

Ernst Ruska-Centre
for Microscopy
and Spectroscopy
with Electrons

ER-C



Atomok nagyítólcencse alatt: modern transzmissziós elektronmikroszkópia az anyagtudományban

Kovács András

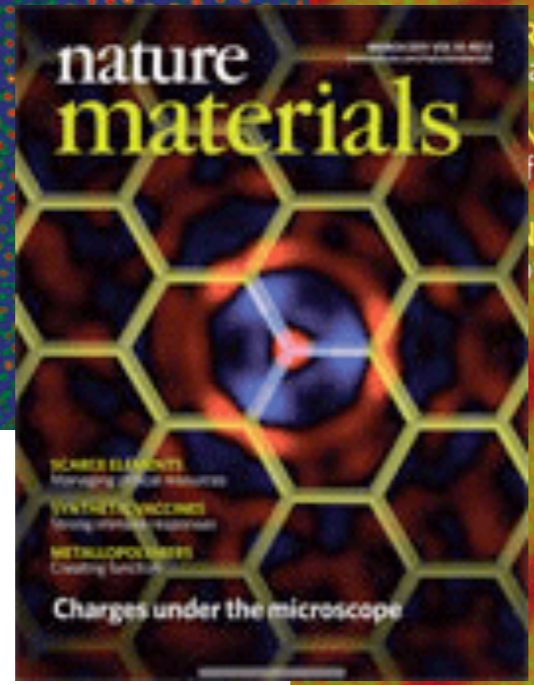
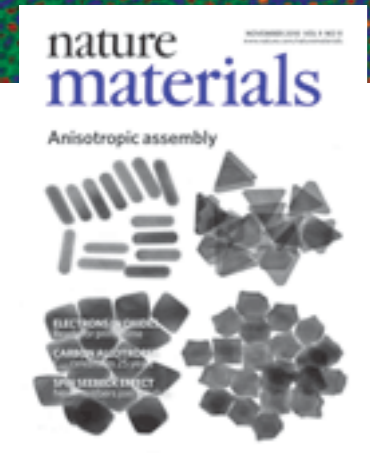
Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons

Peter Grünberg Institute

Forschungszentrum Jülich

Germany

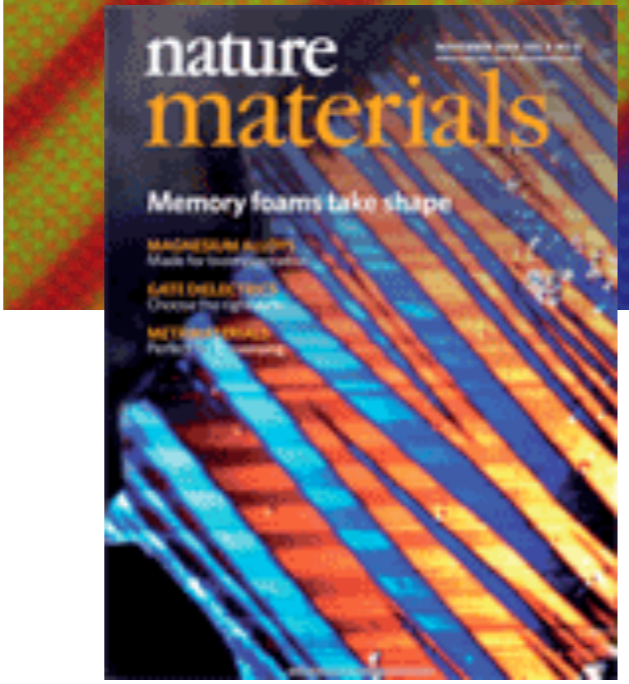
Magyar Fizikus Vándorgyűlés, Debrecen, 21-24 Augusztus 2013



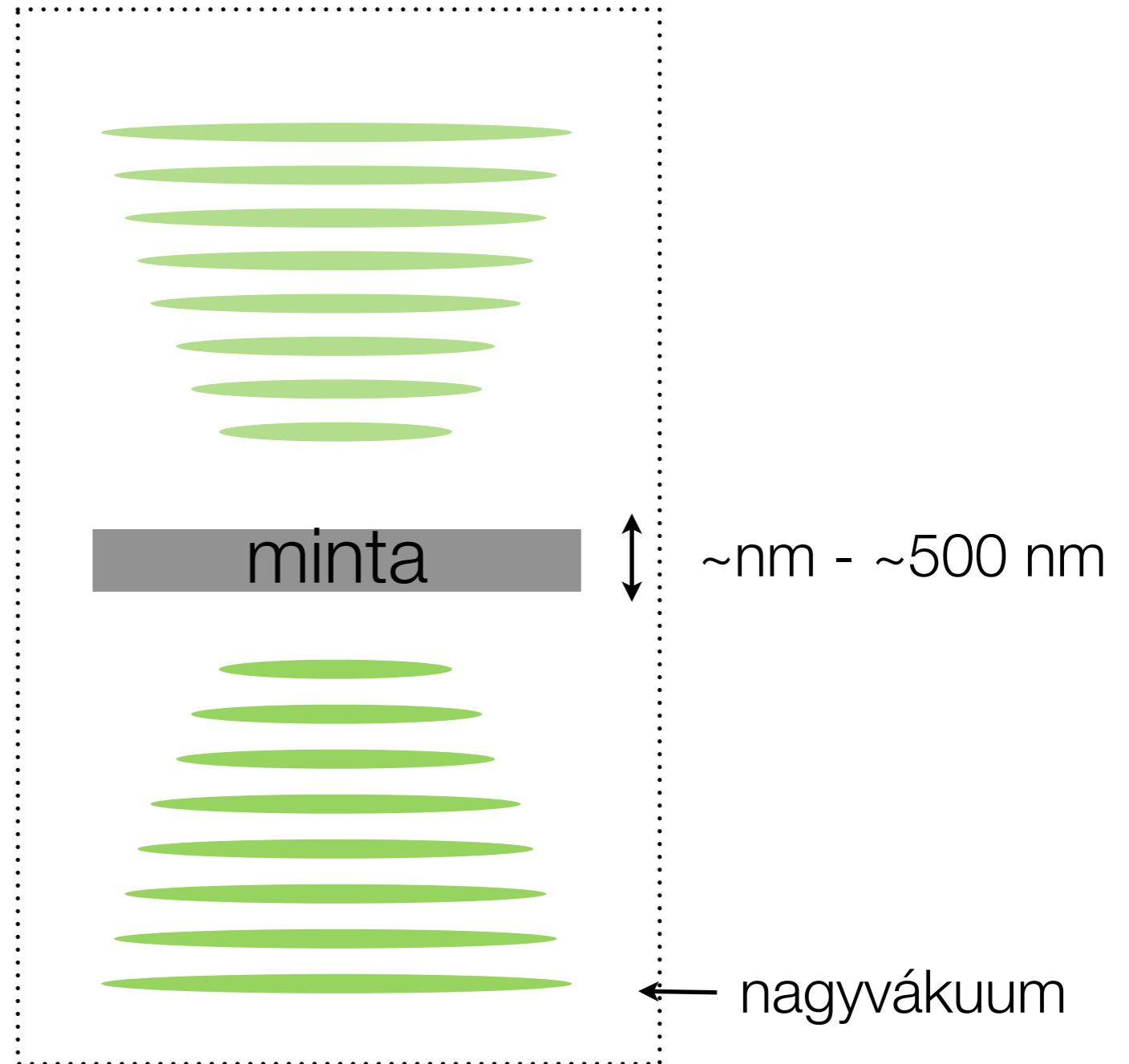
IMMUNOTHERAPY
attack

INDUCTING POLYMERS
fits all

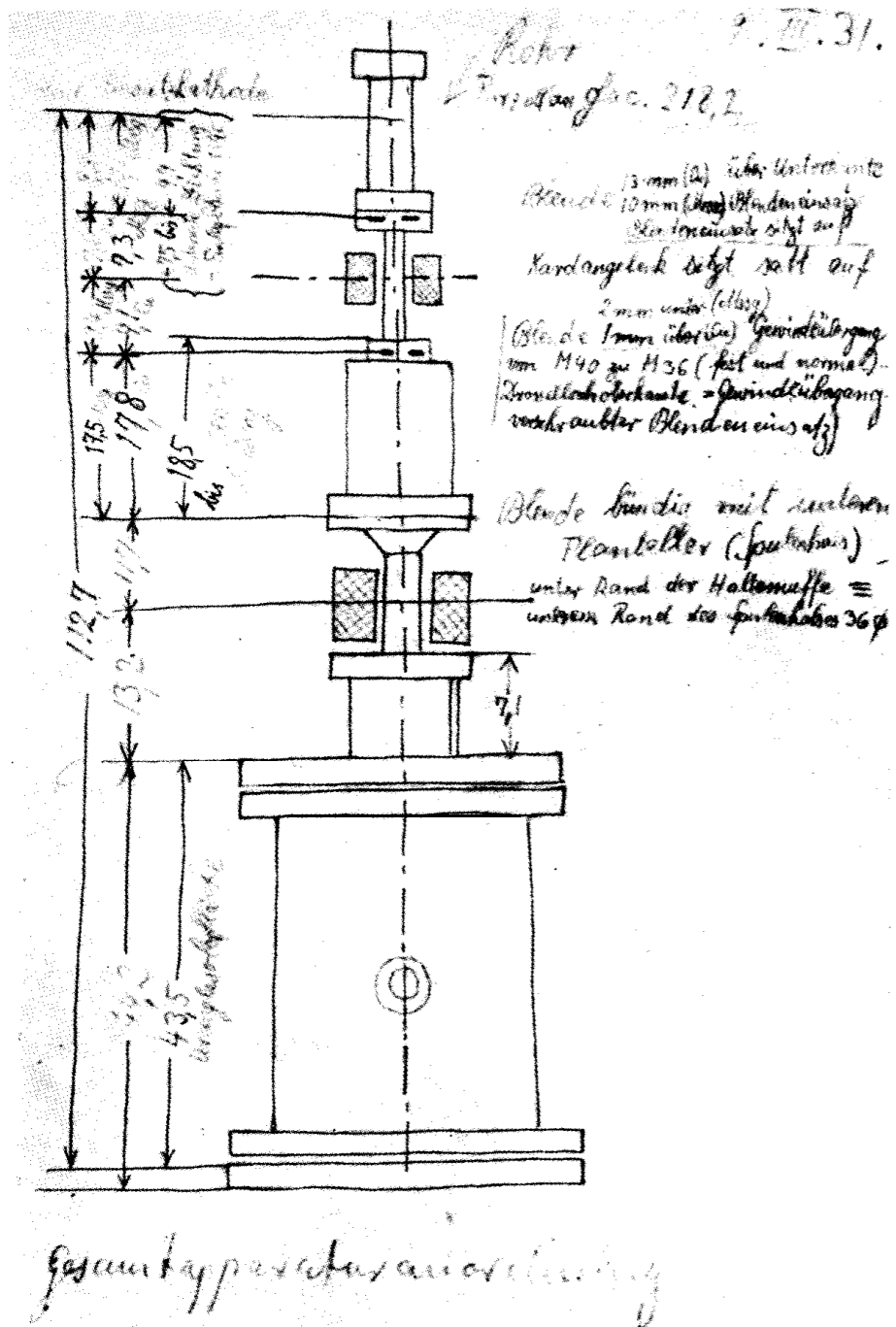
ICAL PROPERTIES
of quantum effects



Transzmissziós elektron- mikroszkópia

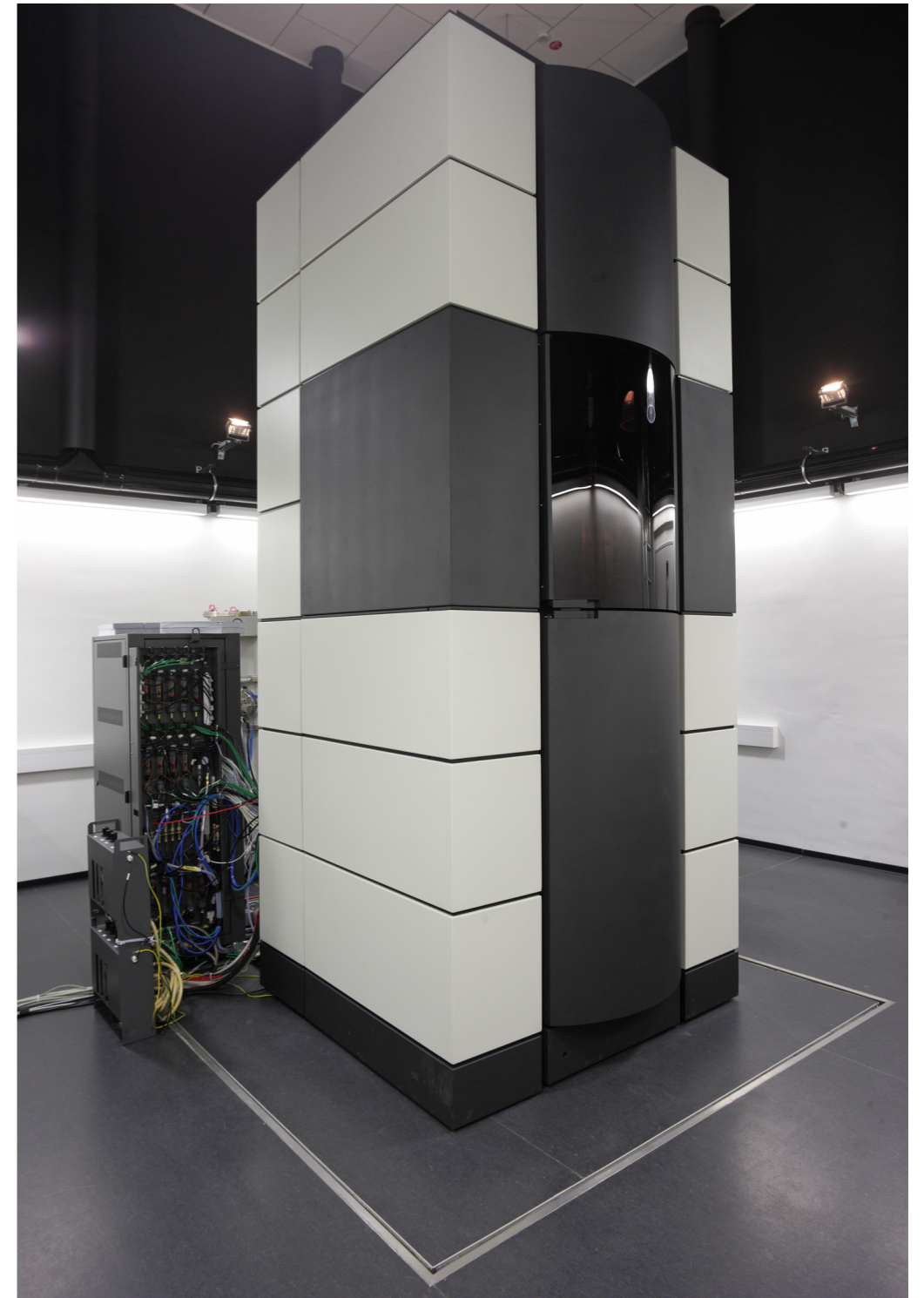


1931

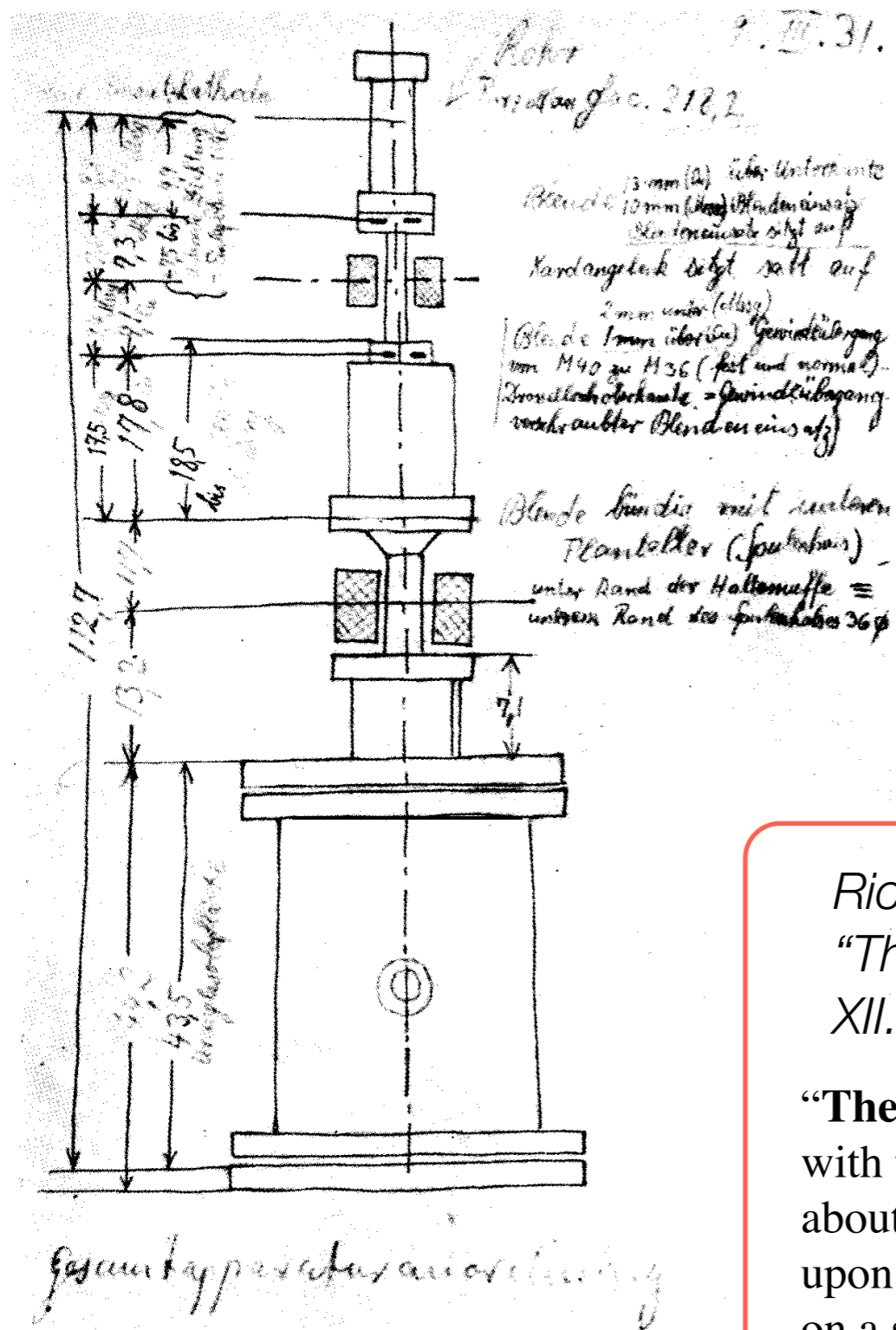


Sketch by Ernst Ruska

2011



PICO at ER-C



- 1931 - Ernst Ruska, Max Knoll
- 1936 - Otto Scherzer
- 1946 - James Hillier, E.G. Ramberg
- 1949 - Gábor Dénes
- 1998 - Harald Rose, Max Haider, K. Urban
- 2005 - első aberráció korrigált mikroszkópok

Richard P. Feynman

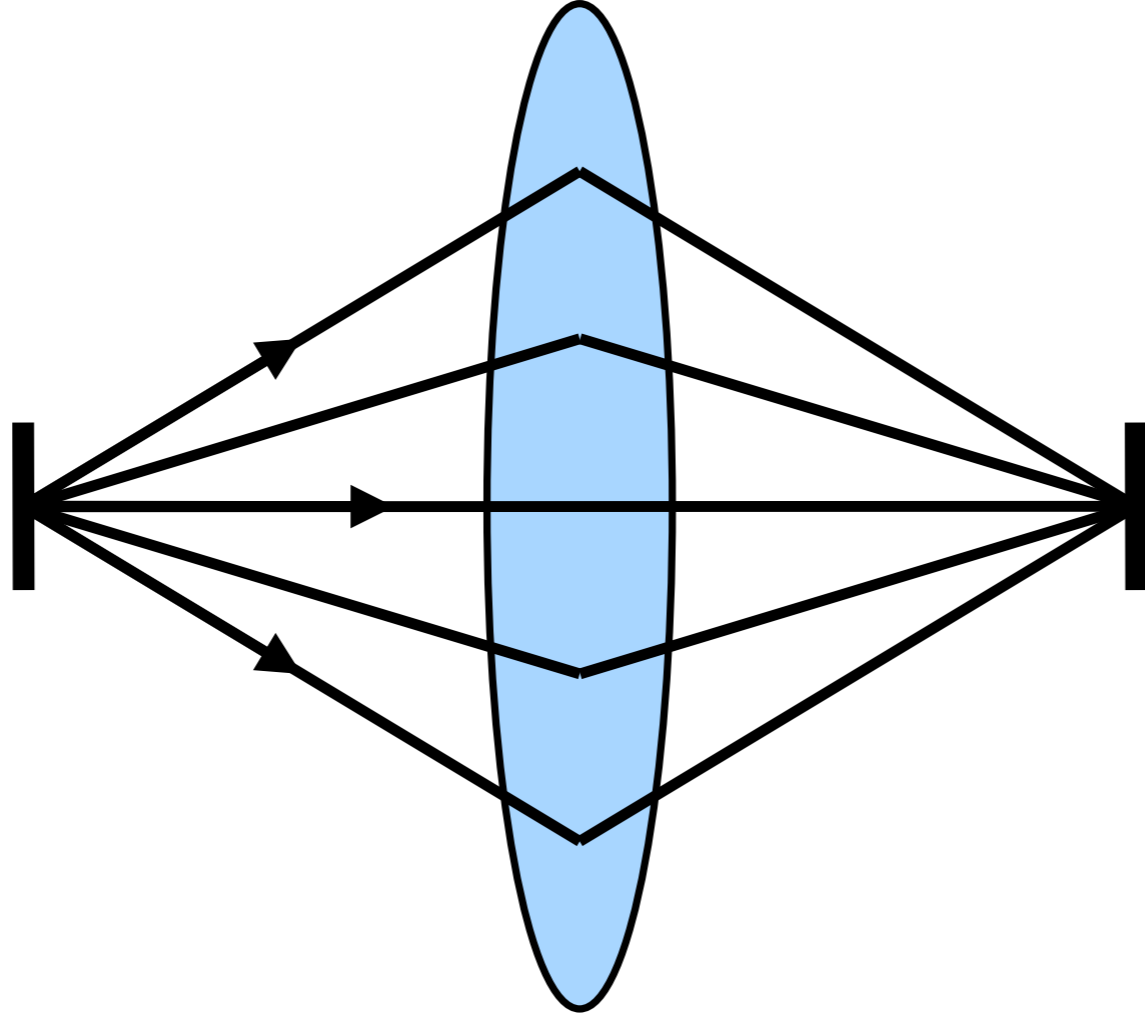
“There’s Plenty of Room at the Bottom”

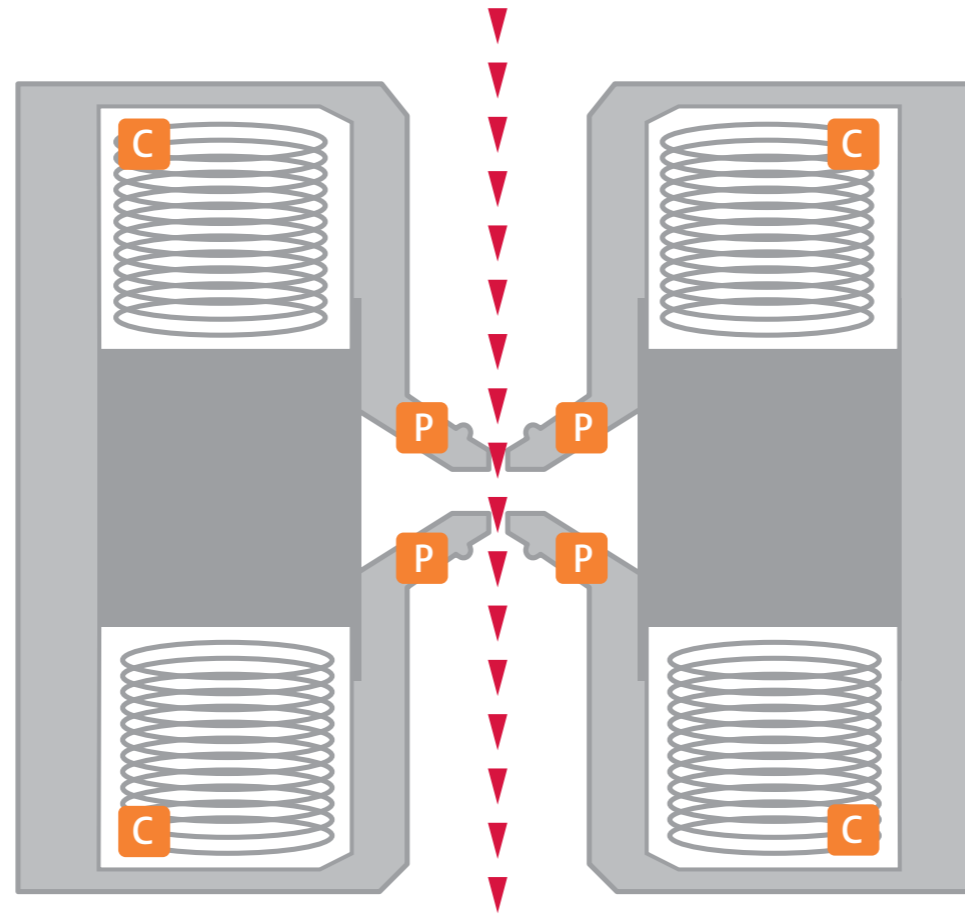
XII. 29. 1959

“**The electron microscope is not quite good enough**, with the greatest care and effort, it can only resolve about 10 angstroms. I would like to try and impress upon you while I am talking about all of these things on a small scale, the importance of **improving the electron microscope by a hundred times**. It is not impossible; it is not against the laws of diffraction of the electron.”



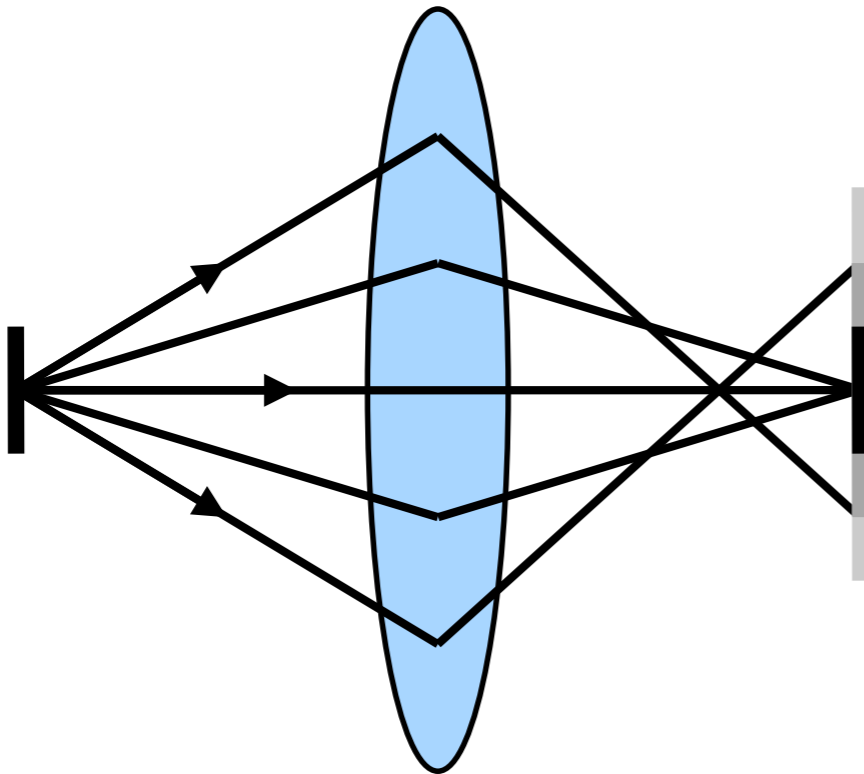
by Tom Harvey, 1962



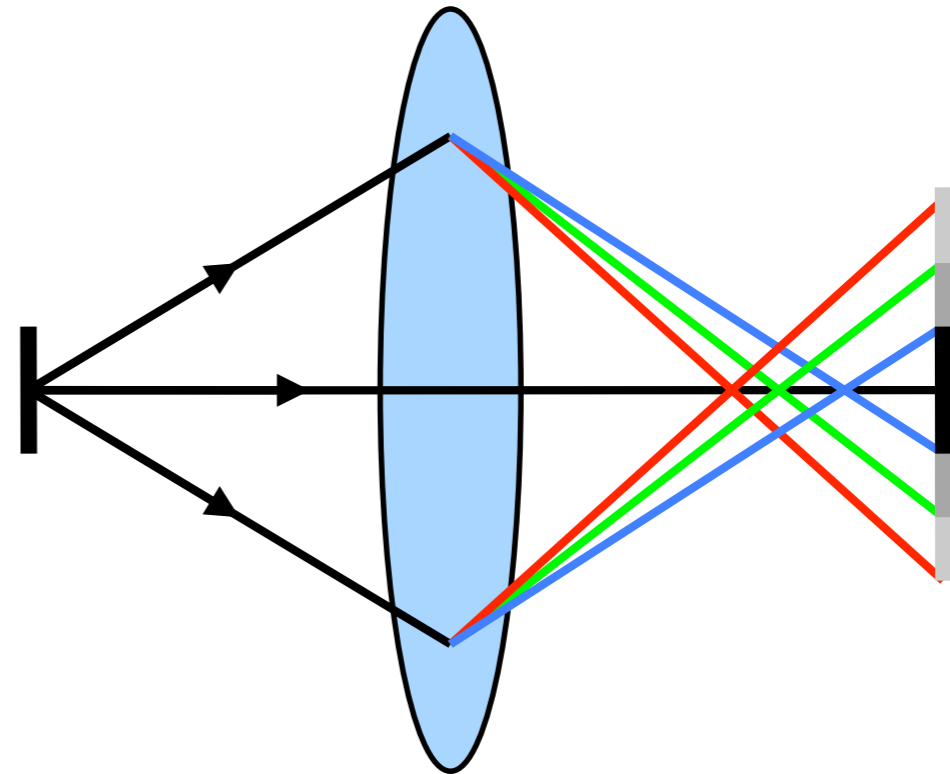


Elektromágneses lencse keresztmetszete. C -
tekercs, P - pólus saru

Lencsehibák

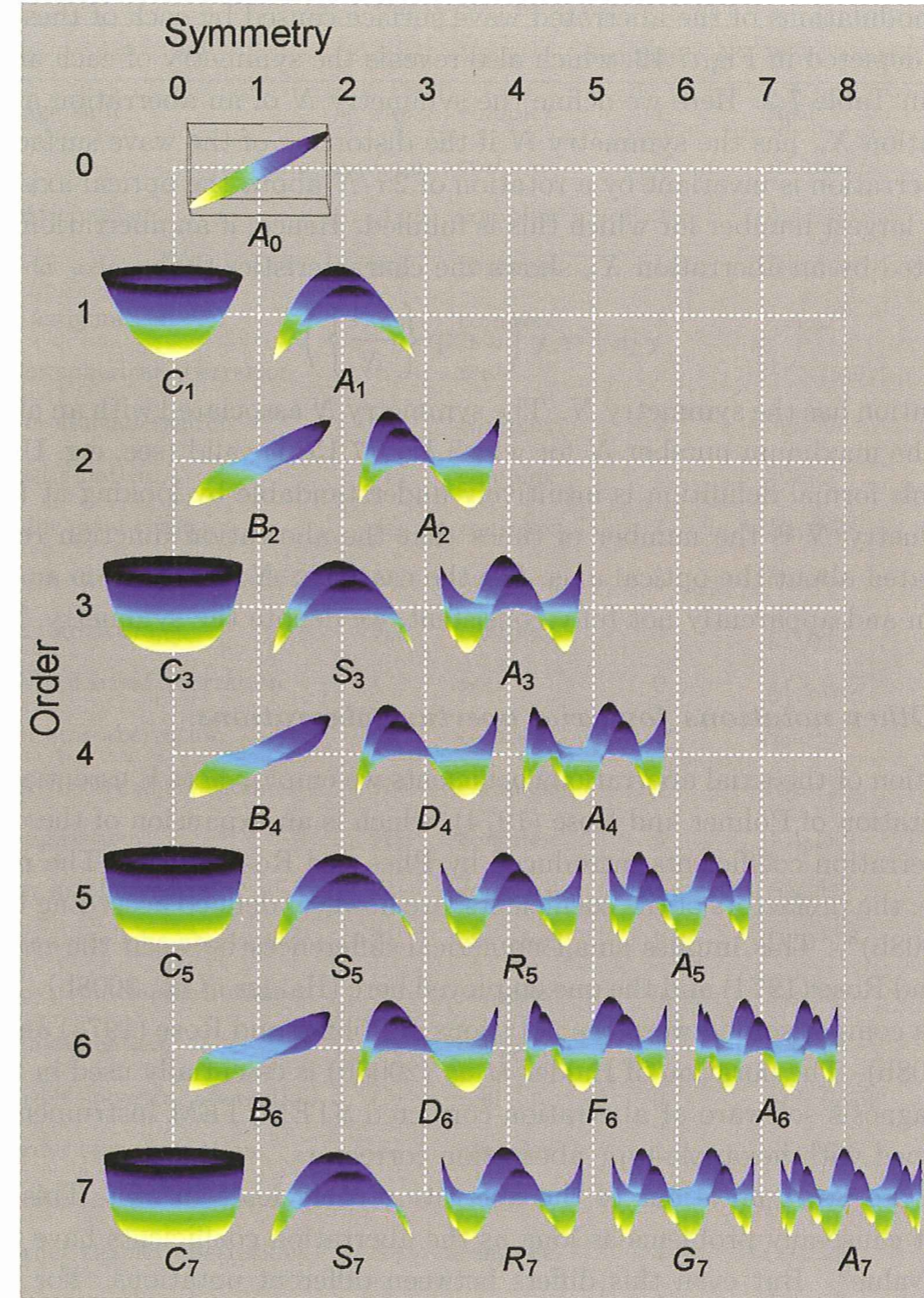


Gömbi hiba
feloldás határ



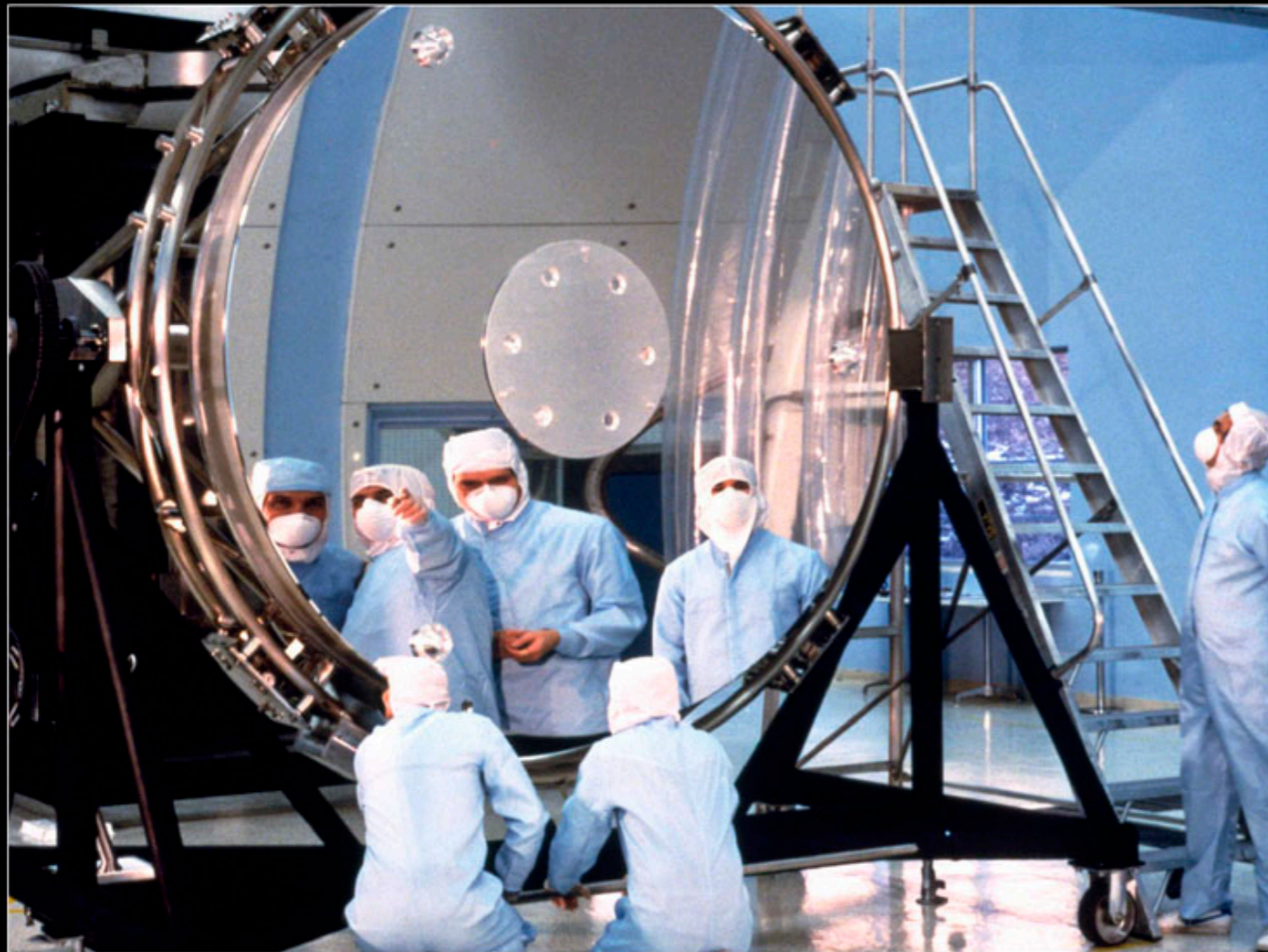
Szín hiba
információ határ

Aberration	Symbol	Value	Symmetry N	Wave aberration $\mathcal{R}(\dots)$
Beam/Image shift	A_0	complex	1	$A_0\bar{\omega}$
Defocus	C_1	real	0	$\frac{1}{2}C_1\omega\bar{\omega}$
Twofold astigmatism	A_1	complex	2	$\frac{1}{2}A_1\bar{\omega}^2$
Second-order axial coma	B_2	complex	1	$B_2\omega^2\bar{\omega}$
Threefold astigmatism	A_2	complex	3	$\frac{1}{3}A_2\bar{\omega}^3$
Third-order spherical aberration	C_3	real	0	$\frac{1}{4}C_3(\omega\bar{\omega})^2$
Third-order star-aberration	S_3	complex	2	$S_3\omega^3\bar{\omega}$
Fourfold astigmatism	A_3	complex	4	$\frac{1}{4}A_3\bar{\omega}^4$
Fourth-order axial coma	B_4	complex	1	$B_4\omega^3\bar{\omega}^2$
Fourth-order three-lobe aberration	D_4	complex	3	$D_4\omega^4\bar{\omega}$
Fivefold astigmatism	A_4	complex	5	$\frac{1}{5}A_4\bar{\omega}^5$
Fifth-order spherical aberration	C_5	real	0	$\frac{1}{6}C_5(\omega\bar{\omega})^3$
Fifth-order star-aberration	S_5	complex	2	$S_5\omega^4\bar{\omega}^2$
Fifth-order rosette aberration	R_5	complex	4	$R_5\omega^5\bar{\omega}$
Sixfold astigmatism	A_5	complex	6	$\frac{1}{6}A_5\bar{\omega}^6$
Sixth-order axial coma	B_6	complex	1	$B_6\omega^4\bar{\omega}^3$
Sixth-order three-lobe aberration	D_6	complex	3	$D_6\omega^5\bar{\omega}^2$
Sixth-order pentacle aberration	F_6	complex	5	$F_6\omega^6\bar{\omega}$
Sevenfold astigmatism	A_6	complex	7	$\frac{1}{7}A_6\bar{\omega}^7$
Seventh-order spherical aberration	C_7	real	0	$\frac{1}{8}C_7(\omega\bar{\omega})^4$
Seventh-order star-aberration	S_7	complex	2	$S_7\omega^5\bar{\omega}^3$
Seventh-order rosette aberration	R_7	complex	4	$R_7\omega^6\bar{\omega}^2$
Seventh-order chaplet aberration	G_7	complex	4	$G_7\omega^7\bar{\omega}$
Eightfold astigmatism	A_7	complex	8	$\frac{1}{8}A_7\bar{\omega}^8$





Hubble space telescope



Working on Hubble's Main Mirror

Image Credit: NASA, 1990

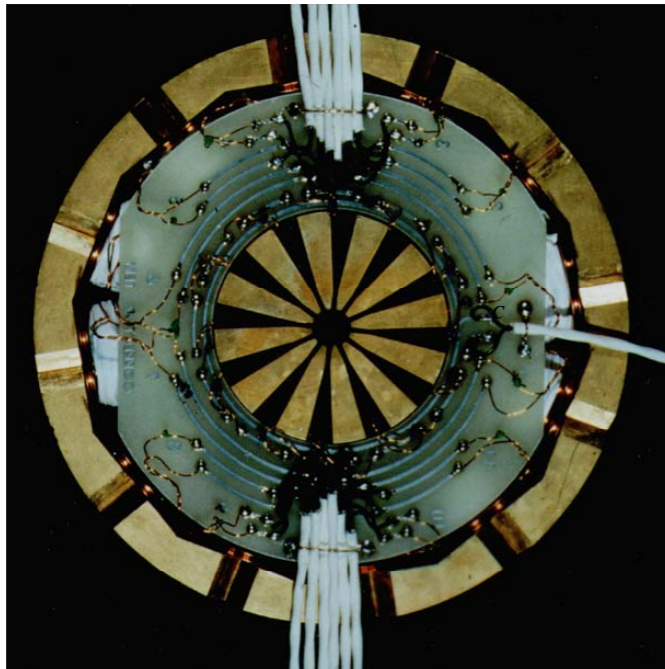
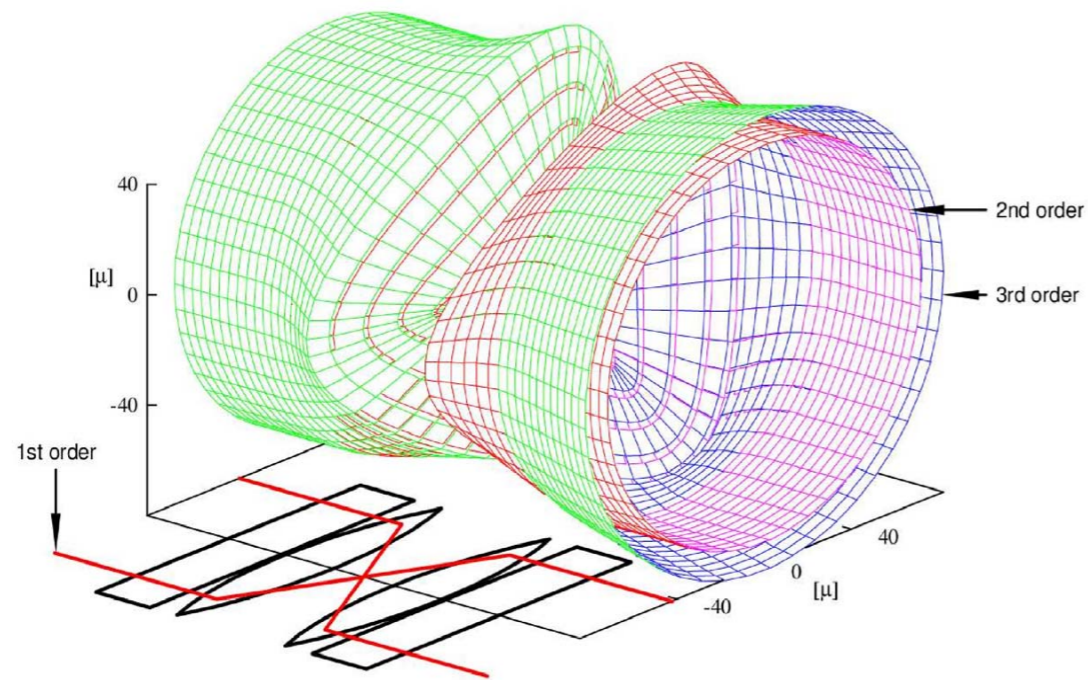
before



after

Aberration corrector using hexapoles and round lens transfer doublet

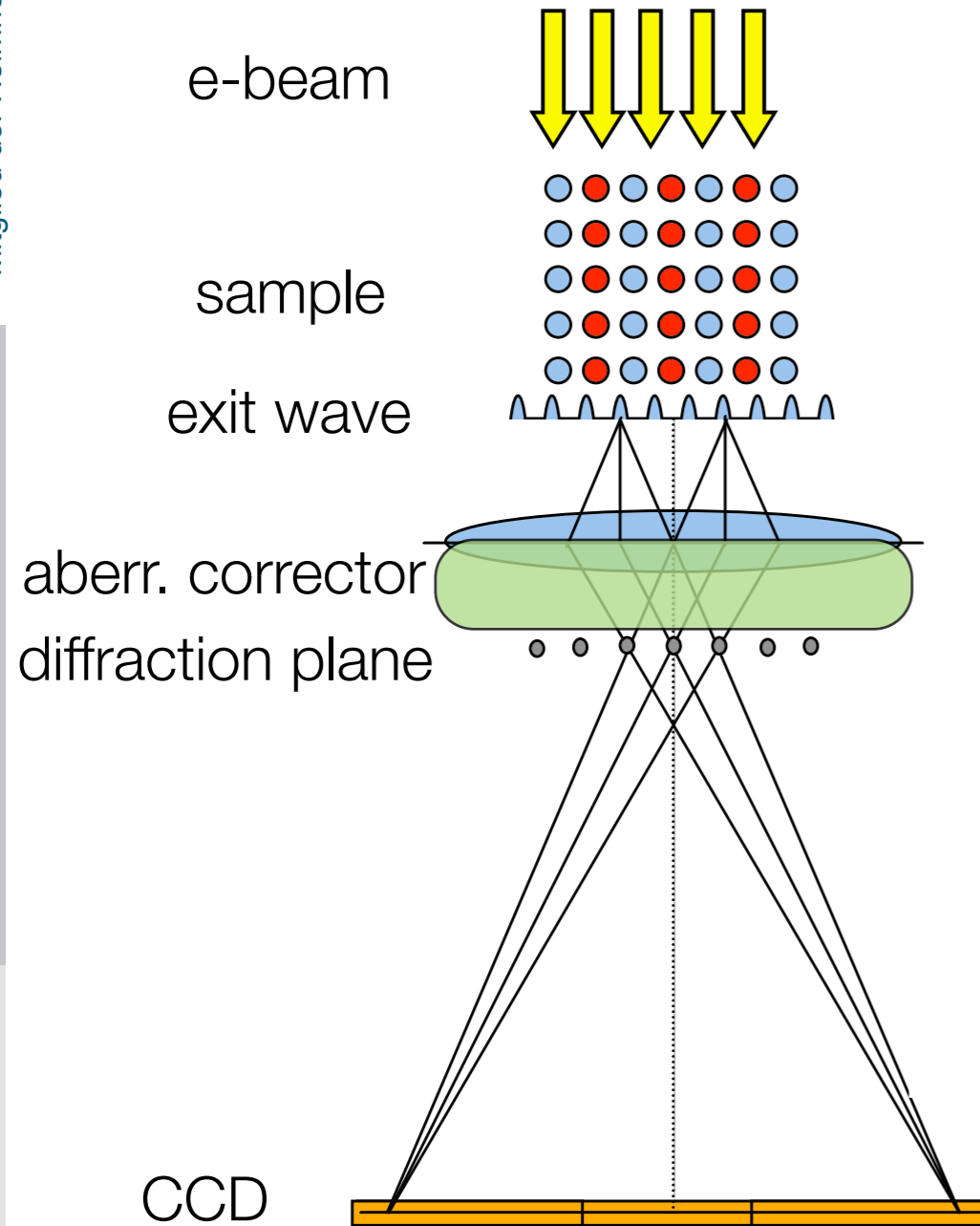
H. Rose, M. Haider, K. Urban, ...



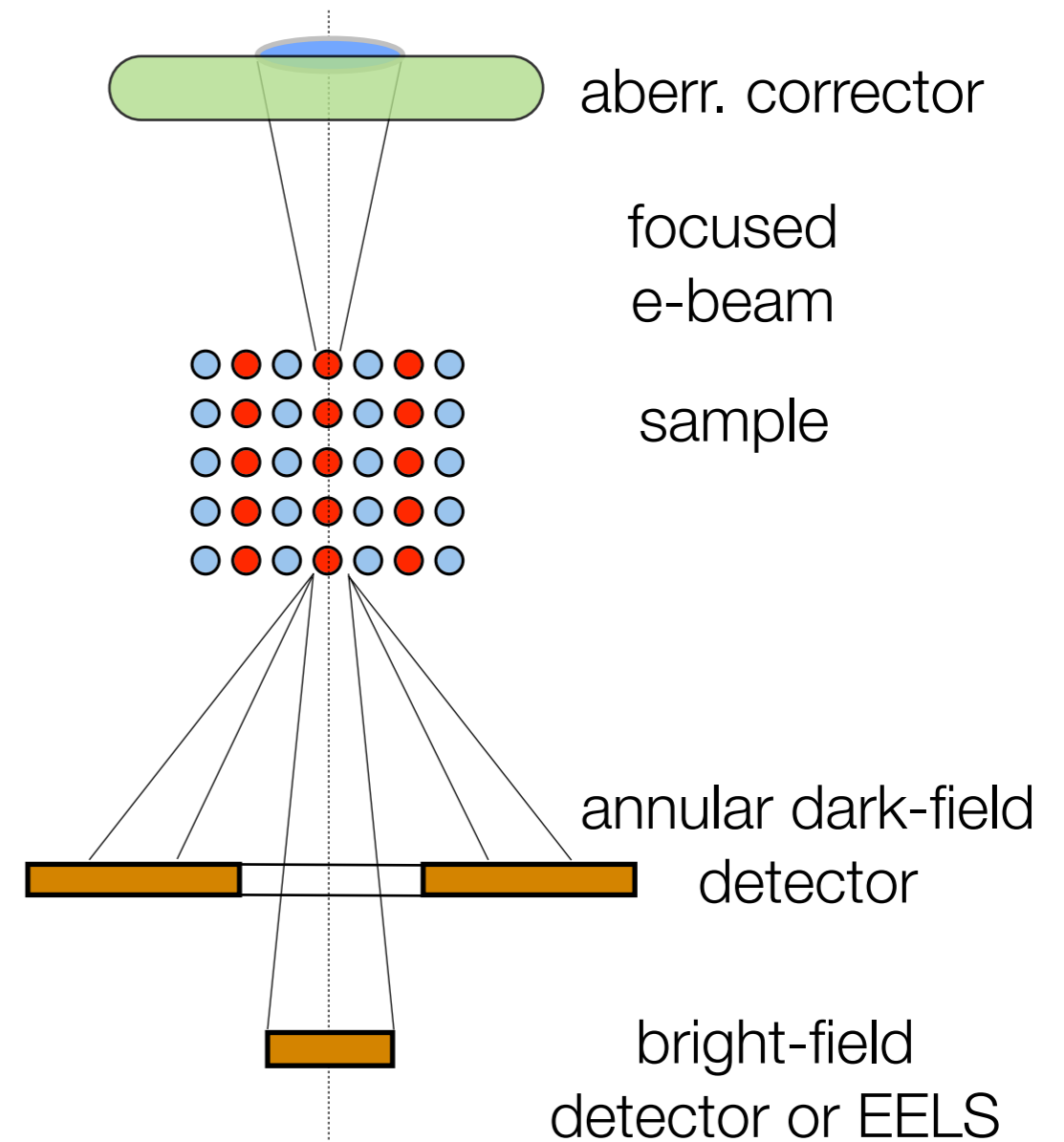
1998



TEM

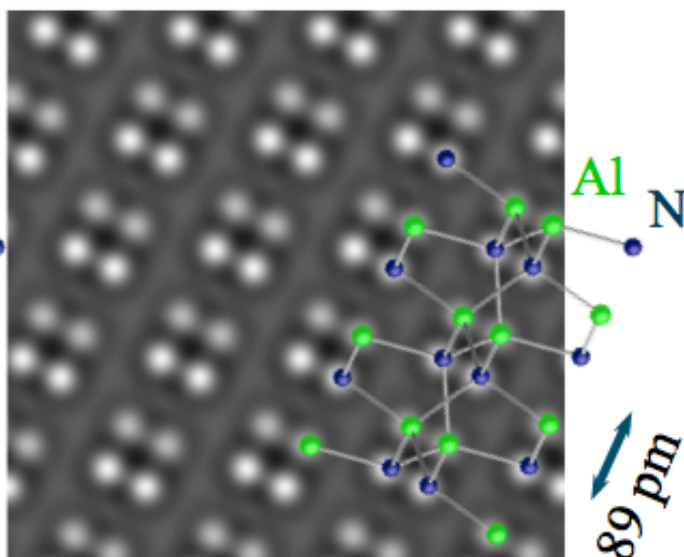
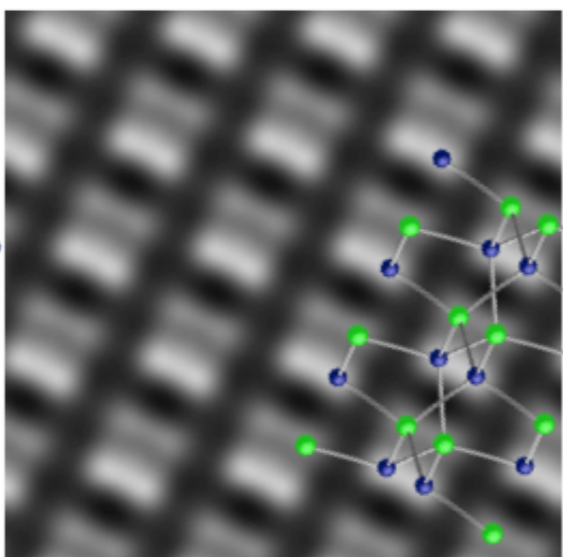
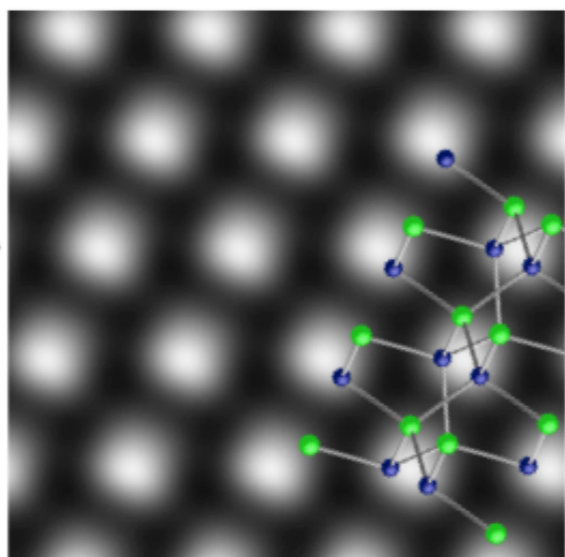
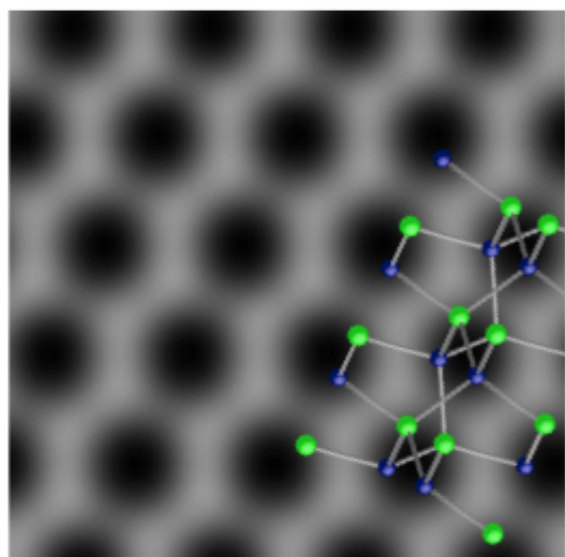


Scanning TEM (STEM)



A TEM felbontás evolúciója

AlN

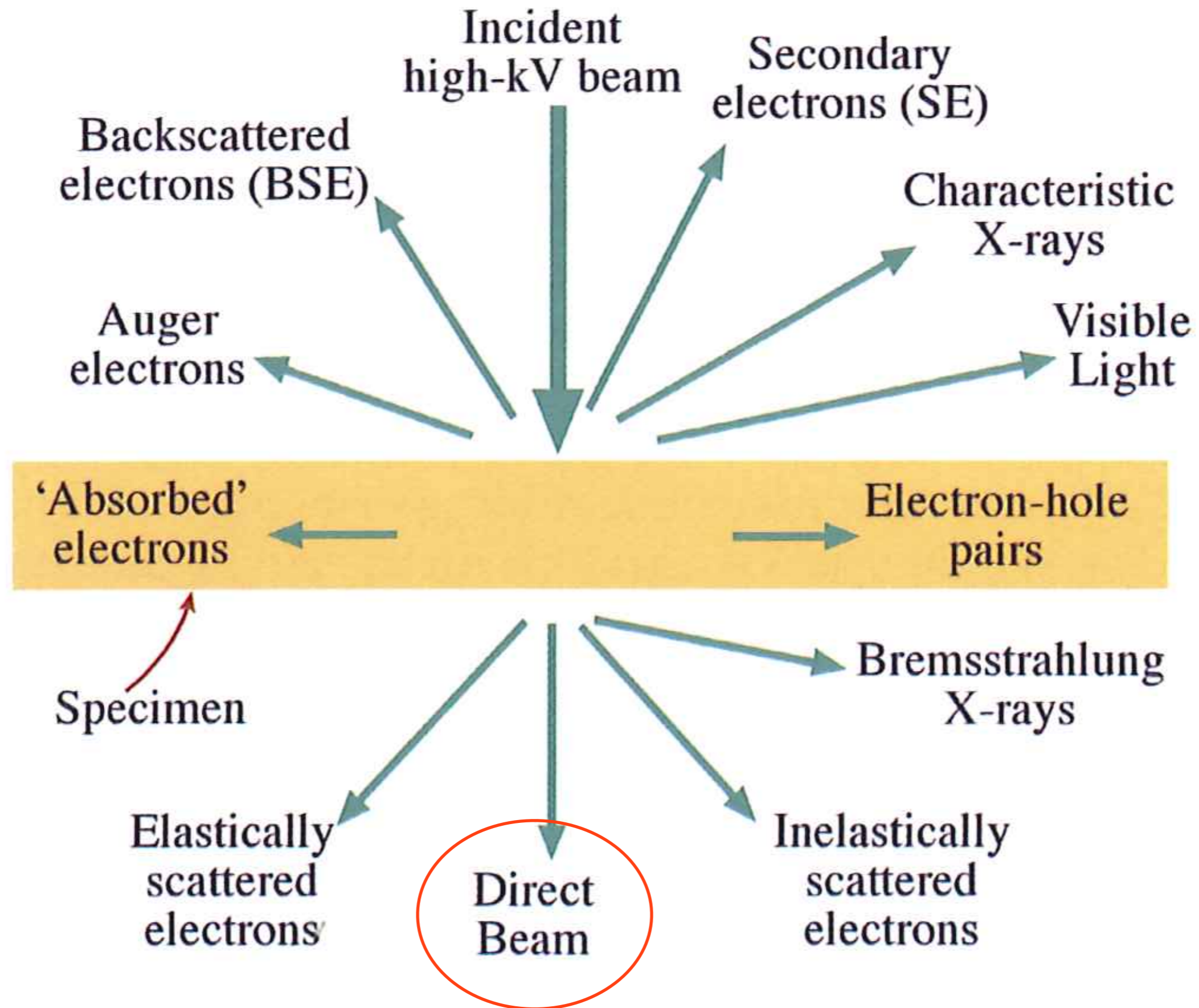


CM30-UT (1992)
300 kV FEG
no corrector

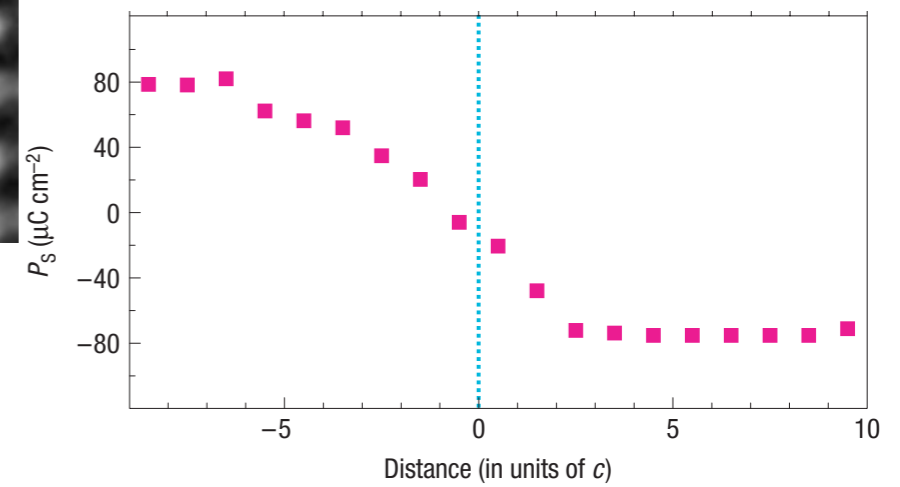
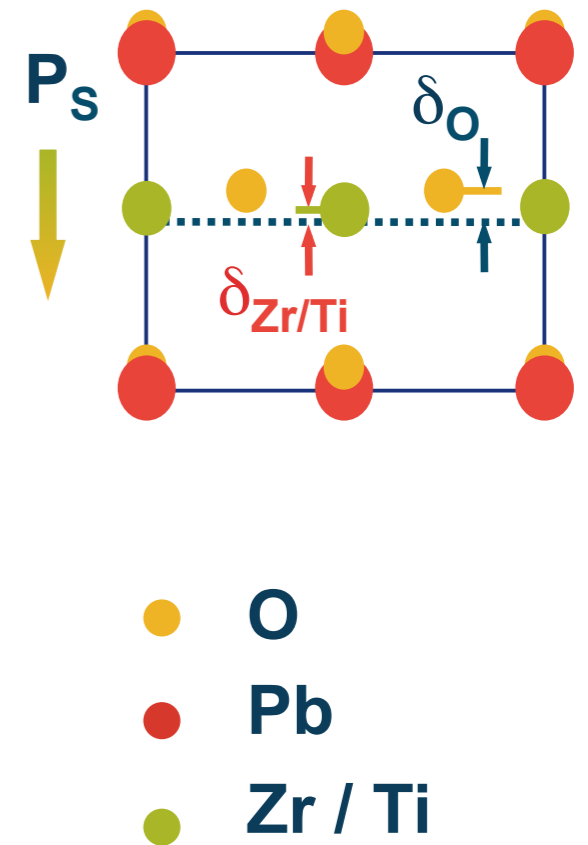
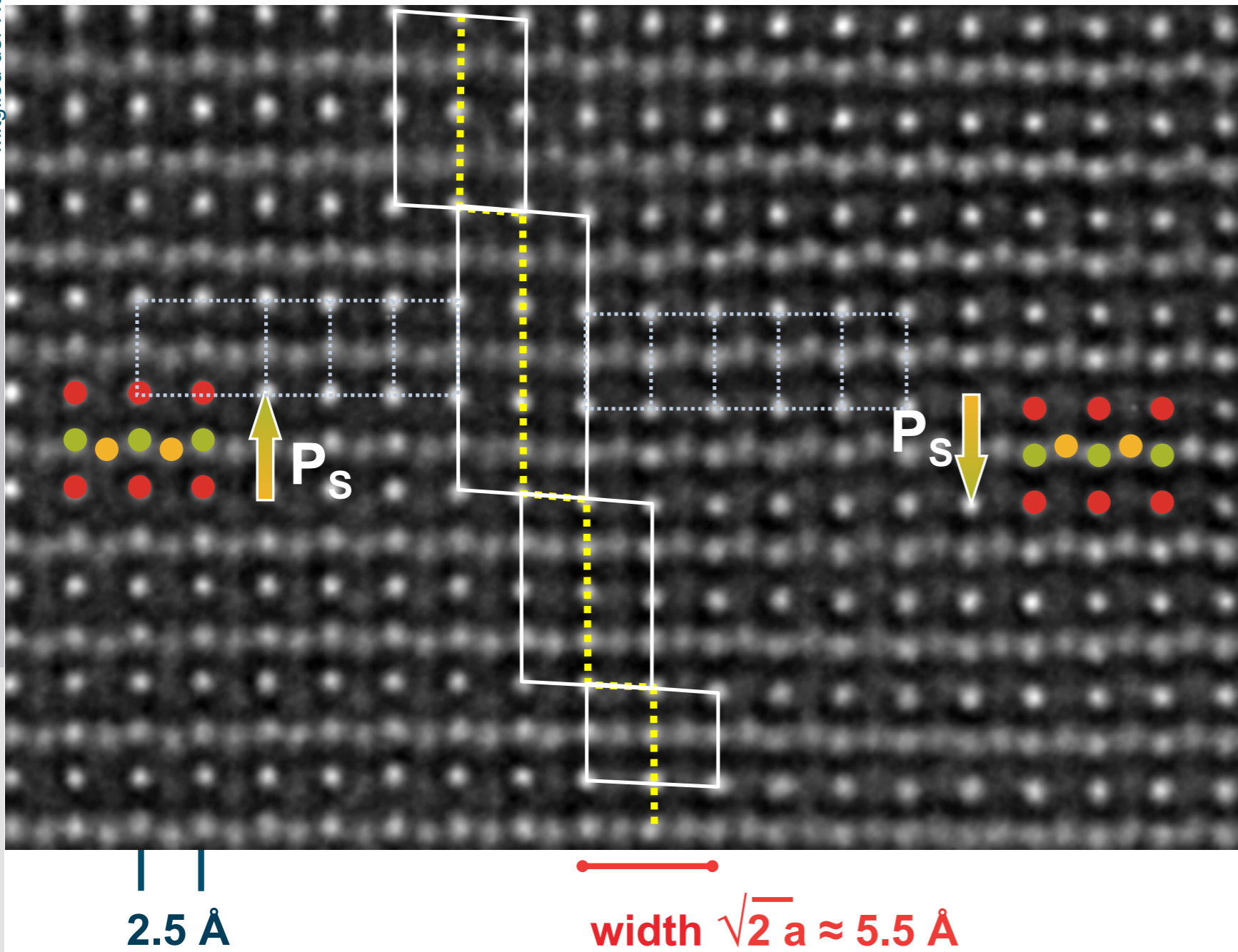
CM200-Cs (1998)
200 kV FEG
Cs corrector

Titan 80-300 (2005)
300 kV FEG
Cs corrector

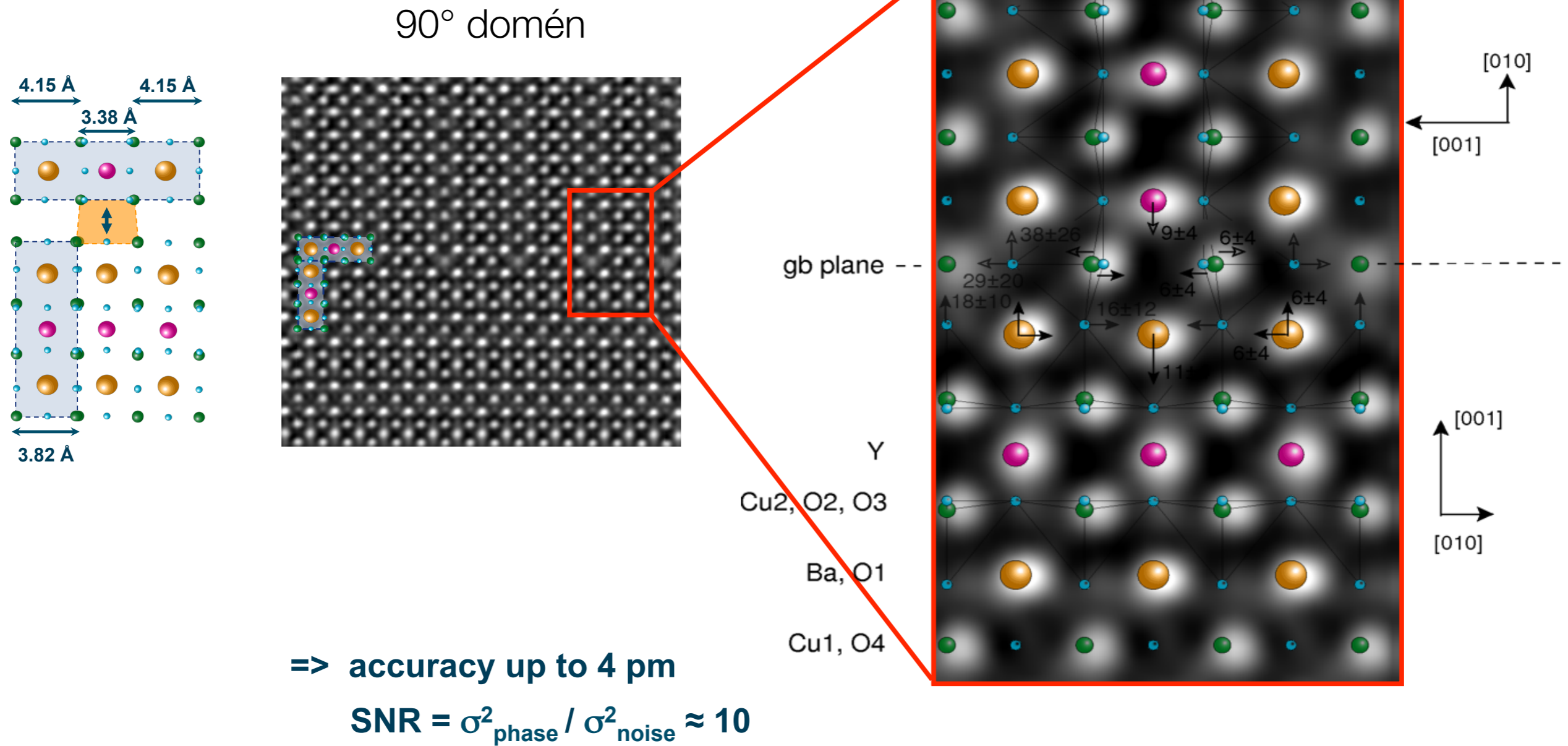
PICO (2012)
300 kV X-FEG
Cc & Cs corrector

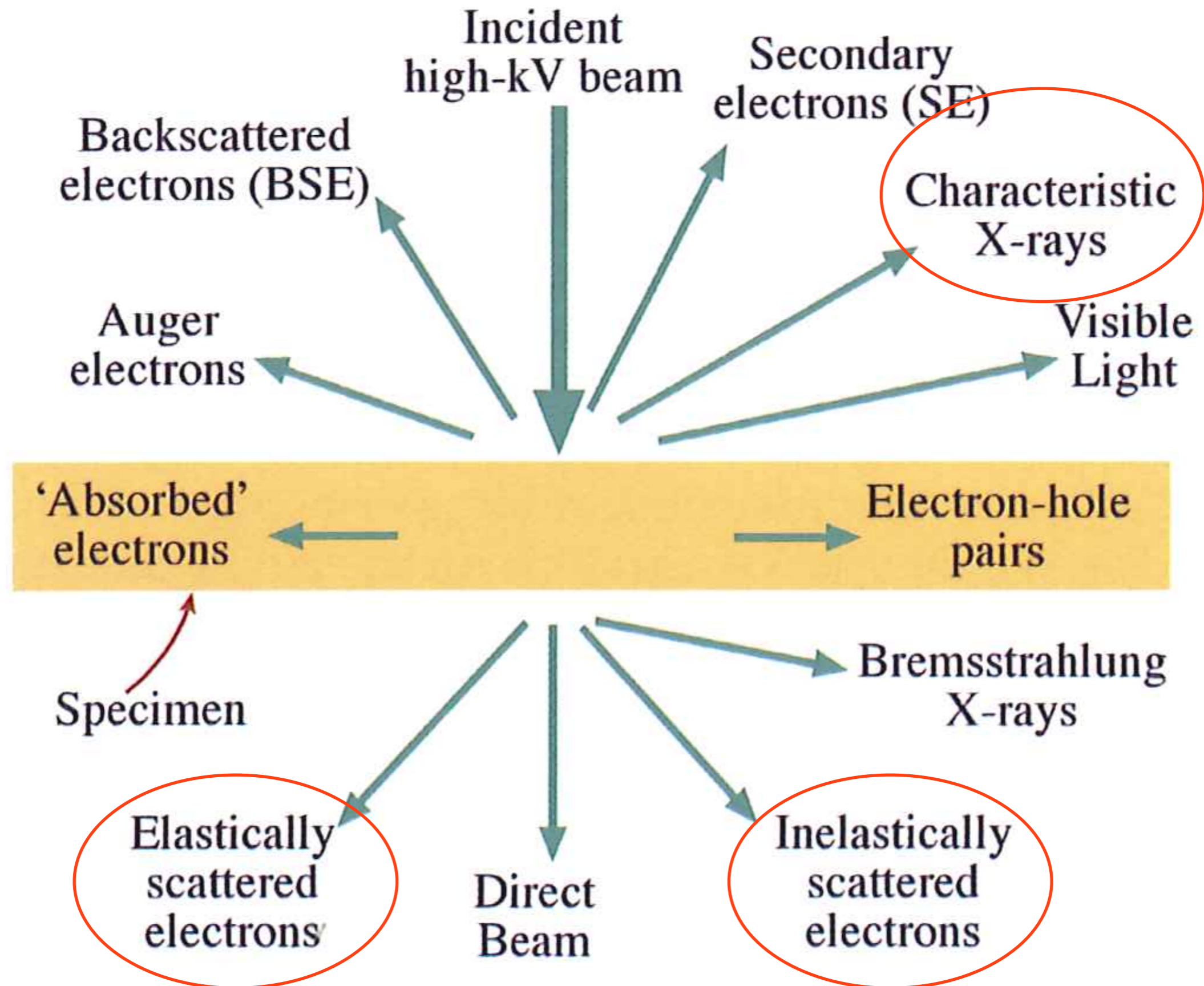


Ferroelektromos domén PZT-ben



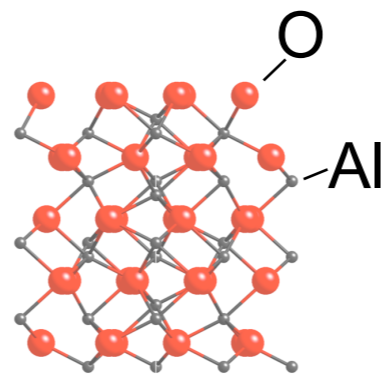
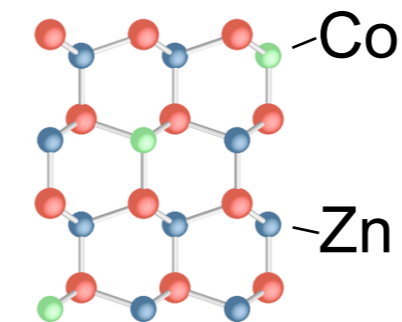
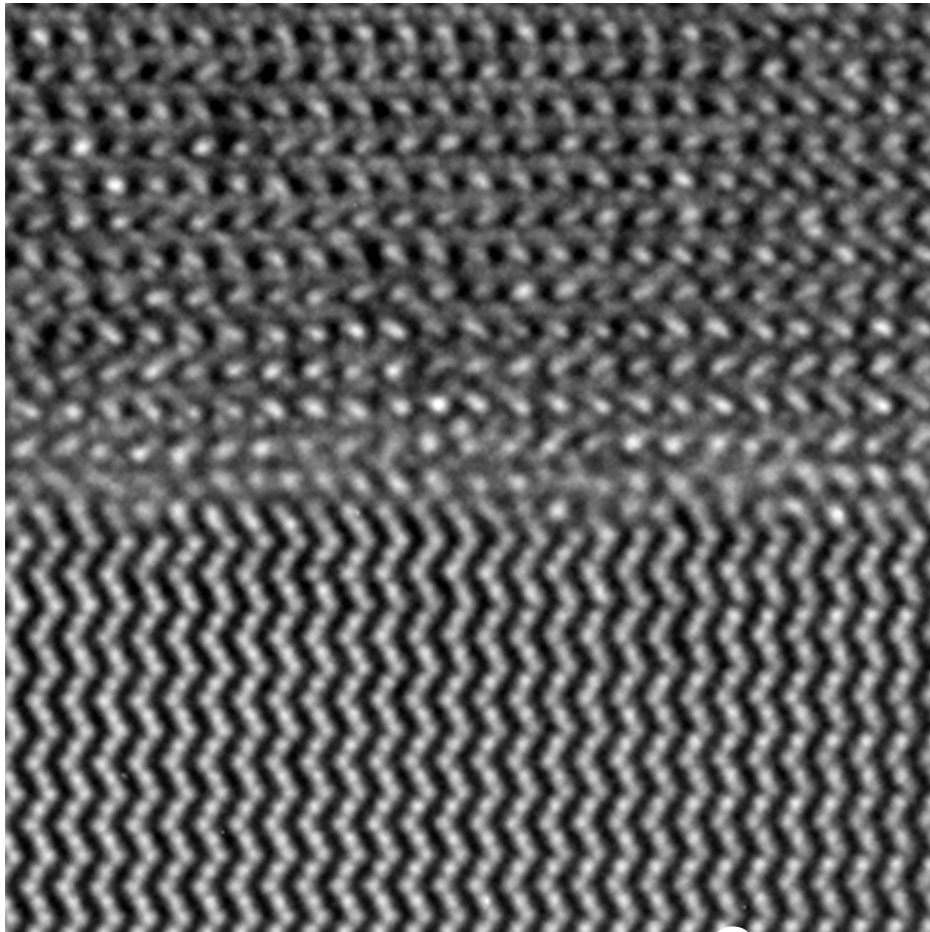
O oszlop $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ szupravezetőben



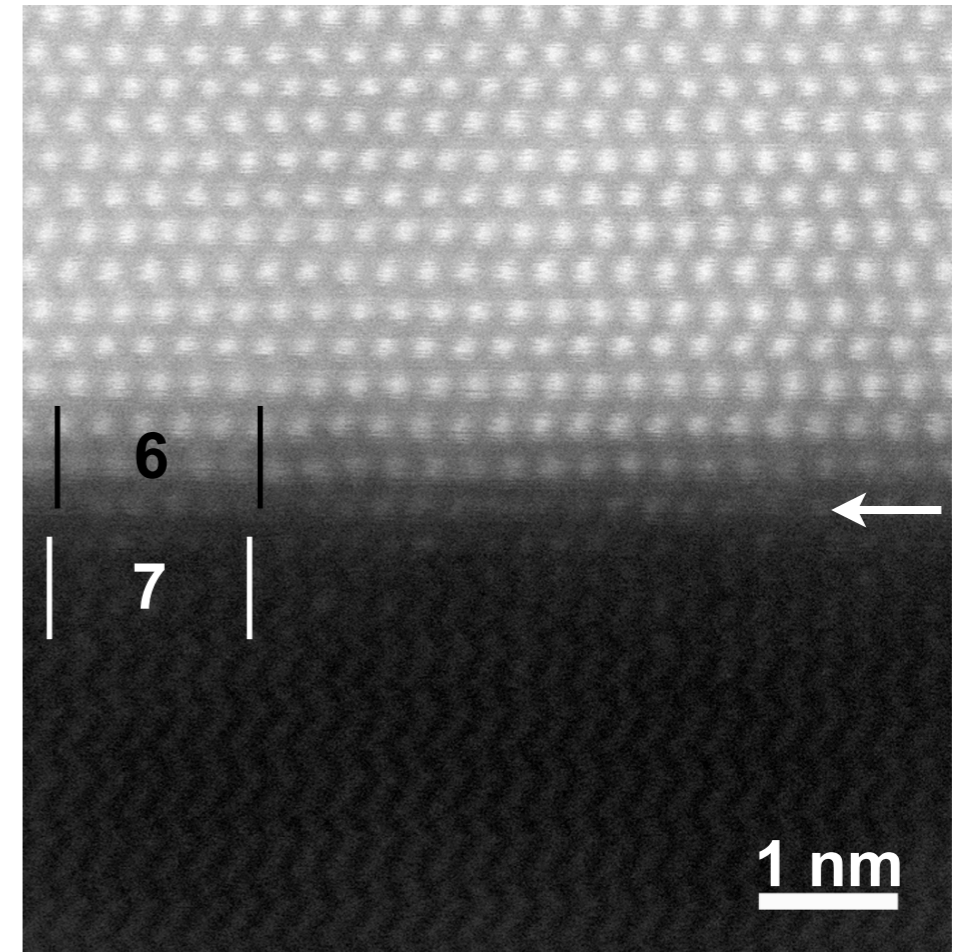


Al_2O_3 és Co:ZnO határártmenete

TEM

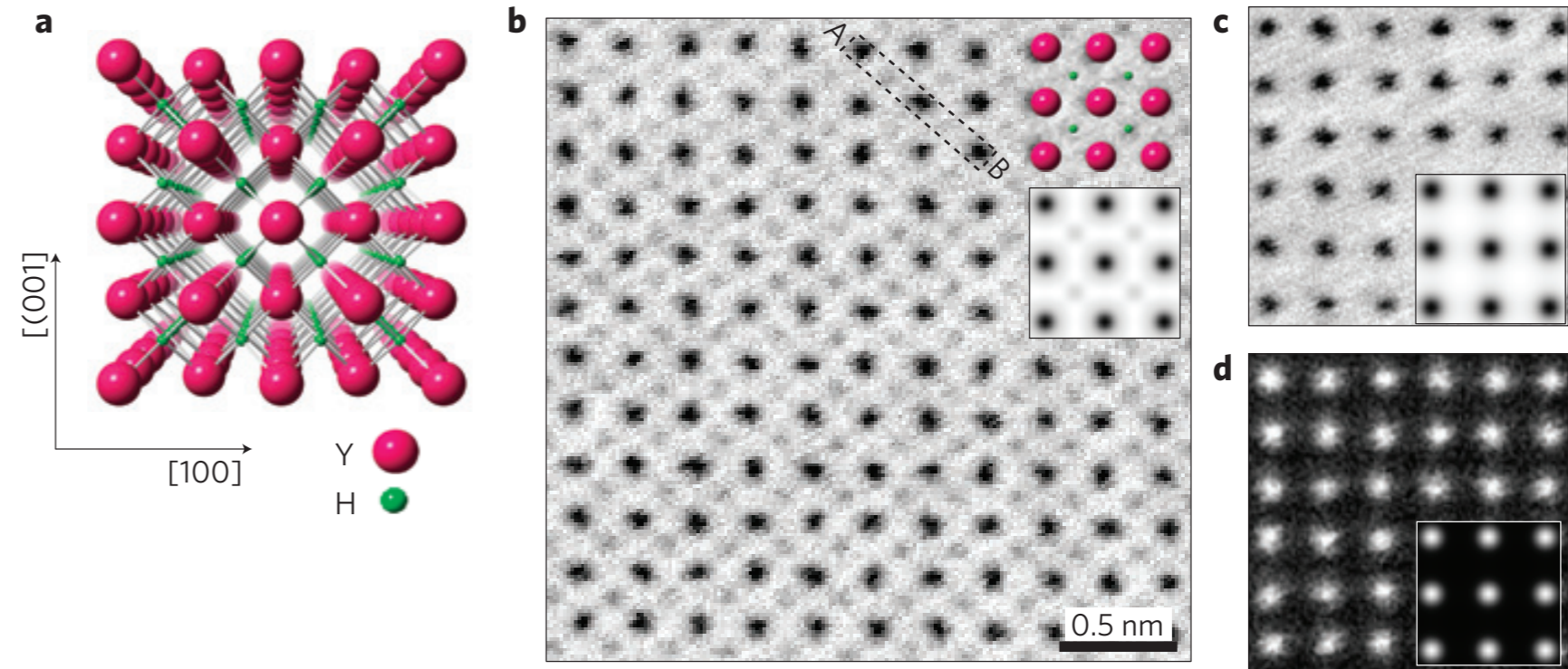
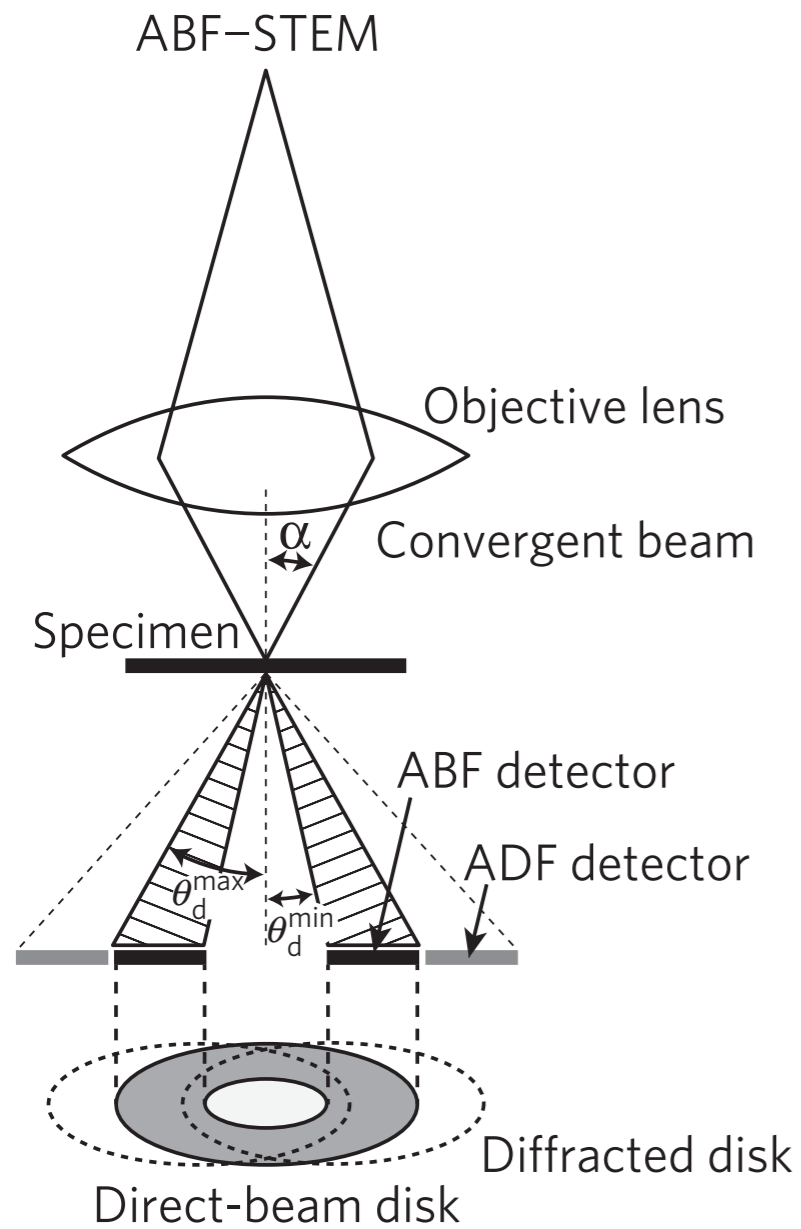


STEM



+ kémiai információ

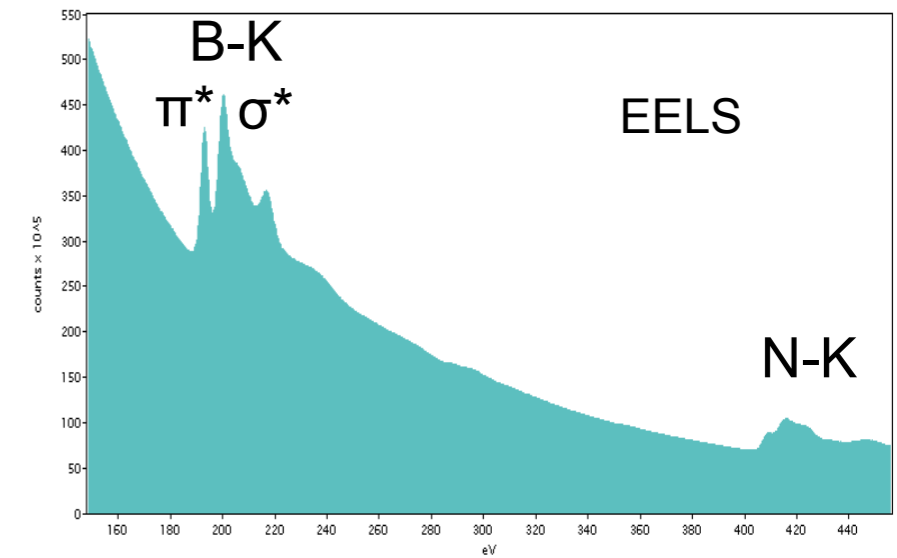
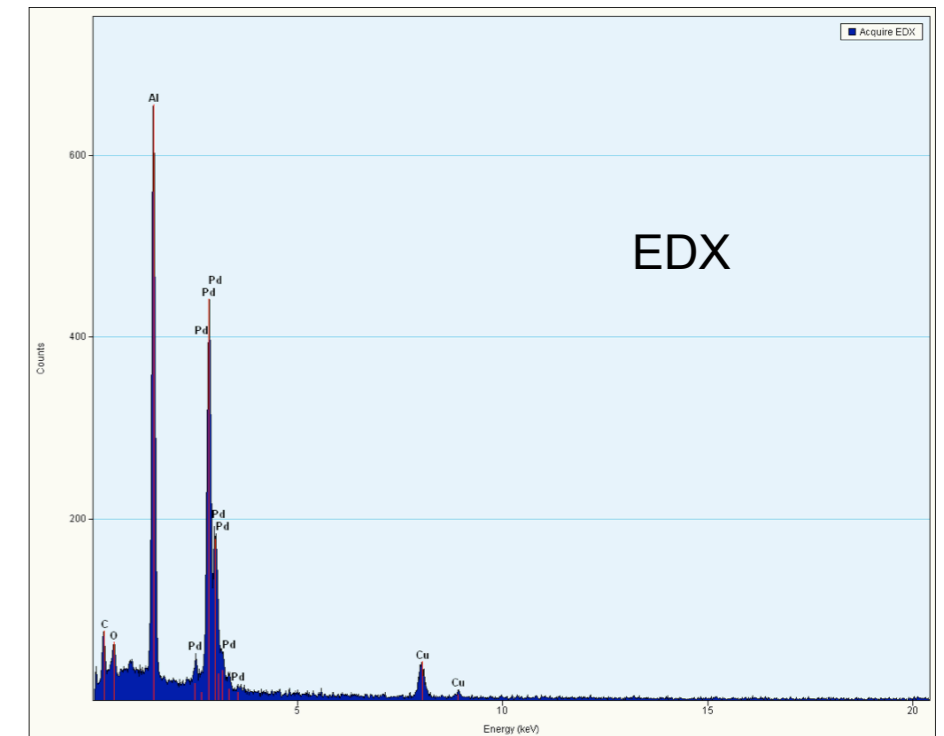
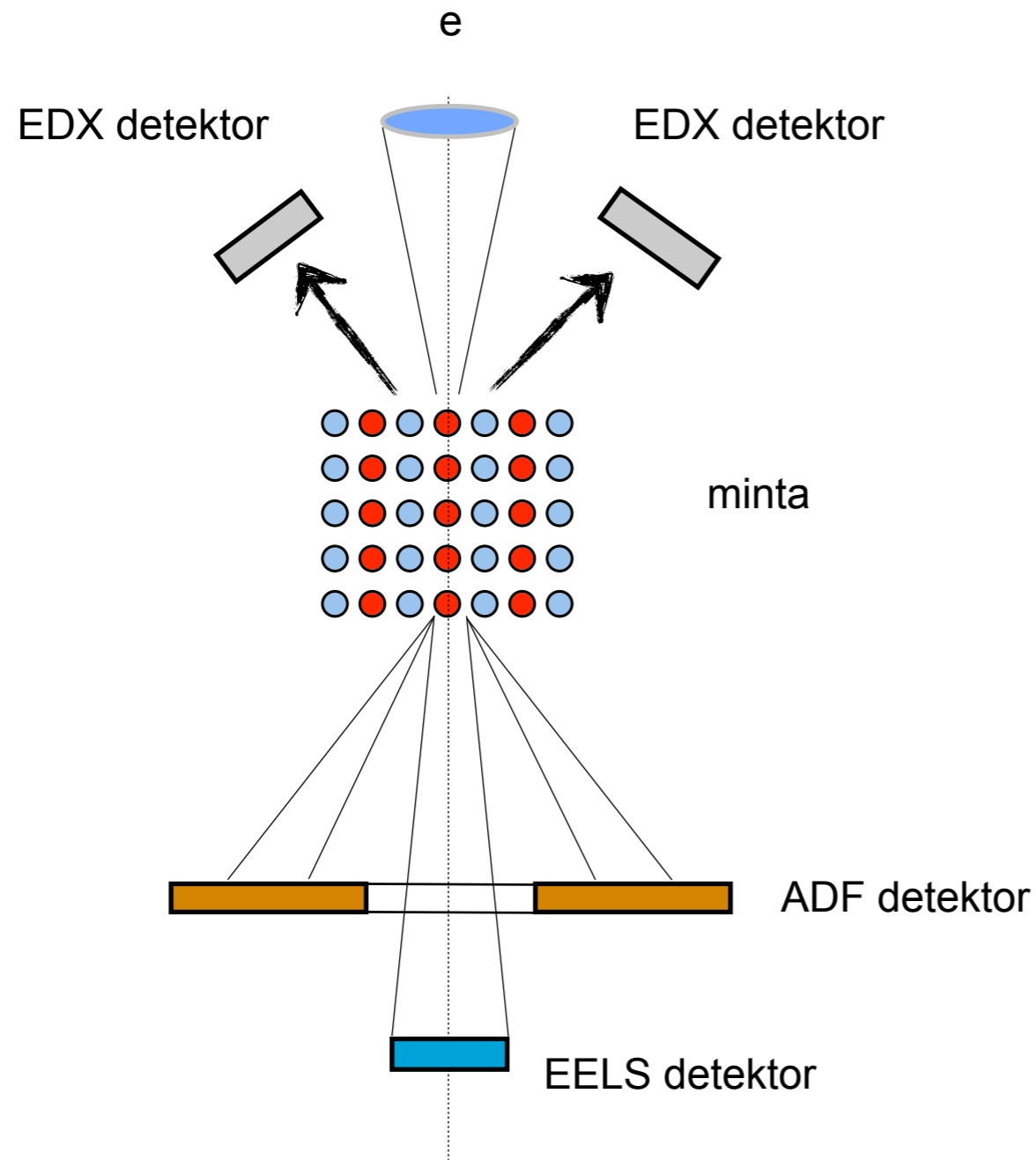
H oszlop leképezés YH₂-ban



Crystal structure of YH₂, ABF image, BF and ADF STEM images.

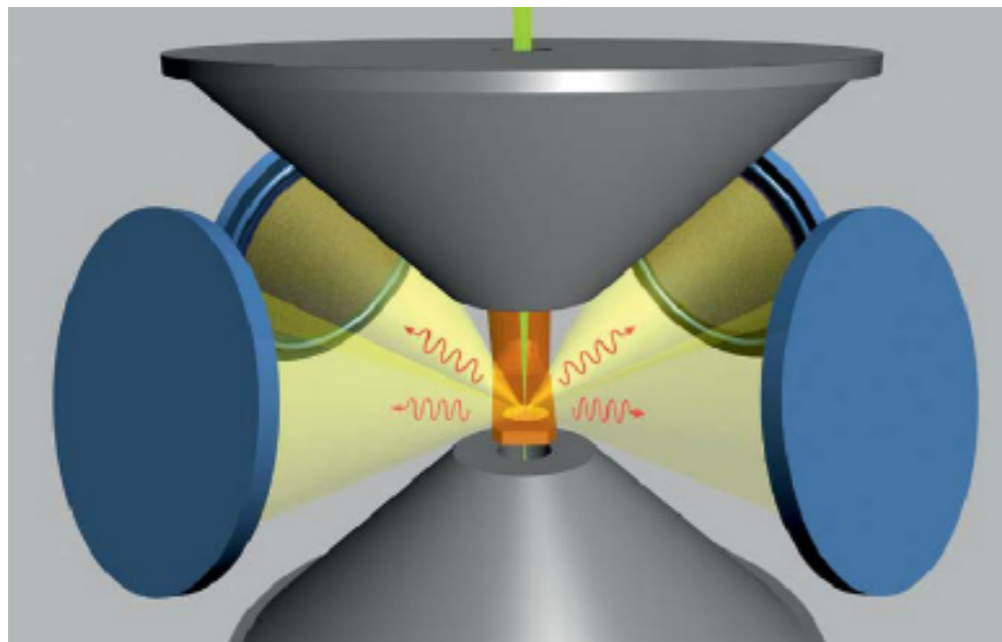
Ishikawa et al Nature Materials 2011

Atomi felbontású EDX vagy EELS spektroszkópia

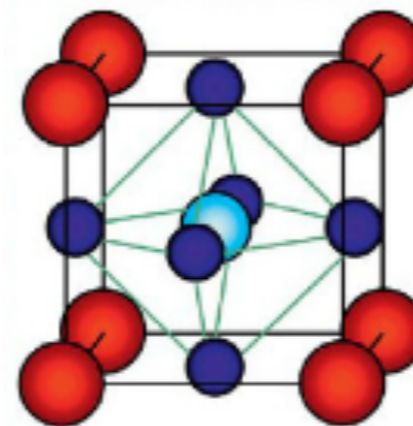
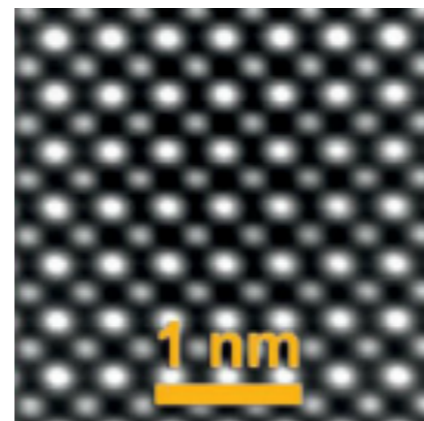


Atomi felbontású EDX

FEI - ChemiSTEM technológia



SrTiO_3

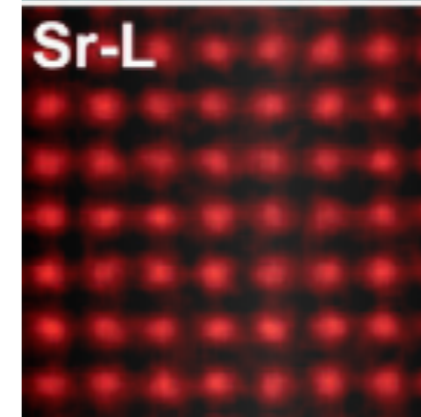
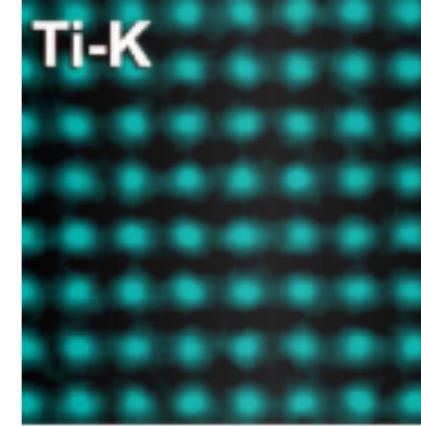
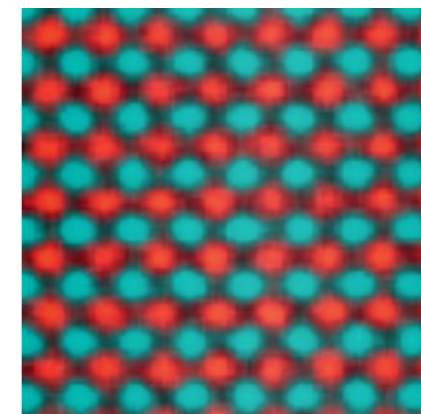


● - Sr

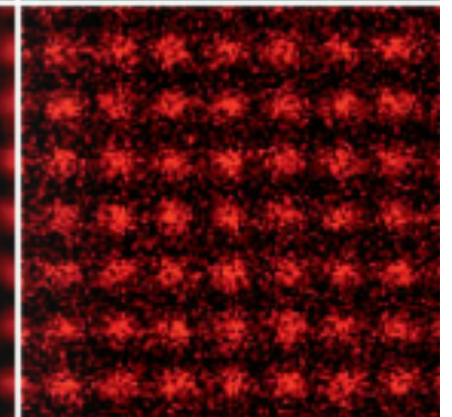
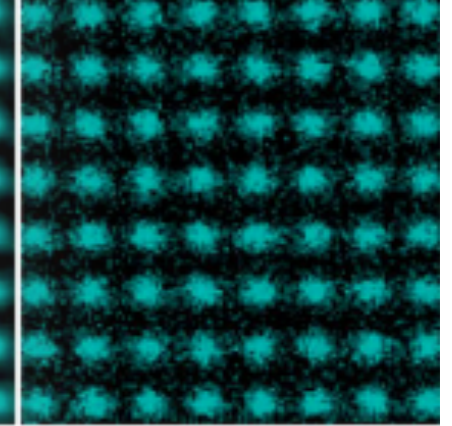
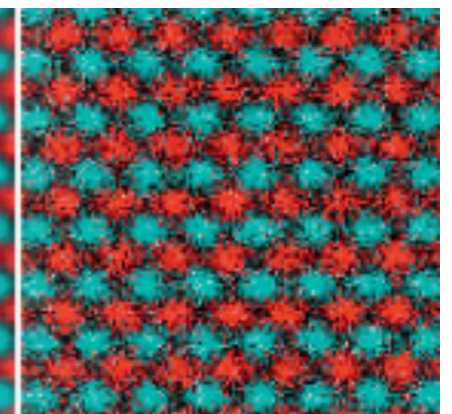
● - Ti

● - O

filtered

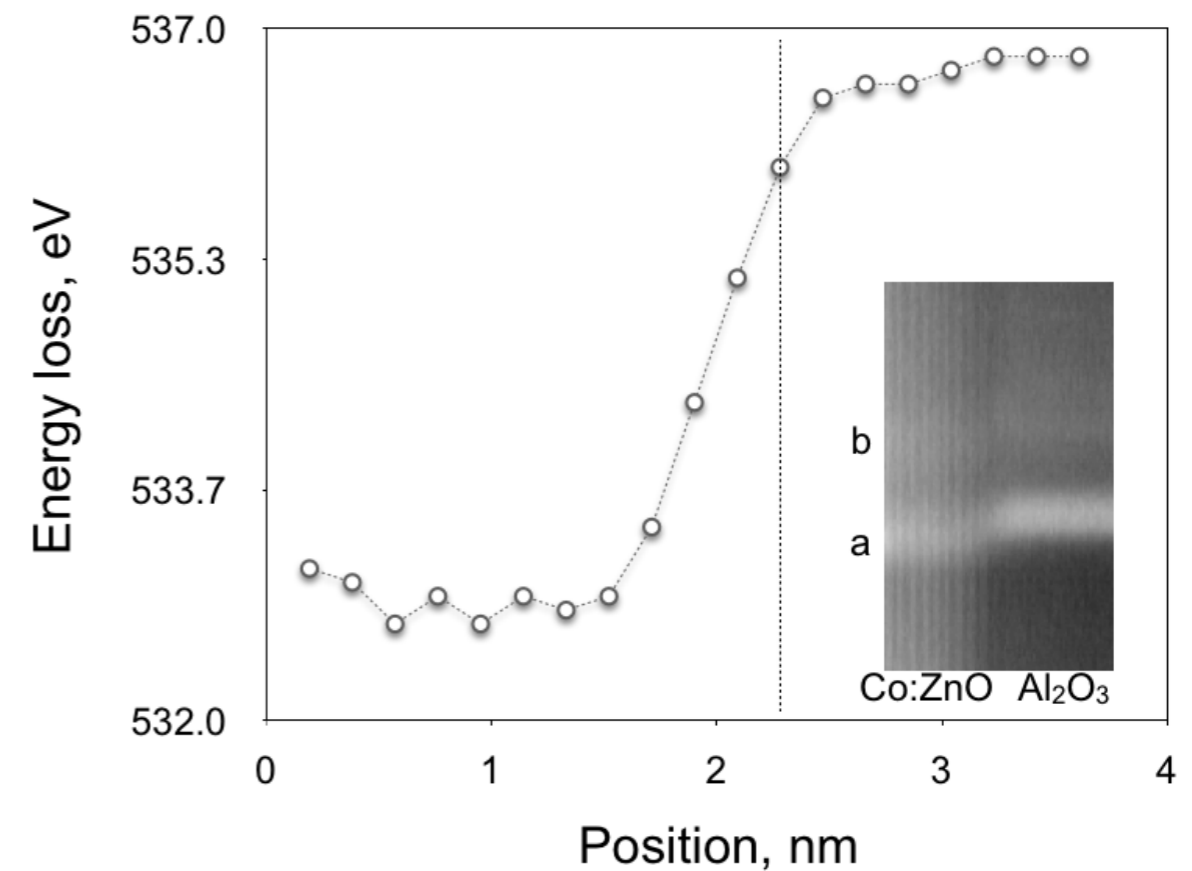
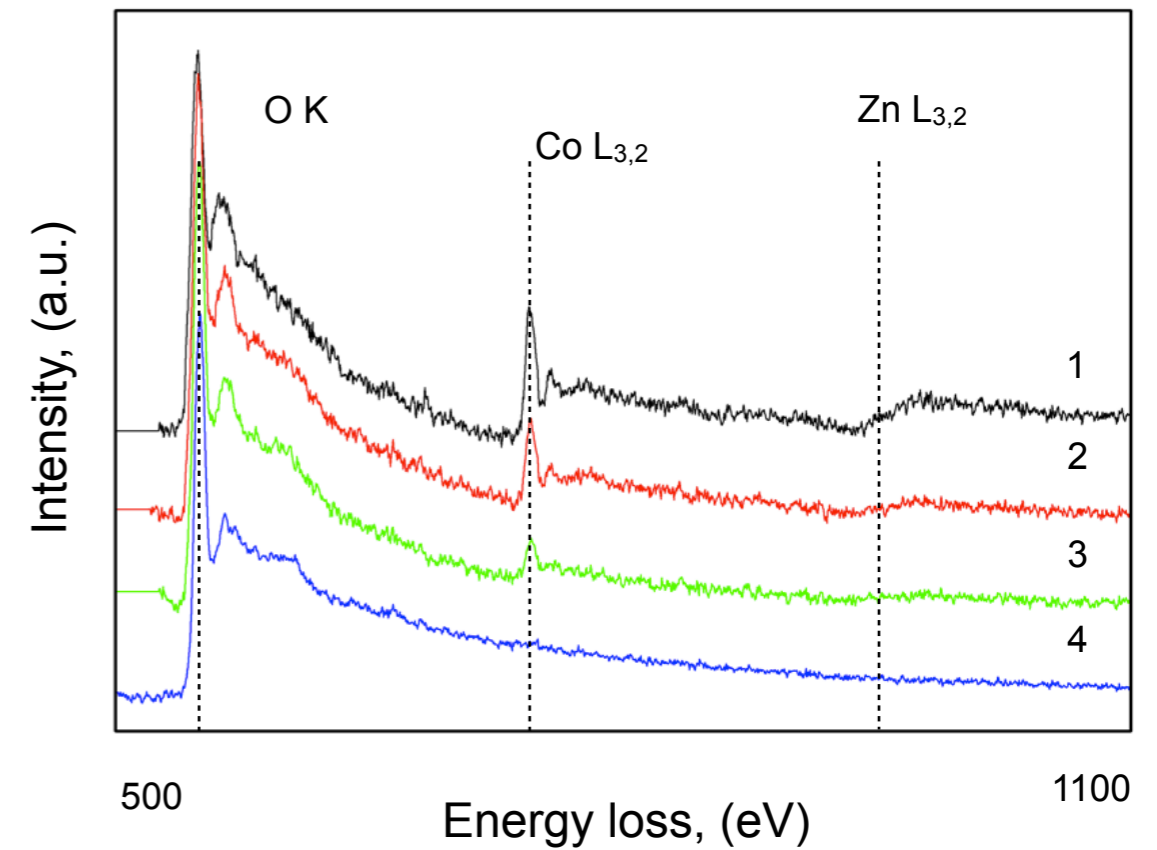
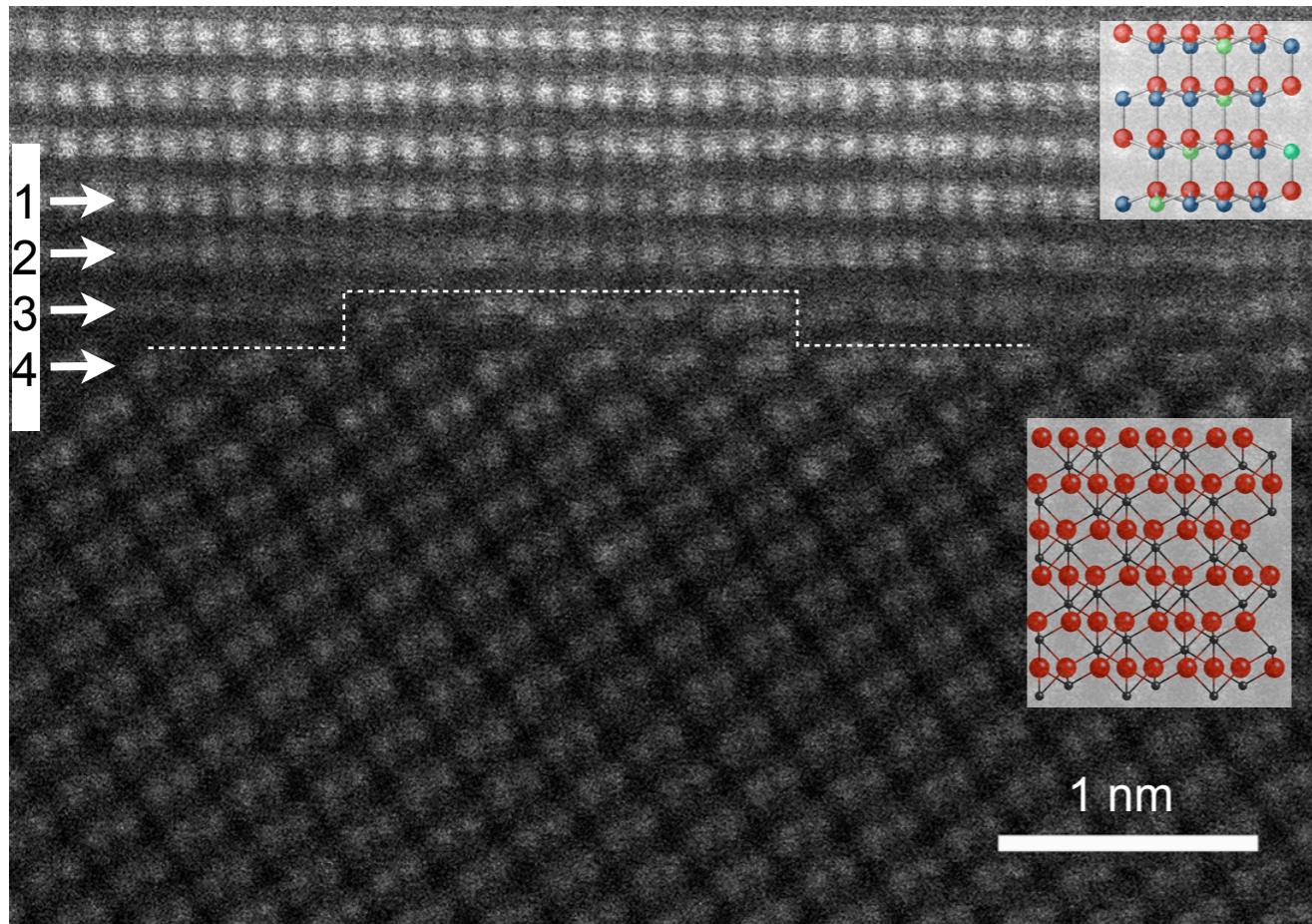


raw



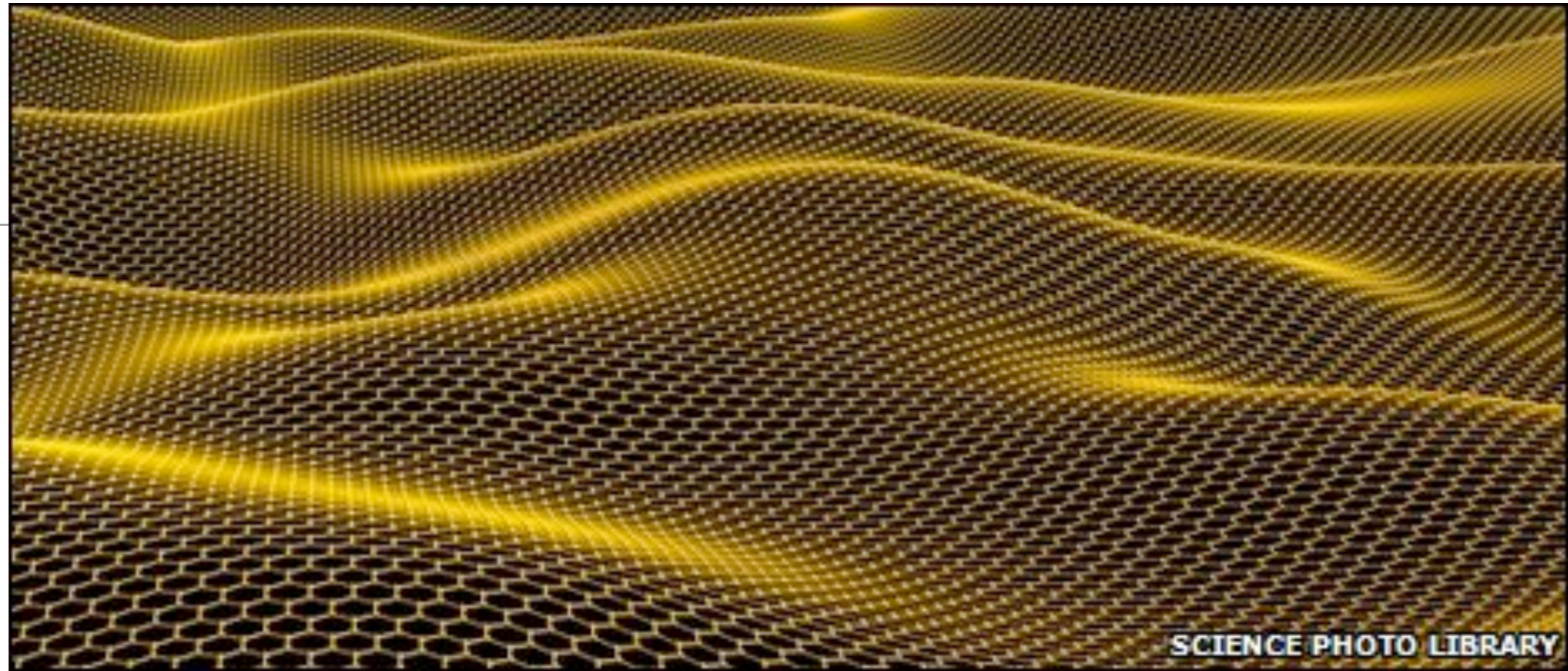
FEI - ChemiSTEM

Al_2O_3 és Co:ZnO határátmenet



Grafén

A. Geim, K. Novoselov
Nobel díj 2010



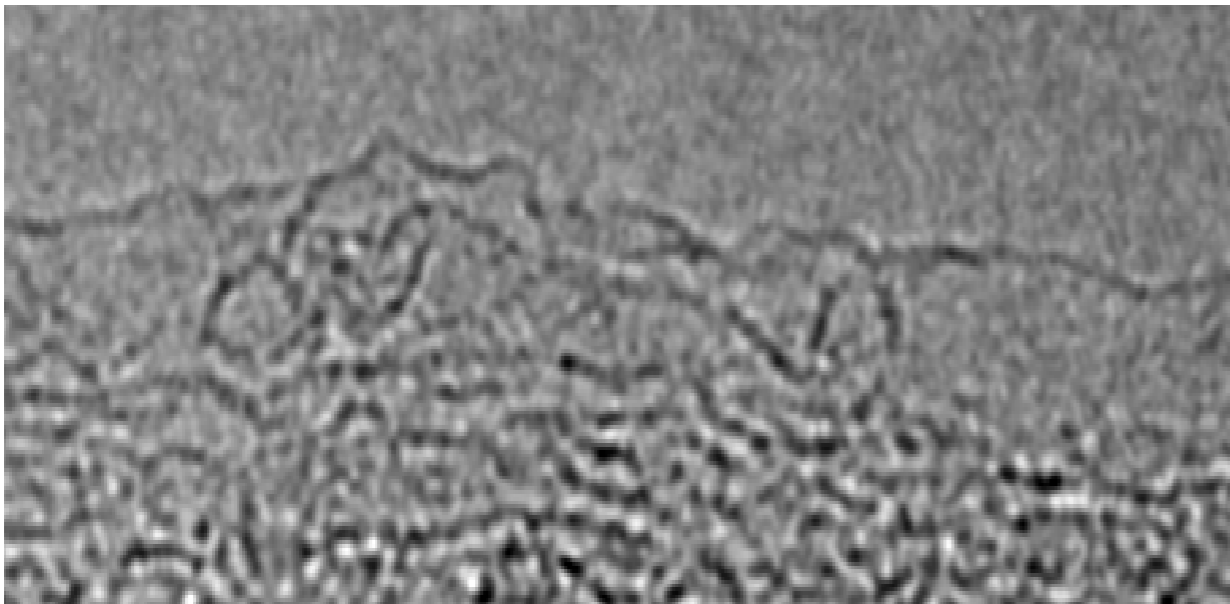
“miracle material”

- Elektron mobilitás $\sim 2 \times 10^5 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}$
- Young állandó 1 TPa (merevség) and szilárdság 130 GPa
- Magas hővezetés $\sim 3000 \text{ W mK}^{-1}$
- Magas optikai abszorpció
- Fenntartható magas áramsűrűség
- Ellenálló

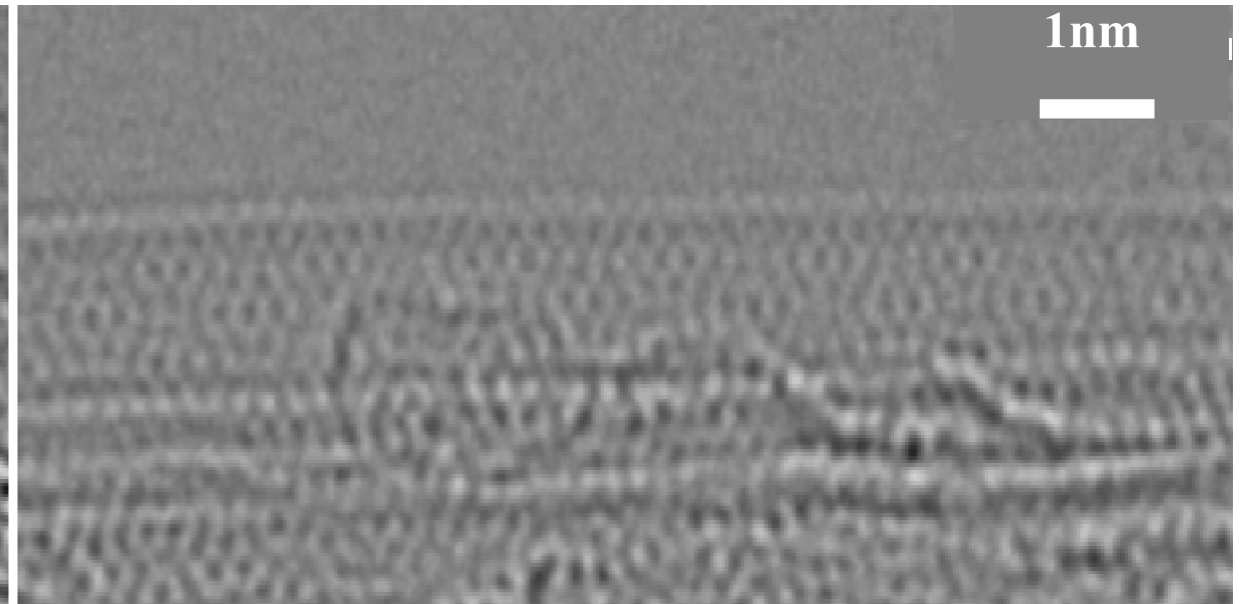
Knock-on damage of C $\sim 86 \text{ kV}$

Sugárérzékeny szén szerkezetek

Többsfalú szén nanocső

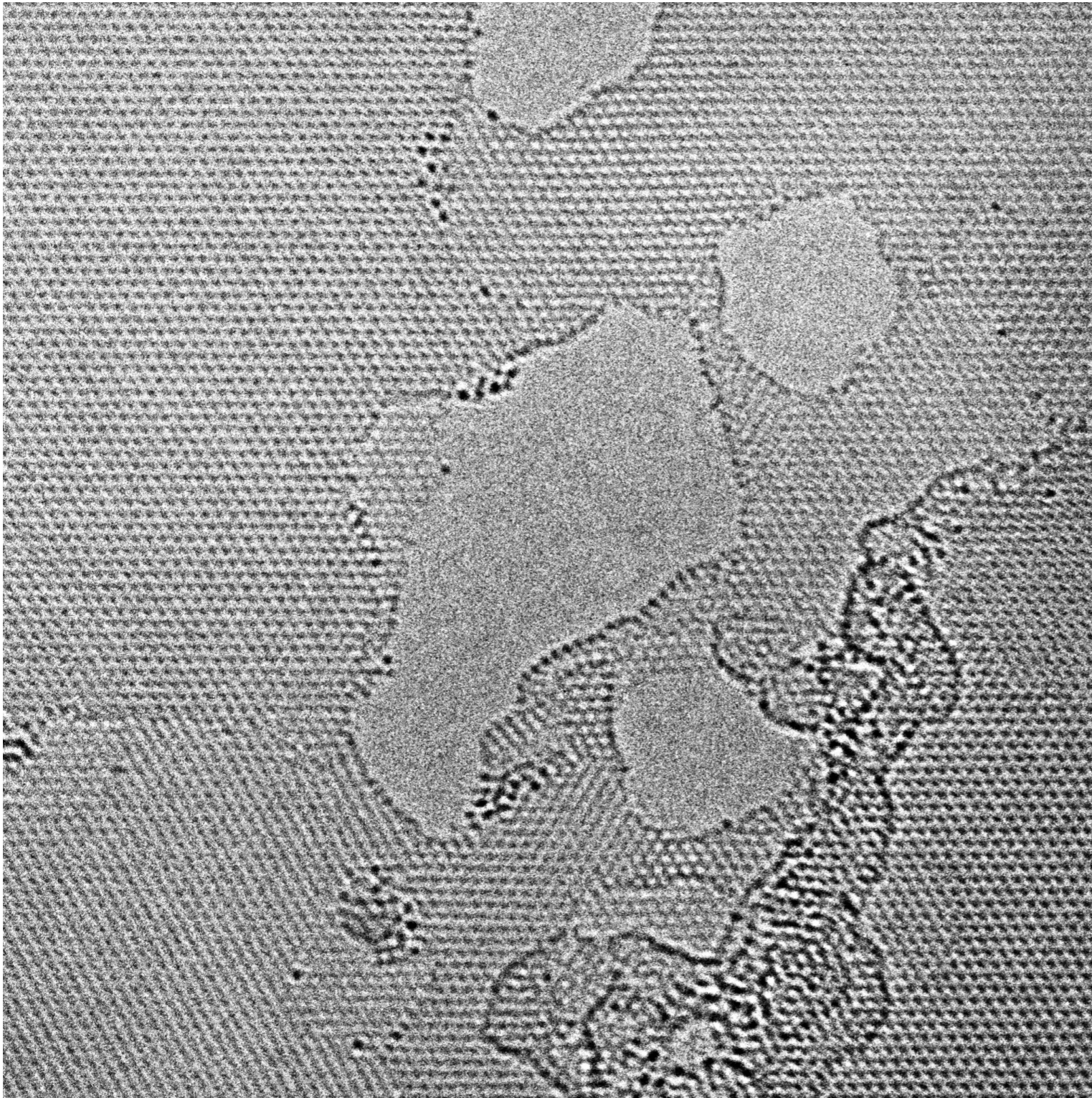


@ 300 kV



@ 80 kV

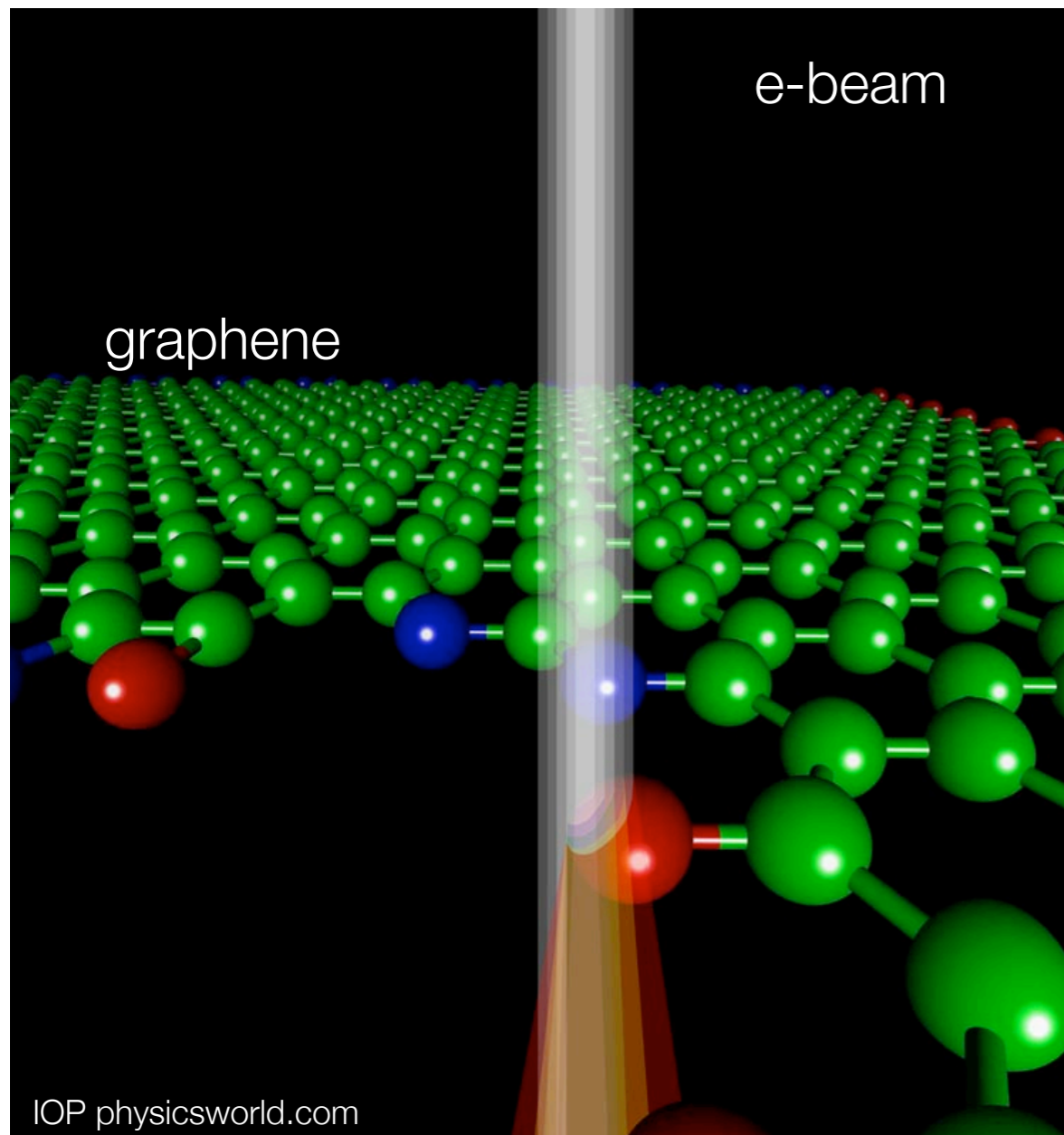
Grafén



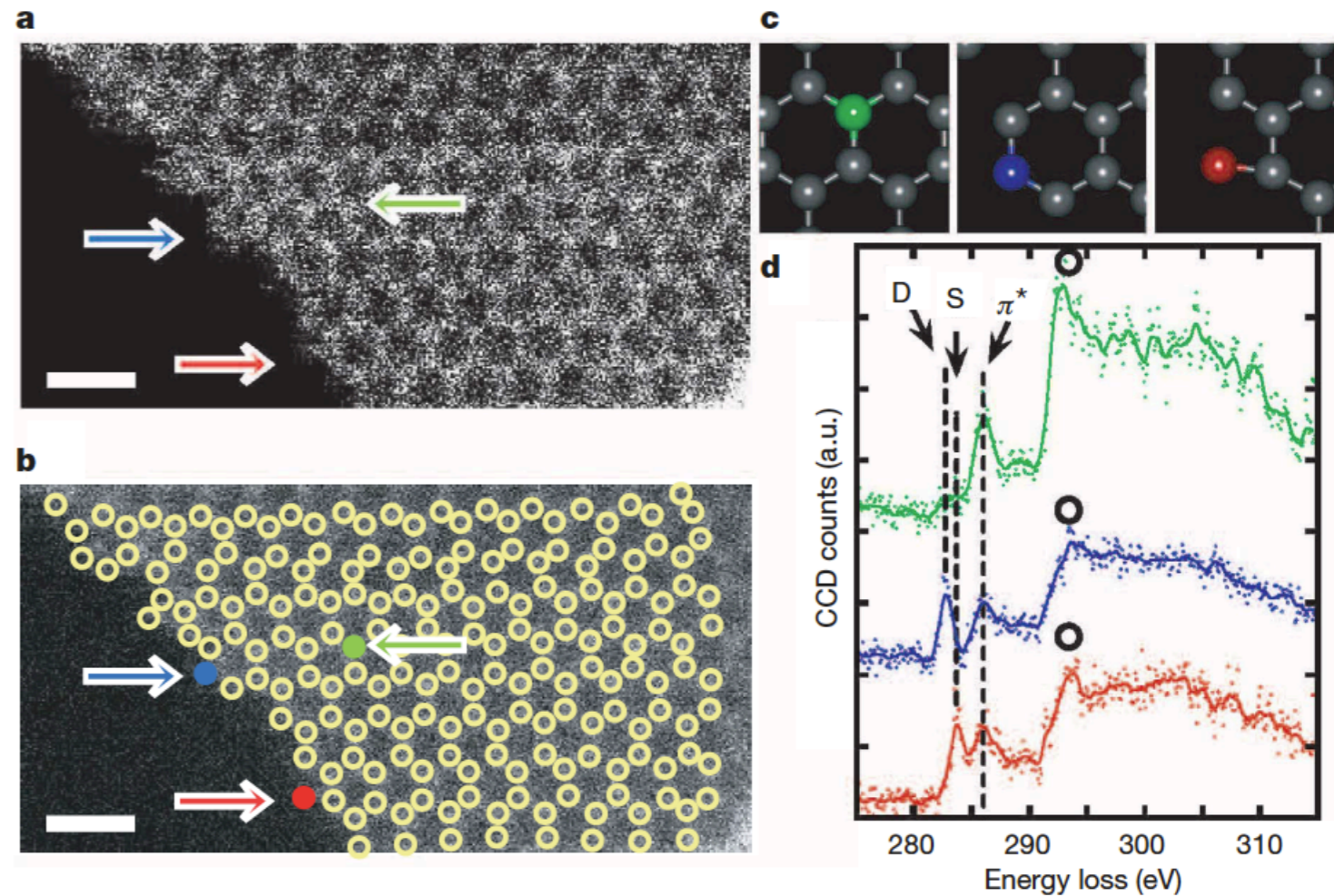
@ 80 kV

J. Jinschek

Atom leképezés és analitika

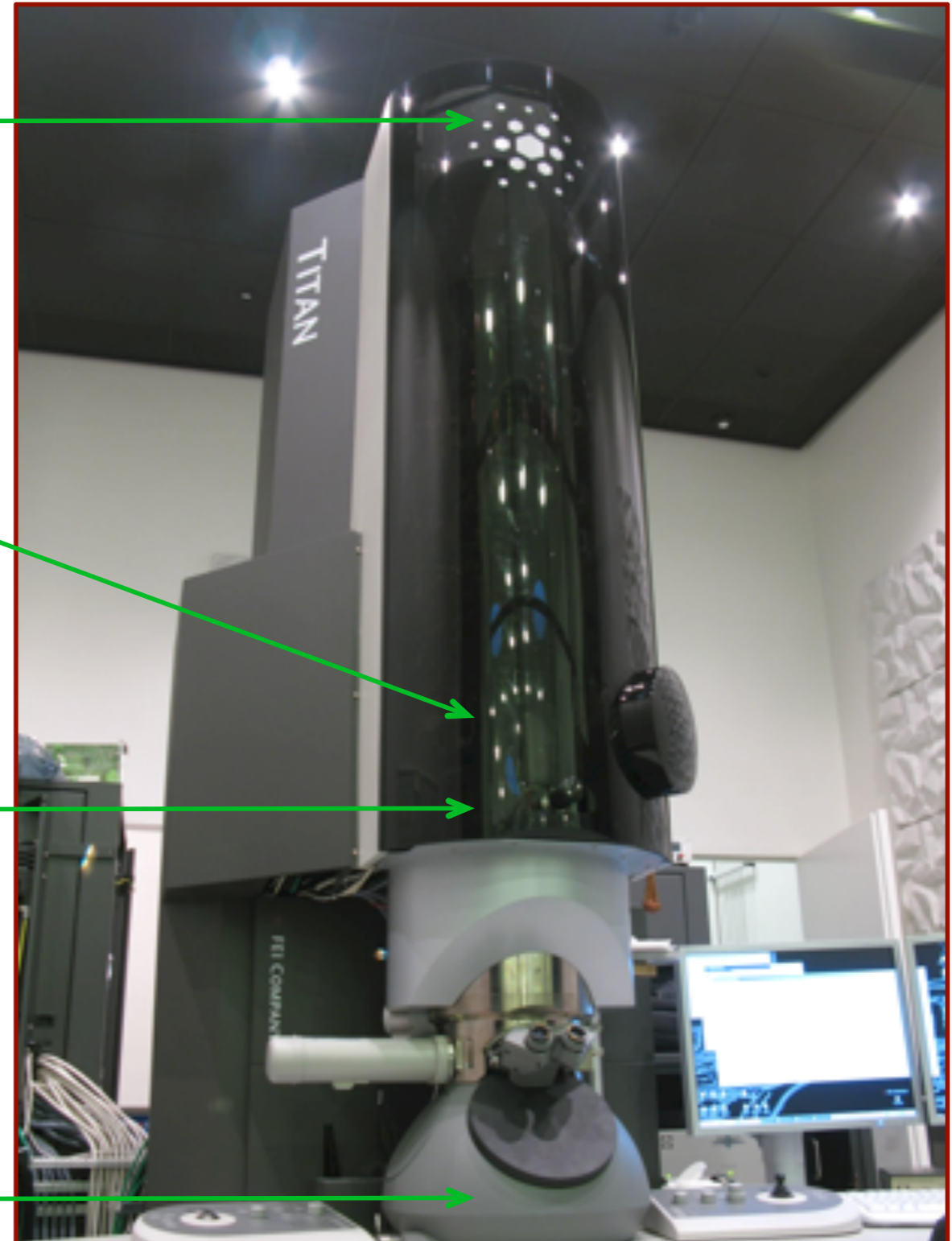
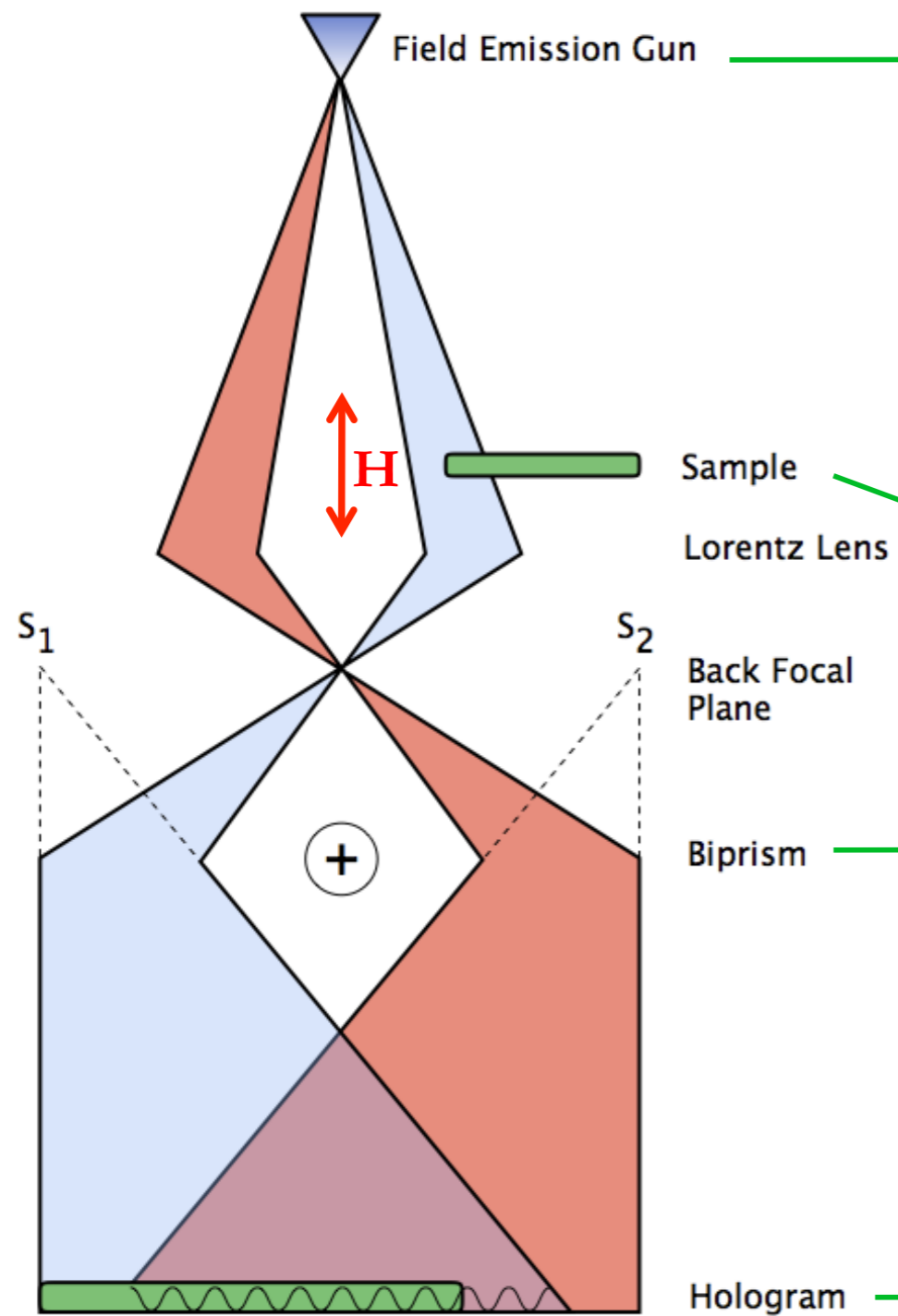


STEM + EELS

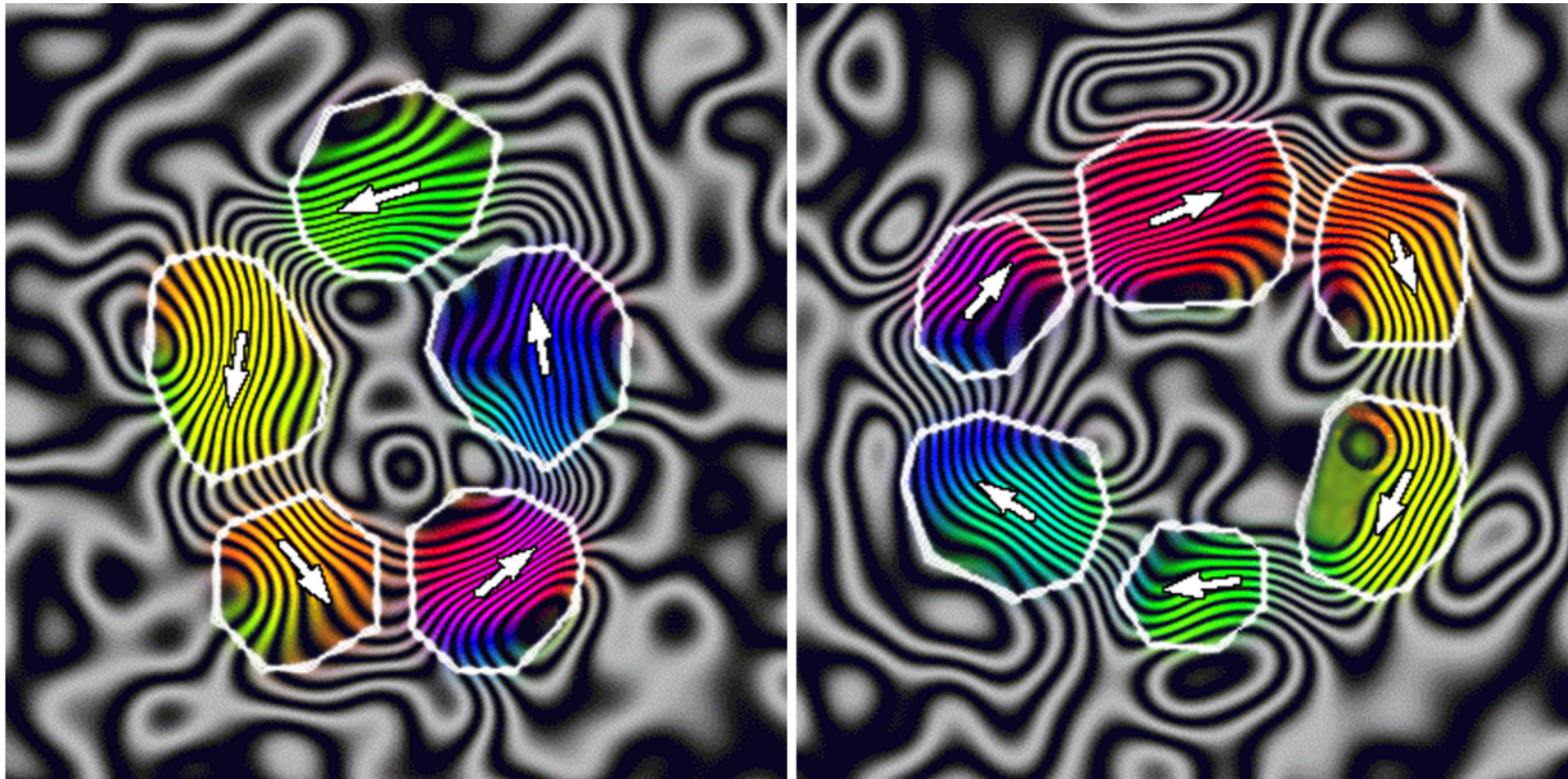


Suenaga, Nature 2010

Electron hologr fia

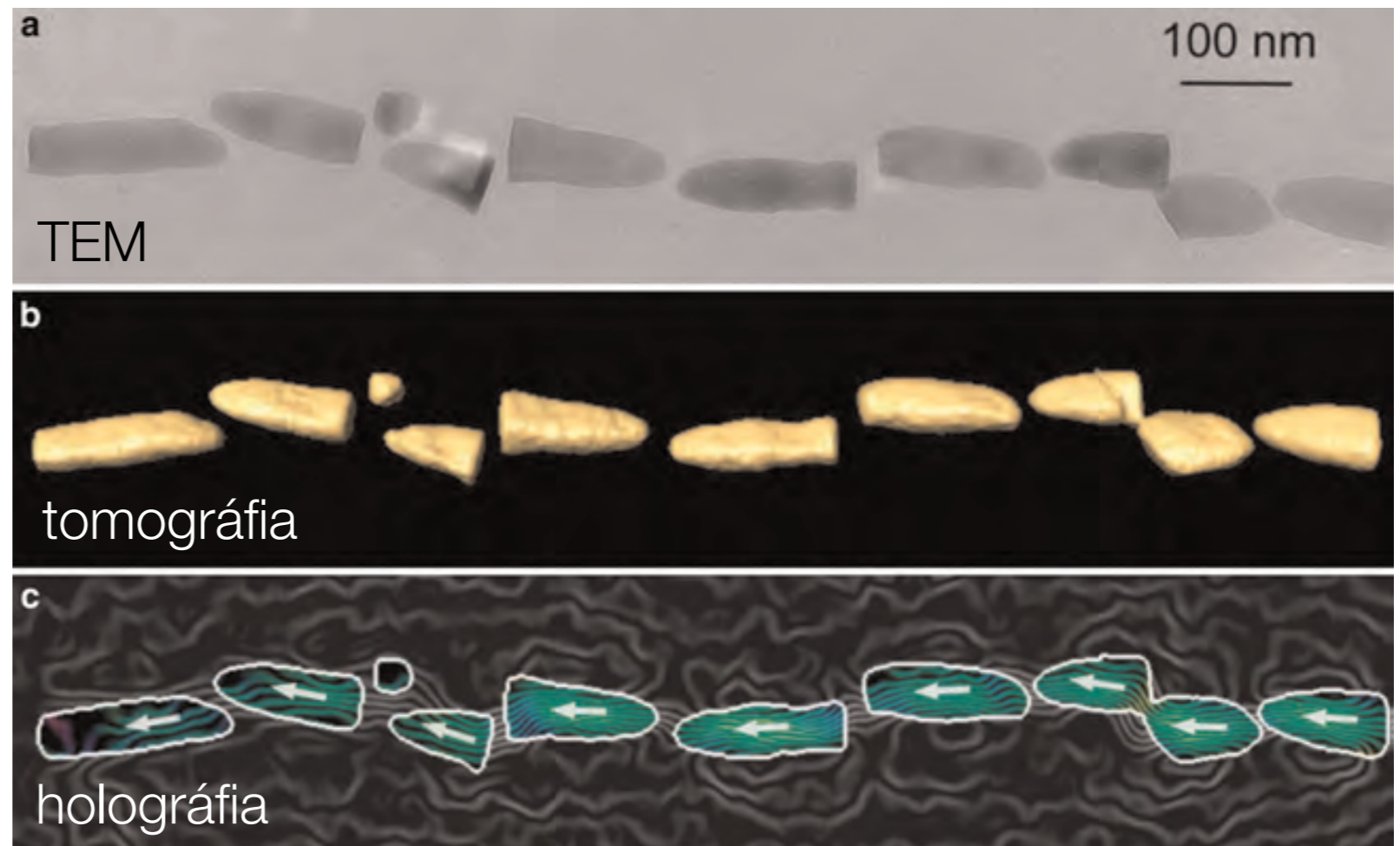
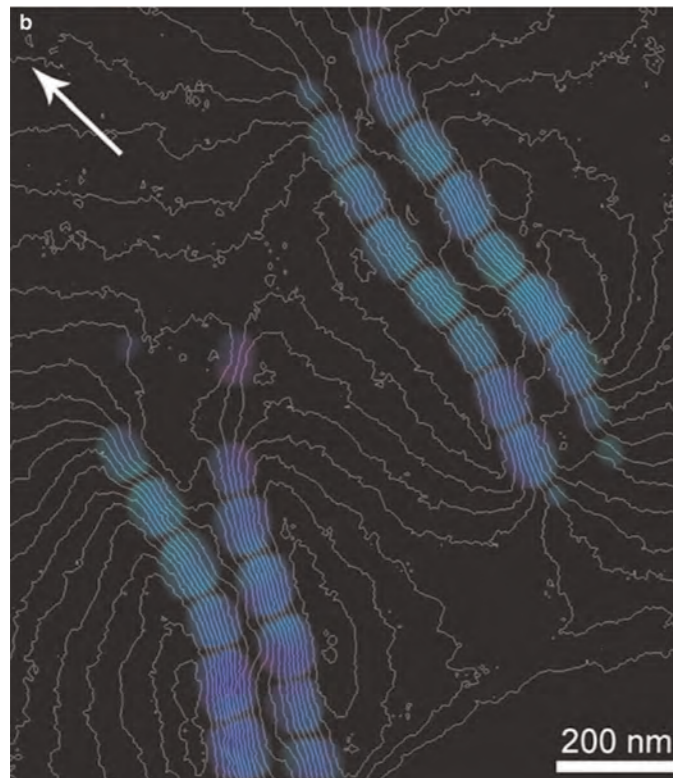
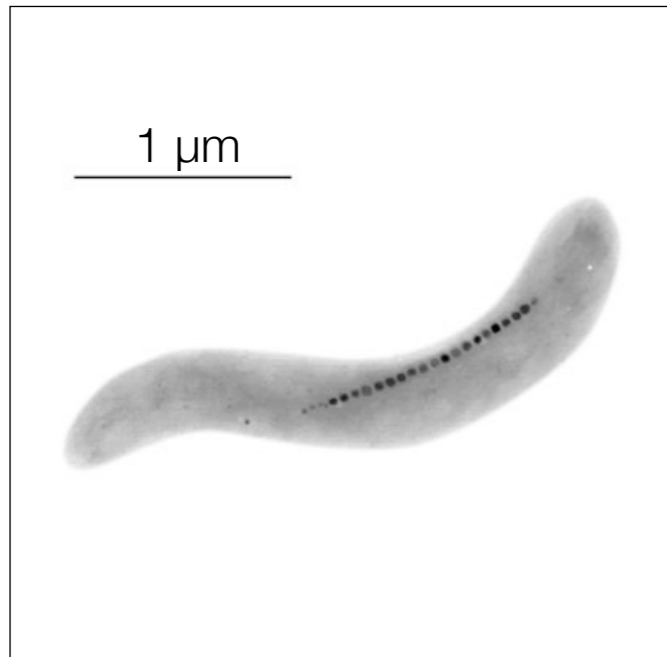


Co nanokristályok mágneses tere



50 nm

Magnetoszómak



Összefoglalásul

Egy modern TEM berendezés

- nagy felbontású szerkezeti, összetételi, elektromos, mágneses és kémiai információkat képes biztosítani;
- elengedhetetlen része biológiai, kémiai, fizikai, nanotechnológiai, geológia kutatásoknak;
- sajnos drága megvenni és fenntartani;
- speciális tudású kutatókat igényel;

ESTEEM-2

<http://esteem2.eu>

esteem2
european network for electron microscopy

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the European network of Transmission Electron Microscopy for materials science. ESTEEM2 offers free access to the most powerful TEM installations in Europe by a simple application procedure.

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[read more](#)

The CEMES-CNRS edits a book on Transmission Electron Microscopy in Micro-nanoelectronics
[read more](#)

European network of transmission electron microscopy for materials science

“PICO”



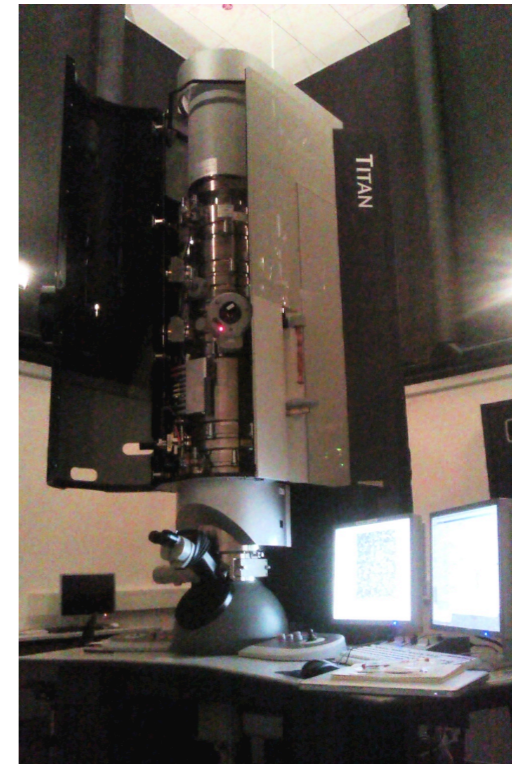
Titan - “S”



Titan - “T”



“HOLO”



(Titan - “A”)



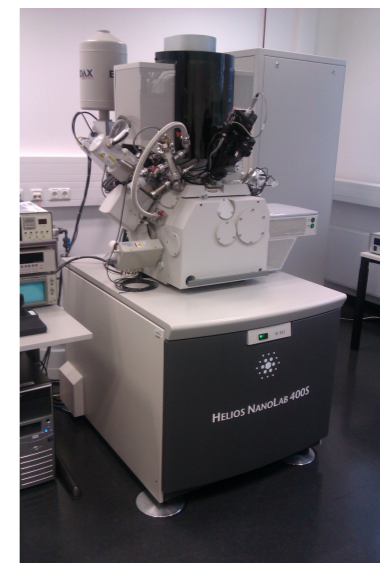
4000EX



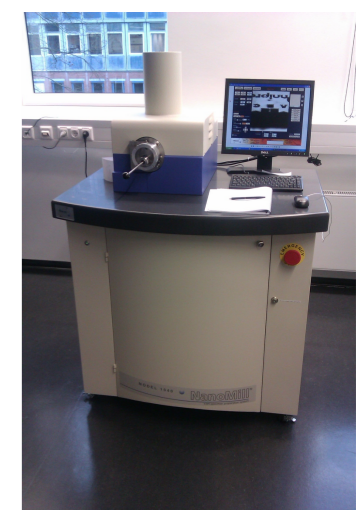
Tecnai F20



CM20 F



Helios



Nanomill