Synchrotrons
-
Core level spectroscopy
-
Preparation of MAX-lab visit

Joachim Schnadt
Jan Knudsen

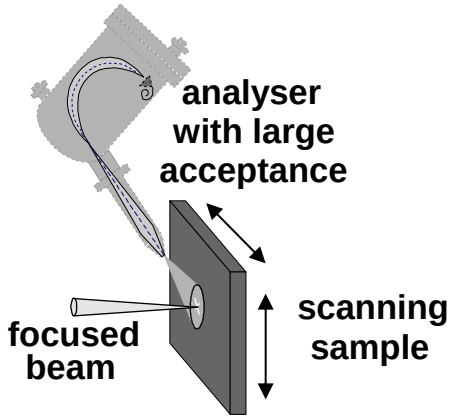
Spectromicroscopy

Spectromicroscopy
= Spectral and spatial information

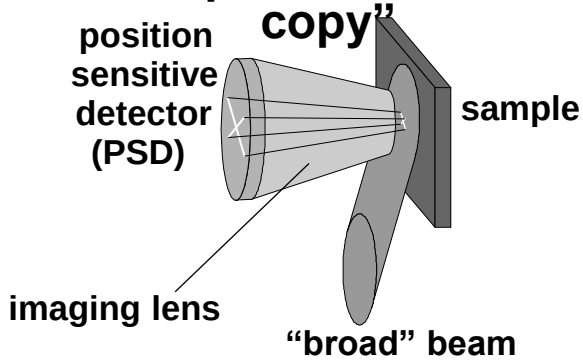
Spectral information from small areas of the sample
and
Image contrast obtained from different spectral features
Chemical Microscopy

Two ways to obtain both spectra and images:

Sequential or scanning
"Microspectroscopy"



Parallel or imaging
"Spectromicroscopy"

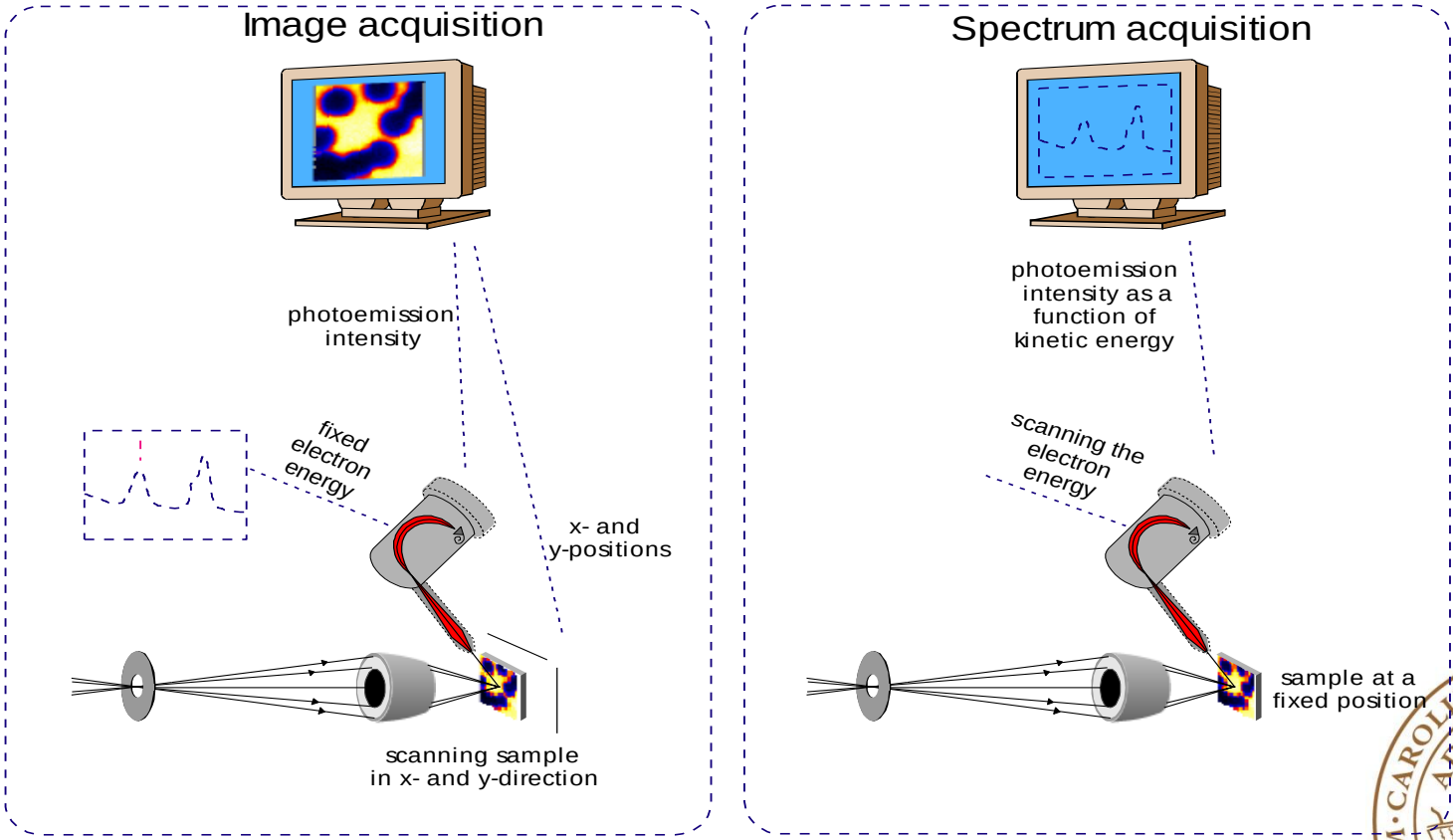


Typical resolutions: **1-1/10 μm** **50-10 nm**

Data acquisition using focusing optics

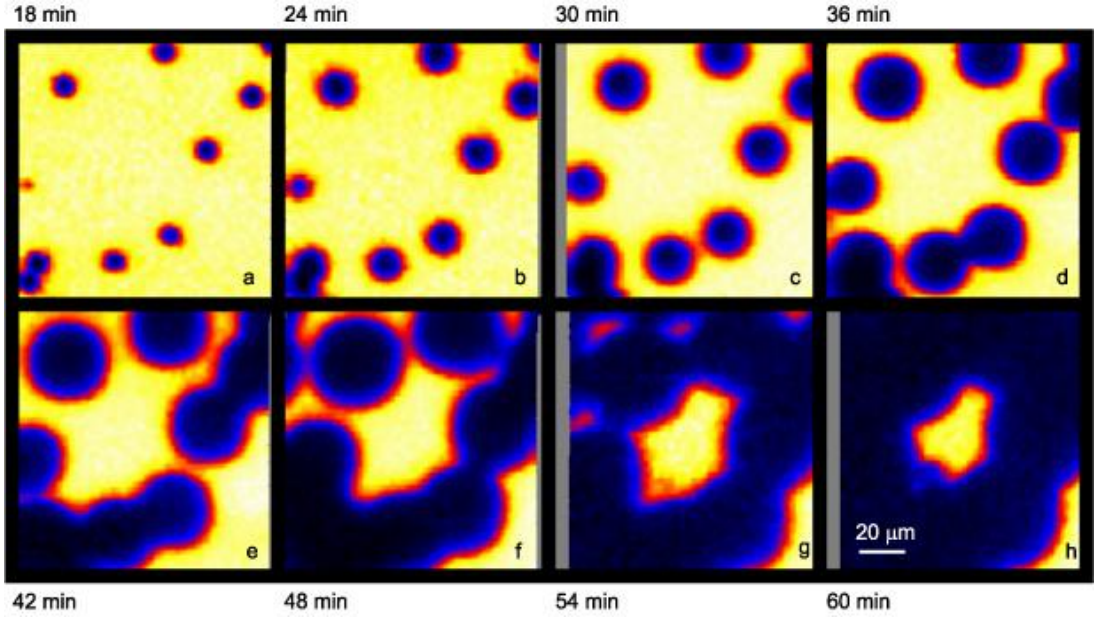
Spectra : As without microscope, but the spectrum is only from a small part of the sample

Images : Pick one binding energy, scan the sample and record the intensity at that binding energy

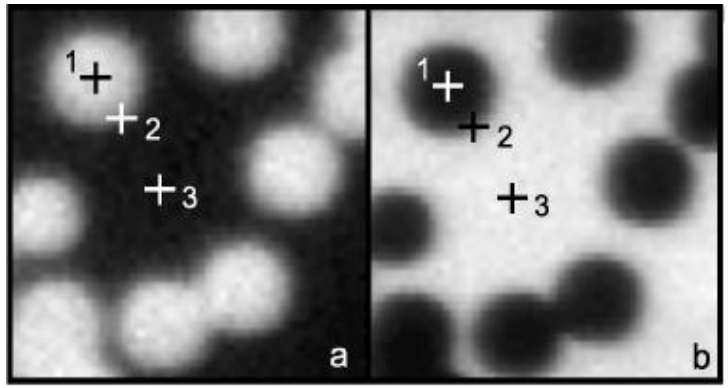


Photoelectron spectromicroscopy

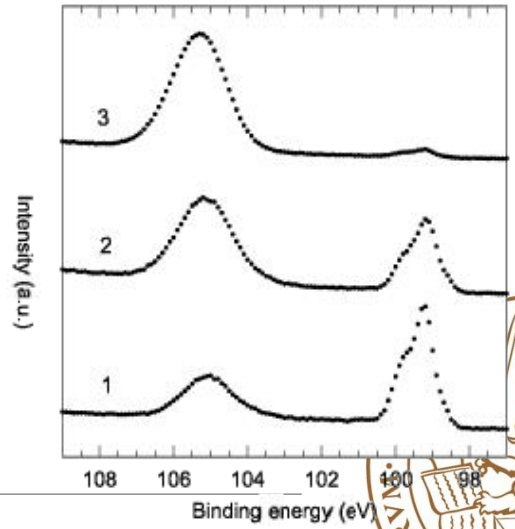
Temperature induced void growth in SiO_2 overlayers on Si(100)



99 eV binding energy, 105 eV binding energy,



- **Annealing temperature 1100°C**
- **Voids in the oxide layer grow with annealing time**
- **All voids are circular and of approximately the same size**
- **For the images above a photon energy of 130 eV was used and the electrons measured at 25 eV kinetic energy**



The VUV Scanning Photoelectron Microscope (SPEM) at MAX-lab

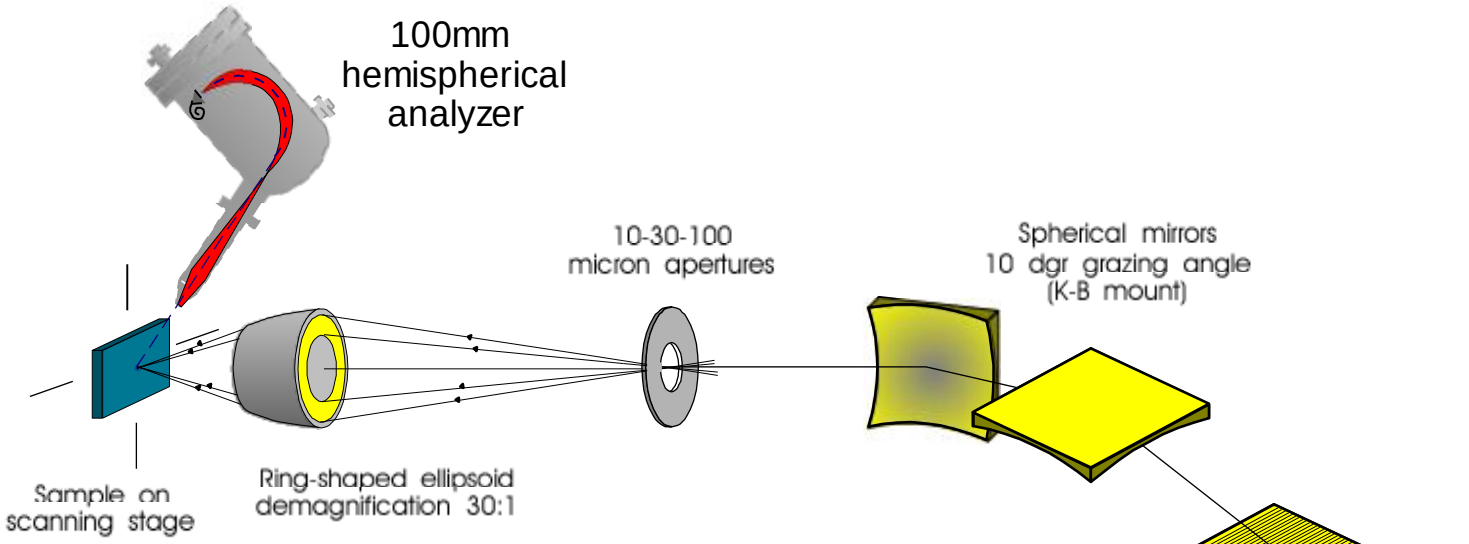
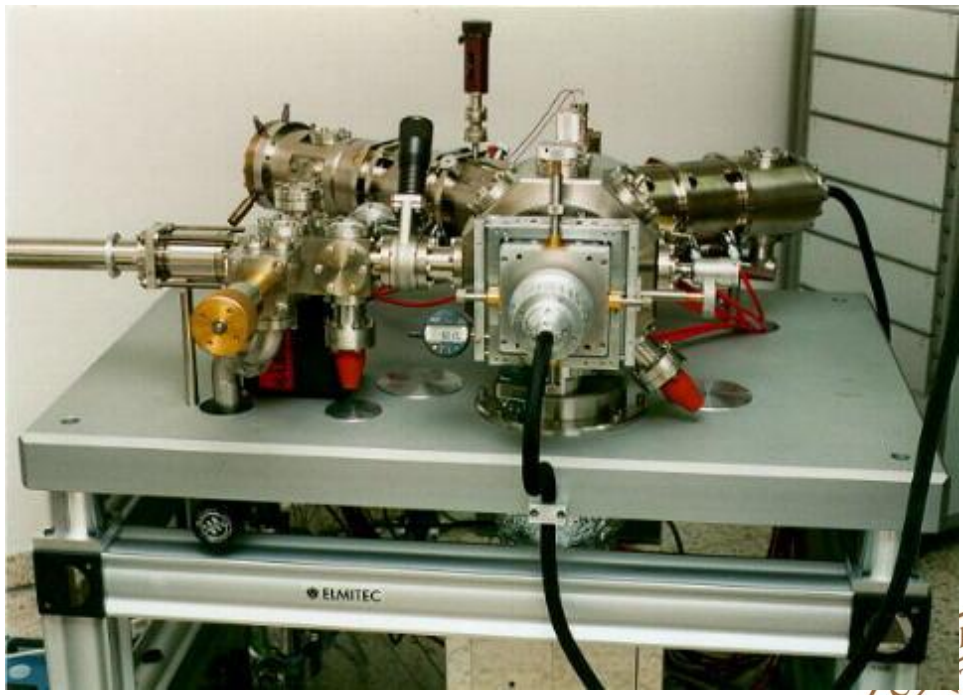


Photo Emission Electron Microscopy (PEEM)
Low Energy Electron Microscopy (LEEM)
(& STM)

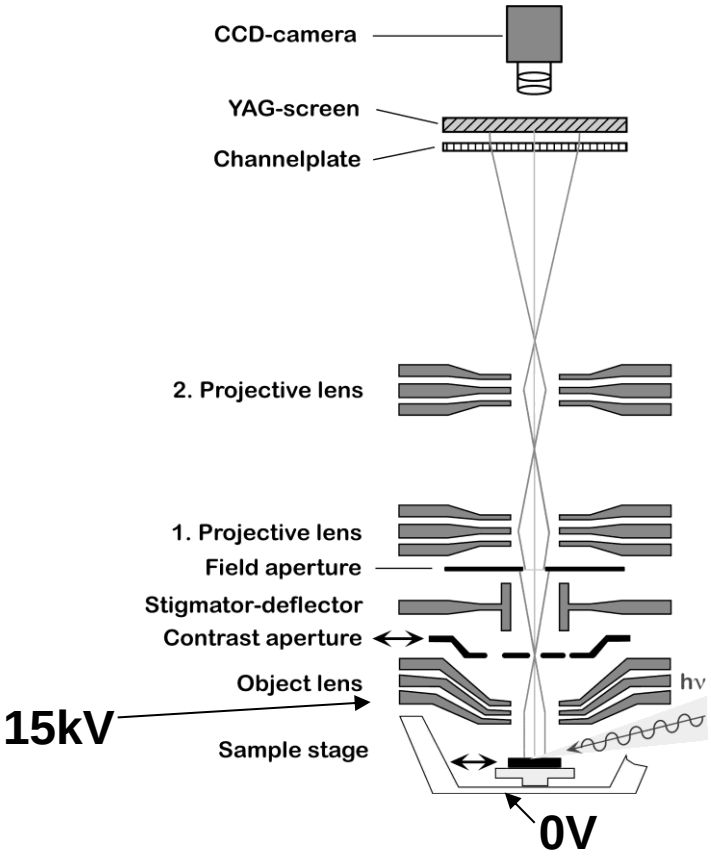
Omicron PEEM



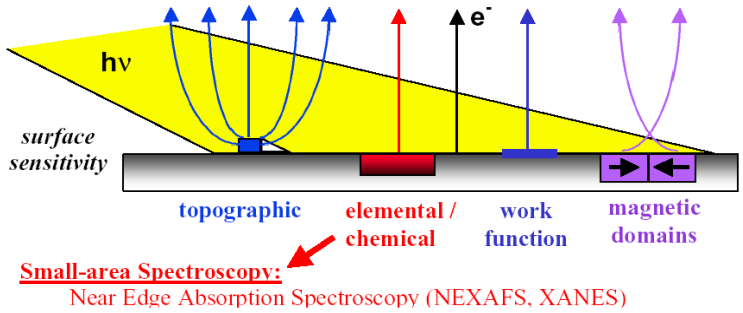
Elmitec PEEM / LEEM

Schematics of PEEM

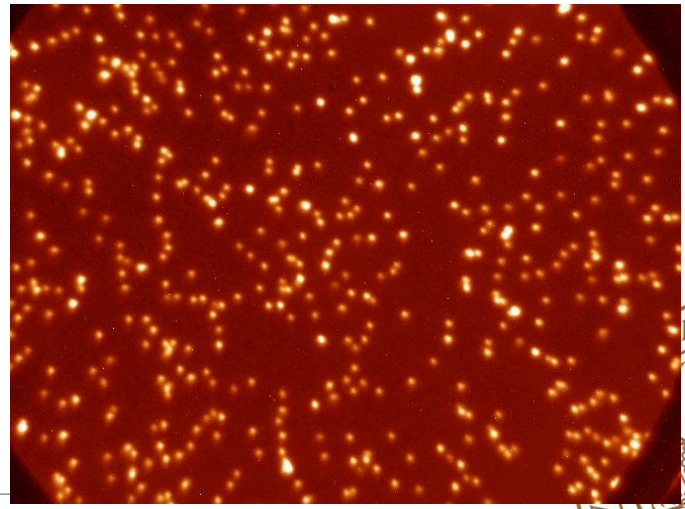
Omicron PEEM



Contrast mechanisms in PEEM



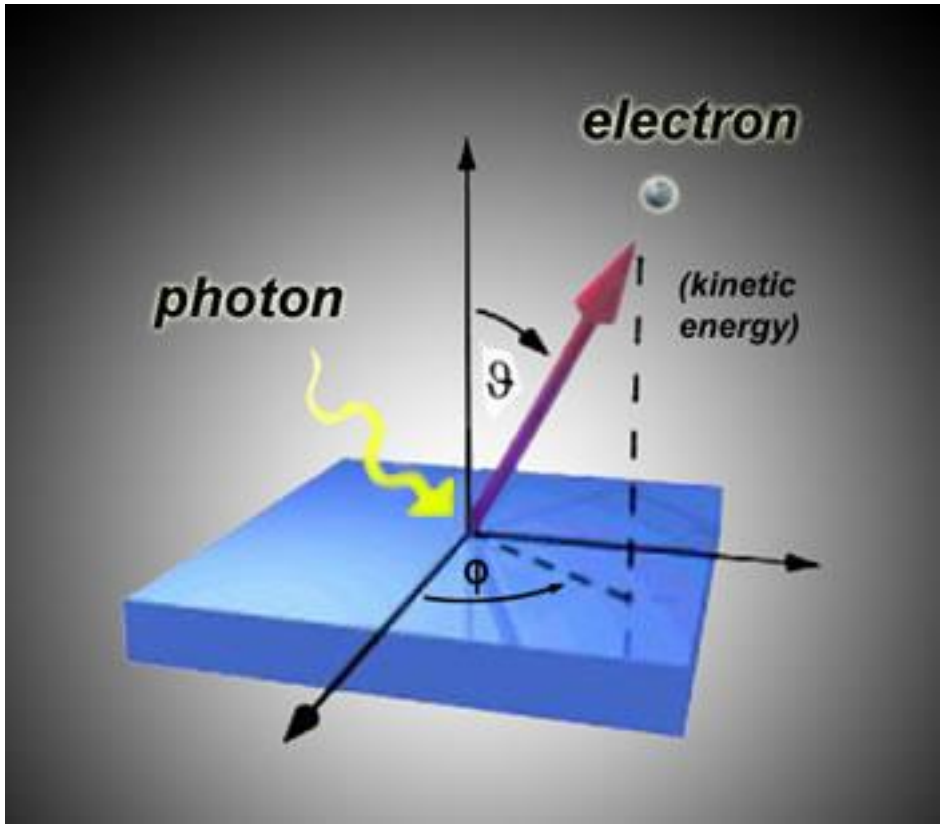
50nm Au particles for nanowire growth



Angle-resolved photoelectron spectroscopy (ARPES)


SIGILL
AD VT RVMQVE
CAROLINÆ
RVM

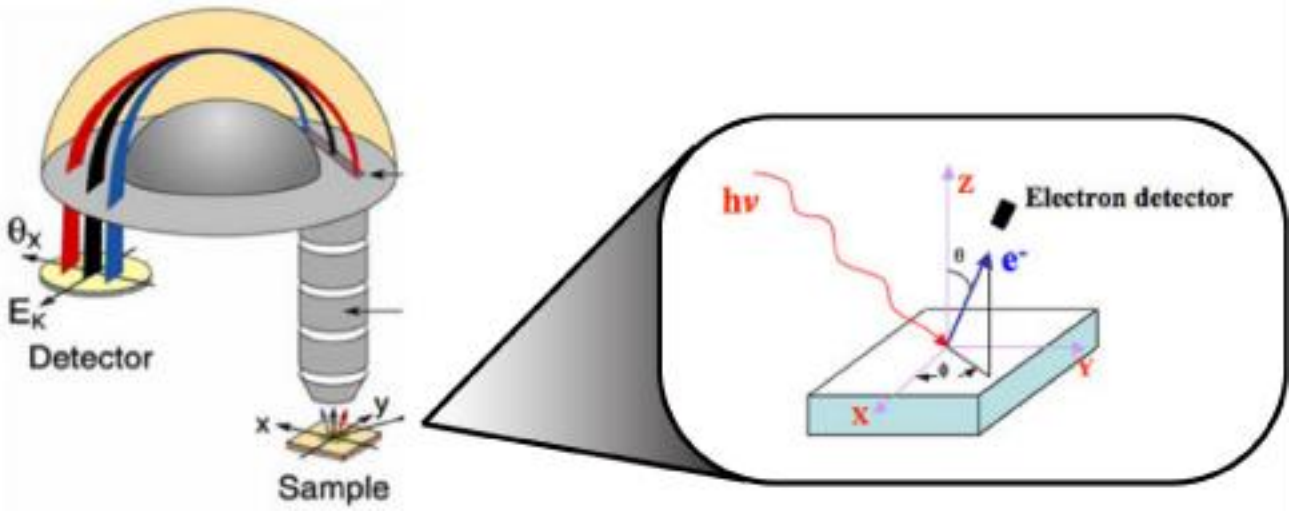
Measurement of APRES



Lawrence Berkeley National Laboratory,
http://www.lbl.gov/Science-Articles/Archive/sabl/2006/Jul/04.html


SIGILL
AD VT RVMQVE
CAROLINÆ
RVM

Measurement of ARPES



Shen Laboratory, Stanford University and Stanford Linear Accelerator
http://arpes.stanford.edu/research_arpesoverview.html

Measurement of band structure

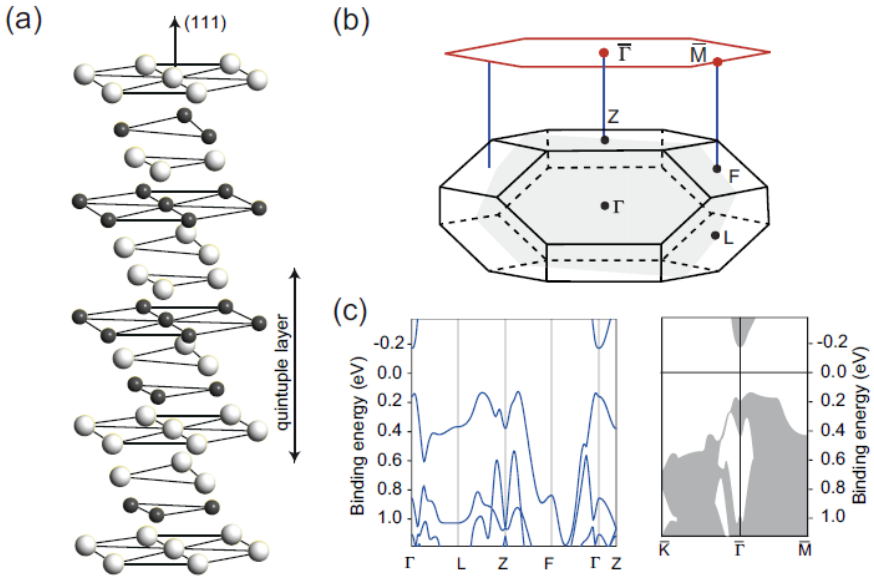
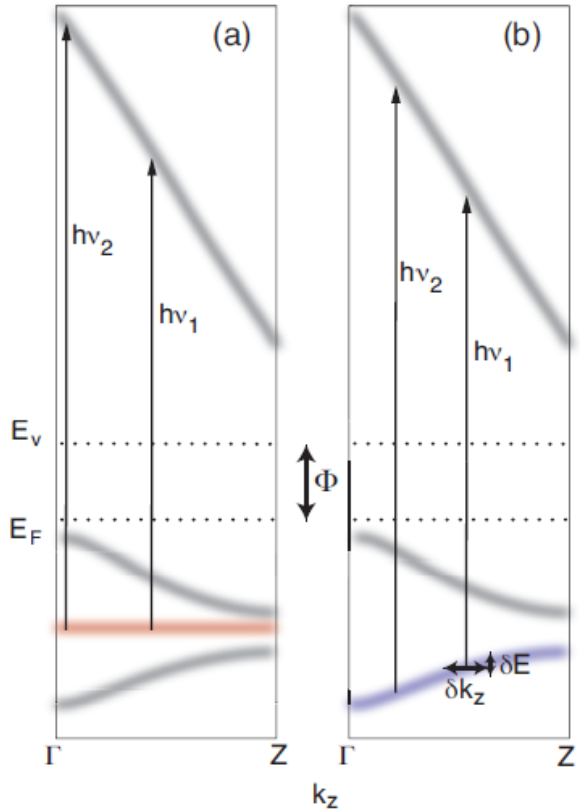


Fig. 6 (a) Crystal structure of Bi_2Se_3 with the quintuple layer building blocks. (b) Bulk and surface Brillouin zones with bulk time-reversal invariant momenta (TRIMs) and their projection to surface TRIMs. (c) Bulk band structure along selected high symmetry points and projection on the (111) surface after Ref. [46].

P. Hofmann, Aarhus University
arXiv:1210.2672v1 [cond-mat.str-el] 9 Oct 2012

Measurement of band structure

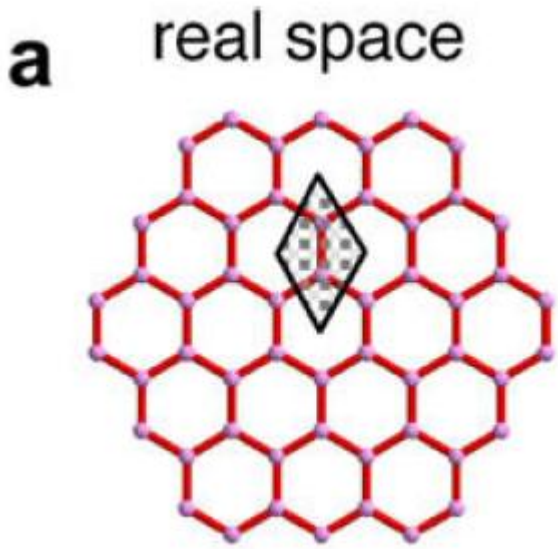


$$E_{kin} = h\nu - E_b - \Phi$$

$$\mathbf{k}_{\parallel} = (\sin(\phi)\hat{\mathbf{x}} + \cos(\phi)\hat{\mathbf{y}})\sin(\theta) \cdot \sqrt{\frac{2m_e E_{kin}}{\hbar^2}}$$

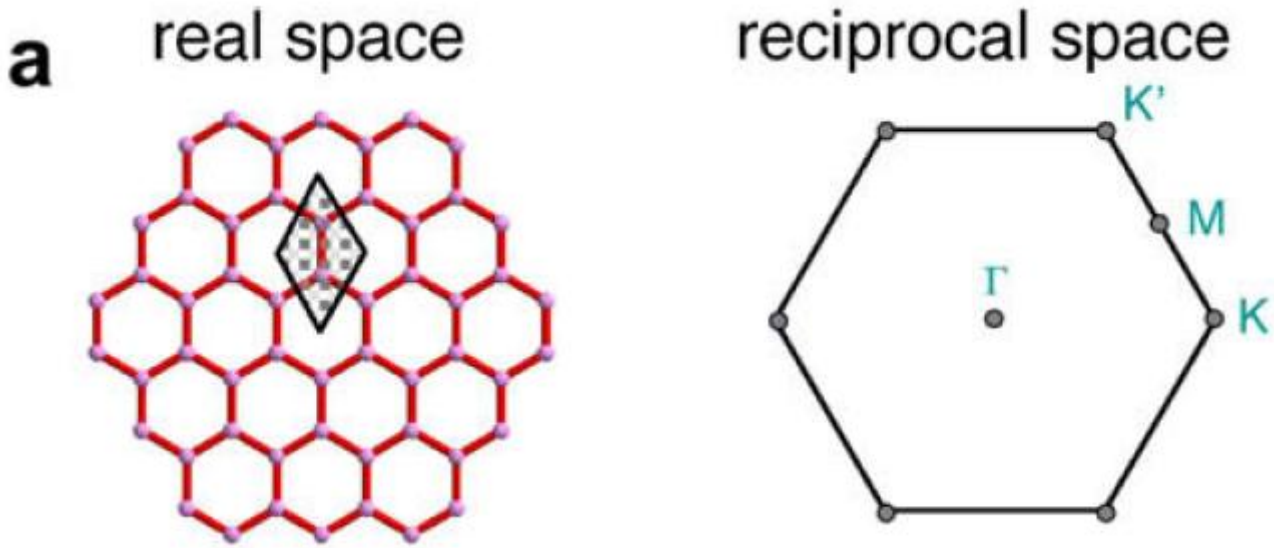
P. Hofmann, Aarhus University
arXiv:1210.2672v1 [cond-mat.str-el] 9 Oct 2012

Graphene = 2 dimensional carbon sheet



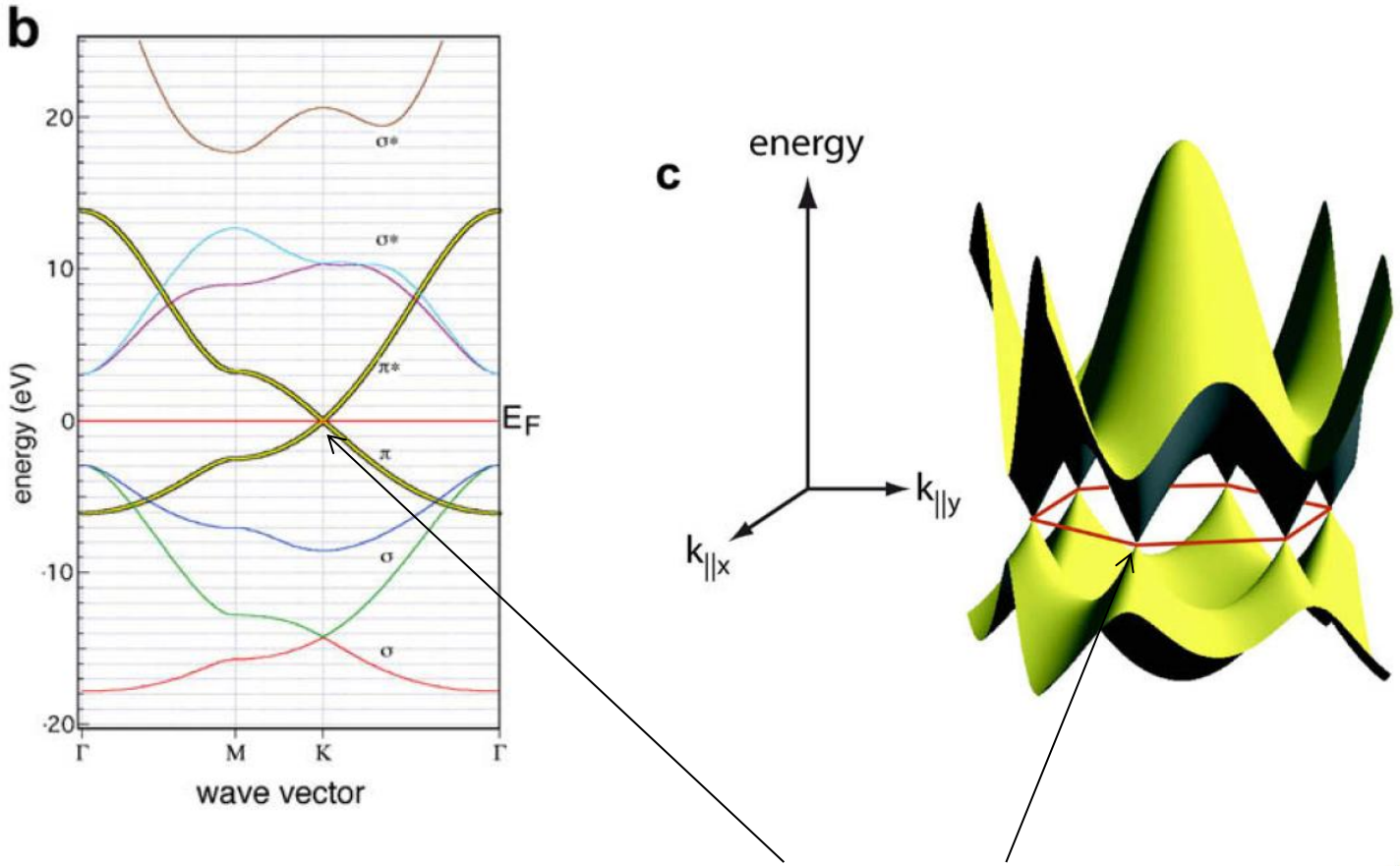
A. Bostwick et al., Prog. Surf. Sci. 84 (2009) 380

Graphene = 2 dimensional carbon sheet



A. Bostwick et al., Prog. Surf. Sci. 84 (2009) 380

Graphene band structure



A. Bostwick et al., Prog. Surf. Sci. 84 (2009) 380

at so-called Dirac points: linear dispersion → zero effective mass

Theory of Relativity

A stationary particle (p=0) has rest energy

$$E = mc^2$$

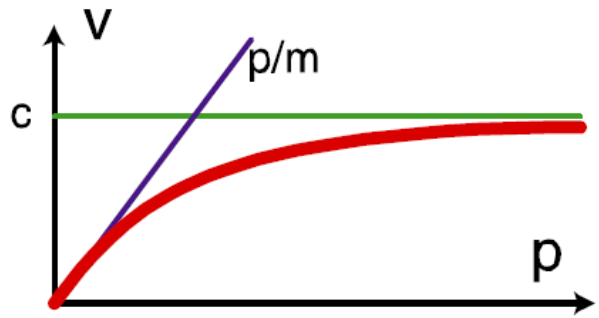
A particle in motion is described by the relativistic dispersion relation:

$$E = \sqrt{(mc^2)^2 + (cp)^2}$$

Albert Einstein 1879-1955

Velocity:

$$v = \frac{\partial E}{\partial p} = c\frac{cp}{\sqrt{(mc^2)^2 + (cp)^2}}$$



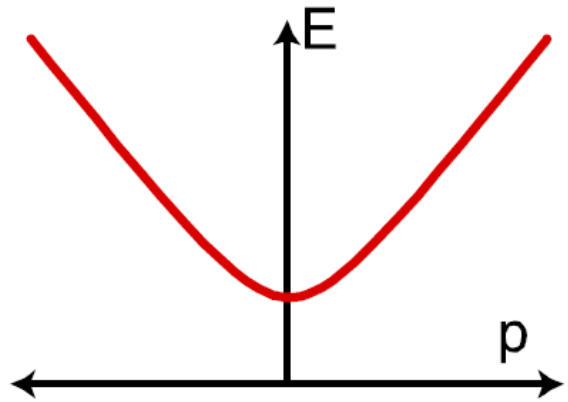
C. Kane, U. Pennsylvania, http://www.physics.upenn.edu/~kane/

Massive Particle (e.g. electron)

$$E = \sqrt{(mc^2)^2 + (cp)^2}$$

Nonrelativistic limit (v<<c)

$$E \approx mc^2 + \frac{p^2}{2m} + \ldots$$

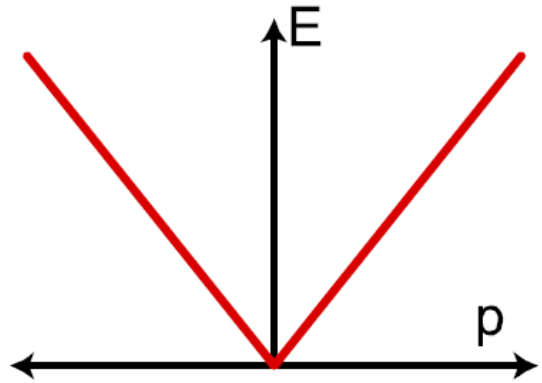


Massless Particle (e.g. photon)

$$m = 0$$

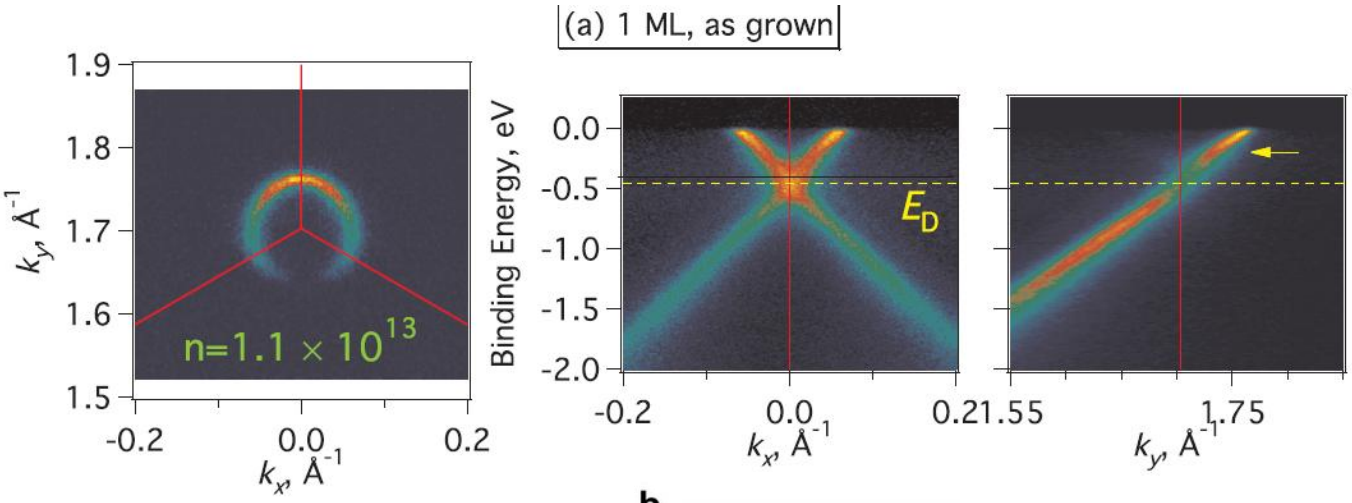
$$E = c\,|\,p\,|$$

$$v = c$$

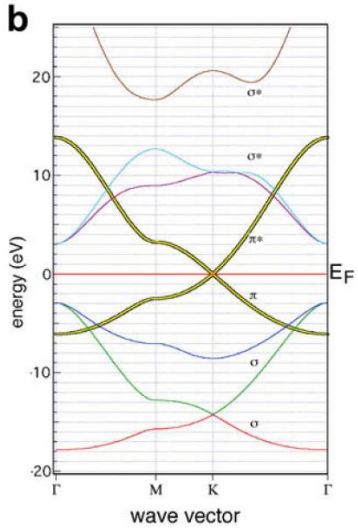


C. Kane, U. Pennsylvania, http://www.physics.upenn.edu/~kane/

Single layer graphene on SiC: ARUPS



Why is the Dirac point not at the Fermi energy?

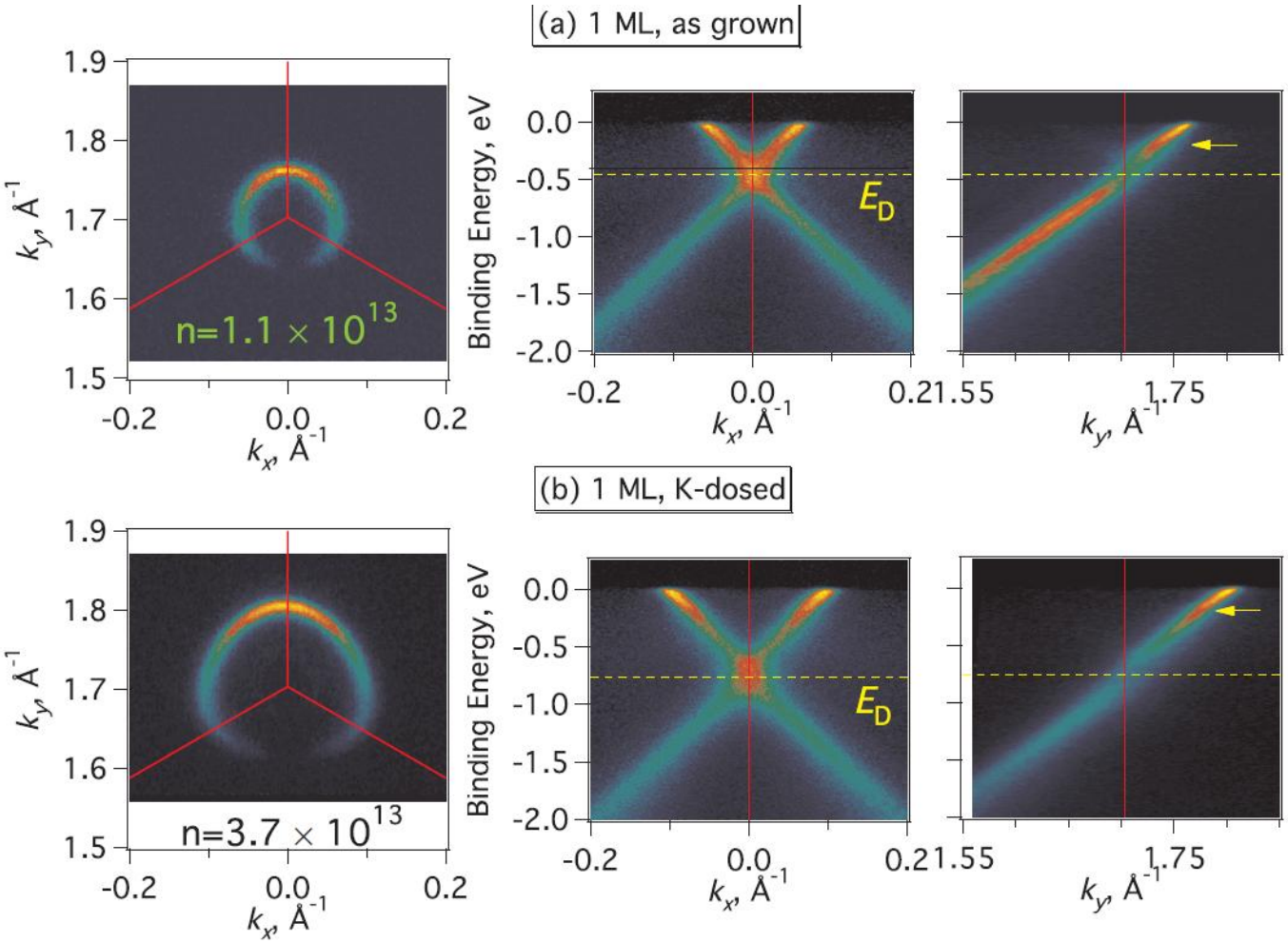


A. Bostwick et al., New. J. Phys. 9 (2007) 385
A. Bostwick et al., Prog. Surf. Sci. 84 (2009) 380

Single layer graphene on SiC

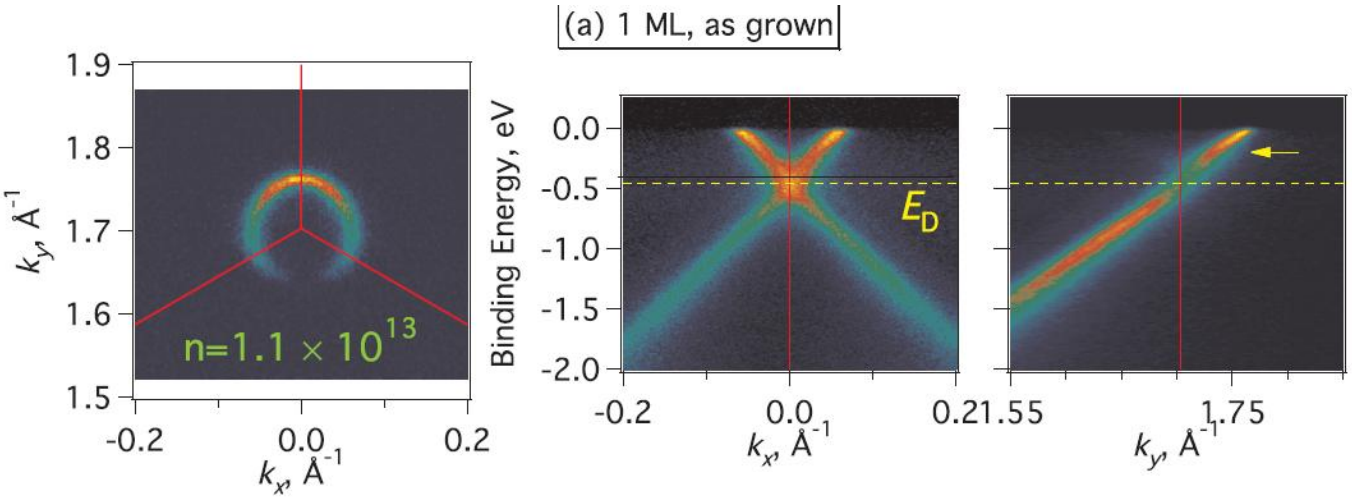
Band structure of as-grown graphene

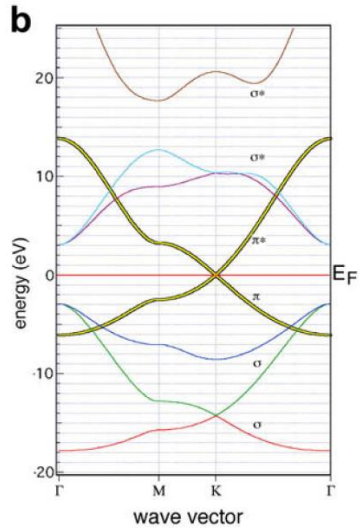
Band structure after dosing of potassium



A. Bostwick et al., New. J. Phys. 9 (2007) 385

Single layer graphene on SiC





Doping of the graphene layer by the SiC support

A. Bostwick et al., New. J. Phys. 9 (2007) 385
A. Bostwick et al., Prog. Surf. Sci. 84 (2009) 380

Other topics

- Photoelectron diffraction
- Energy referencing for semiconductors and insulators
- Other satellites: shake-up/shake-off, charge transfer satellites
- Variation of photoionisation cross sections (Cooper minima)
- Angle dependence of photoemission (orbital dependence, band structure by ARPES)
- Dynamics: resonant photoemission
- …