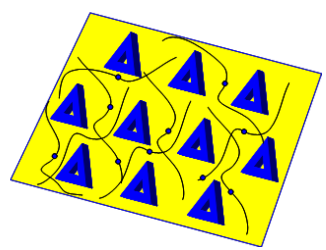
ARPES

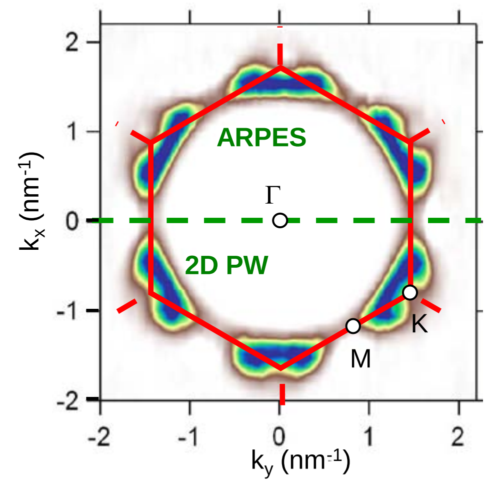


Dislocation networks



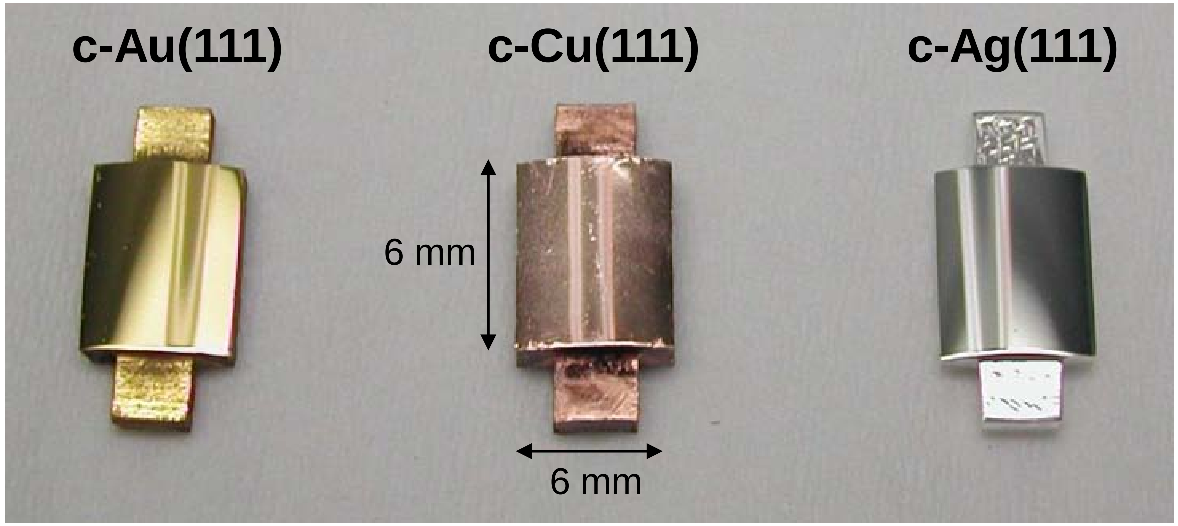
2D-lattice

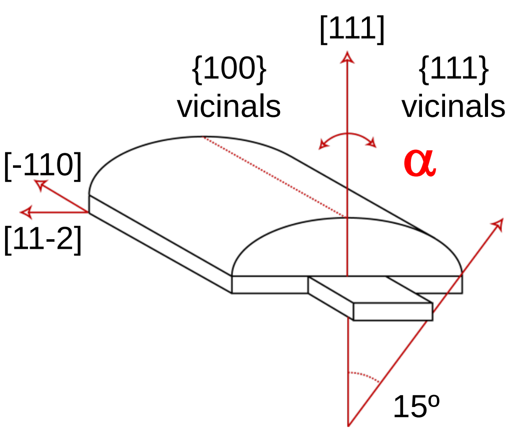


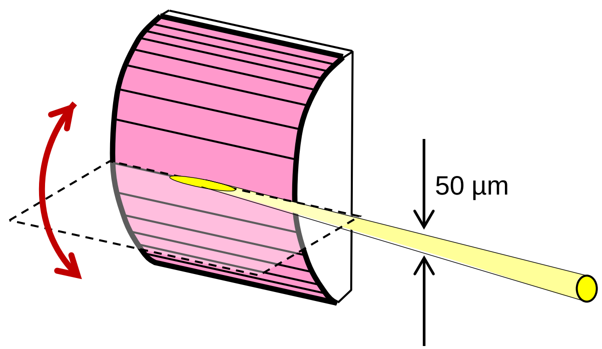


Tunable step lattices: curved surfaces

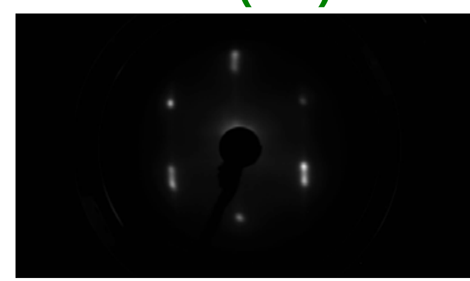
NanoPhysicsLAB
san sebastian







c-Ni(111)



We aim at fabricating samples that can be mounted using standard holders and be prepared through regular cleaning procedures

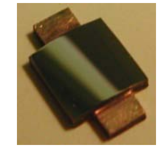
BIHURCRYSTAL

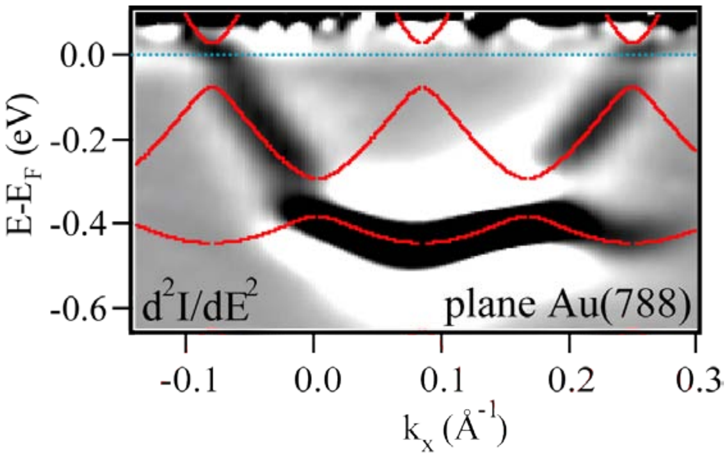
Flat versus curved crystals in ARPES

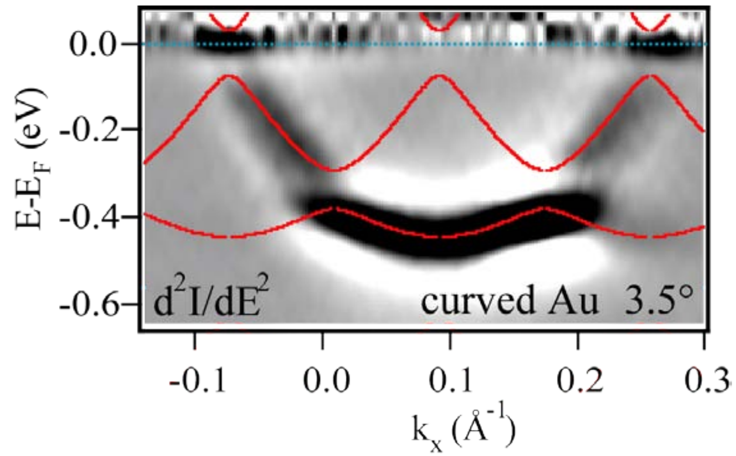
Au(788) **α=3.5**

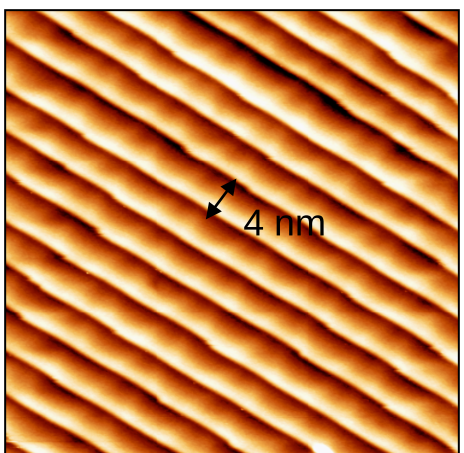
flat crystal

curved crystal

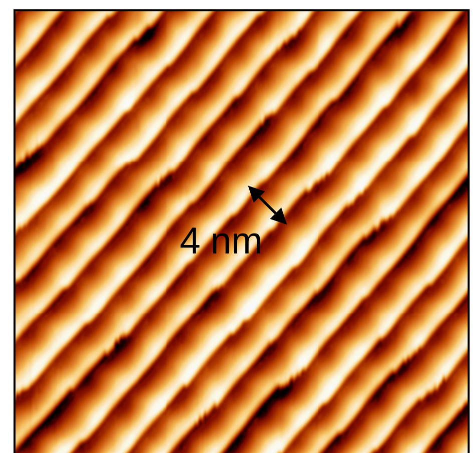






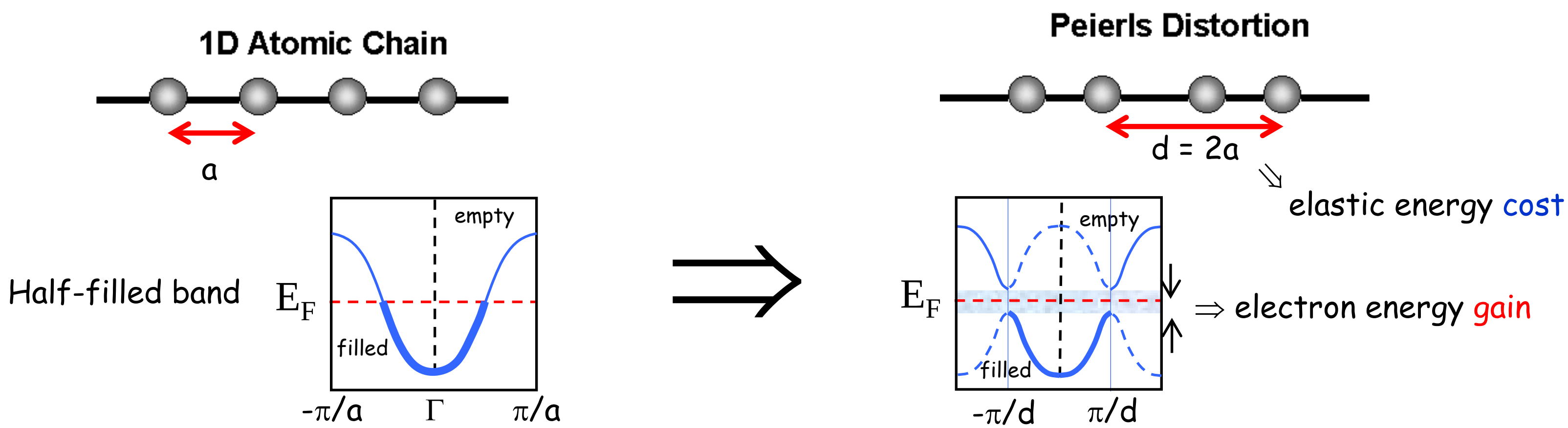


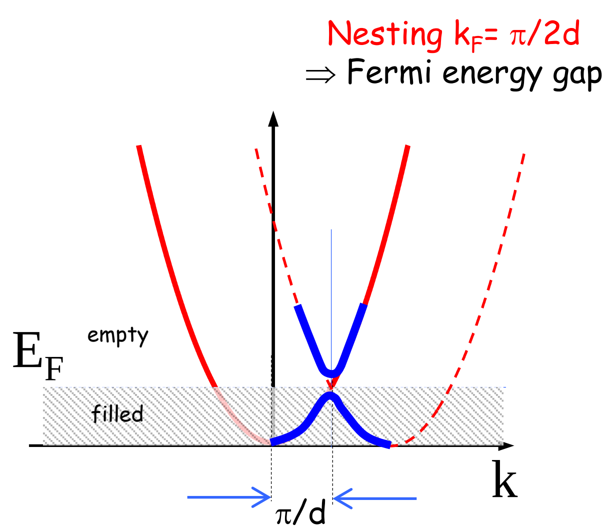
ARPES measurements from flat and curved crystals with the same crystallographic orientations are completely analogous



Curved surfaces for what?

Noble metals: structure/electronic interplay?





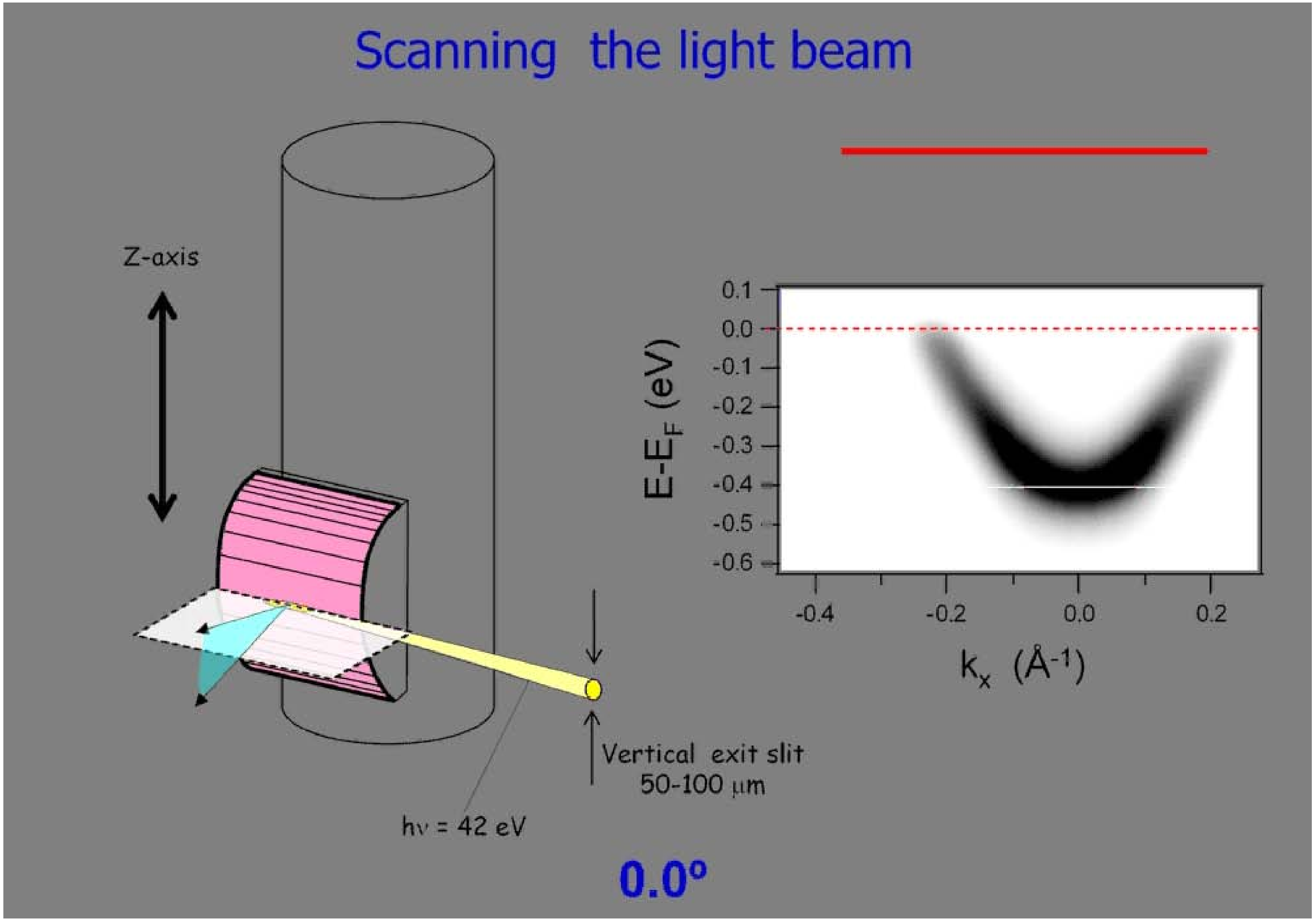
What kind of structural instabilities arise by approaching in 1D nesting of the Shockley state in a step superlattice?

Outline

- ARPES from noble metal curved surfaces:
  - ✓ *tuning umklapps and gaps*
  - ✓ *revisiting step barrier strength*

- Thin films on curved surfaces:
  - ✓ *Ag/c-Au(111): lateral scattering in quantum-wells*
  - ✓ *$BiAg_2$/c-Ag(111): SOC bands*

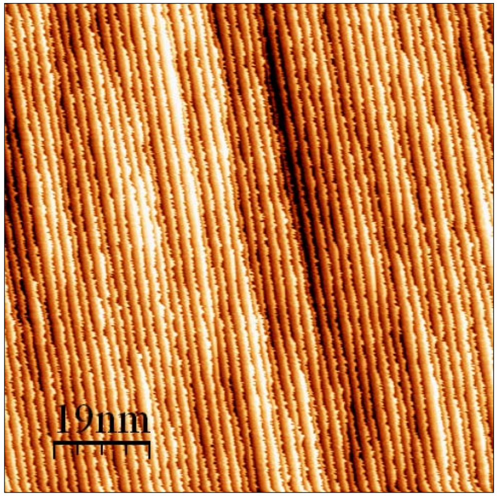
c-Cu(111)



Scanning the light beam
Z-axis
Vertical exit slit
50-100 μm
hν = 42 eV
0.0°
E-E_F (eV)
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.4
-0.2
0.0
0.2
k_x (Å^-1)

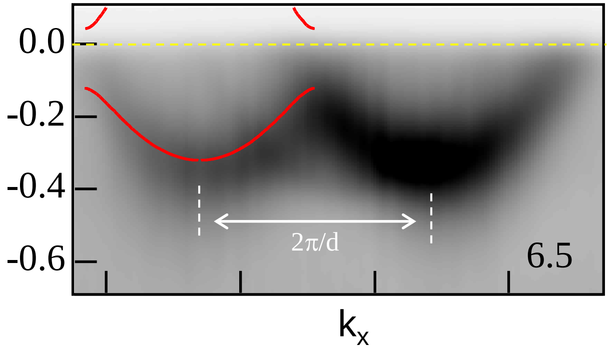
Step edge roughening in c-Cu(111)

$\alpha = 7.1$



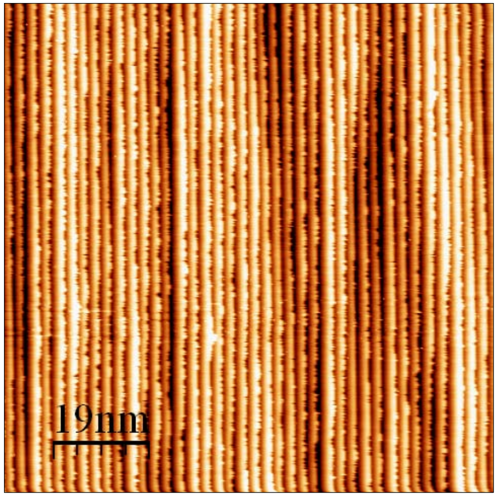
$\alpha = 6.5$, $d = \lambda_F/2$

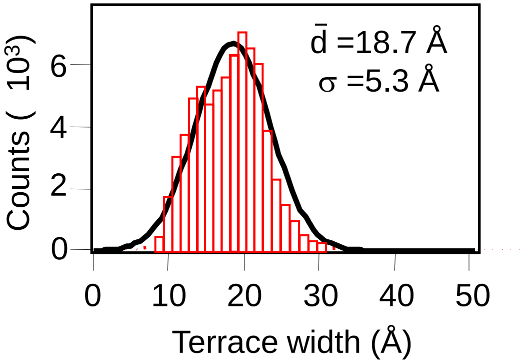
(Fermi gap)



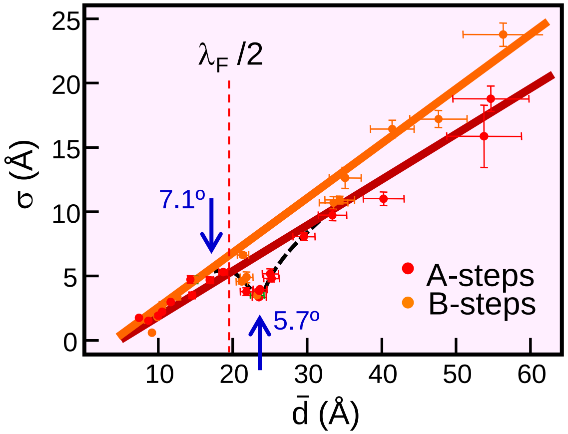
J. E. Ortega *et al.*, Phys. Rev. B **83**, 085411 (2011)

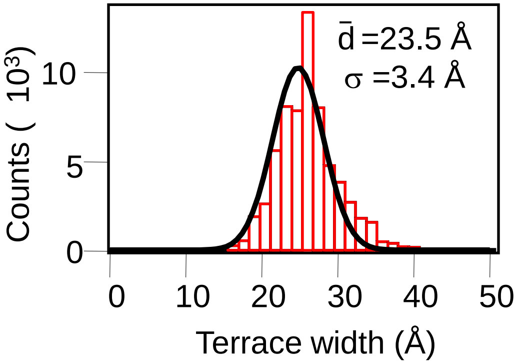
$\alpha = 5.7$





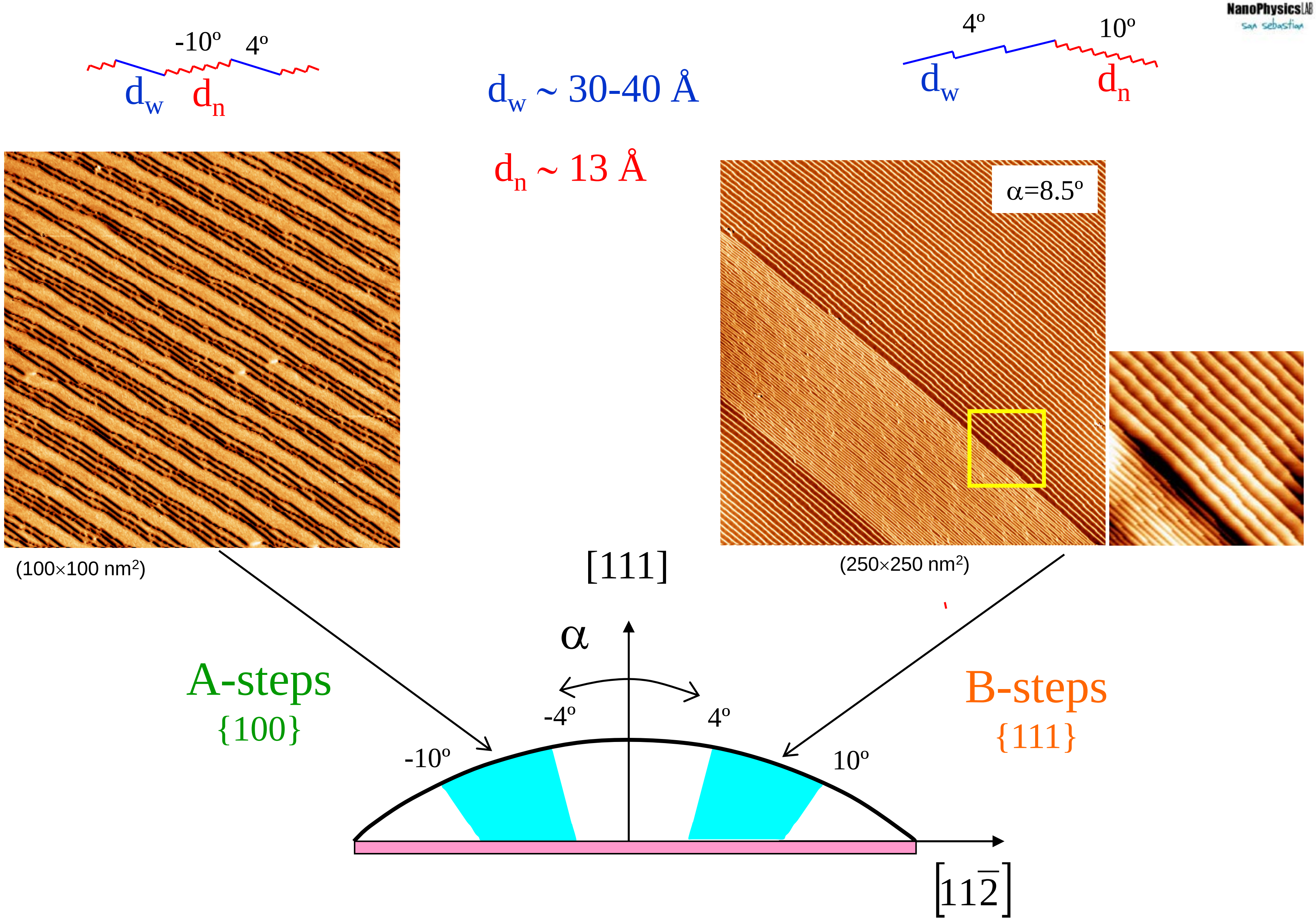
Rough step edges





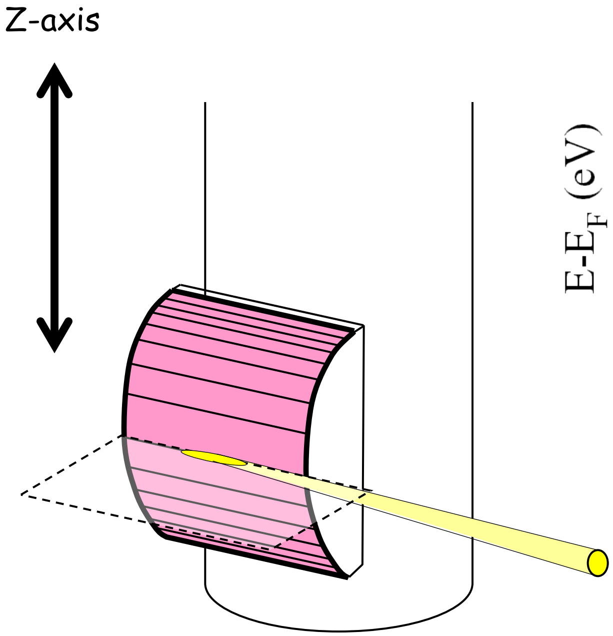
Sharp step edges

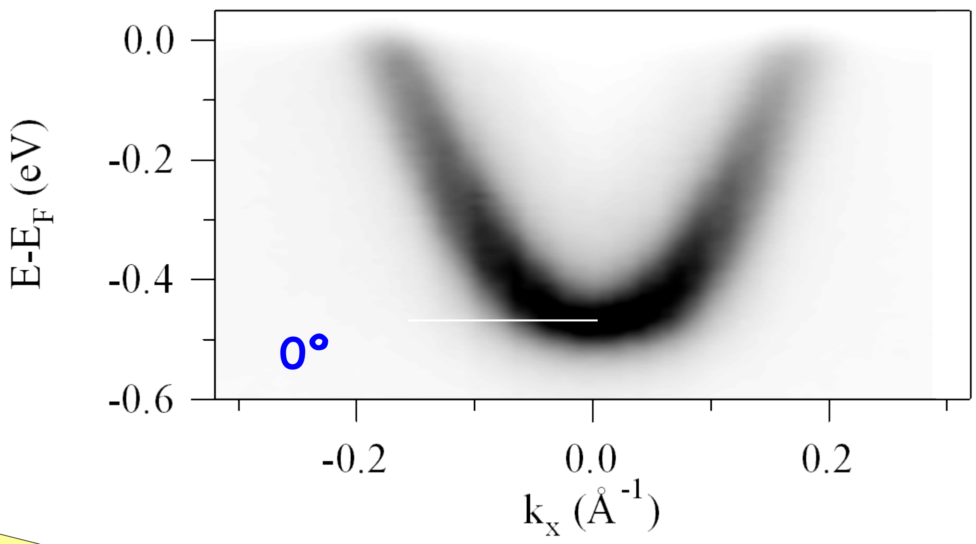
Au(111) faceting



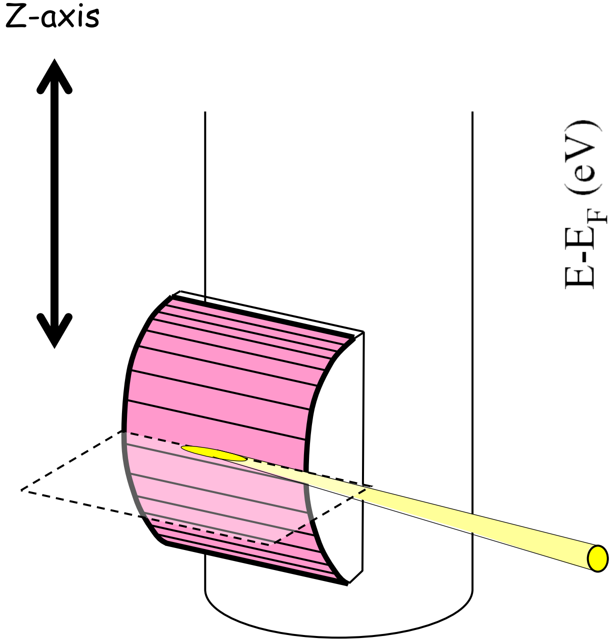
Electronic states at the faceting transition in Au(111)

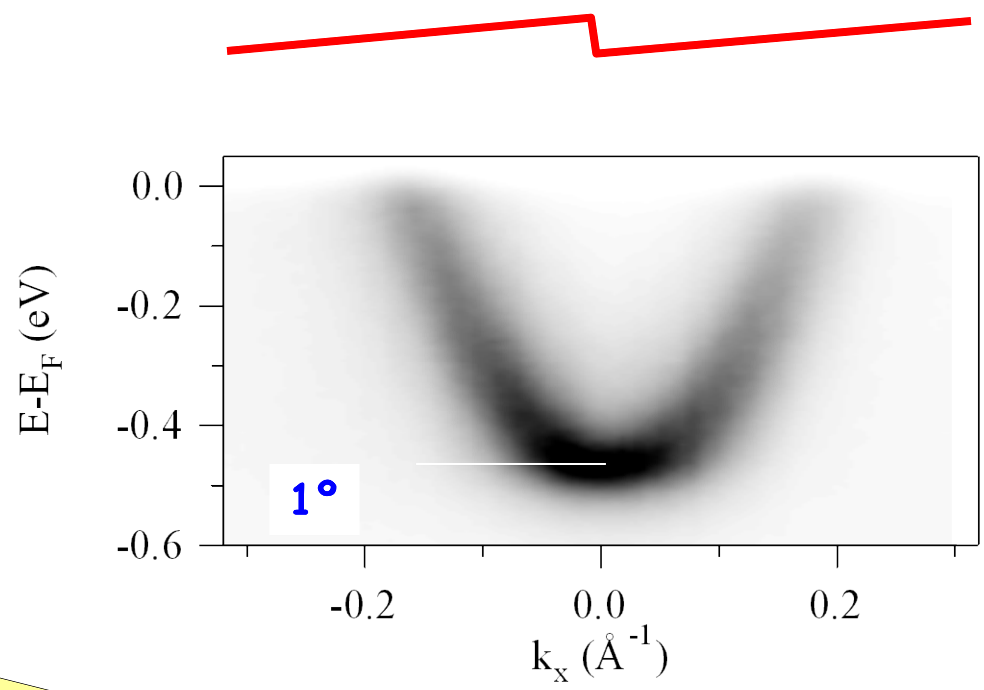
M. Corso *et al.,* J. Phys. Condens. Matter **21**, 353001 (2009).



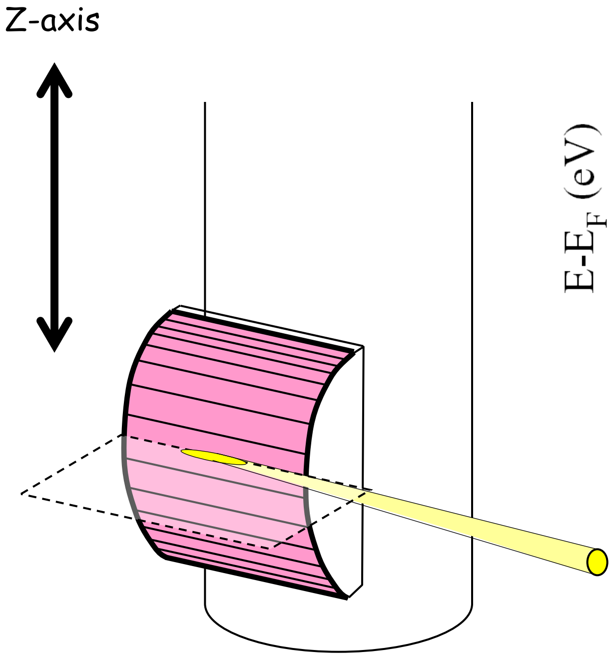


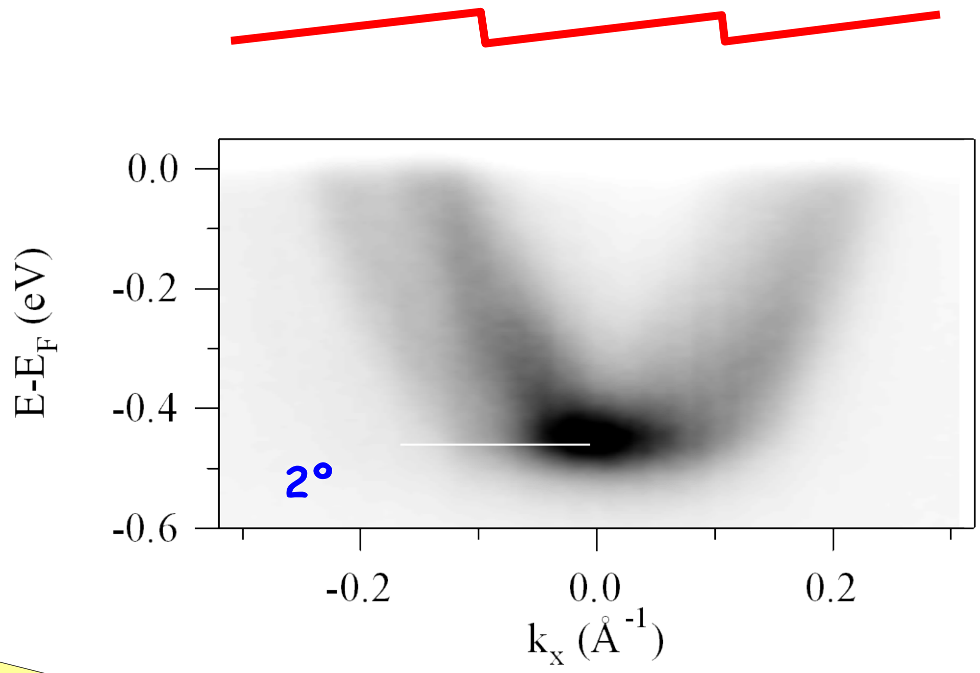
Electronic states at the faceting transition in Au(111)



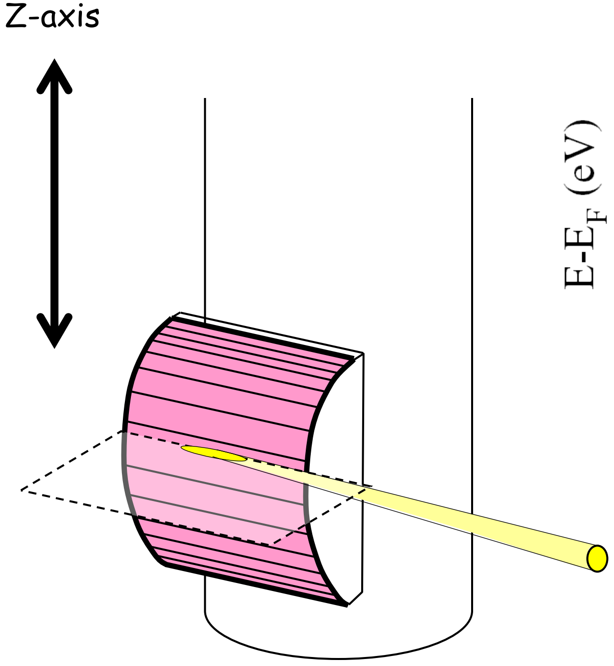


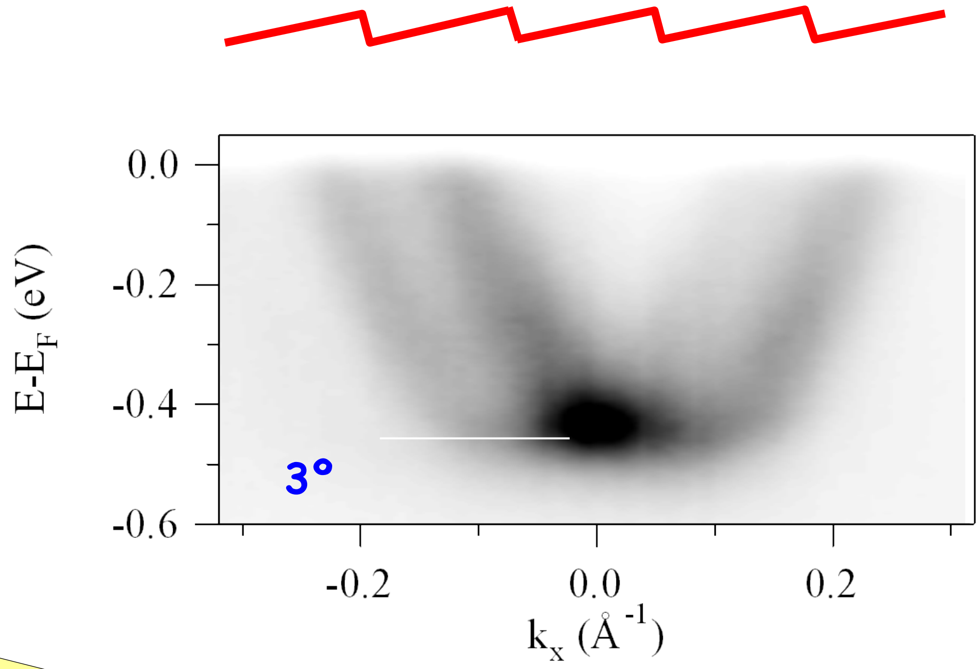
Electronic states at the faceting transition in Au(111)





Electronic states at the faceting transition in Au(111)

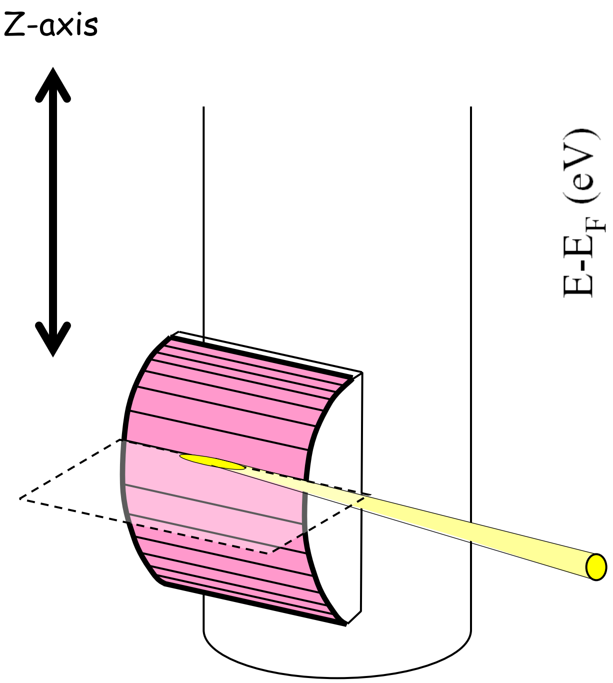


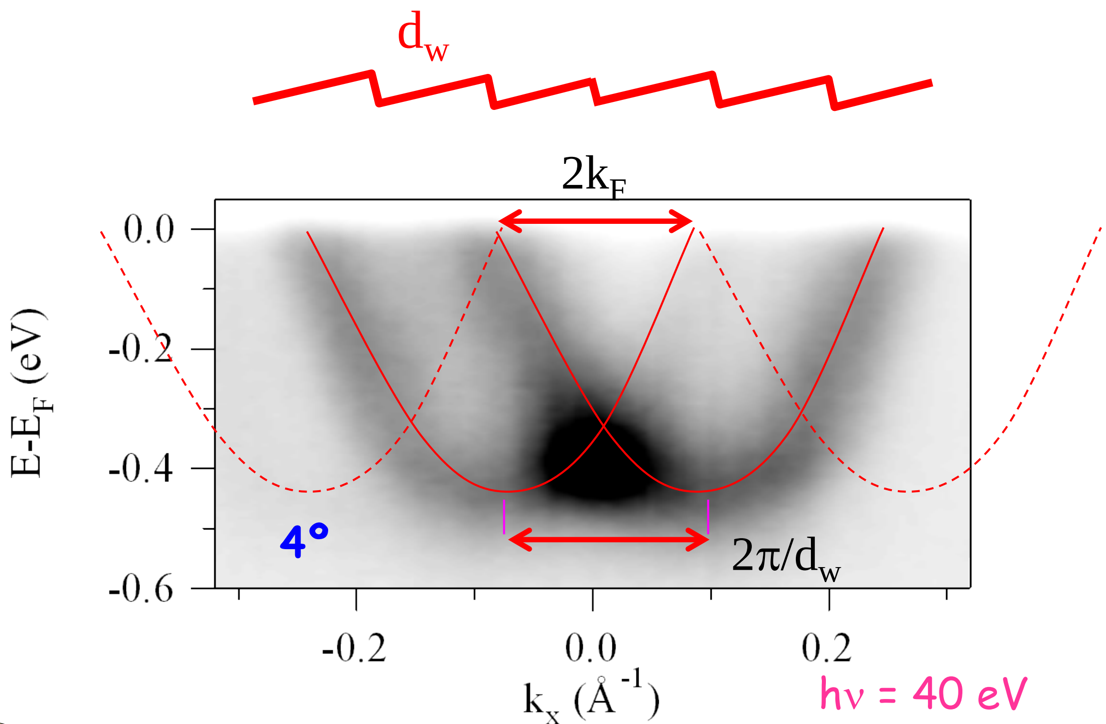


Electronic states at the faceting transition in Au(111)

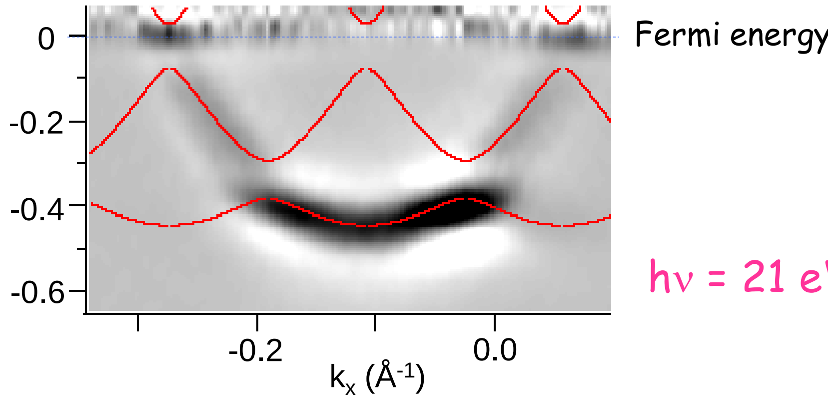
M. Corso *et al.*, J. Phys. Condens. Matter **21**, 353001 (2009).

Lower onset of faceting





hν = 40 eV

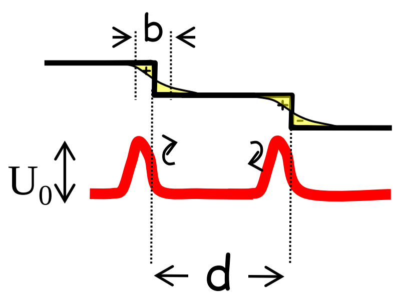


hν = 21 eV

A step lattice Fermi gap opens up at the lower onset of faceting

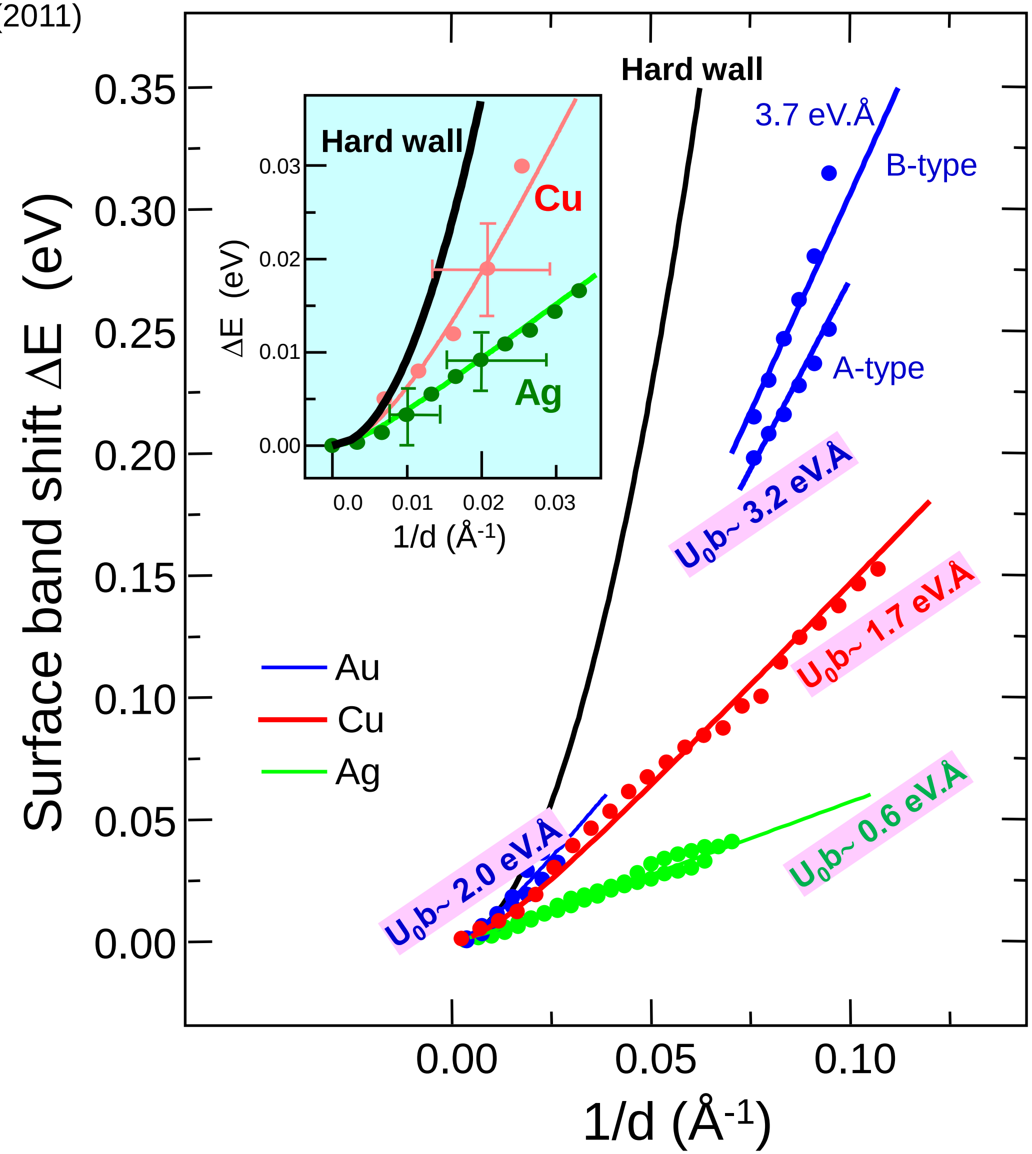
Step scattering through curved surfaces I: **terrace-size effect**

J. E. Ortega *et al.*, Phys. Rev. B **83**, 085411 (2011)



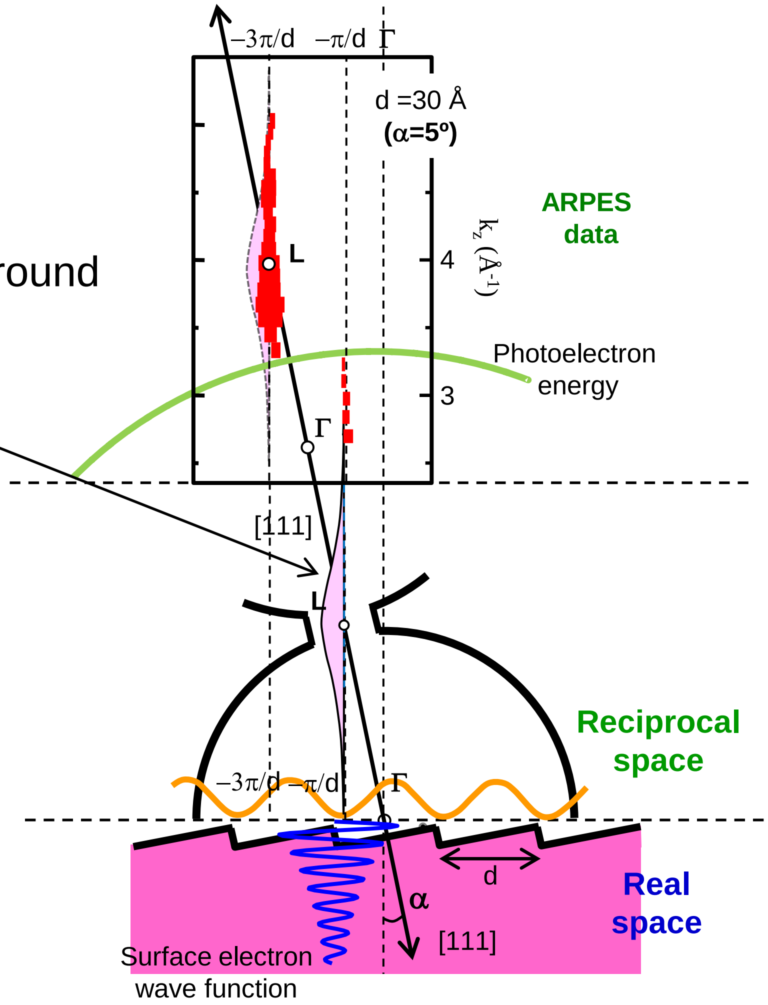
1D Kronig-Penney model

$$\Delta E = \frac{2\hbar^2}{m^*}\frac{1}{d^2}\left(tg^{-1}\left(\frac{U_0 b}{\sqrt{\frac{2\hbar^2}{m^*}\Delta E}}\right)\right)^2$$

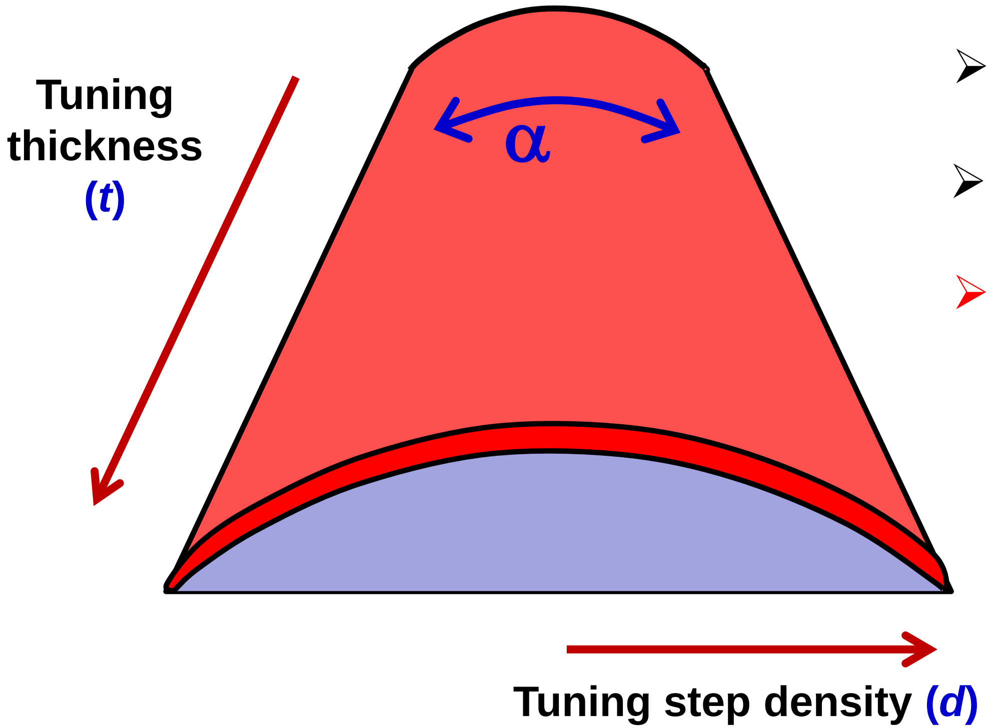


Step scattering through curved surfaces II: **wave function plane**

Spectral distribution around the L-point neck

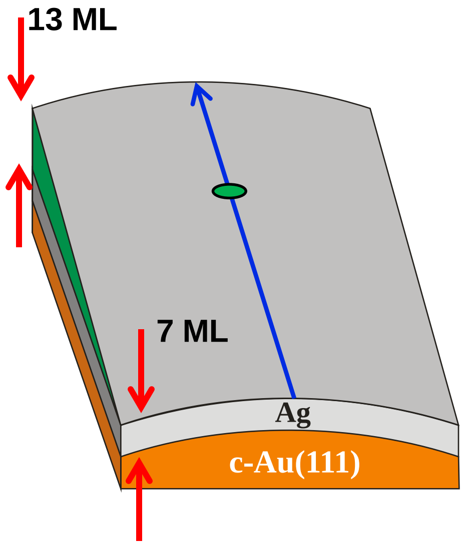


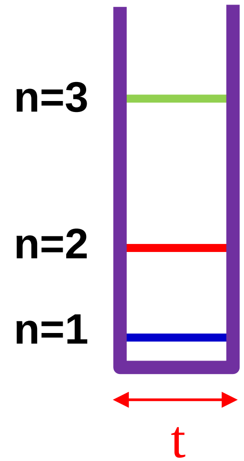
Thin films on curved surfaces

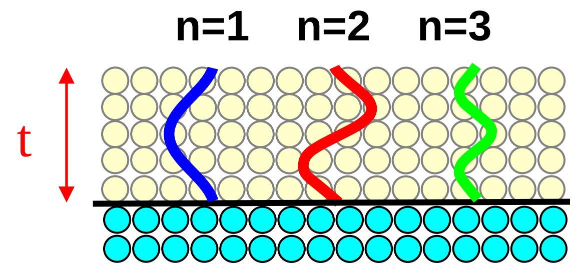


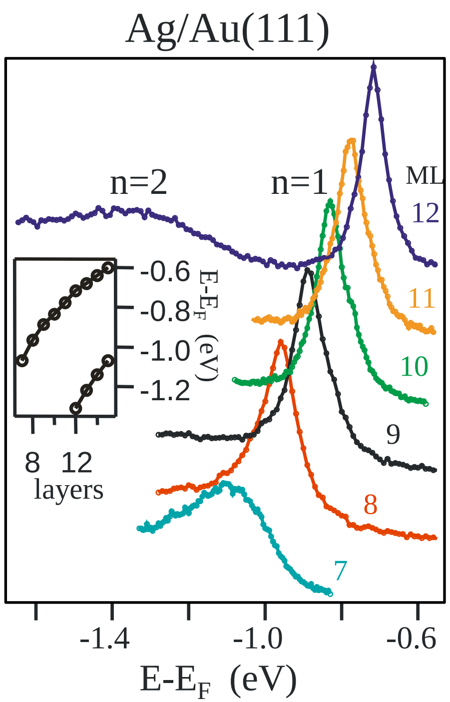
- Ag films on c-Au(111)
- $BiAg_2$ monolayer on c-Ag(111)
- *Ag monolayer on c-Cu(111)*

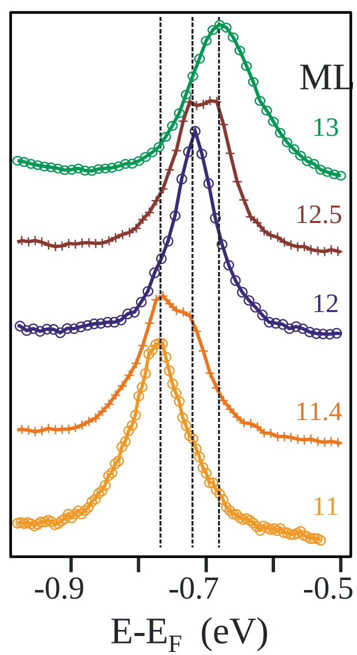
Quantum wells

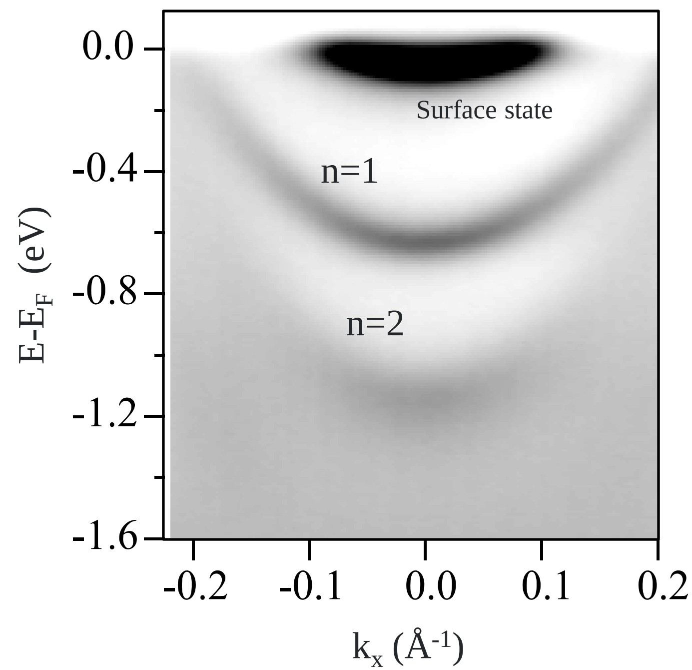




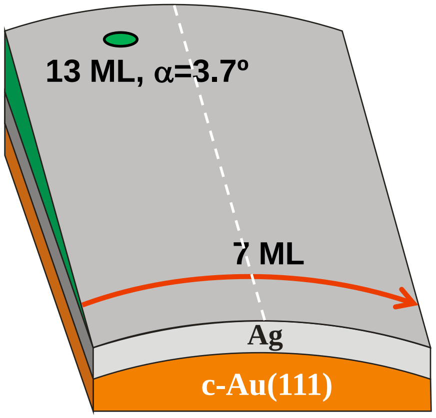




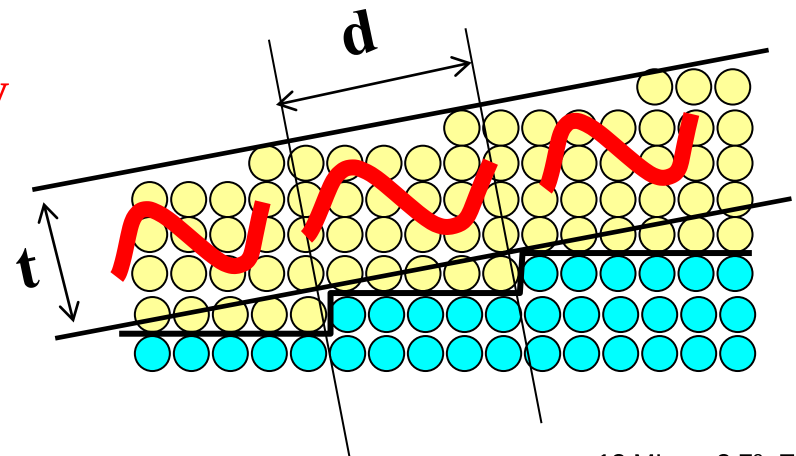


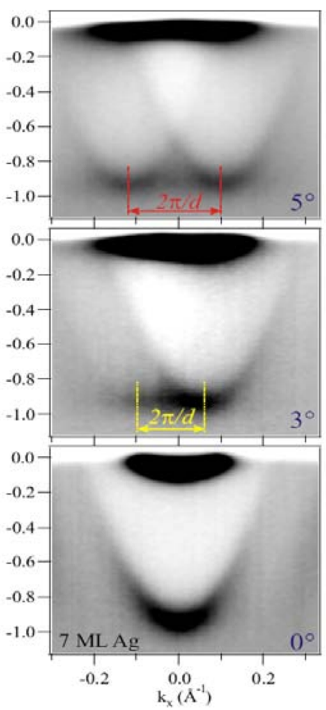


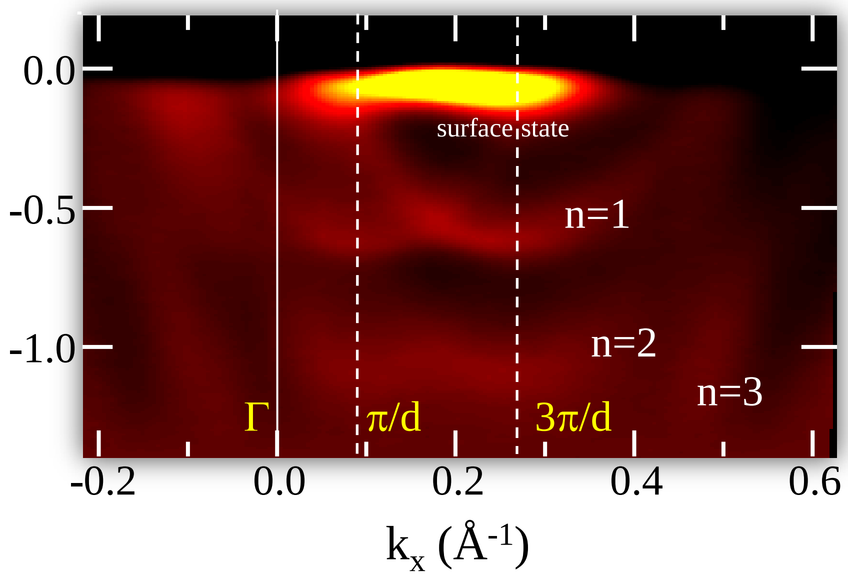
Stepped quantum wells

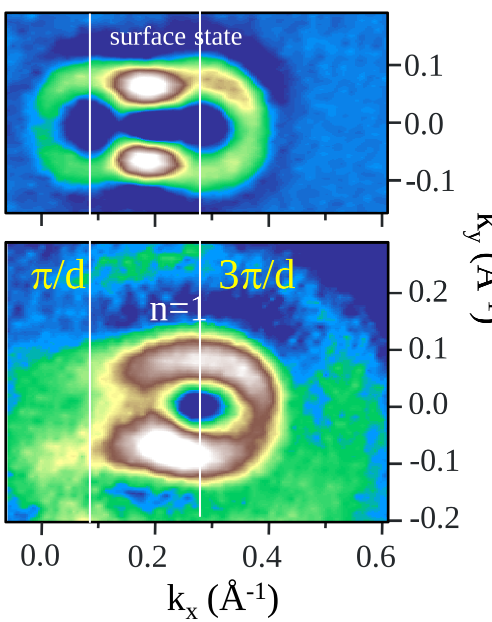


hν=41 eV





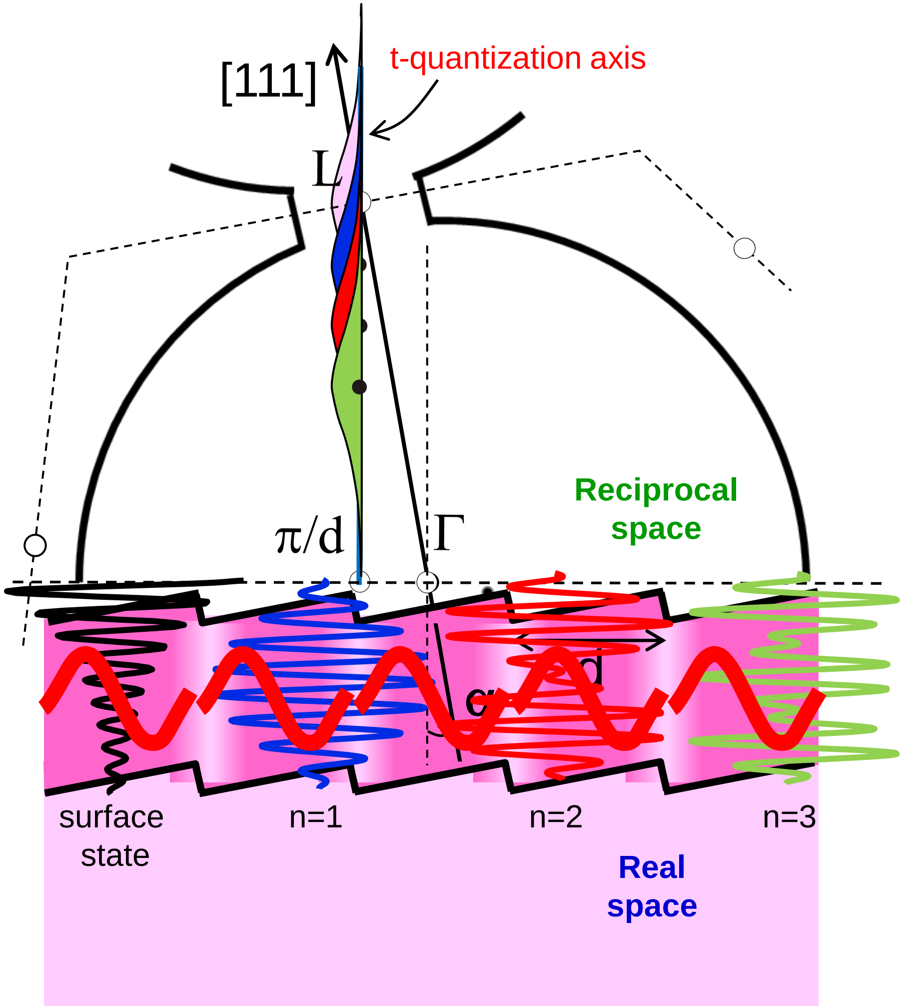




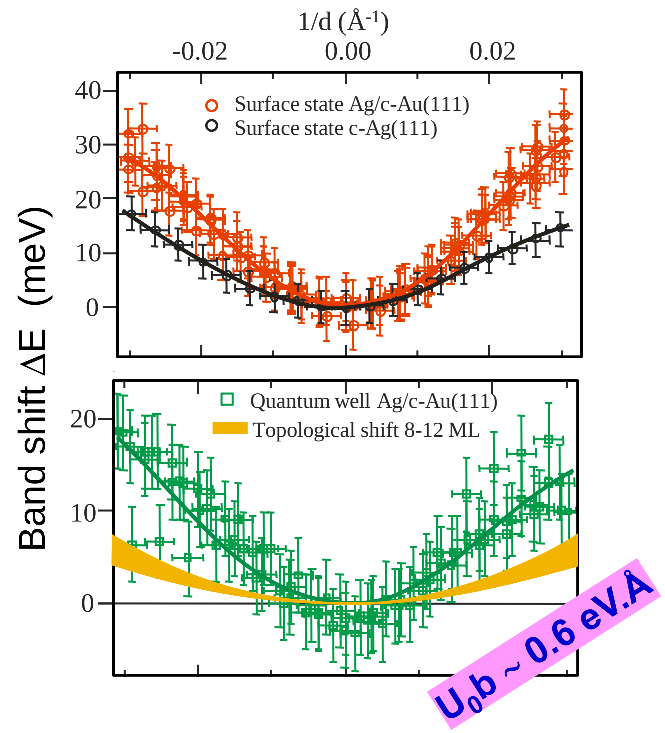
QW and surface states exhibit the same superlattice nature in thin stepped films

Stepped quantum wells

Wave function

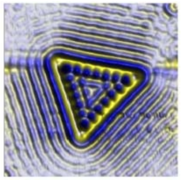


Terrace size effect

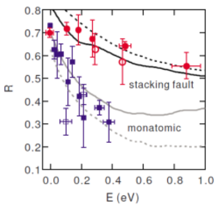


Lateral scattering at stacking faults?

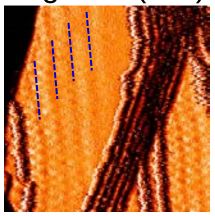
Ag(111)



Ag/Si111)



Ag/c-Cu(111)



30 nm

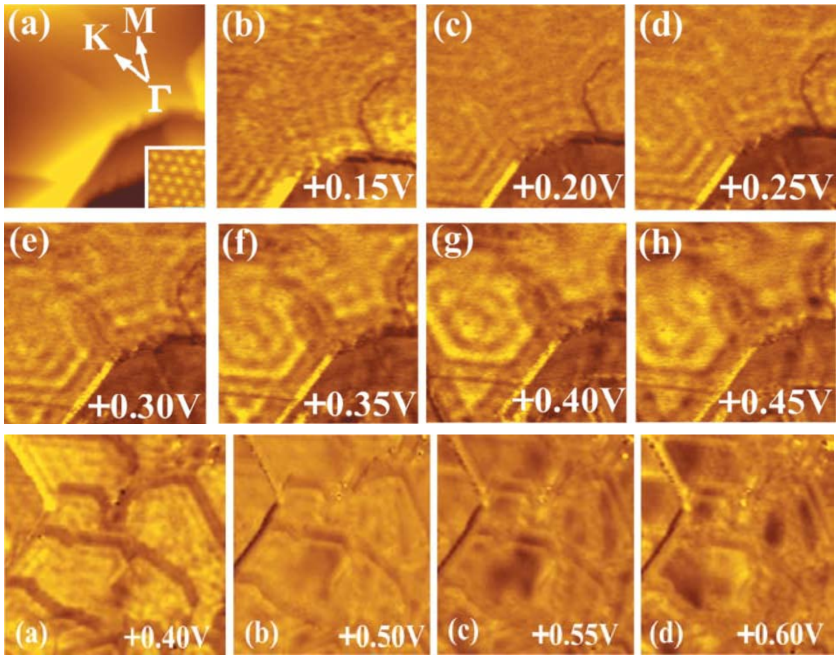
Mugarza et al. (unpublished) and
PRB **82,** 113413 (2010)

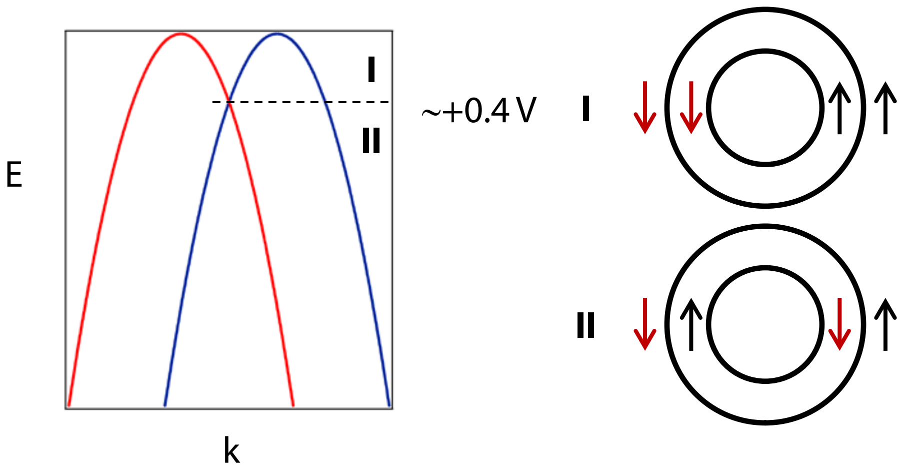
Scattering in a Rashba surface alloy

Quantum Interference of Rashba-Type Spin-Split Surface State Electrons

Hiroyuki Hirayama,* Yuki Aoki, and Chiaki Kato
Department of Materials Science and Engineering, Tokyo Institute of Technology, J1-3, 4259 Nagatsuda, Midori-ku, Yokohama 226-8502, Japan
(Received 2 April 2011; published 7 July 2011)

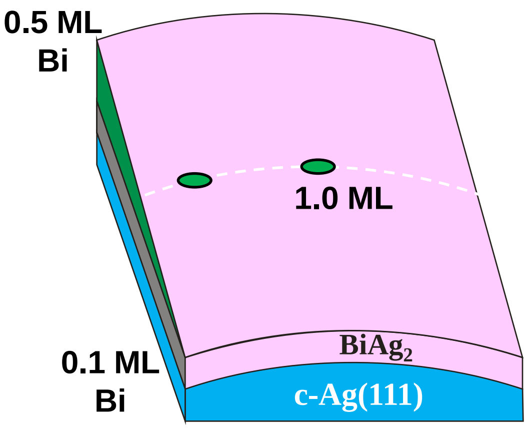
We studied the quantum interference of electrons in the Bi (p_x, p_y) orbital-derived $j = 1/2$ spin-split surface states at Bi/Ag(111)$\sqrt{3} \times \sqrt{3}$ surfaces of 10 monolayer thick Ag(111) films on Si(111) substrates. Surface electron standing waves were observed clearly at the energy (E) below the intersection of the two spin-split downward dispersing parabola bands (E_x). The E dependence of the standing wave pattern reveals the dispersion as the average of the two spin-split surface bands due to the interference between $|(k + \Delta), \uparrow\rangle$ and $|-(k - \Delta), \uparrow\rangle$ [or $(|(k - \Delta), \downarrow\rangle$ and $|-(k + \Delta), \downarrow\rangle]$ states. In contrast, it was impossible to deduce the dispersion from the standing wave pattern at $E \geq E_x$ because the surface electron cannot find its backscattered state with the same spin polarization.

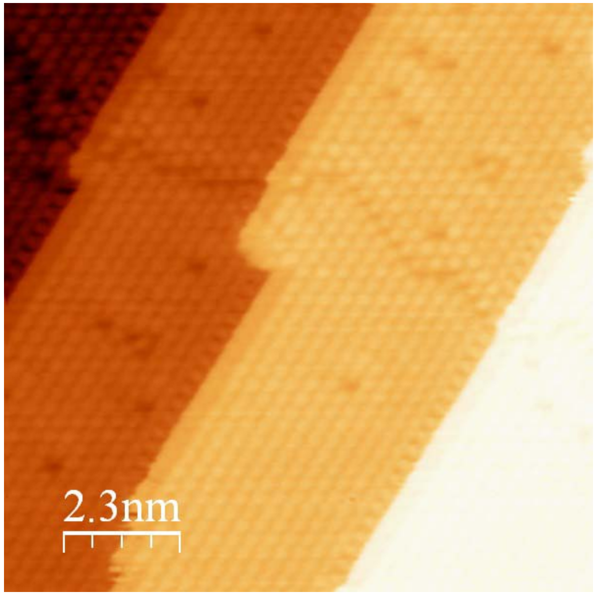


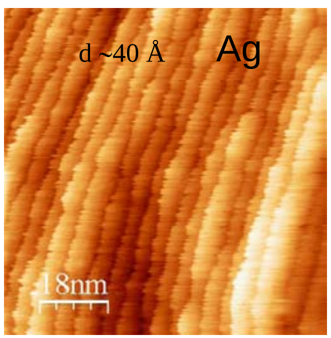


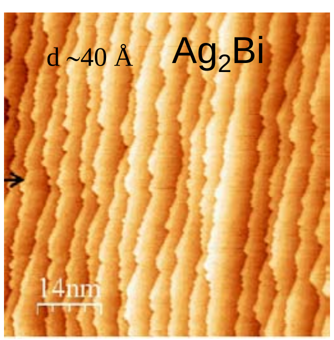
- ❑ No standing waves observed in region I (E > +0.4 V)
- ❑ Standing waves in region II (E< + 0.4 V)

$BiAg_2$/c-Ag(111)

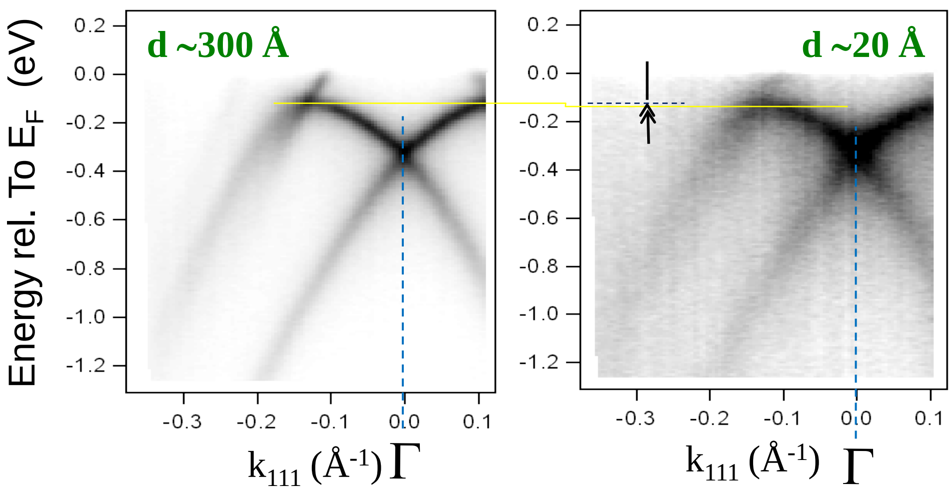




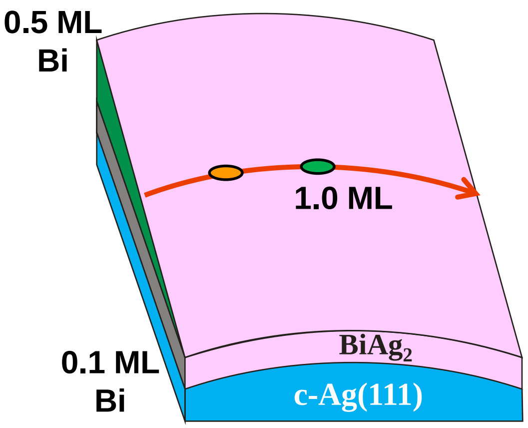




(111)-like band with a small downward shift for a high step density

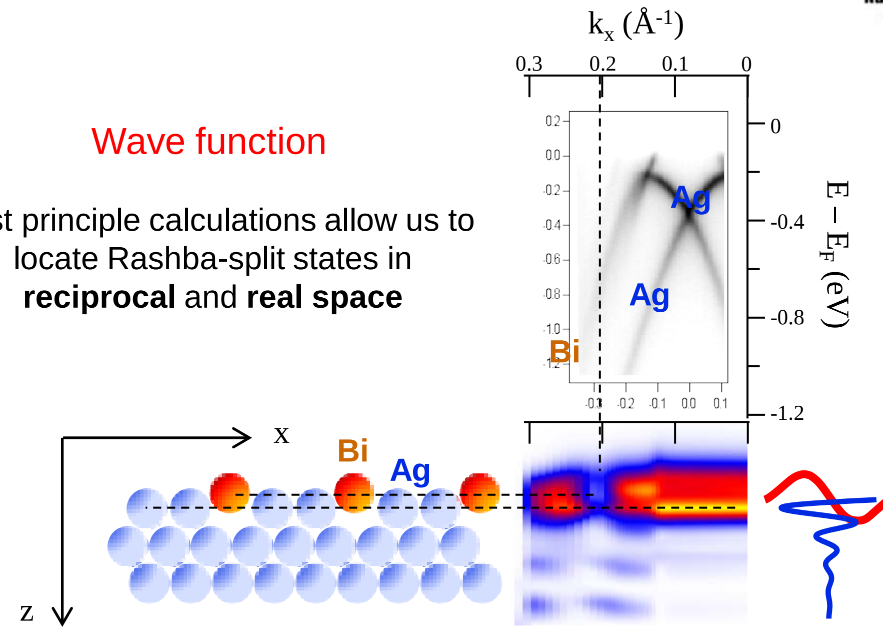


BiAg$_2$/Ag(111)

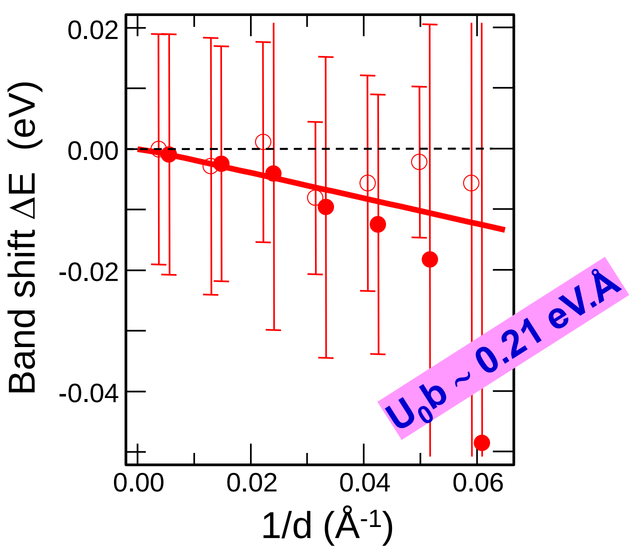


Wave function

First principle calculations allow us to locate Rashba-split states in **reciprocal** and **real space**

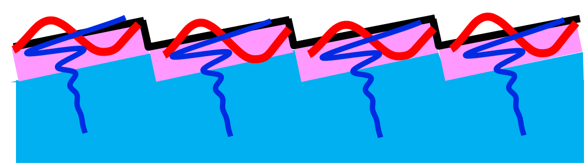


Terrace size effect

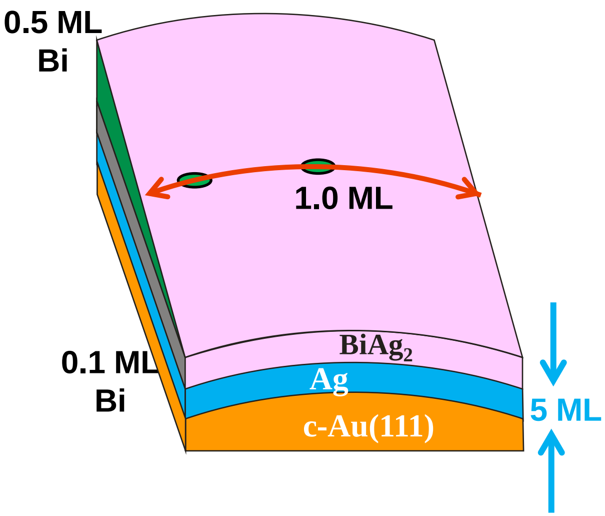


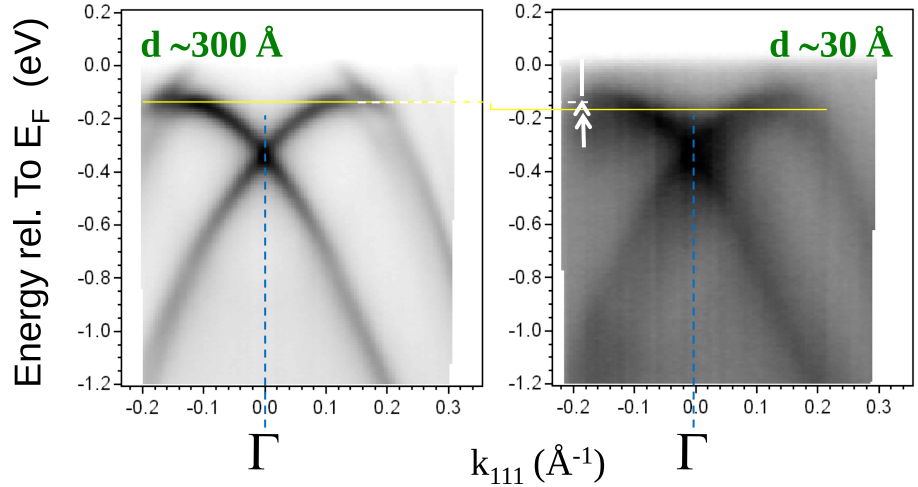
Spin split states around Γ and below E_F are mostly located at Ag atoms under the surface plane

⇒ *weak sensitivity to step dipoles*



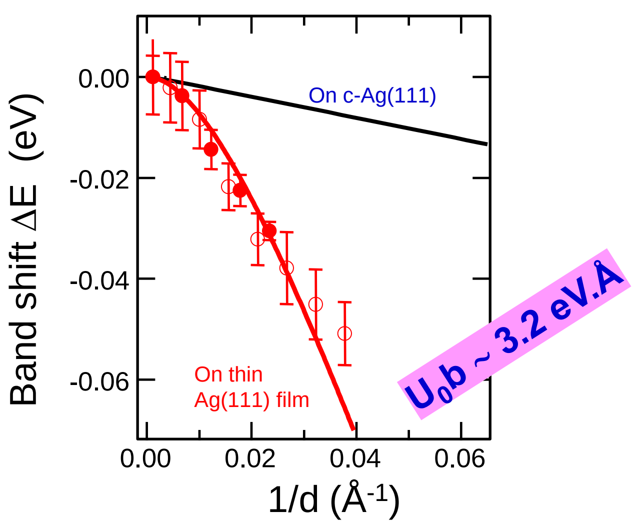
$BiAg_2$/Ag/c-Au(111)



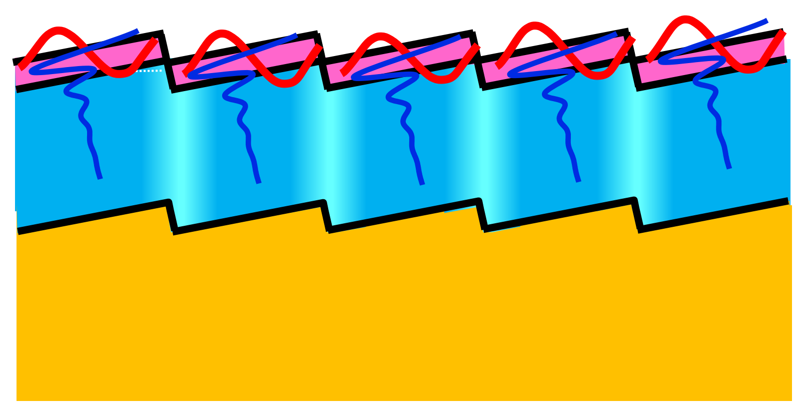


Terrace size effect

Wave function



Lateral scattering increases in BiAg2 grown on thin films
due to vertical stacking faults below surface steps



Summary

We probe lateral scattering of electrons, and wave function properties at stepped systems using ARPES

1. *In noble metal surfaces, we observe weak scattering at step lattices.*

2. *QW states of thin stepped Ag films exhibit scattering at stacking fault planes of the film*

3. *Rashba split states of the $BiAg_2$ monolayer are quasi transparent to monatomic steps, but undergo scattering at stacking faults.*

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Thanks for your attention!!