ANDERSON CAIRES

TEM

“A Aula”

Outline

Figures

D.B. Williams, C.B. Carter; Transmission Electron Microscopy – A Textbook for Materials Science, 2nd Edition, Springer Publisher, 2009

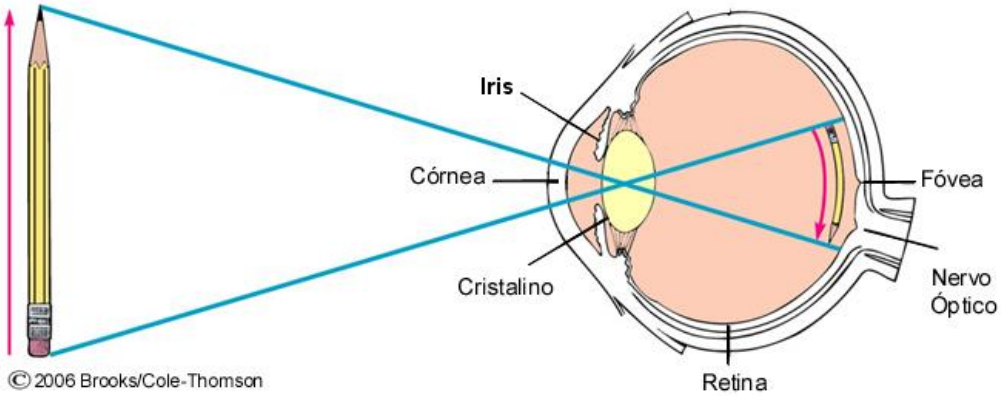
History of the Light Microscope - https://loci.wisc.edu/outreach/history-light-microscope

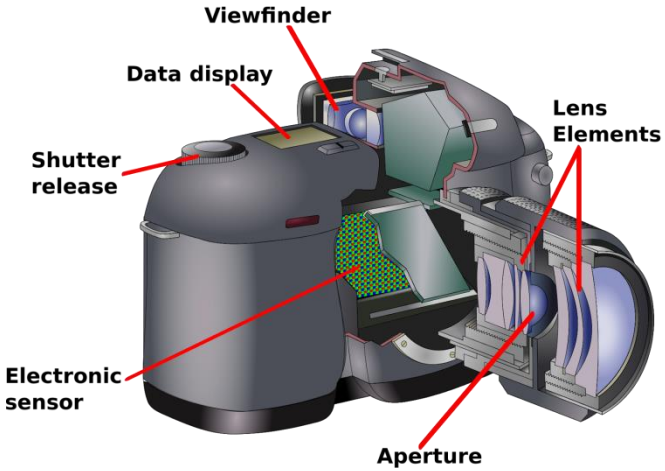
Wikipedia

CM-UFMG

Artigos citados

FEI Company Flick

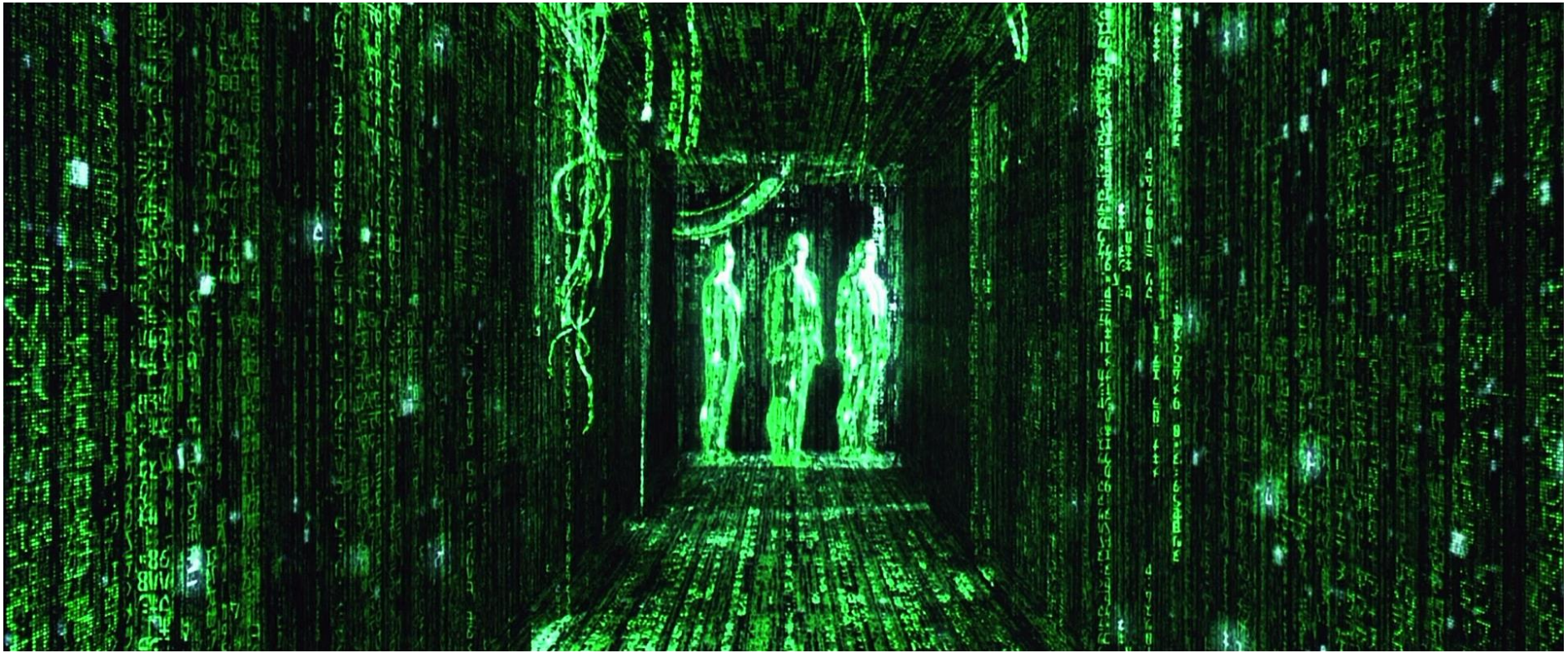




Fonte: Licença de uso creative commons

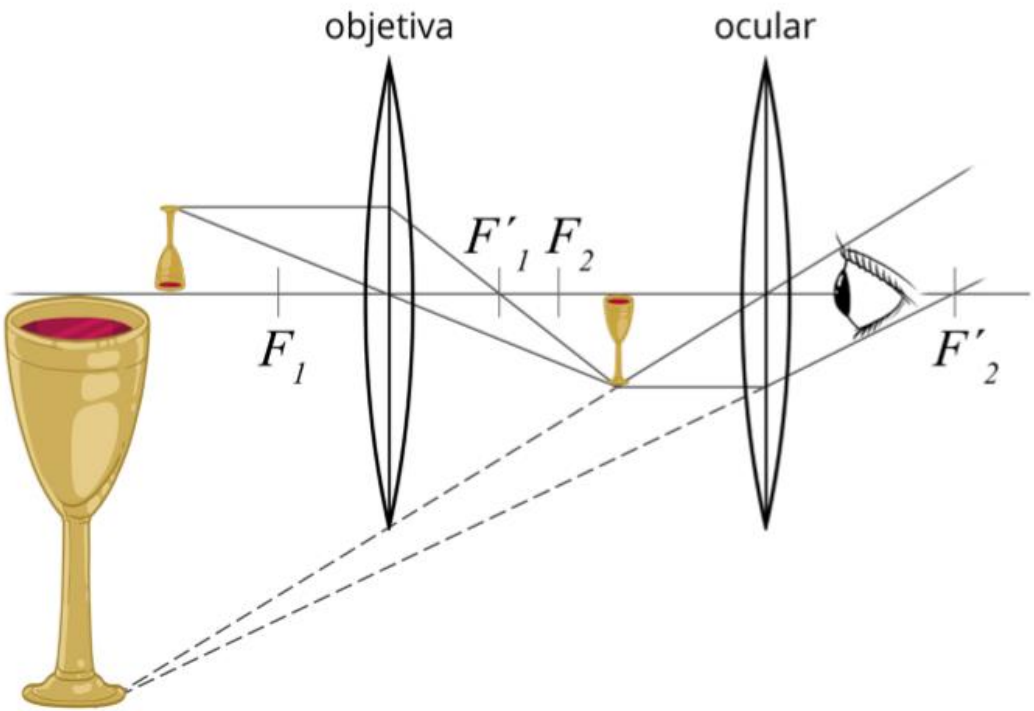
SEM

TEM



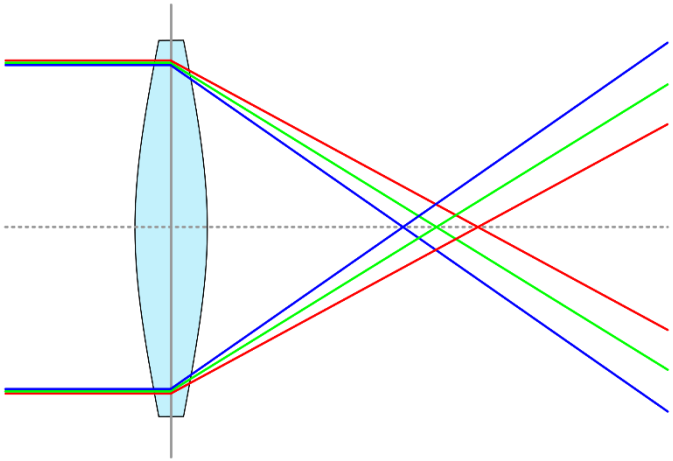
Fonte: Licença de uso creative commons

Simple Microscopes

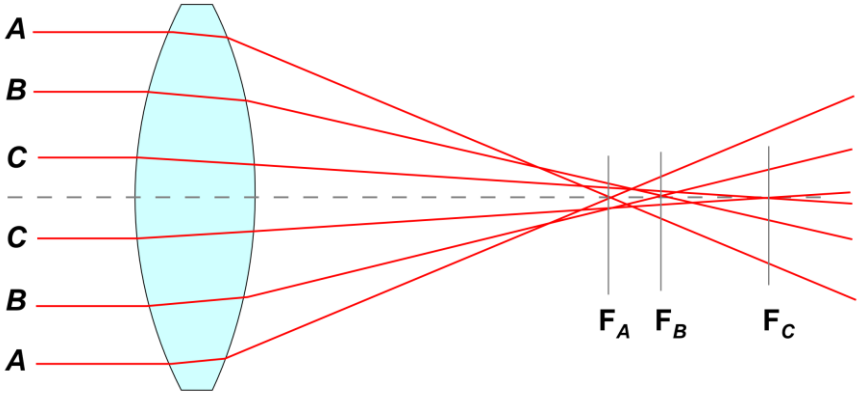


Fonte: Licença de uso creative commons

Chromatic aberration



Spherical aberration



Fonte: Wikipédia, licença de uso creative commons

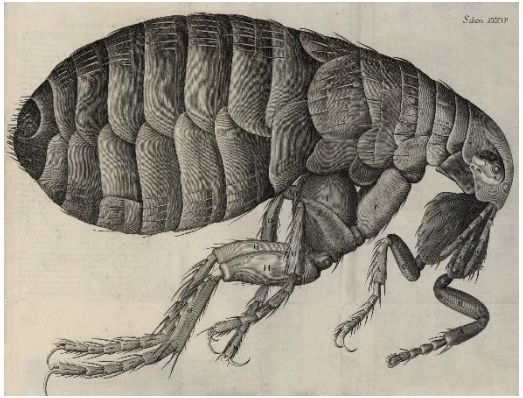
Galileo

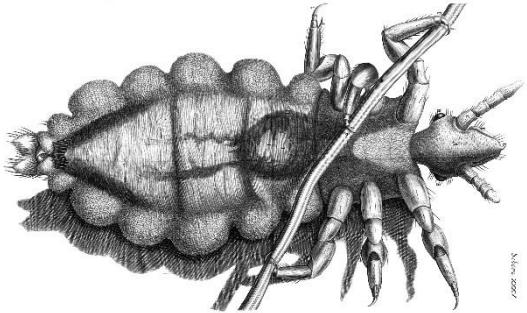
https://loci.wisc.edu/outreach/history-light-microscope

1609 - Galileo Galilei develops a compound microscope with convex and a concave lens.

Hooke

Hooke microscope

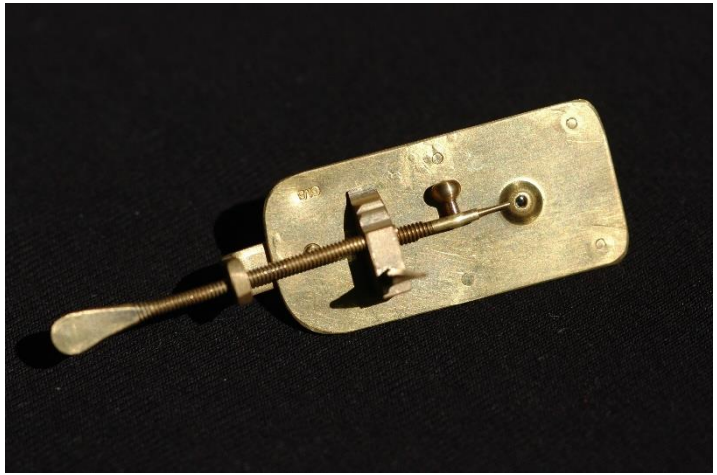




1665 - Robert Hooke's book called Micrographia officially documented a wide range of observations through the microscope.

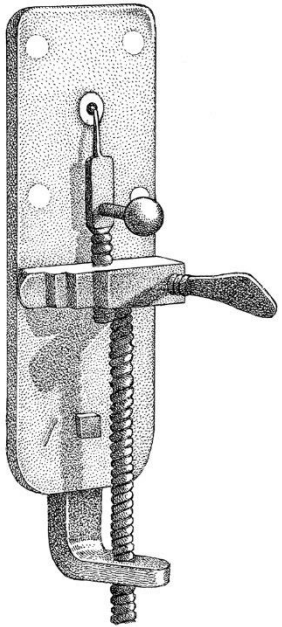
https://loci.wisc.edu/outreach/history-light-microscope

Van leeuwenhoek

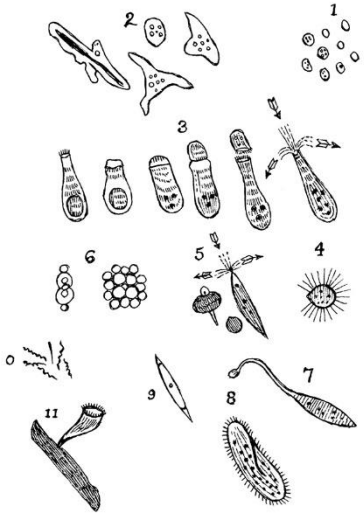


Van leeuwenhoek

1674 - Anton van Leeuwenhoek used his knowledge of grinding lenses to achieve greater magnification which he utilized to make a microscope, enabling detailed observations



LEEUWENHOEK'S MICROSCOPE



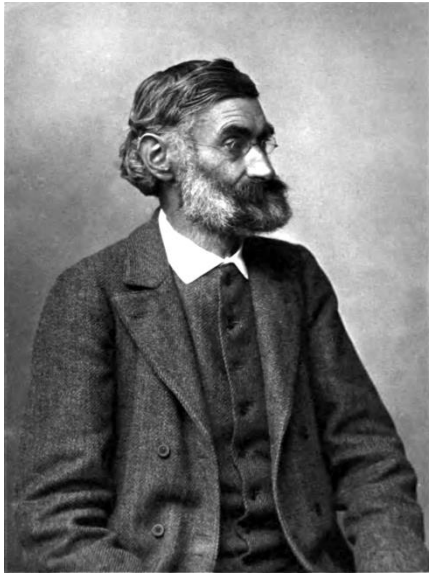
LEEUWENHOEK'S ANIMALCULES

https://loci.wisc.edu/outreach/history-light-microscope

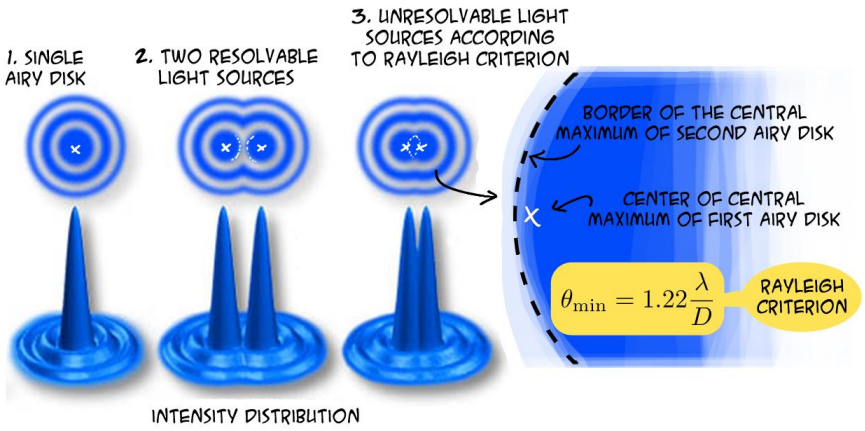
History of the Light Microscope

https://loci.wisc.edu/outreach/history-light-microscope

Resolution – Abbe Diffraction Limit



Ernst Abbe
1840 - 1905

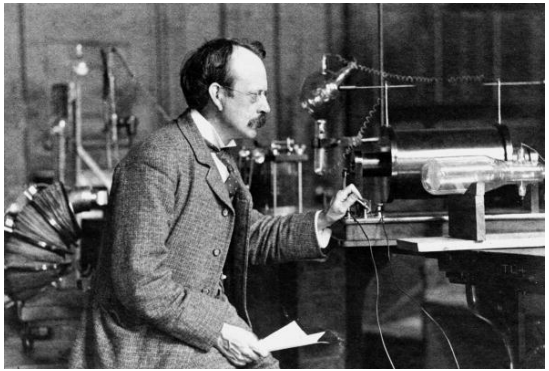


$$R_d = \frac{\lambda}{2(nsen\theta)}$$

λ = 550 nm **(Verde)**

R_d **~ 300 nm**

The Electron Discovery



Joseph John Thomson 1856 - 1940

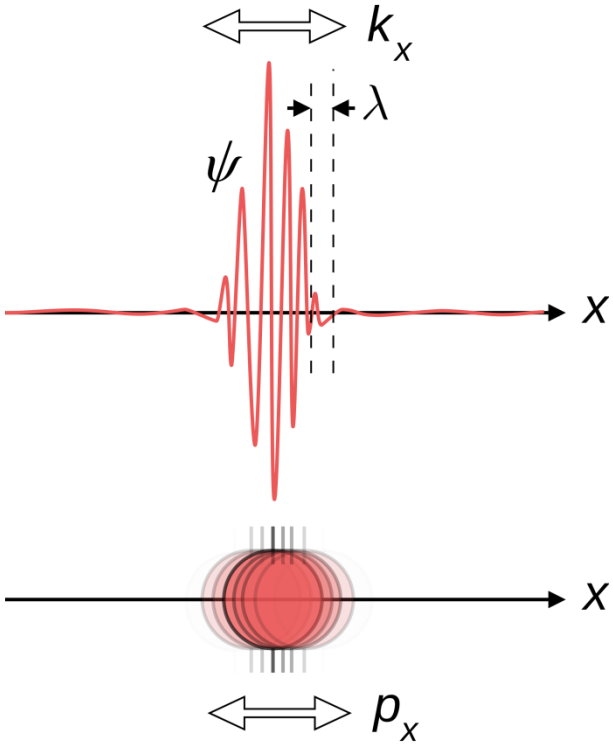
In 1897 Thomson showed that the cathode rays are negatively charged particles, performing experiments to measure the mass to charge ratio (me/e) of these particles. He was awarded the 1906 Nobel Prize in physics

(1802) T. Young ..... Light is a wave !!
(1897) J.J. Thomson ..... Electron is a particle !!
(1905) A. Einstein ..... Light is a particle !!

Fonte: Wikipédia, licença de uso creative commons

The Duality Particle-Wave

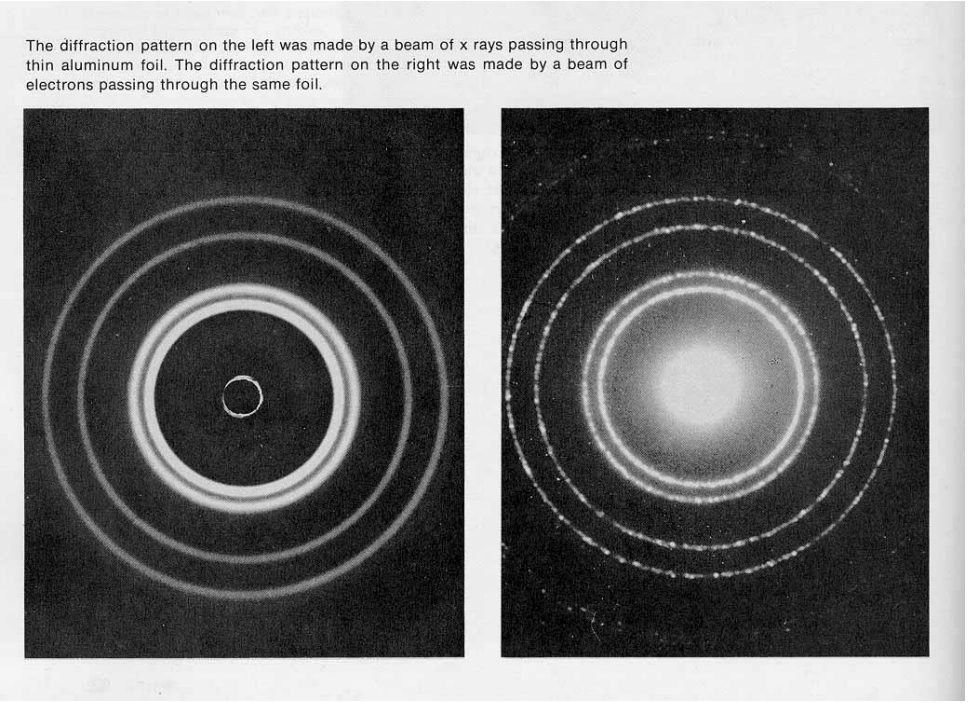
Louis de Broglie 1892 – 1987

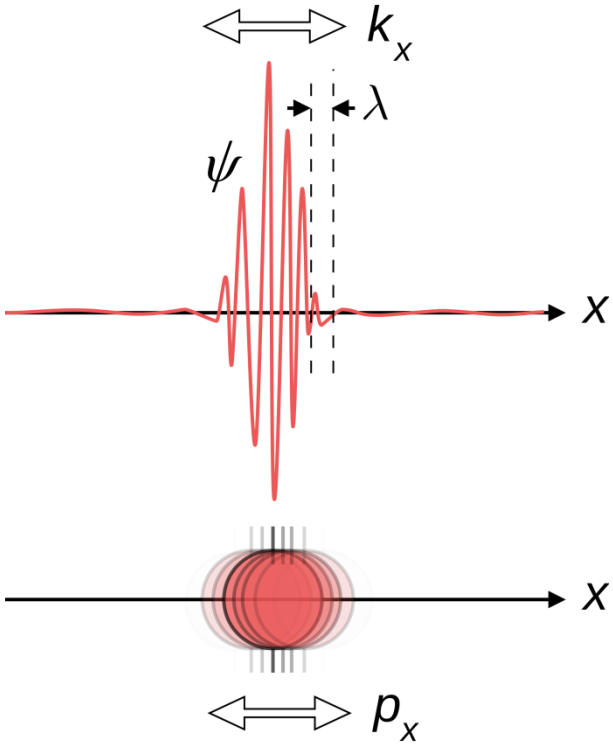


$$\lambda = \frac{h}{p}$$

Fonte: Wikipédia, licença de uso creative commons

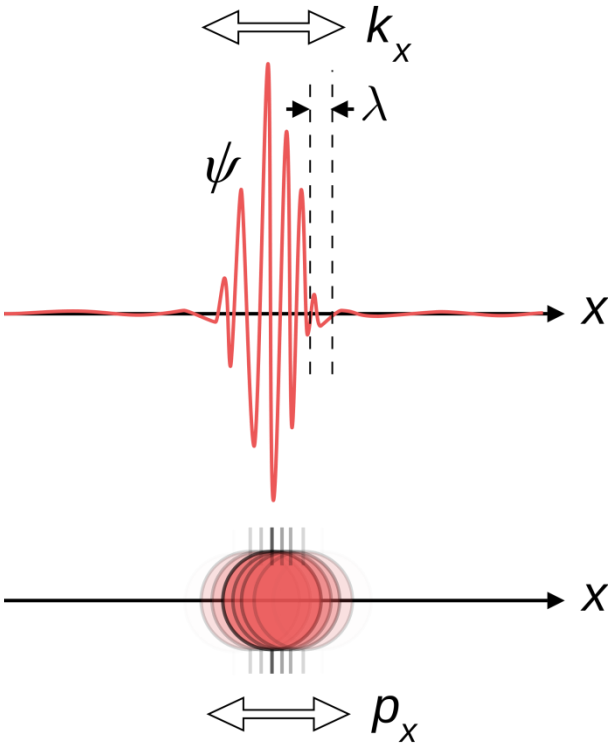
The Duality Particle-Wave





Fonte: Wikipédia, licença de uso creative commons

The Duality Particle-Wave



$$\lambda = \frac{h}{p}$$

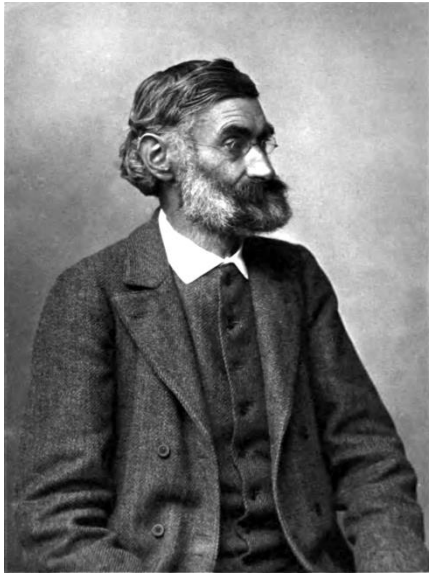
$$eV = \frac{m_0 v^2}{2}$$

$$p = m_0 v = (2 m_0 e V)^{1/2}$$

$$\lambda = \frac{h}{(2 m_0 e V)^{1/2}}$$

Fonte: Wikipédia, licença de uso creative commons

Resolution – Abbe Diffraction Limit



Ernst Abbe
1840 - 1905

$$\lambda = \frac{h}{(2m_0 eV)^{1/2}}$$

TABLE 1.2 Electron Properties as a Function of Accelerating Voltage

Accelerating voltage (kV)	Non-relativistic wavelength (nm)	Relativistic wavelength (nm)	Mass ($\times m_0$)	Velocity ($\times 10^8$ m/s)
100	0.00386	0.00370	1.196	1.644
120	0.00352	0.00335	1.235	1.759
200	0.00273	0.00251	1.391	2.086
300	0.00223	0.00197	1.587	2.330
400	0.00193	0.00164	1.783	2.484
1000	0.00122	0.00087	2.957	2.823

$$R_d = \frac{\lambda}{2(nsen\theta)}$$

Rd ~ 0.05 Å

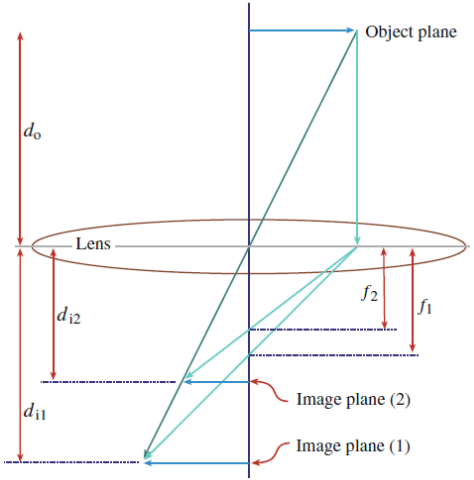
Modern TEMs: Rd ~ 0.5 Å

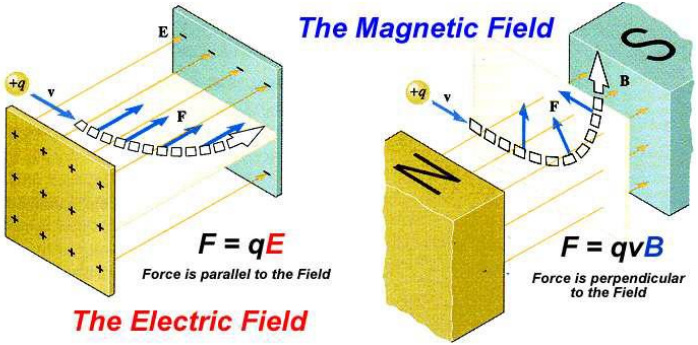
Isolated neutral atoms - 0.3 and 3 ångströms.

A Microscope Needs Lenses !!

Hans Busch
1884 - 1973

Electron optics was born in 1927, when Hans Busch showed that the elementary lens equation is applicable to short magnetic coils





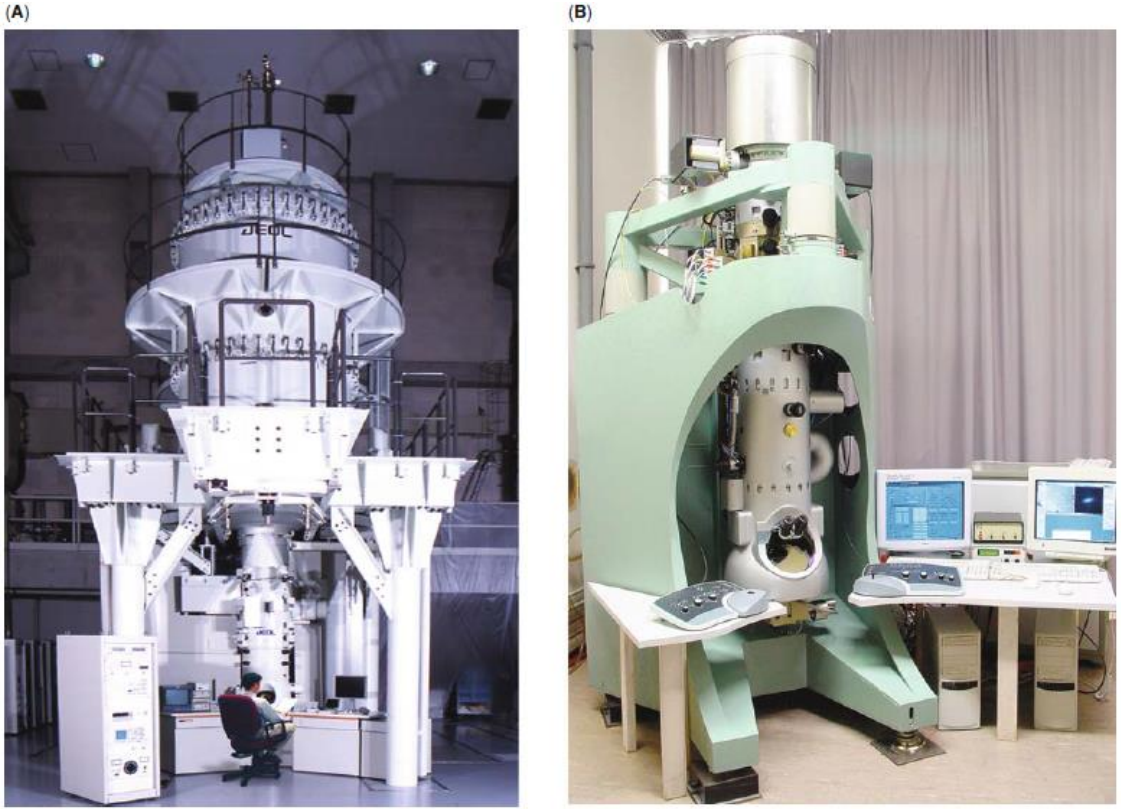
D.B. Williams and C.B. Carter

First Electron Microscope

D.B. Williams and C.B. Carter

Modern TEMs

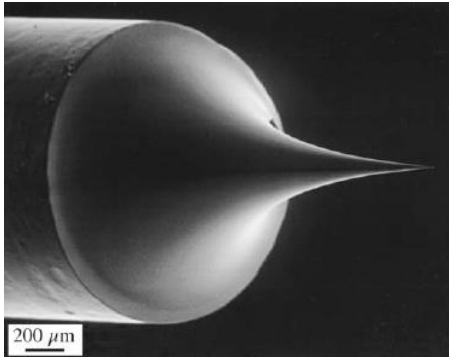
- **Aumento de V aumenta resolução**
- **Raios-X**
- **Custo**
- **Alguns Materiais**

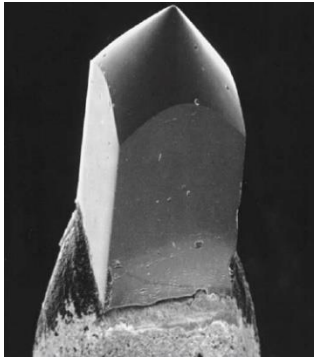


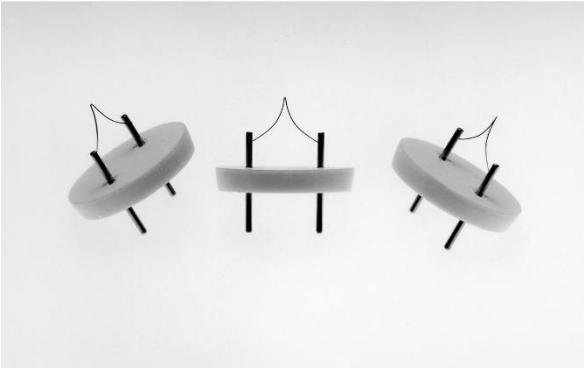
D.B. Williams and C.B. Carter

The Instrument

Gun







LaB6

Tungsten Filament

Field Emission

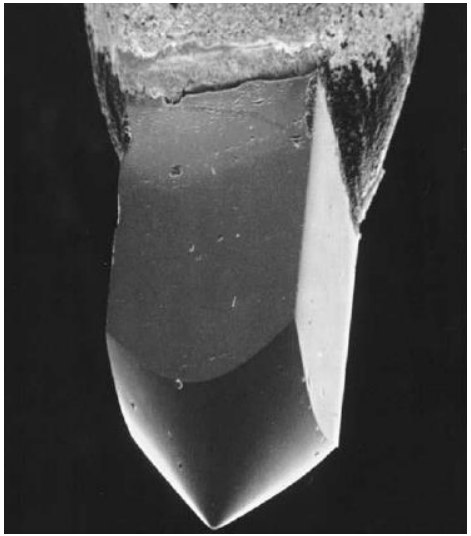
$$J = AT^2 e^{-\frac{\Phi}{kT}}$$

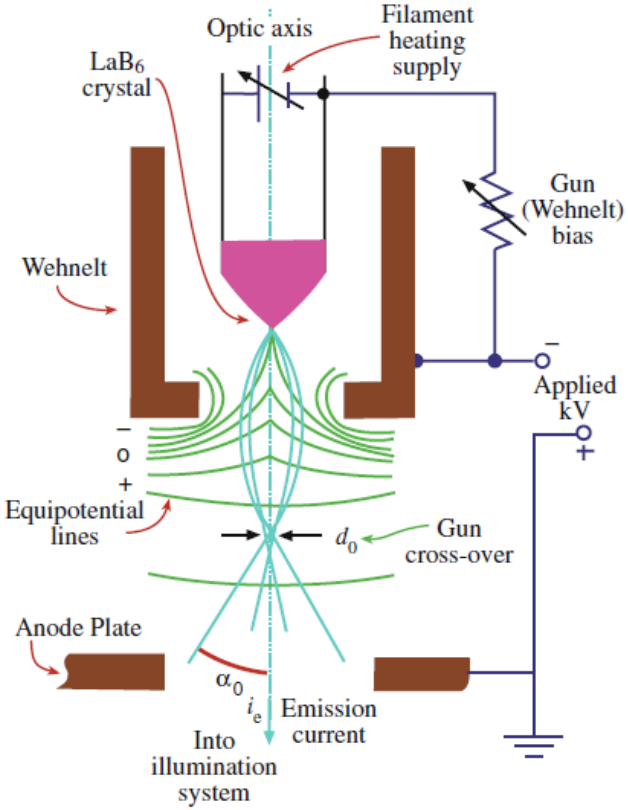
Richardson's Law

D.B. Williams and C.B. Carter

Gun

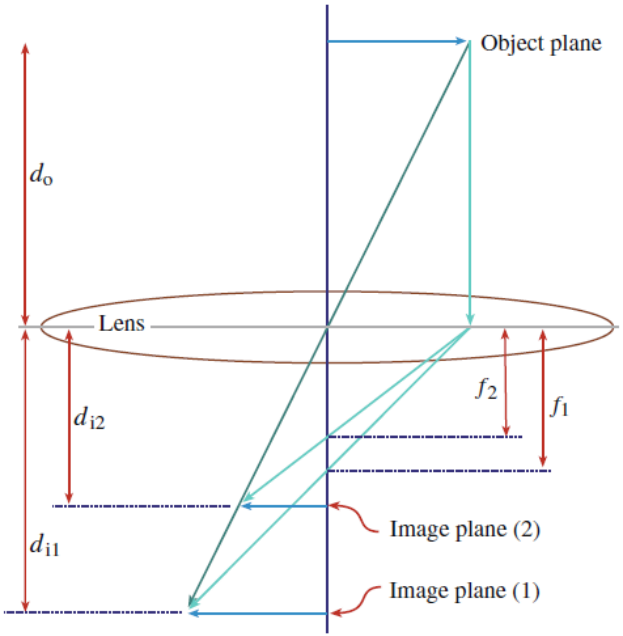
LaB6

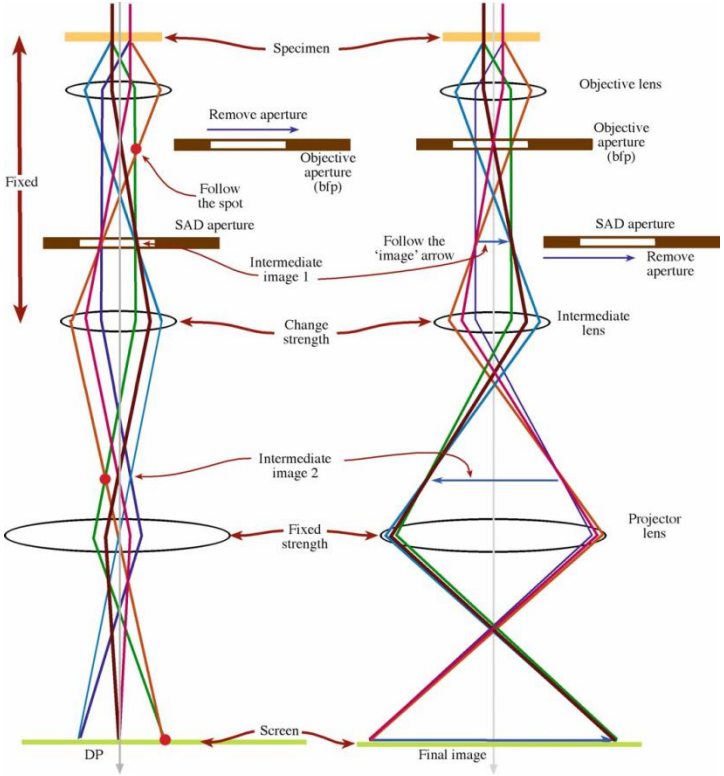




D.B. Williams and C.B. Carter

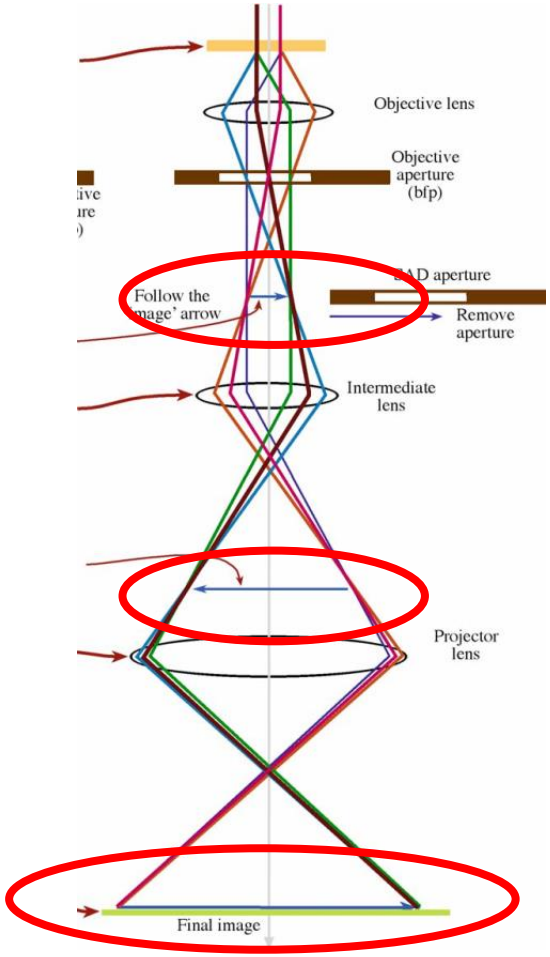
Lenses

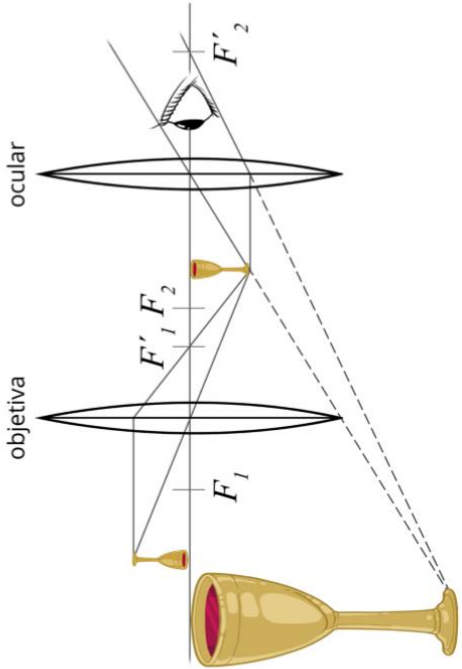




D.B. Williams and C.B. Carter

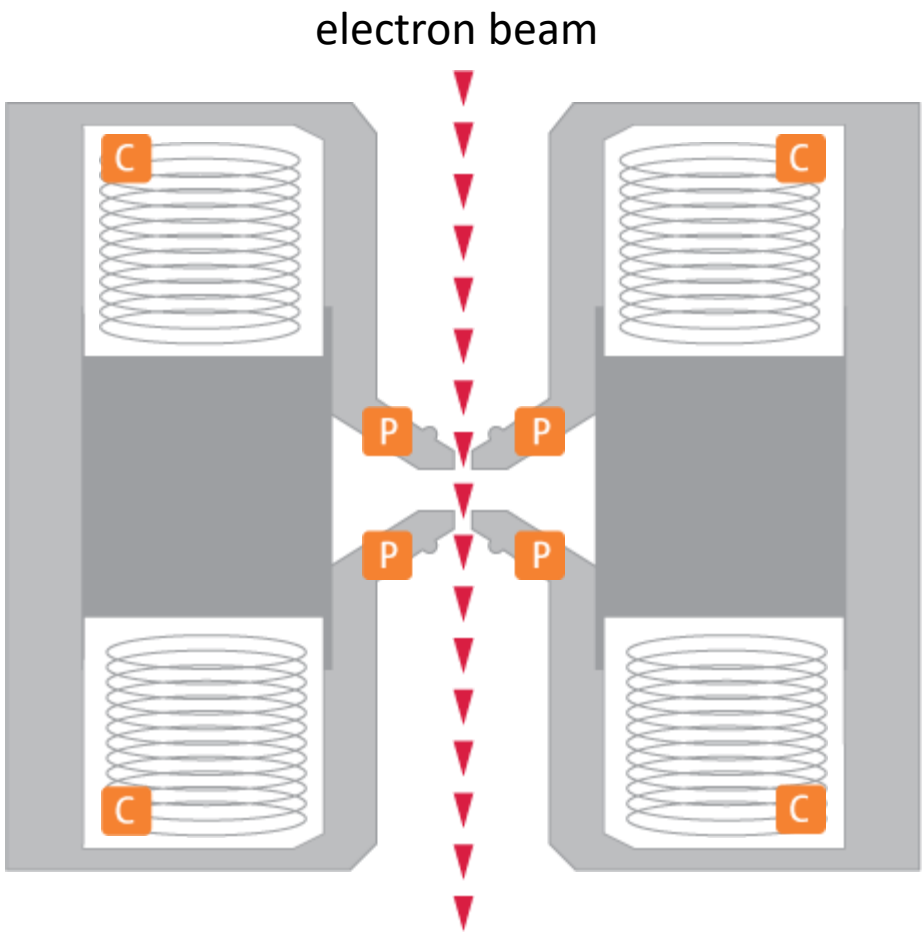
Lenses





D.B. Williams and C.B. Carter

Lenses



C electrical coil

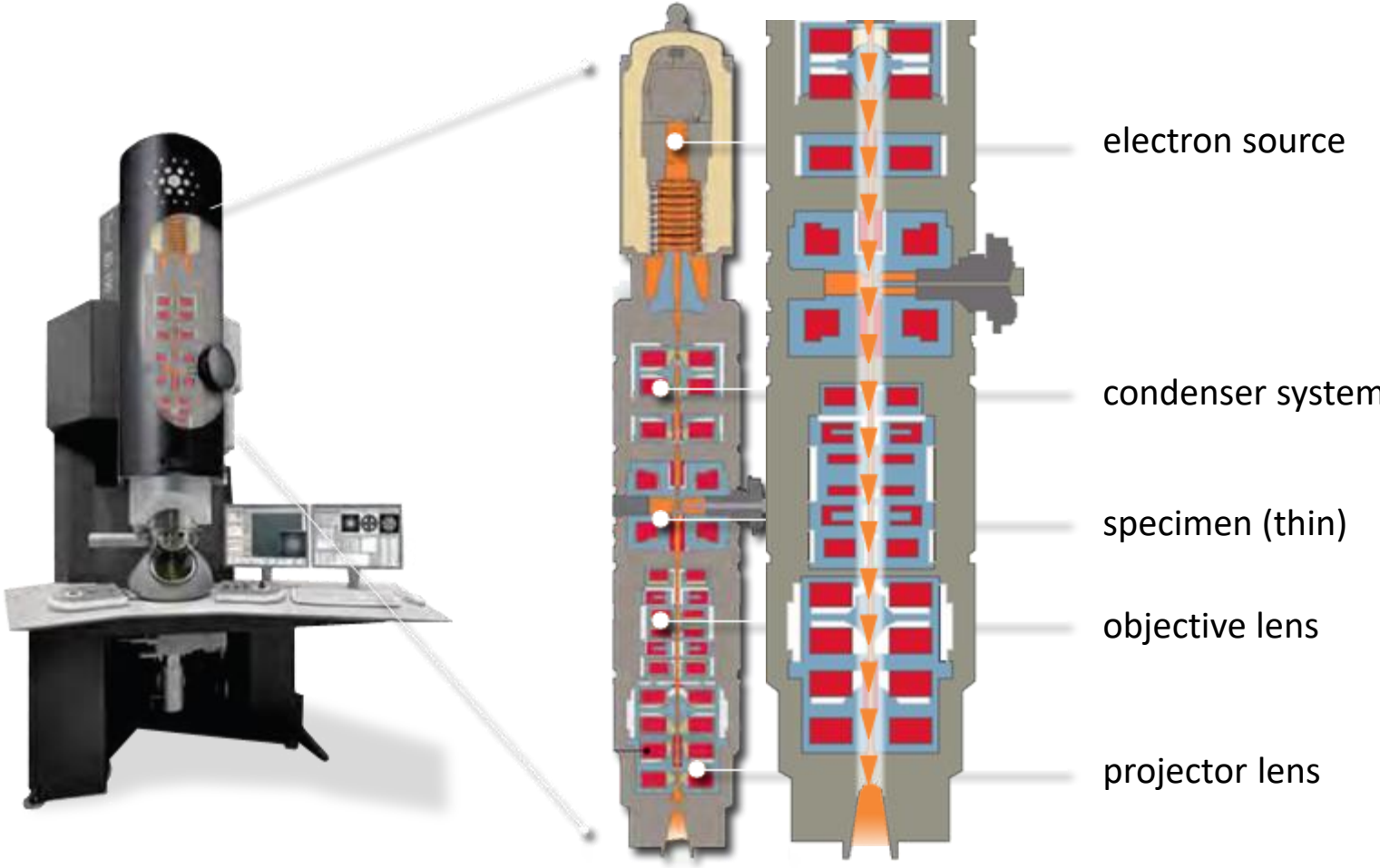
P soft iron pole piece

An Introduction to Electron Microscopy, FEI Company booklet: http://www.fei.com/introduction-to-electron-microscopy/

Lenses

D.B. Williams and C.B. Carter

Lenses



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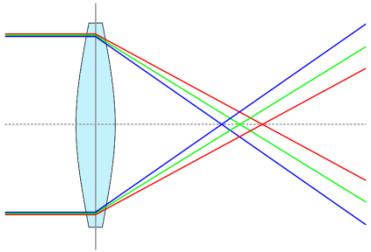
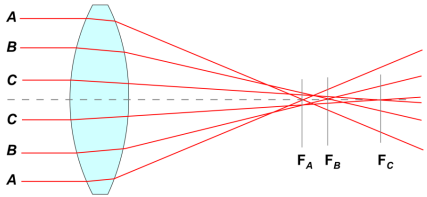
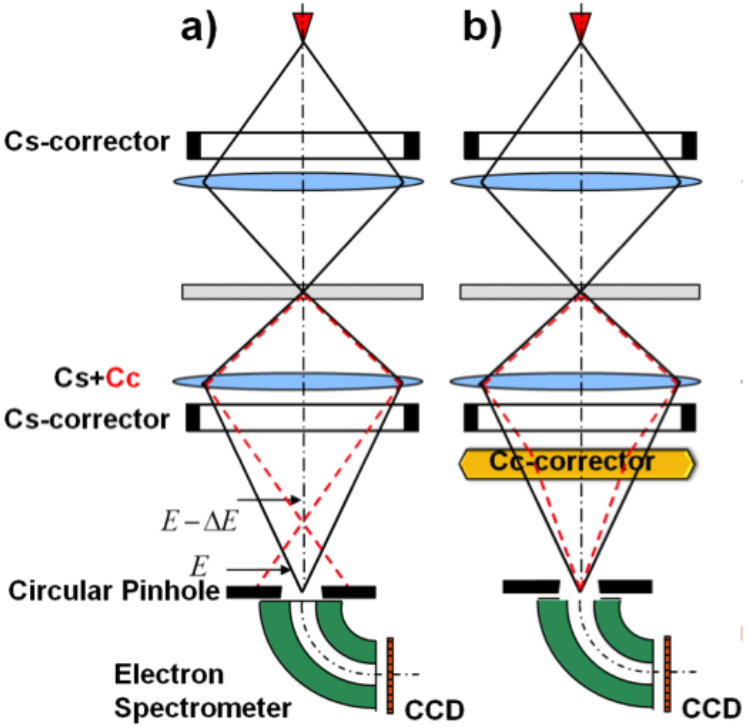
Modern TEMs

Chromatic aberration



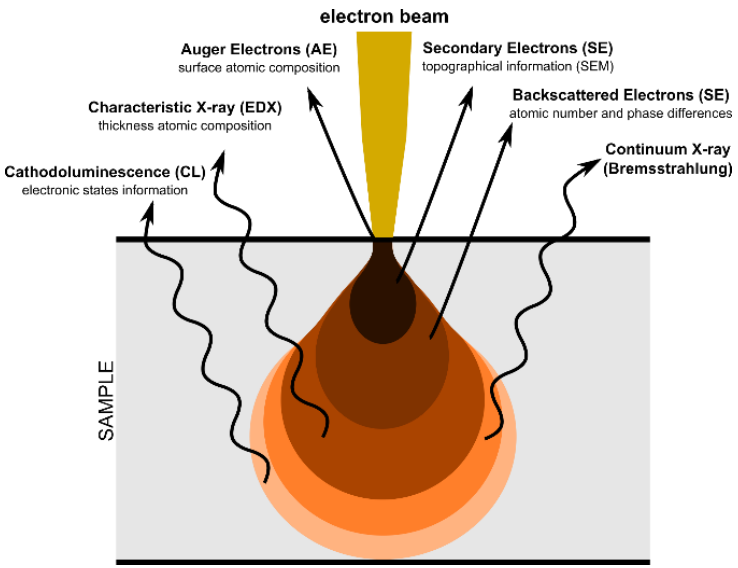
Spherical aberration

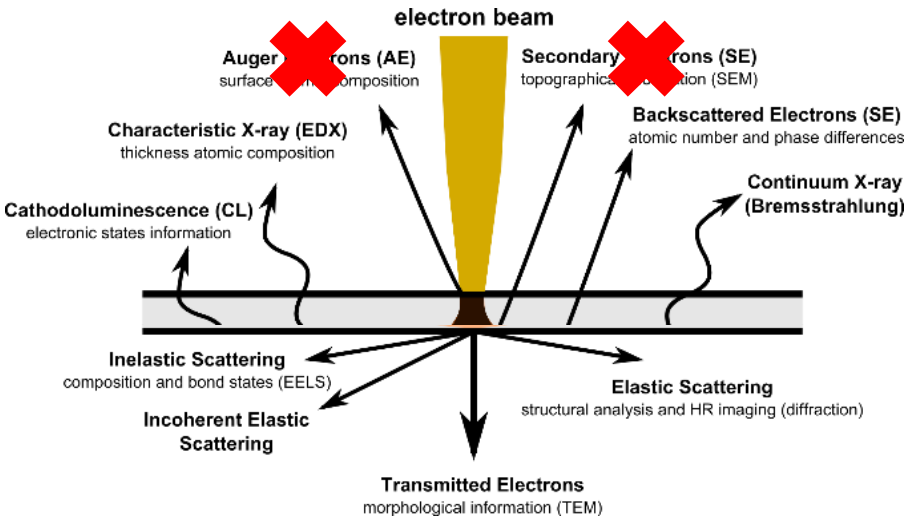




Fonte: Licença de uso creative commons

Light matter interaction





Fonte: Licença de uso creative commons

Wikipedia
http://archive.cnx.org/contents/3666ae2b-a4ba-46aa-b6e2-411c91e47ef4@1/transmission-electron-energy-loss-spectroscopy

Imaging

AMPLITUDE CONTRAST

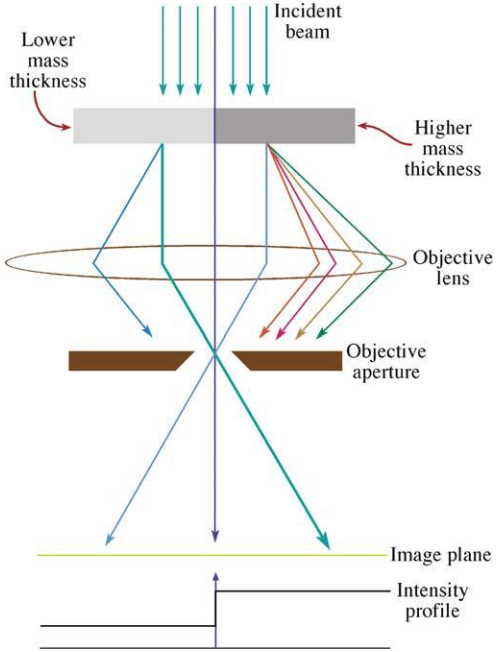
MASS-THICKNESS CONTRAST

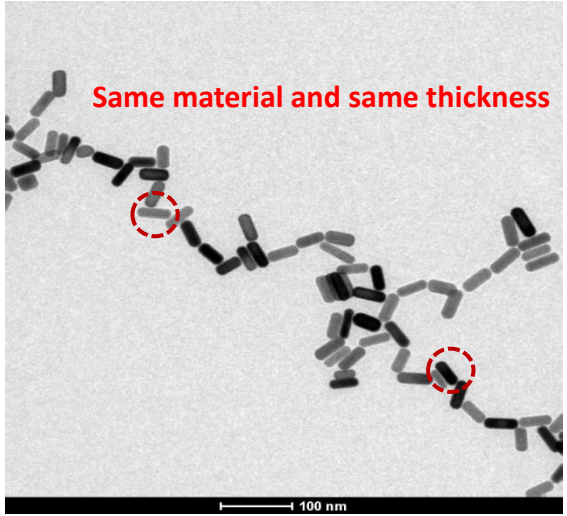
Z-CONTRAST

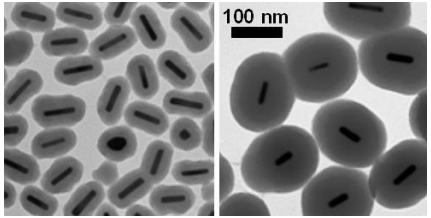
DIFFRACTION CONTRAST

Amplitude contrast results from variations in mass or thickness or a combination of the two

Thicker or higher-Z areas of the specimen (darker) will scatter more electrons off axis than thinner, lower mass (lighter) areas.

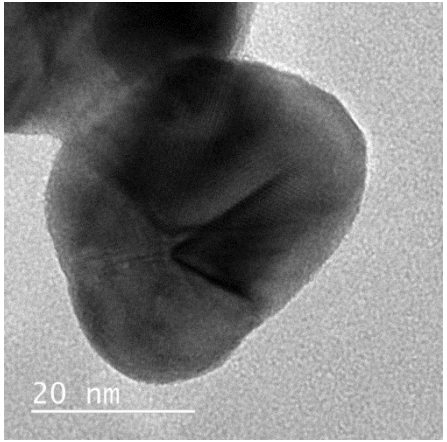


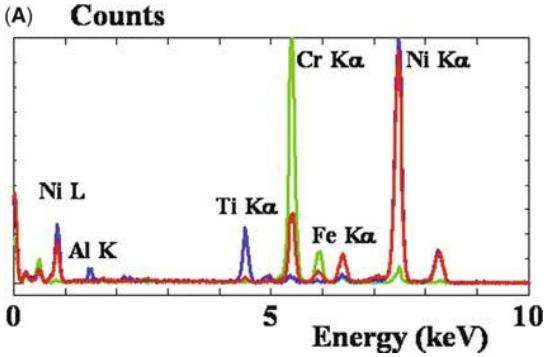


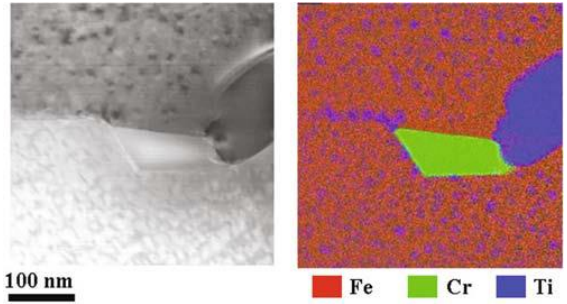


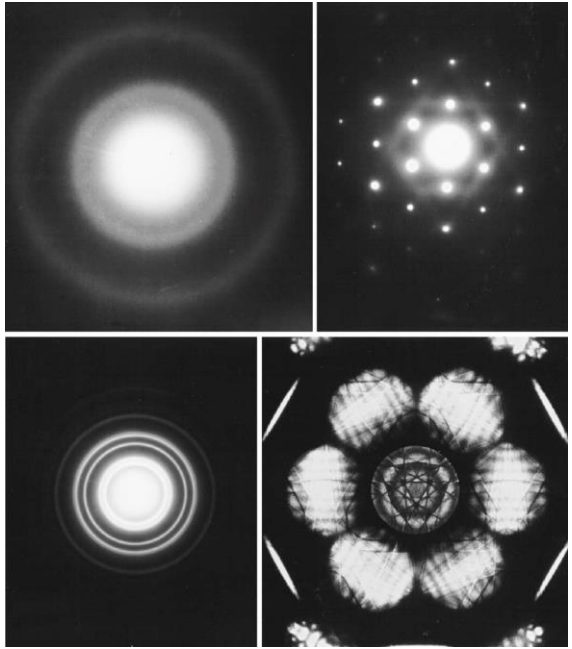
D.B. Williams and C.B. Carter
CAIRES – CM/UFMG

TEM Results









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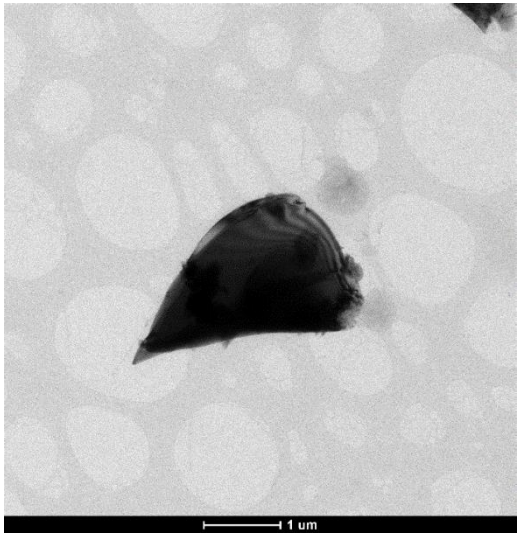
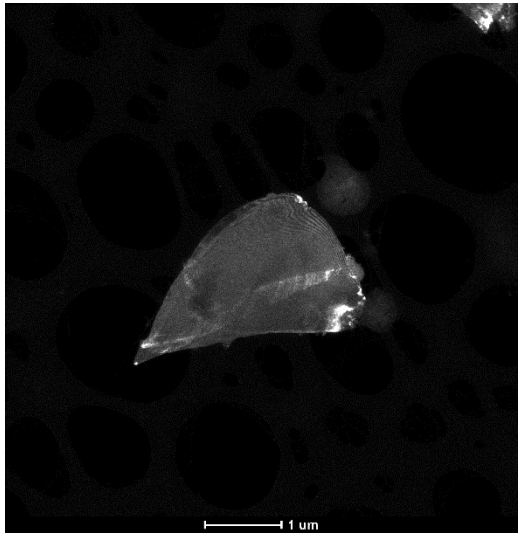
TEM Results

Bright-Field and Dark-Field

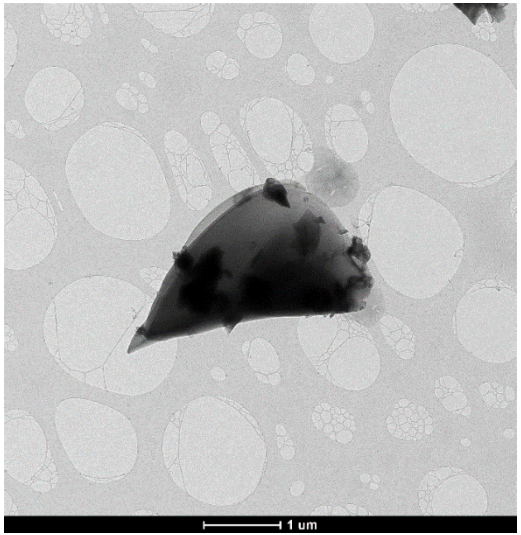


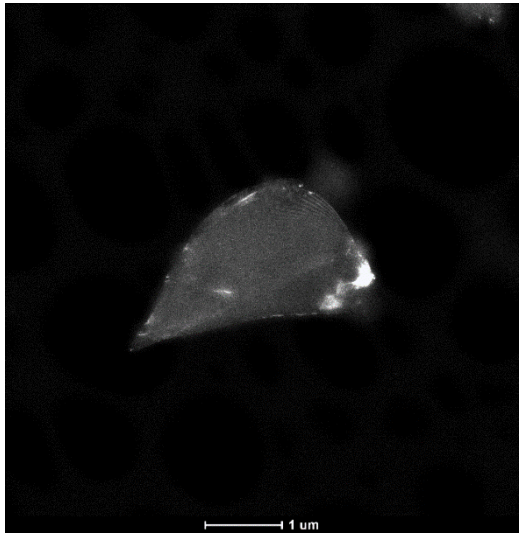


Si {111}

TEM Results

Bright-Field and Dark-Field





Si {110}

Limitations of the TEM

A Sampling

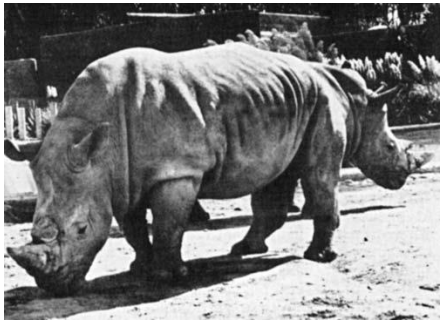
Interpreting Transmission Images

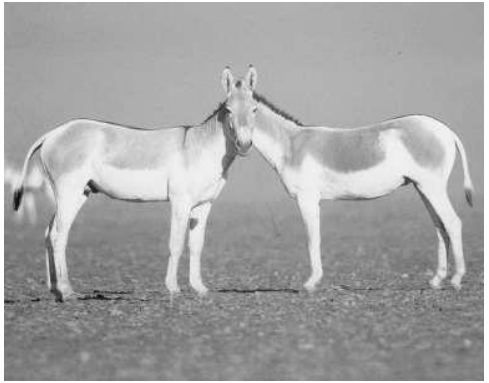
Electron Beam Damage and Safety

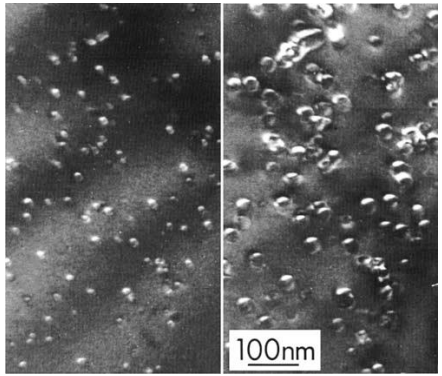
Specimen Preparation

A major limitation of the TEM is
we need thin specimens.

Thinner is better !!!!!







D.B. Williams and C.B. Carter

Limitations of the TEM

A Sampling

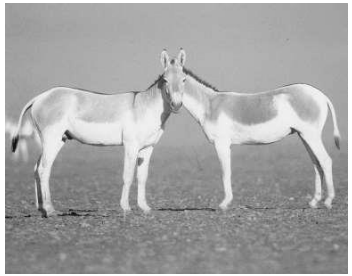
Interpreting Transmission Images

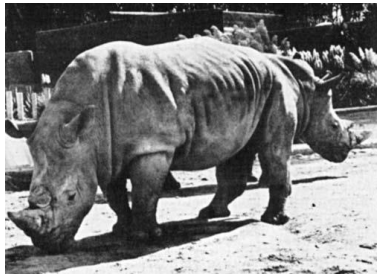
Electron Beam Damage and Safety

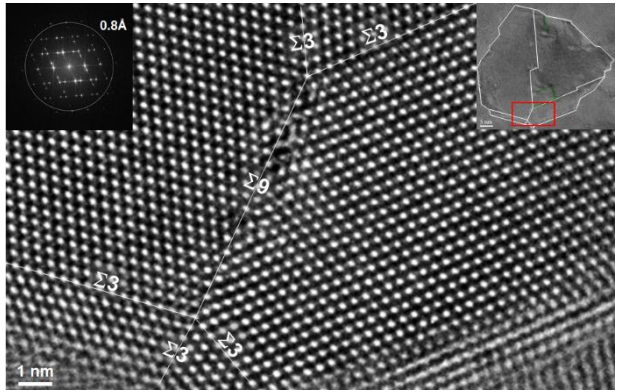
Specimen Preparation

A major limitation of the TEM is
we need thin specimens.

Thinner is better !!!!!







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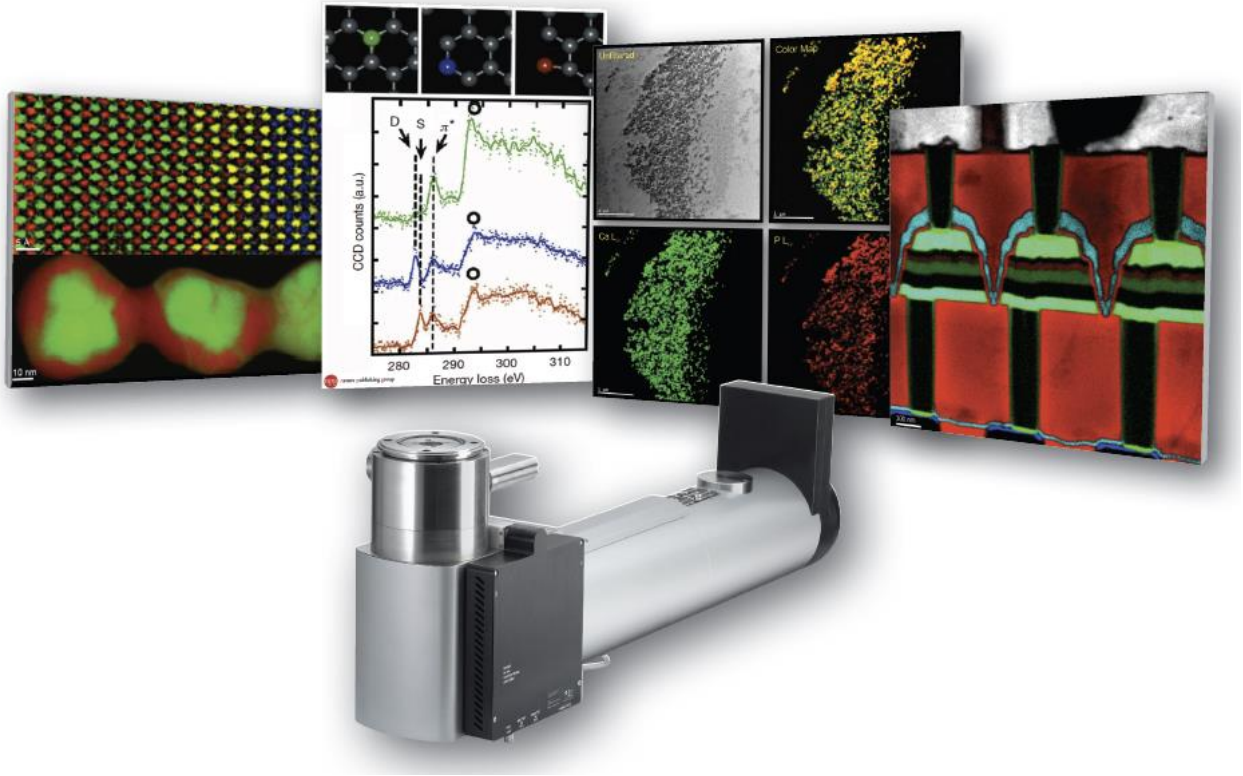


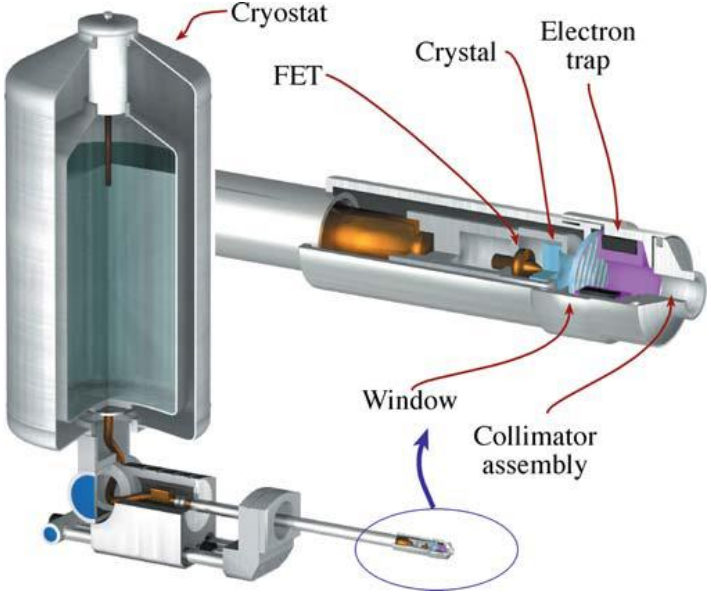
http://www.nanolabtechnologies.com/stem-eels-eds

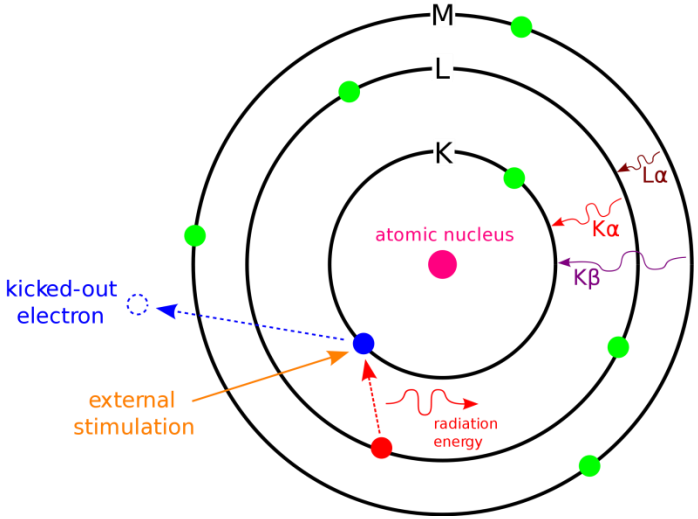
EELS/EDS

EELS/EDS

Detecta todos os elementos da tabela periódica.
Melhor resolução espacial
Melhor sensibilidade analítica

EDS





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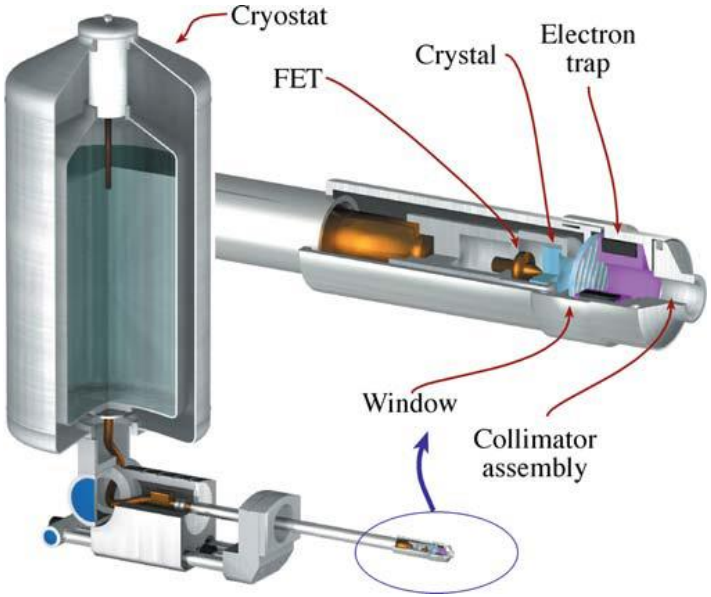
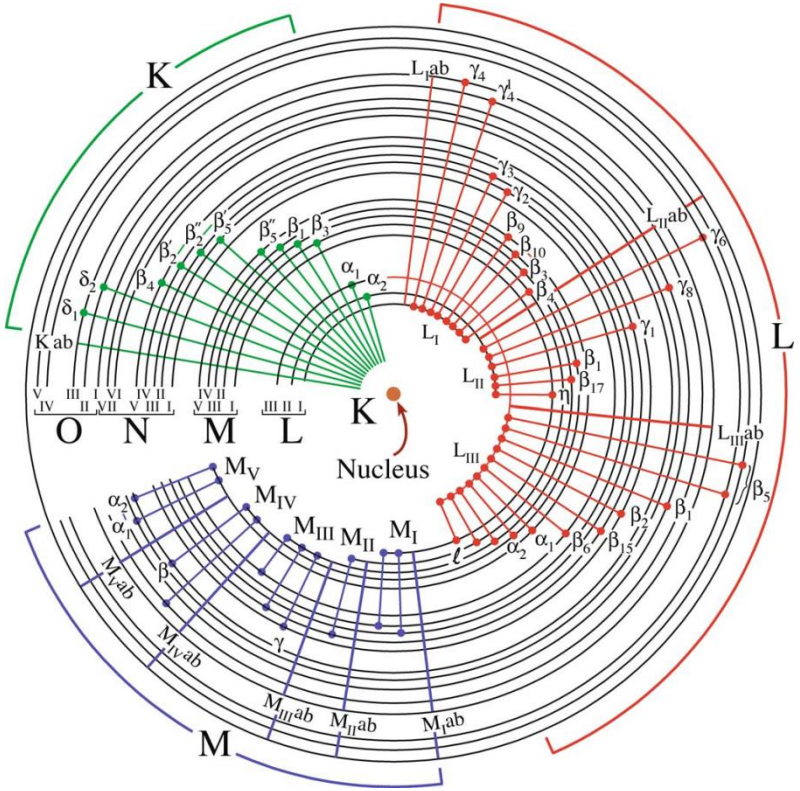
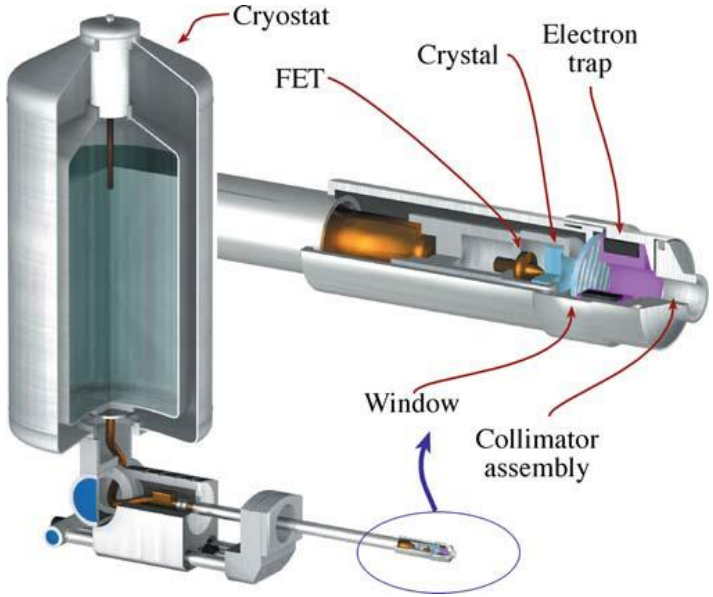
EDS

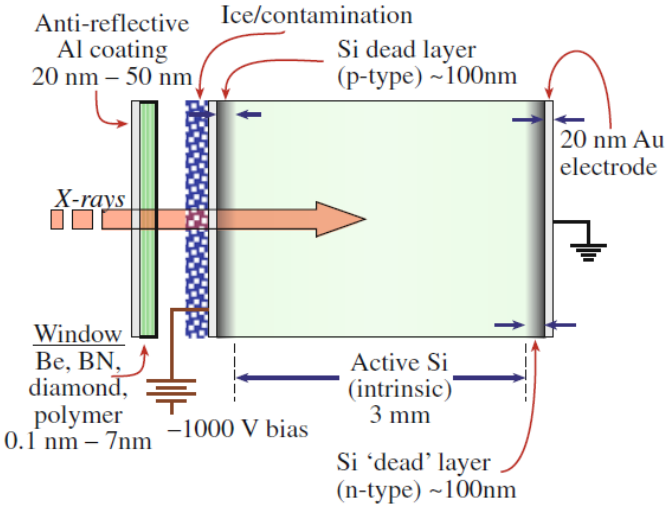




D.B. Williams and C.B. Carter

EDS





D.B. Williams and C.B. Carter

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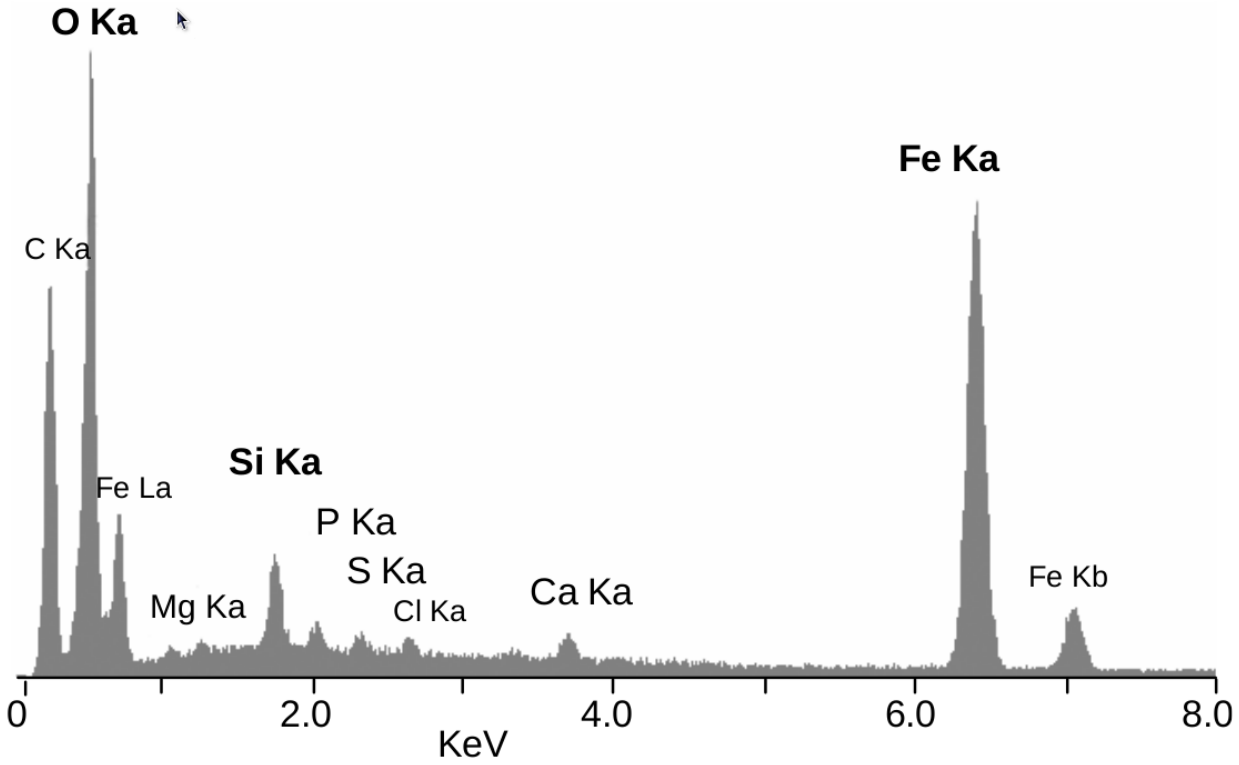

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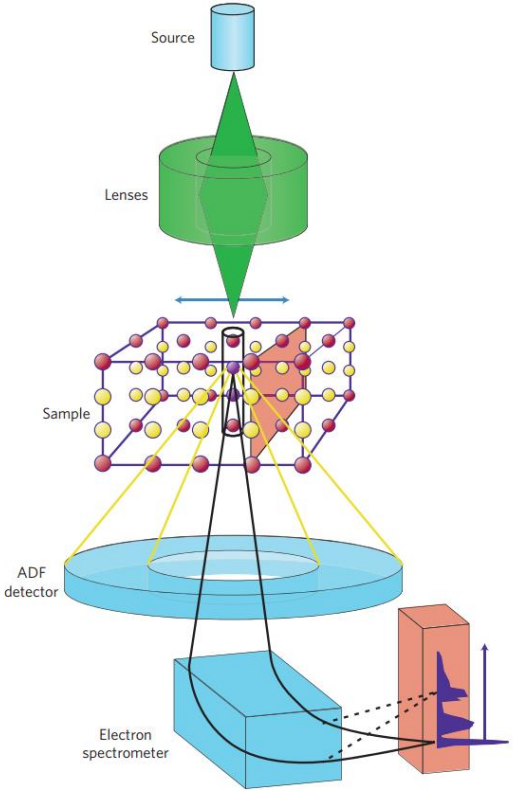
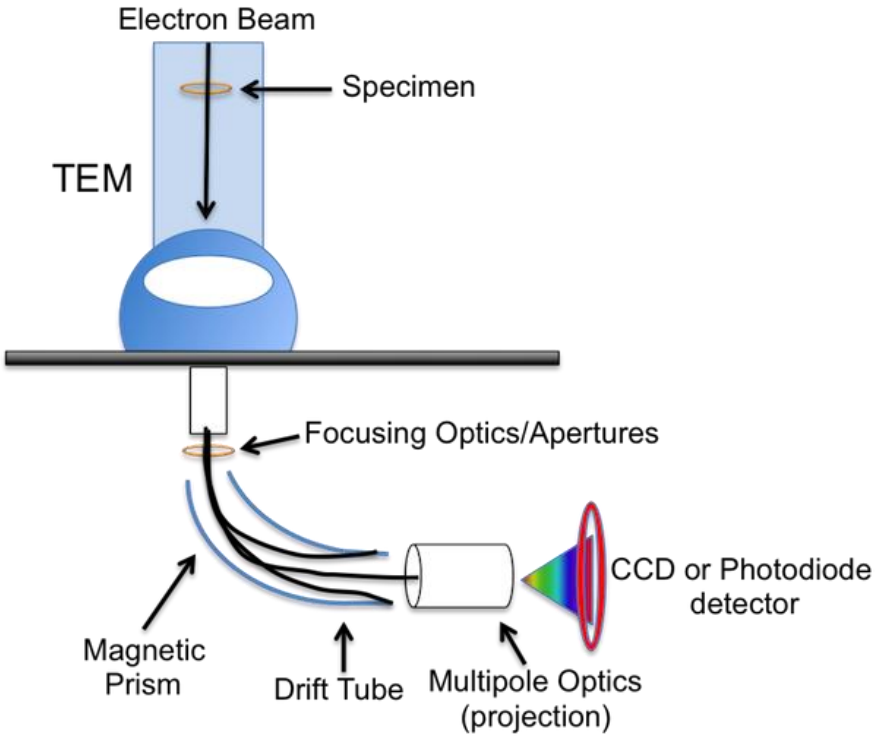
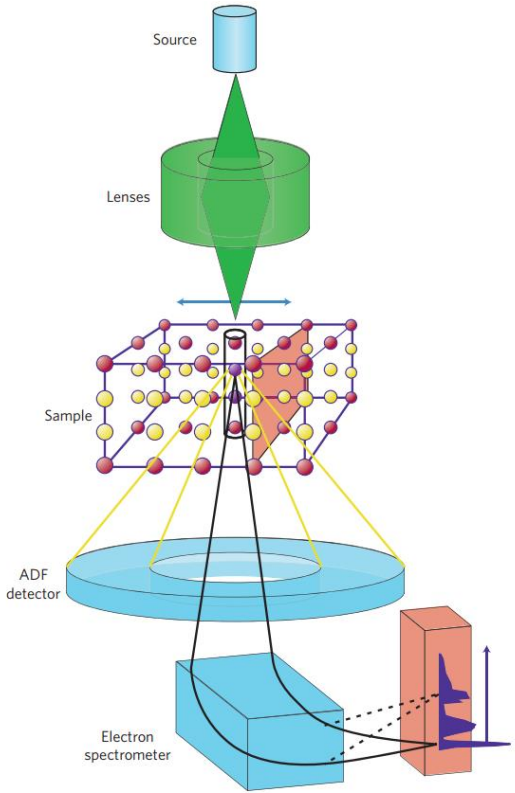
EELS

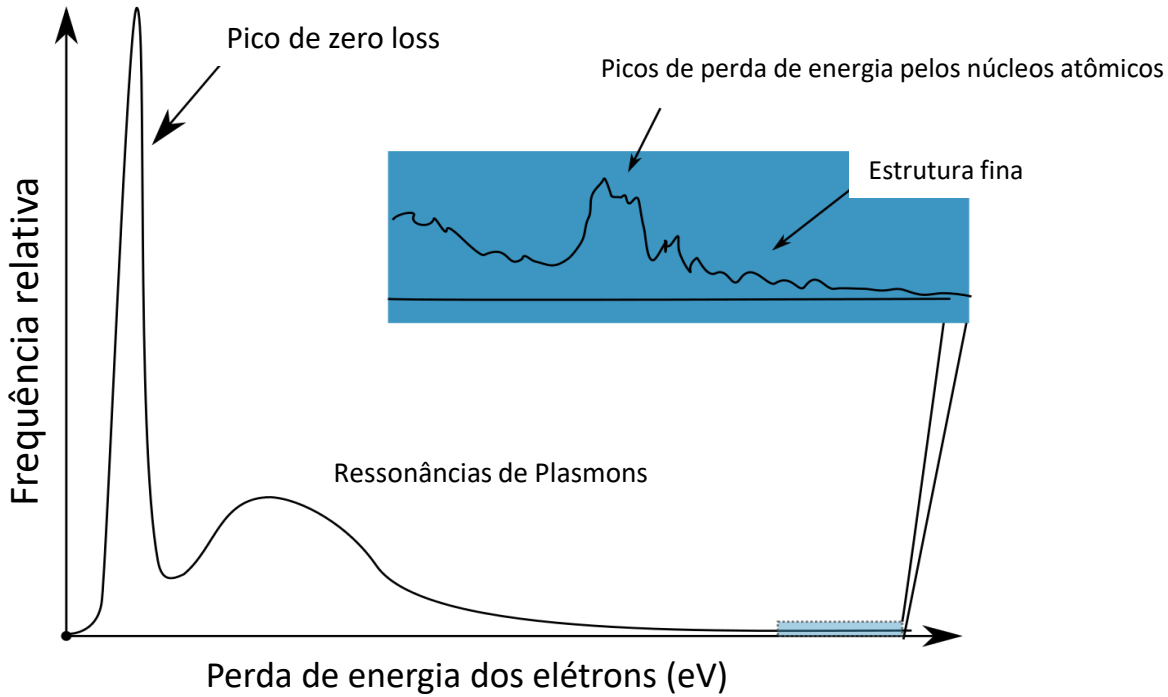




Nature Materials 8, 263 - 270 (2009)
https://en.wikipedia.org/wiki/Electron_energy_loss_spectroscopy

EELS





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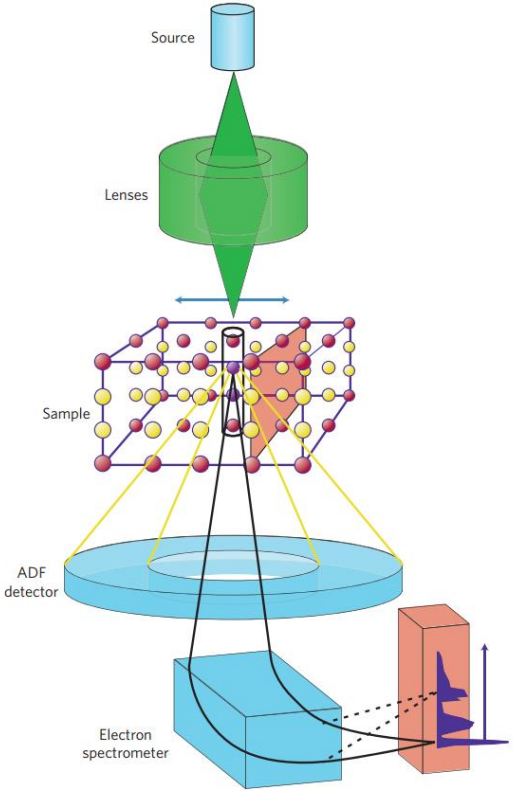

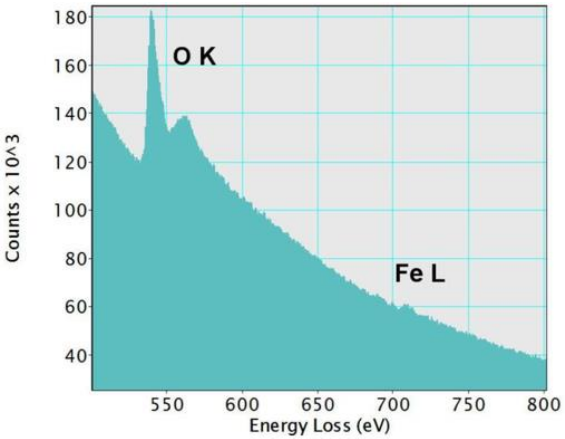

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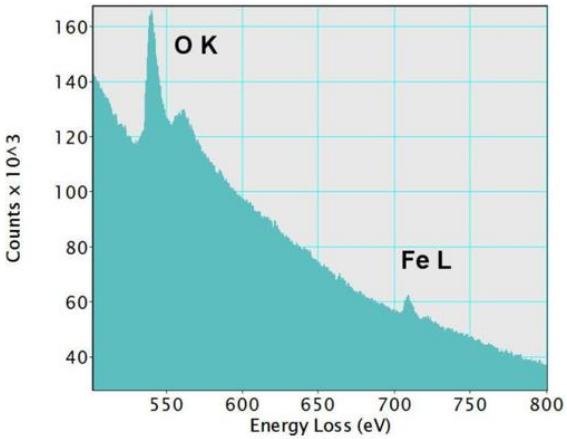

(b)

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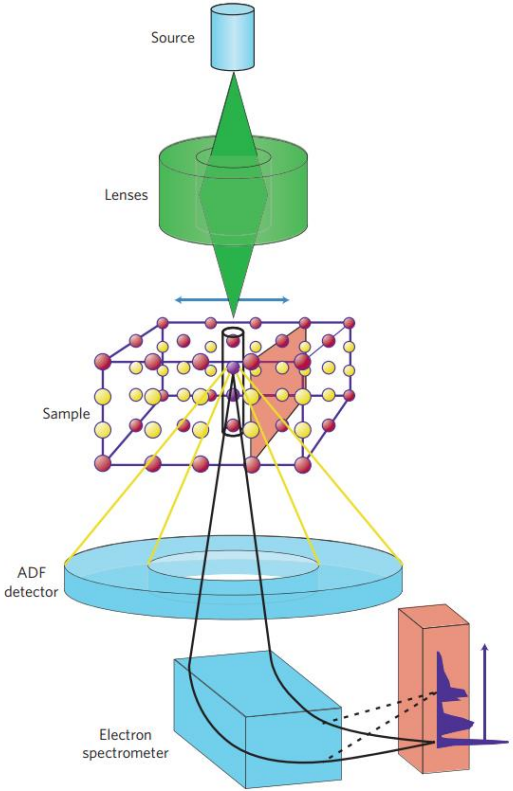
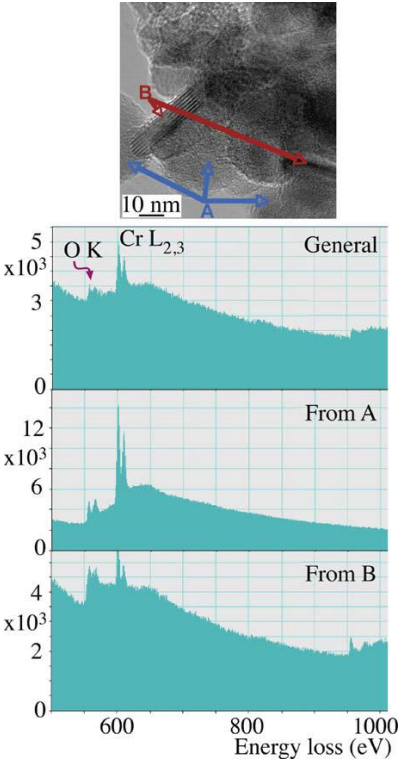
EELS





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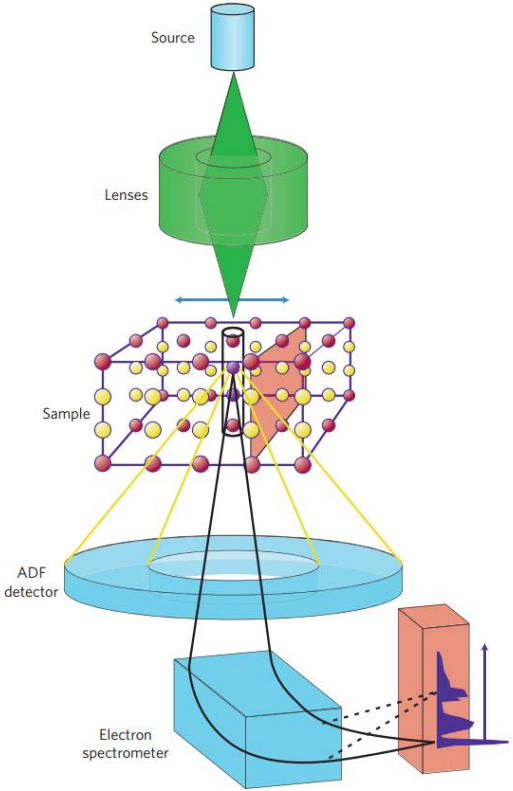

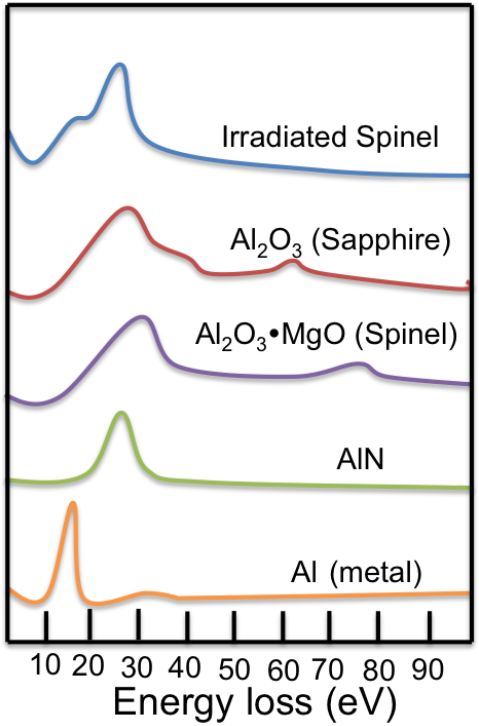

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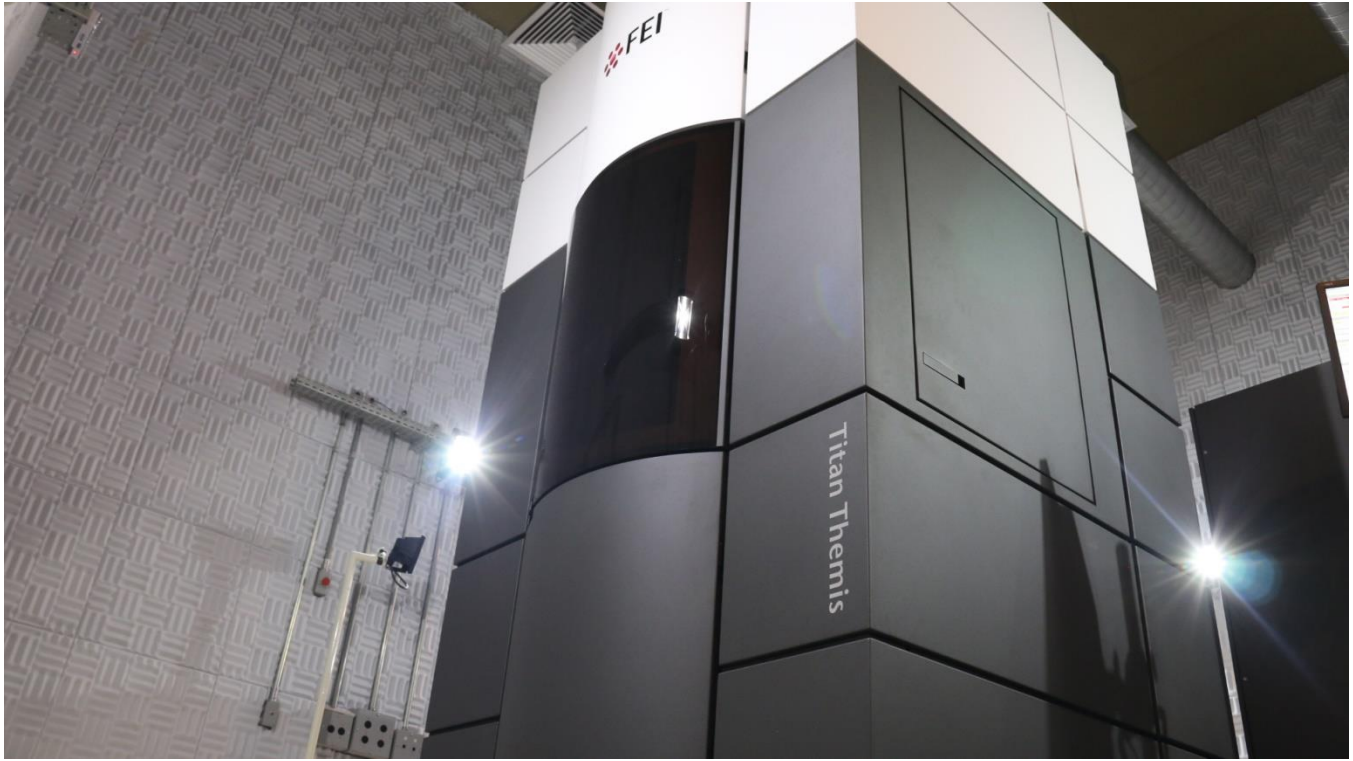
Vídeo Tecnai



Nature Materials 8, 263 - 270 (2009)
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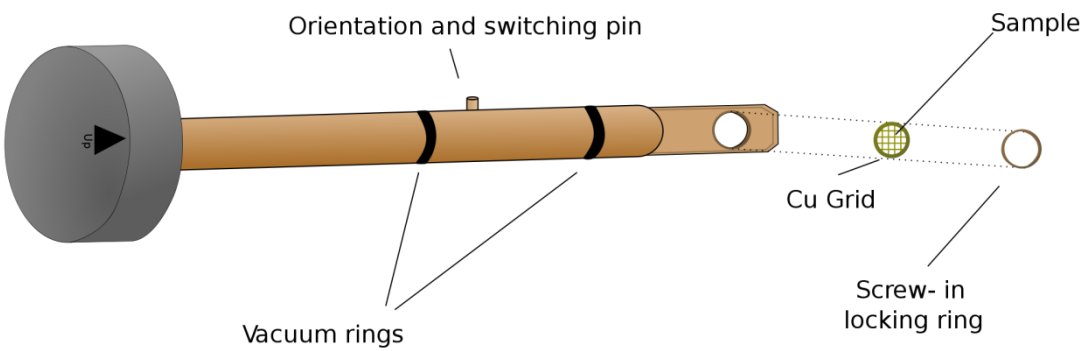
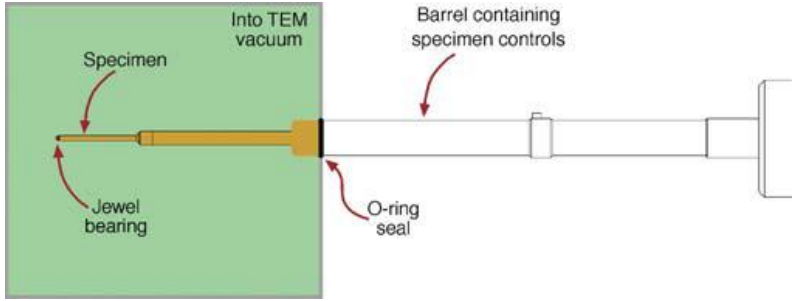
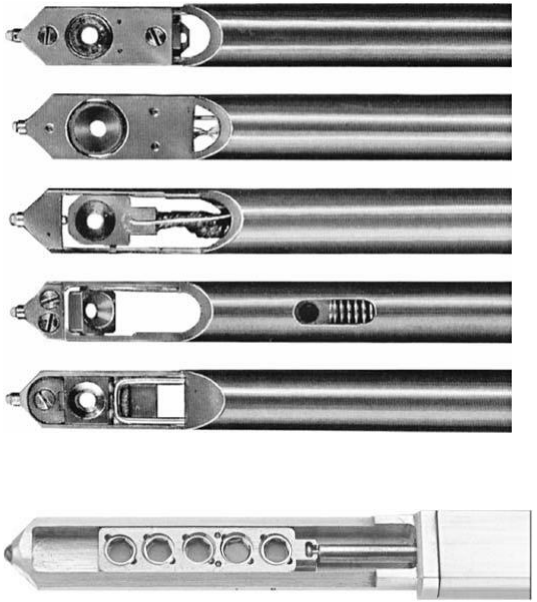
Vídeo TITAN

Sample Preparation







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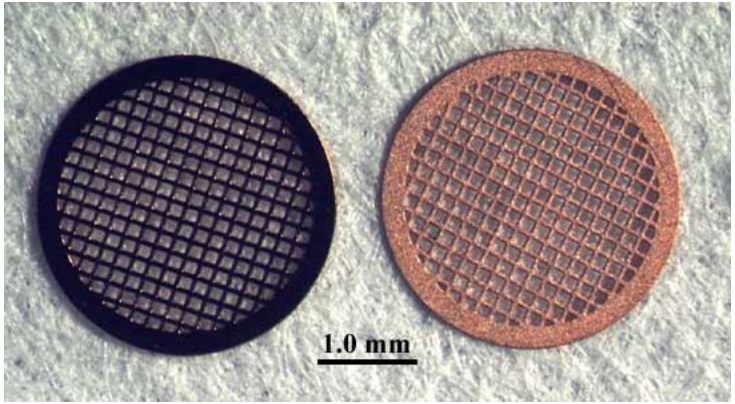
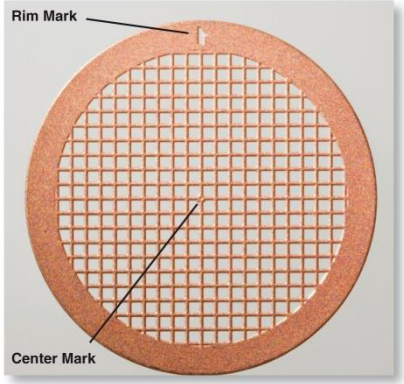
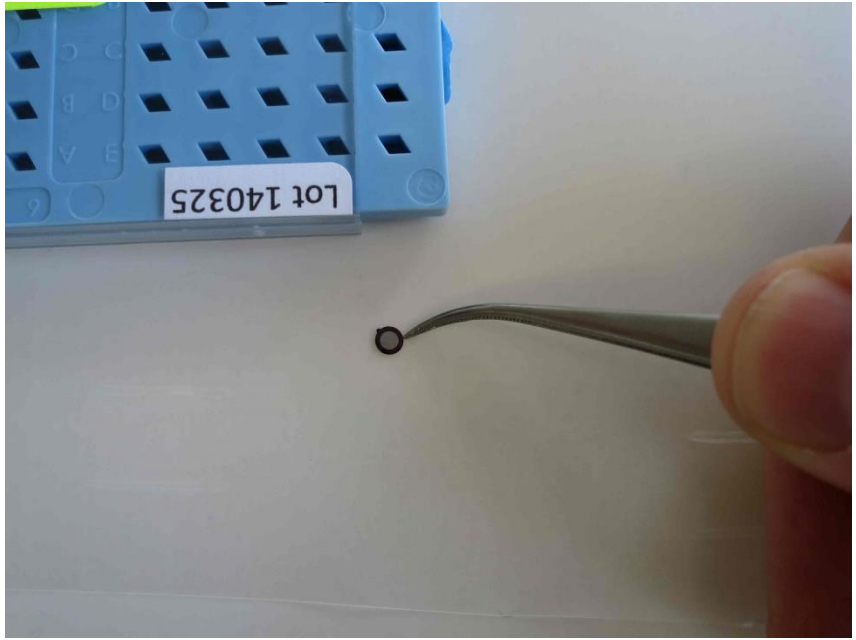
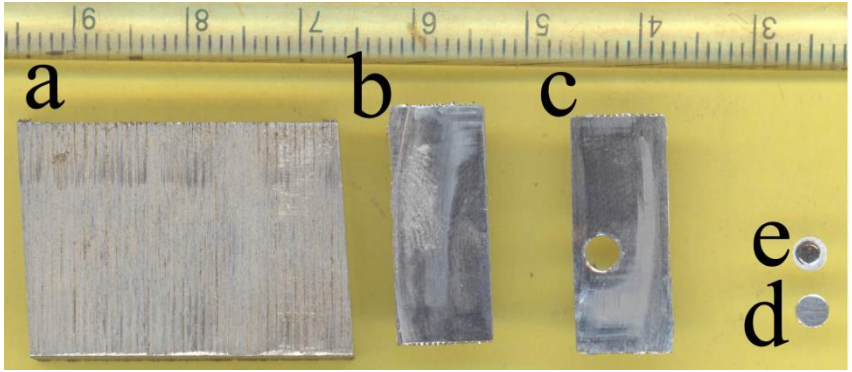


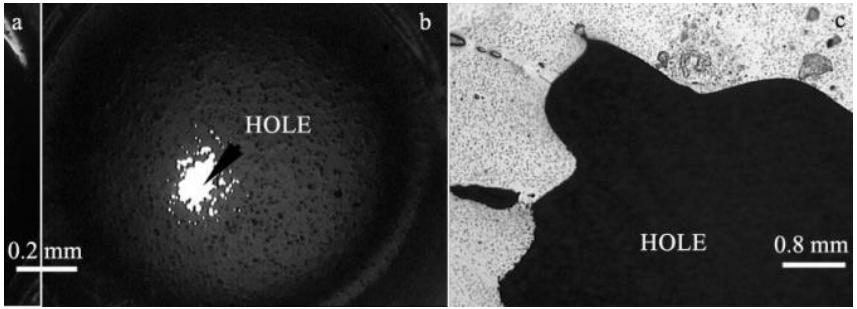




Sample Preparation

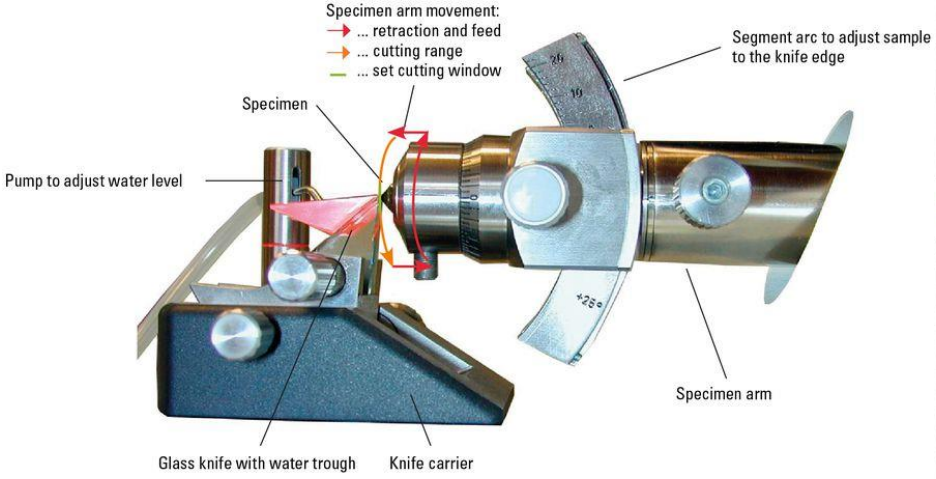
Vídeo Sample Preparation





Microscopy: Science, Technology, Applications and Education
A. Méndez-Vilas and J. Díaz (Eds.)

Sample Preparation



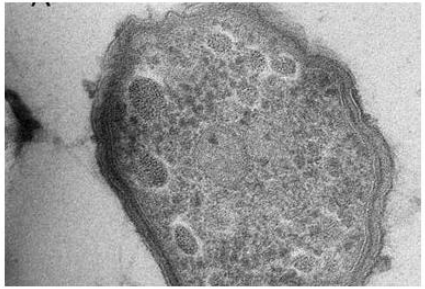


Fig. 6: Acidithiobacillus sp. HV2/2. Courtesy of Dr. Andreas Klingl, University of Marburg

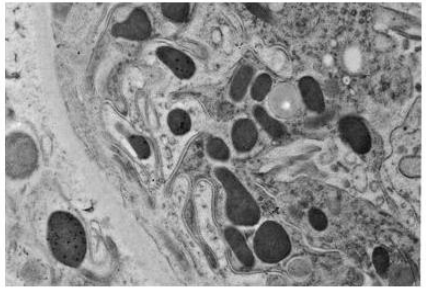
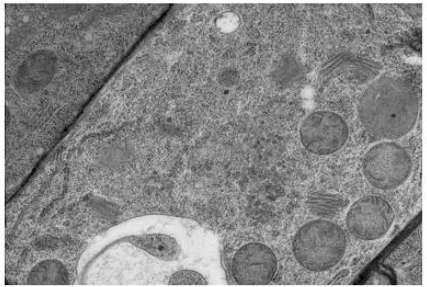


Fig. 7: Kidney, rat. Courtesy of L. Edelmann, University Hamburg, Germany



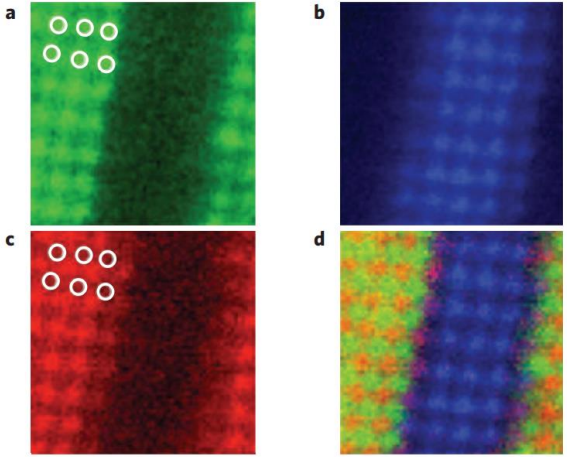
Robert Ranner , Leica Microsystems:
http://www.leica-microsystems.com/science-lab/brief-introduction-to-ultramicrotomy/

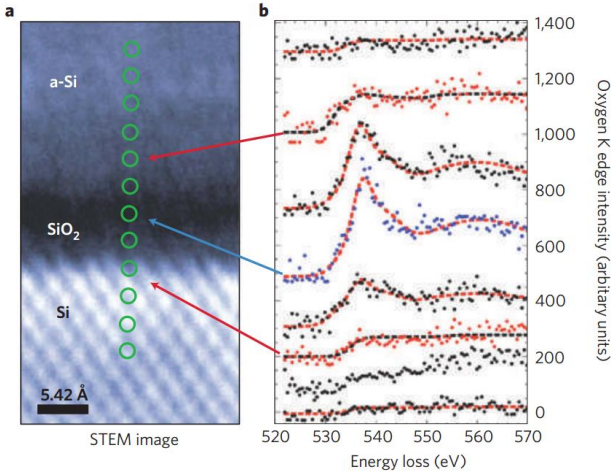
Sample Preparation

Vídeo Sample Preparation BIO

Applications

Mapping



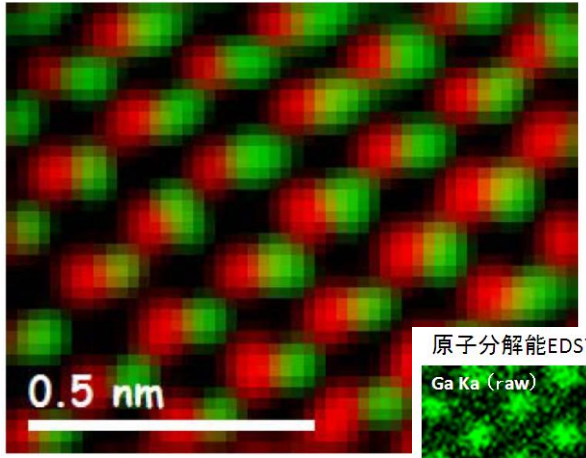


La (a), Ti (b), Mn (c) e todos (d)

Muller Group Research, 2009. *Nature Materials* **8**, 263 - 270 (2009)

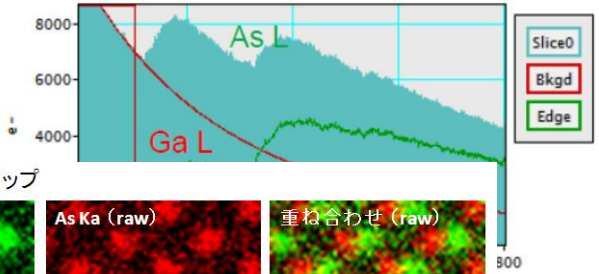
Mapping

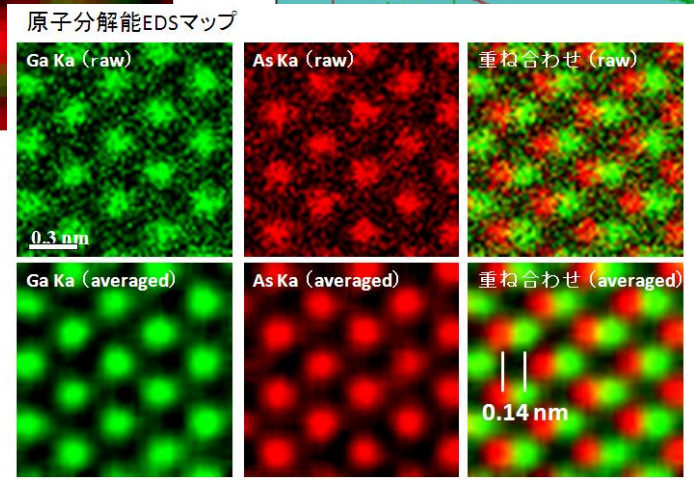
Fast Atomic EELS Map of GaAs



- Ga $L_{2,3}$ at 1115 eV
- As $L_{2,3}$ at 1323 eV

Extracted EELS spectrum





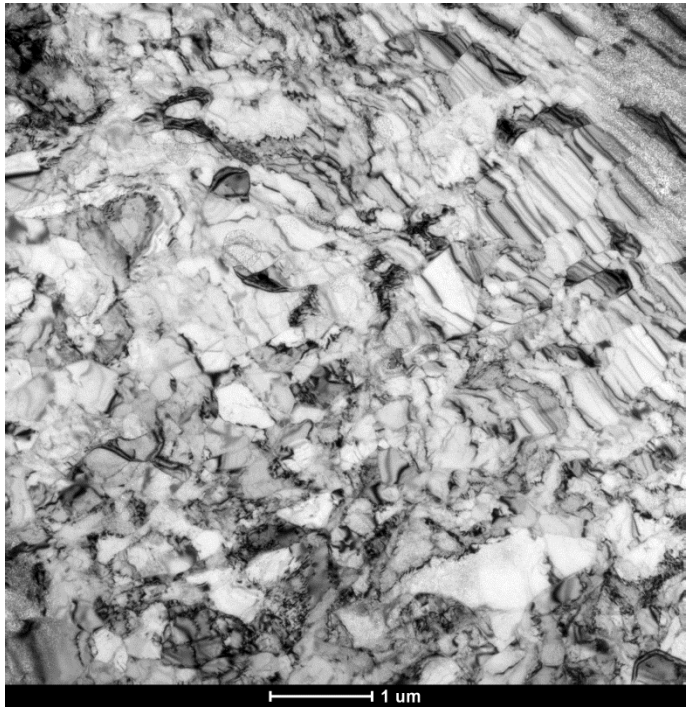
試料：GaAs<110>　　測定時間：14分

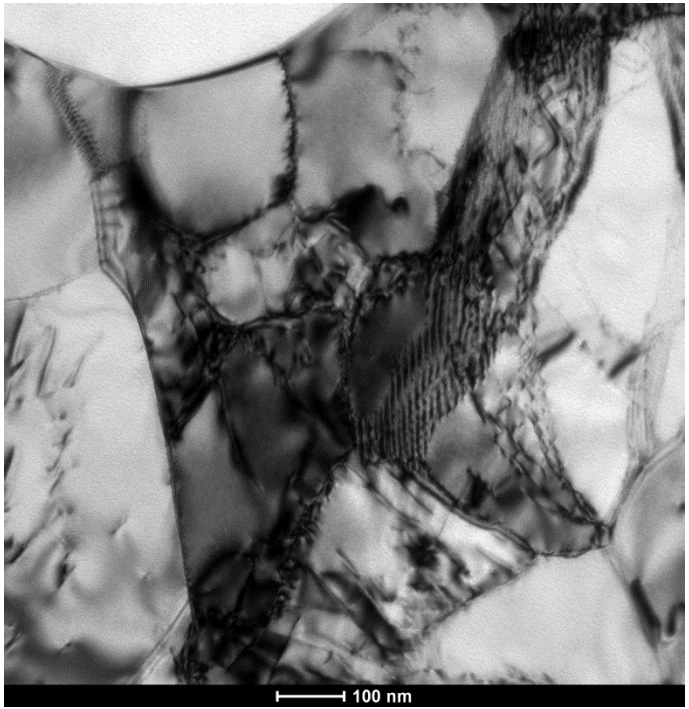
Muller Group Research, 2009. *Nature Materials* **8**, 263 - 270 (2009)

centro de microscopia da UFMG

Metallurgy

Ferritic stainless steel

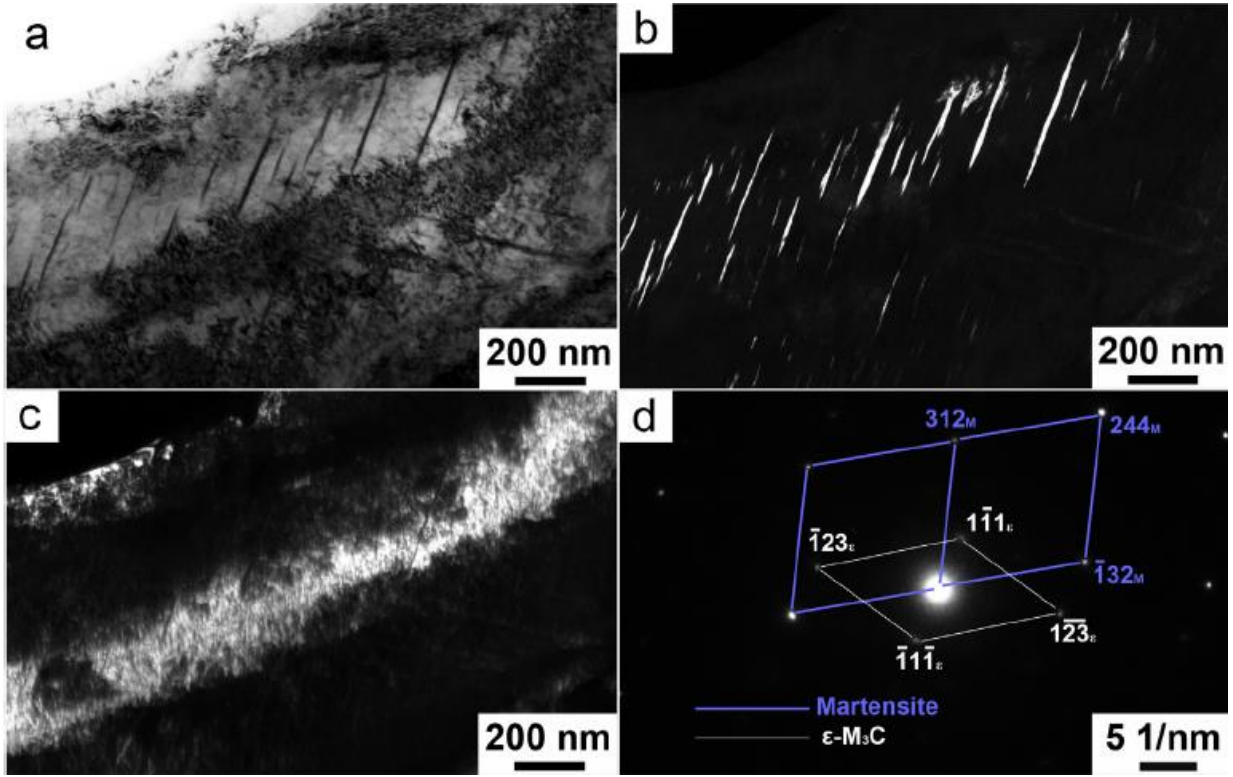




Courtesy of Daniela/Berenice DEMET-UFMG

Metallurgy

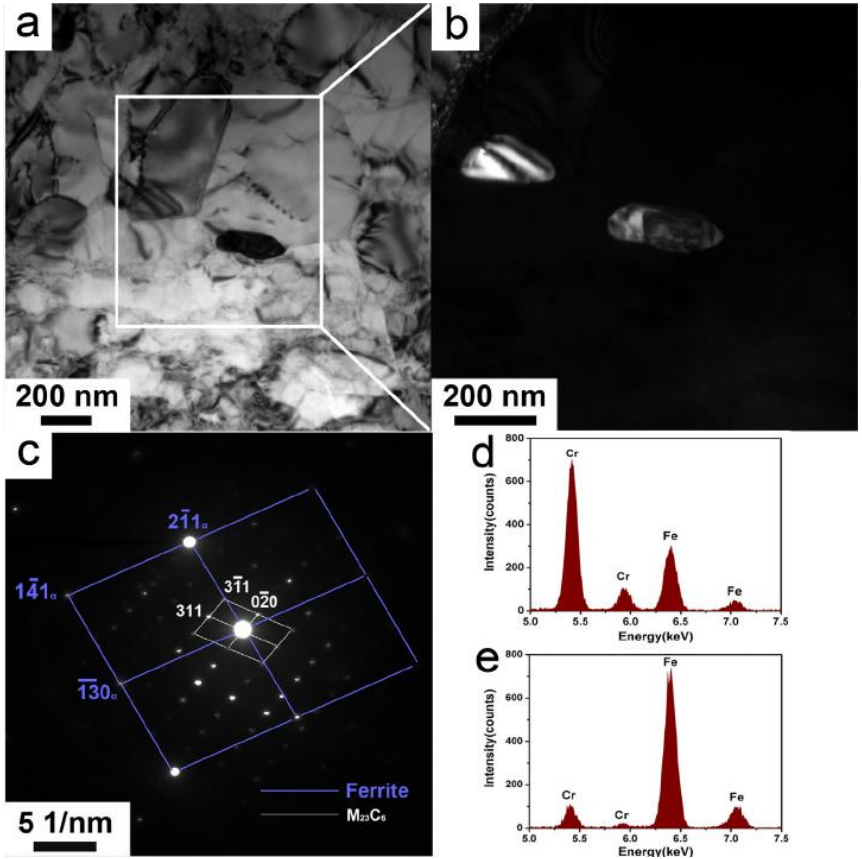
Martensitic stainless steel



Si-Yuan Lu *et al*. The effect of tempering temperature on the microstructure and electrochemical properties of a 13 wt.% Cr-type martensitic stainless steel. 2015 · Electrochimica Acta.

Metallurgy

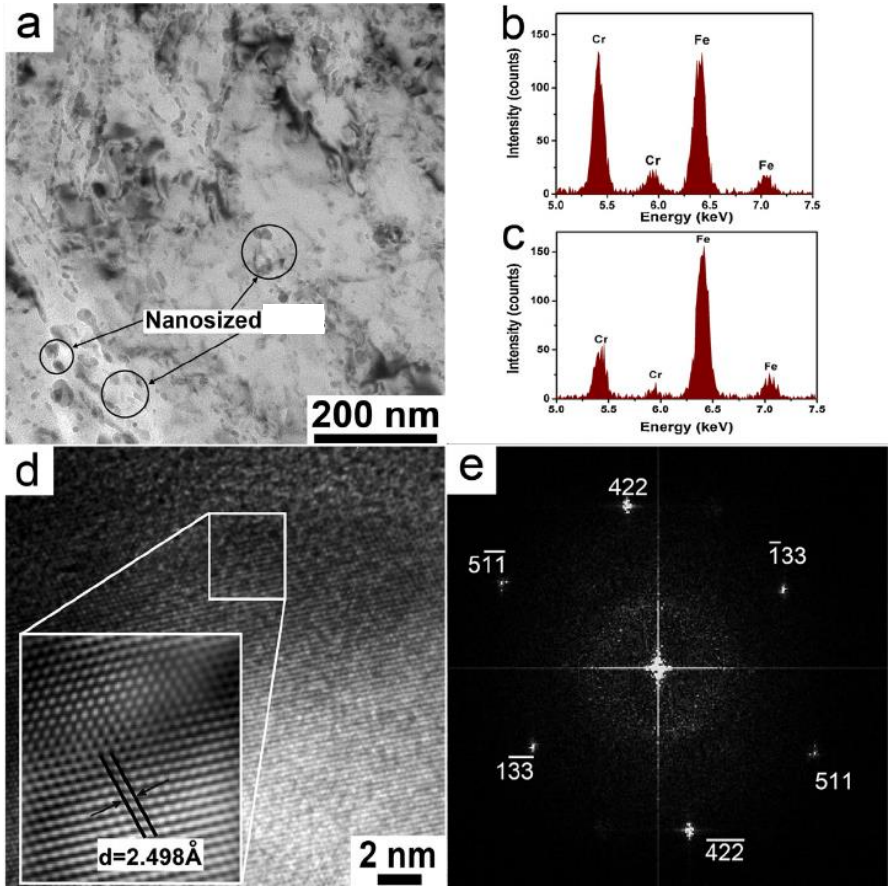
Martensitic stainless steel



Si-Yuan Lu *et al*. The effect of tempering temperature on the microstructure and electrochemical properties of a 13 wt.% Cr-type martensitic stainless steel. 2015 · Electrochimica Acta.

Metallurgy

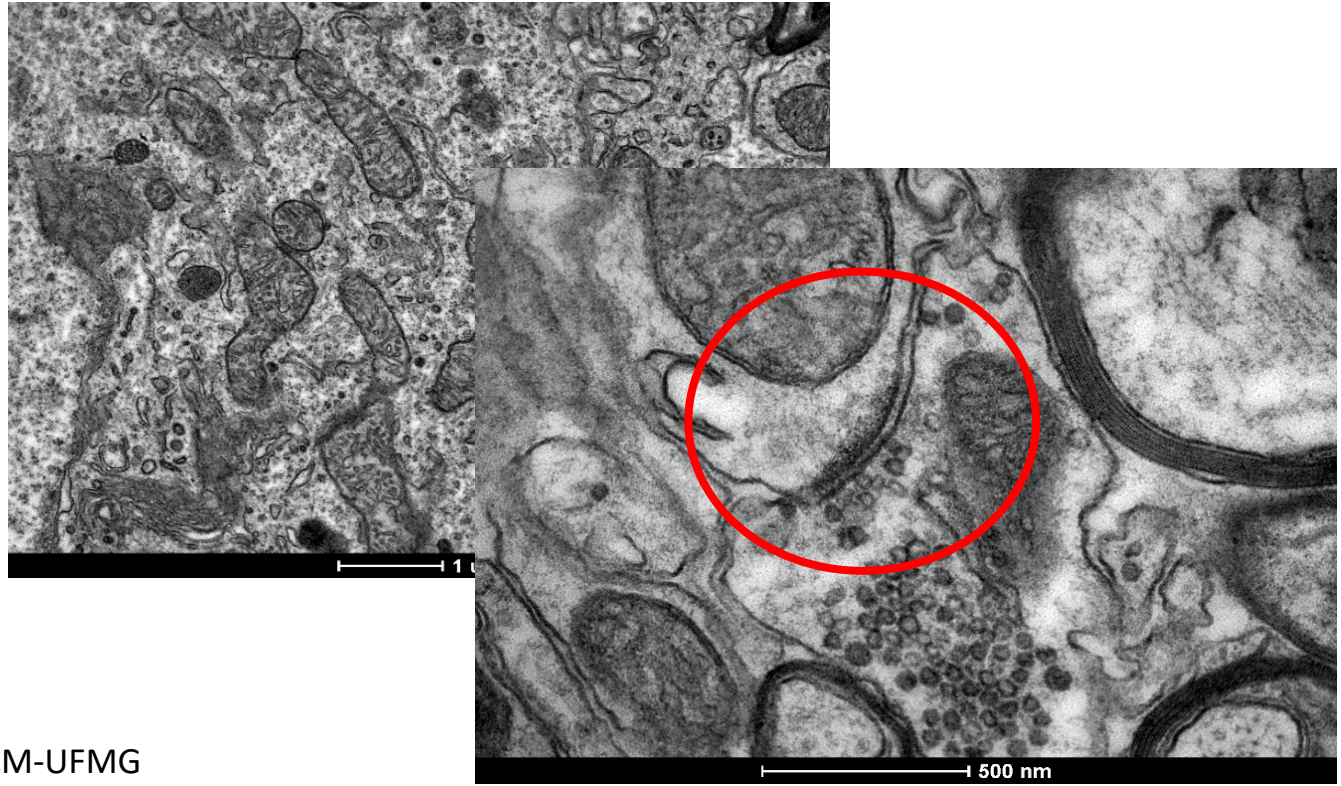
Martensitic stainless steel



Si-Yuan Lu *et al*. The effect of tempering temperature on the microstructure and electrochemical properties of a 13 wt.% Cr-type martensitic stainless steel. 2015 · Electrochimica Acta.

Biology

Neural synapse



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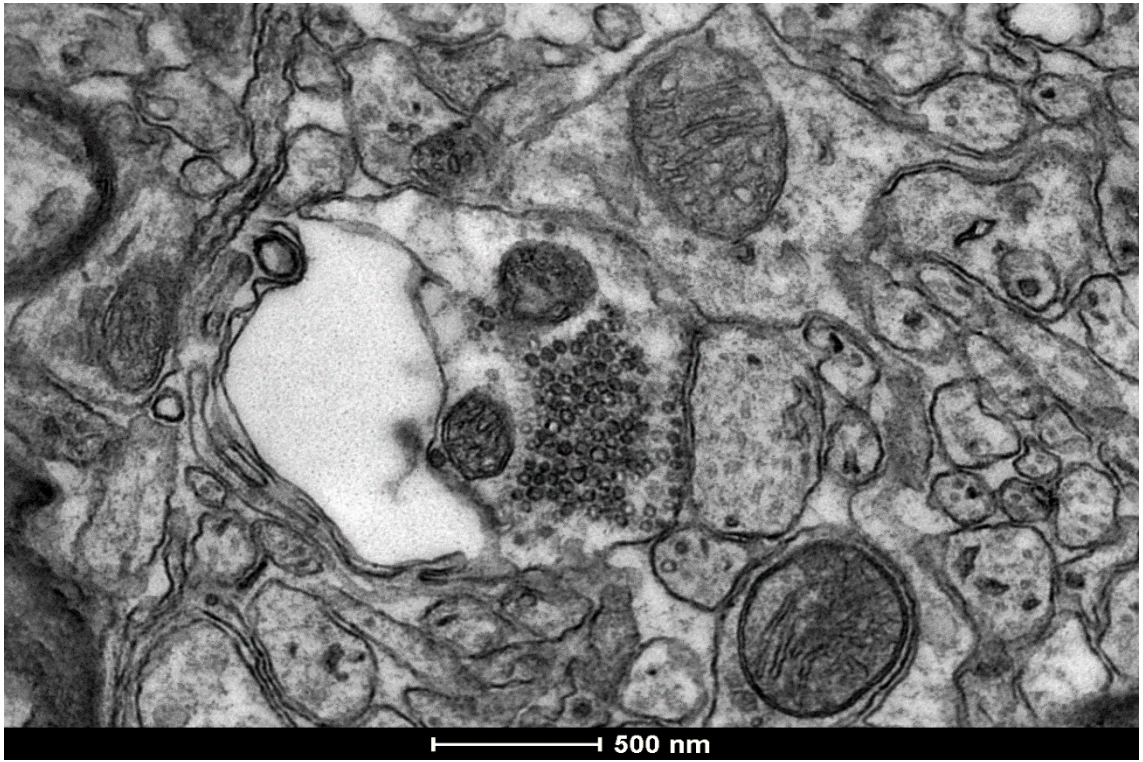
CAIRES, A.J

Biology

Neural synapse



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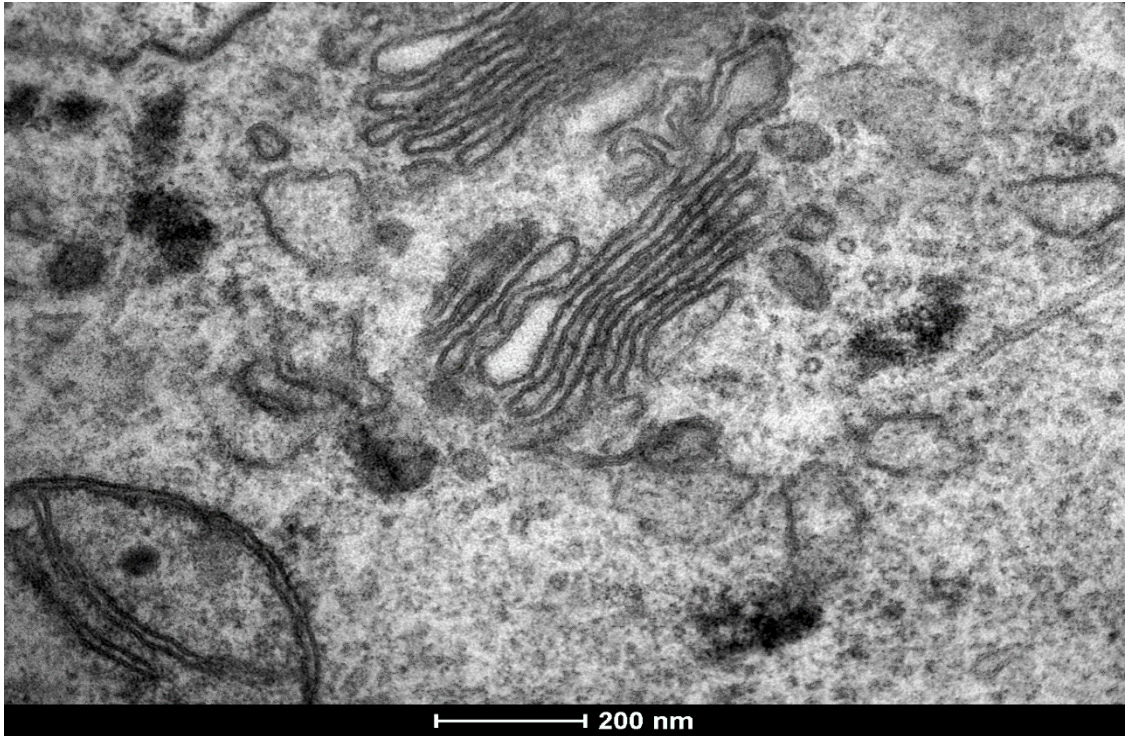
CAIRES, A.J

Biology

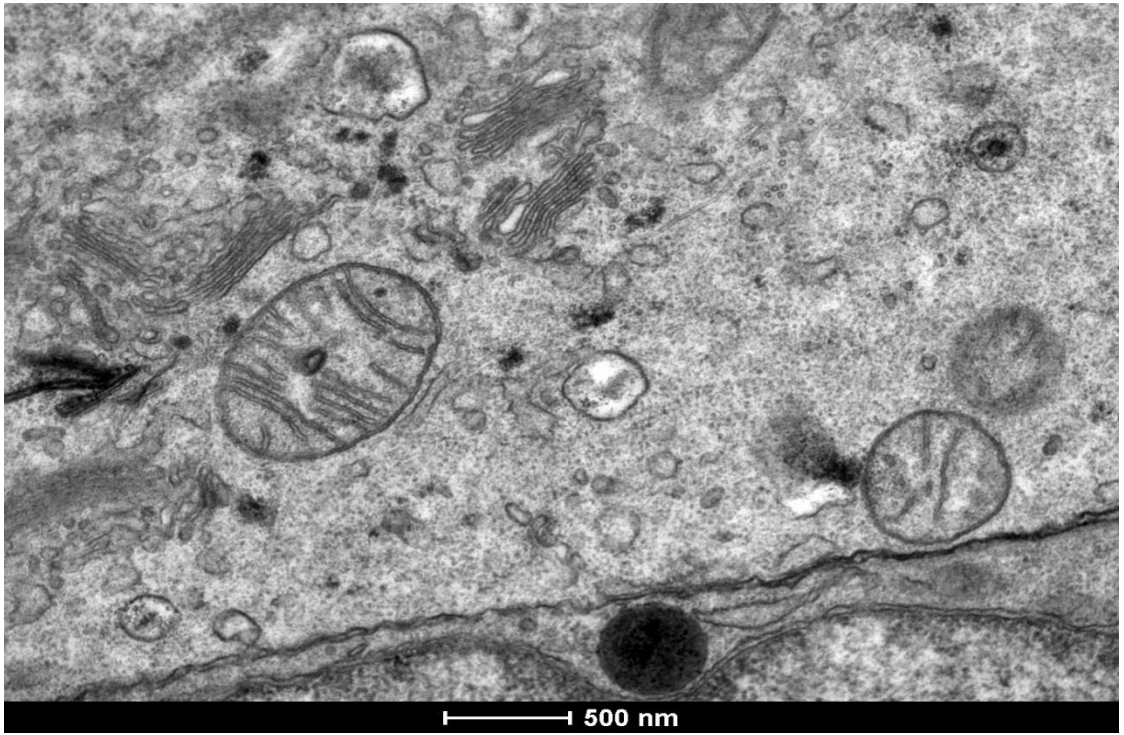
Golgi complex



CM-UFMG
CAIRES, A.J

Biology

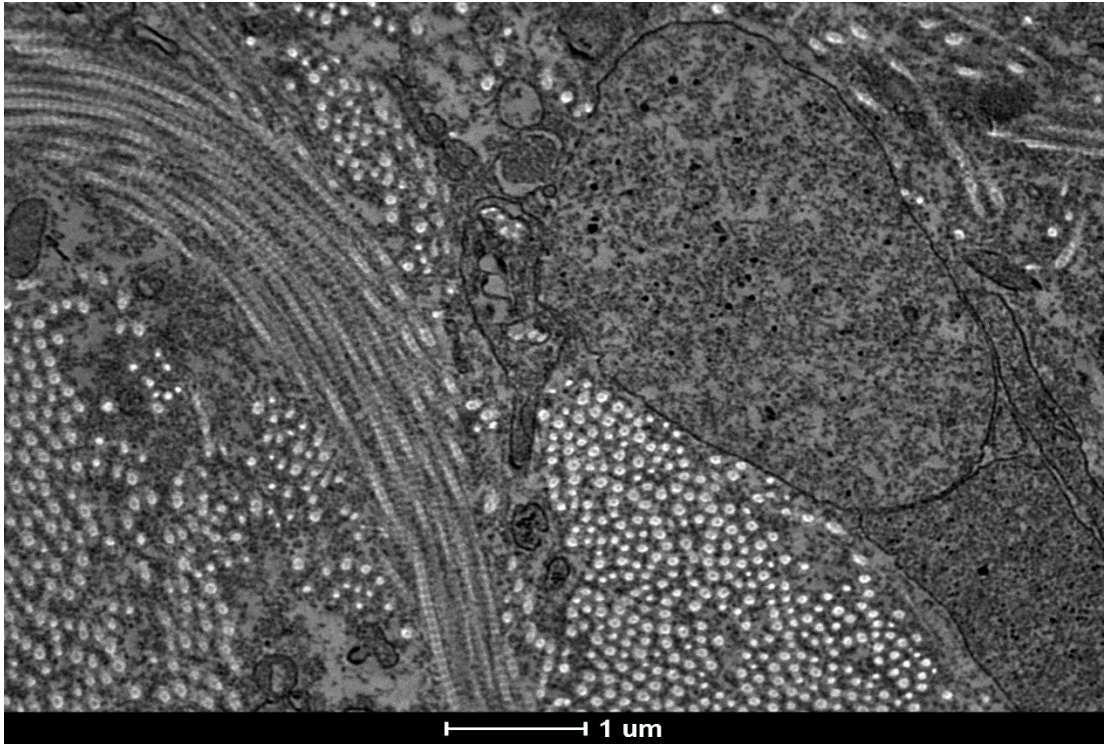
Mitochondria



CM-UFMG
CAIRES, A.J

Biology

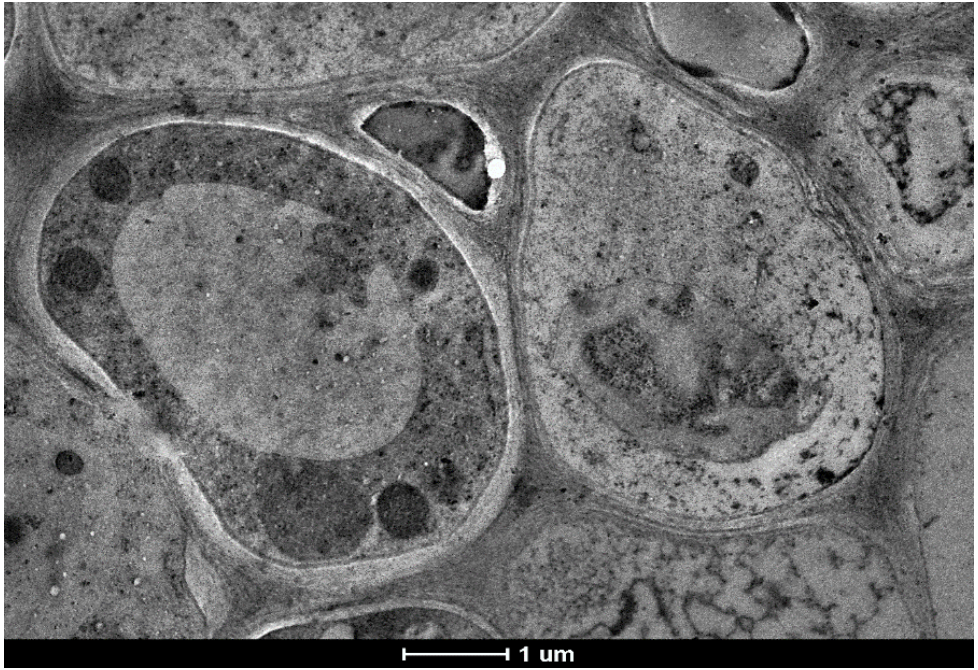
Collagen



CM-UFMG
CAIRES, A.J

Biology

Plant cell



CM-UFMG
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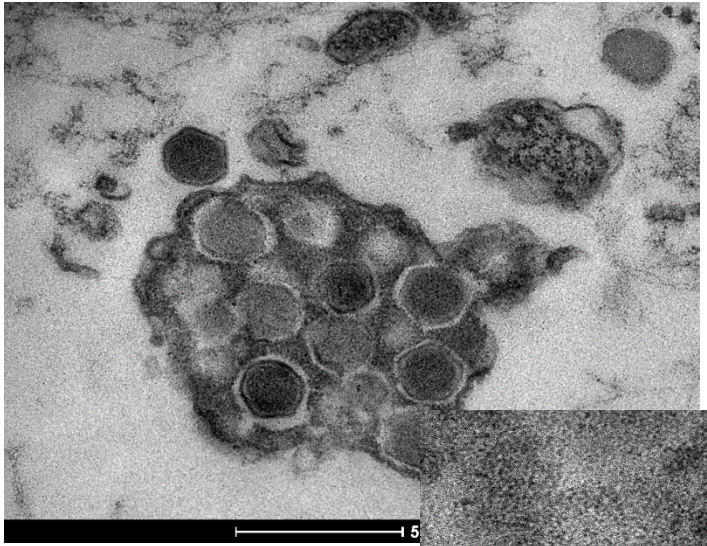

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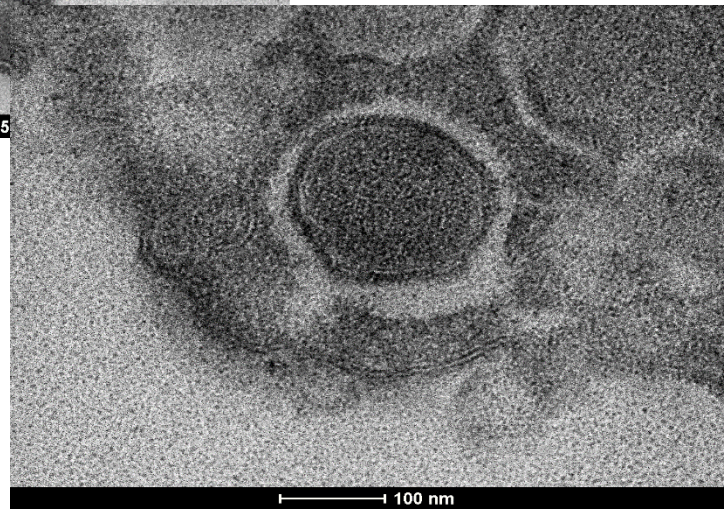

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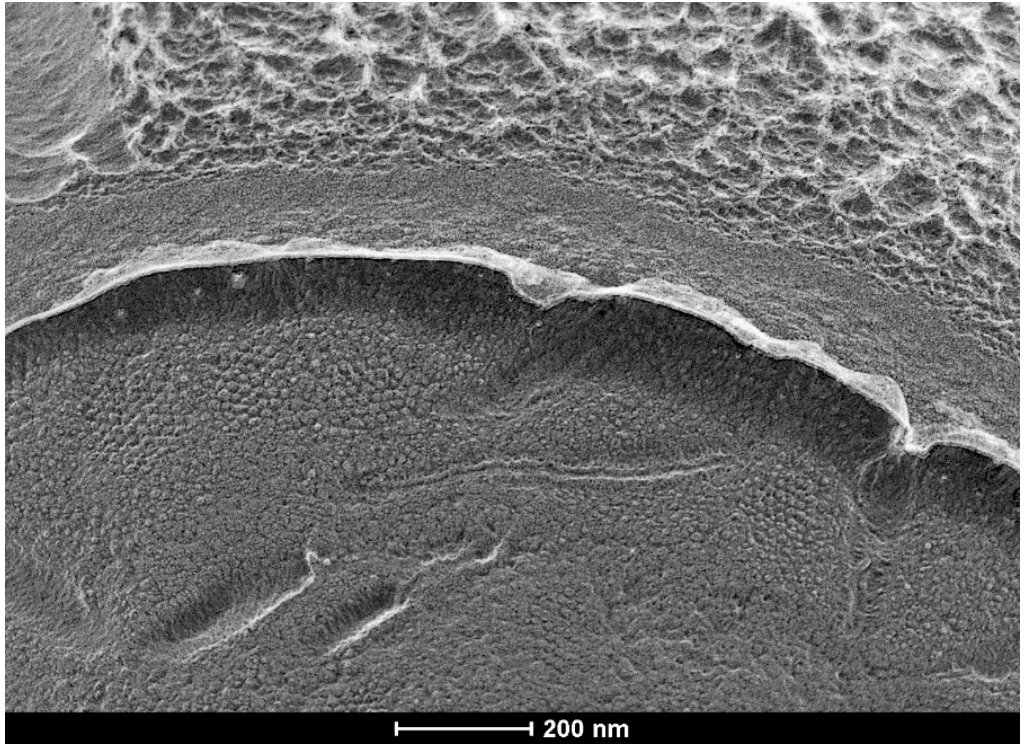

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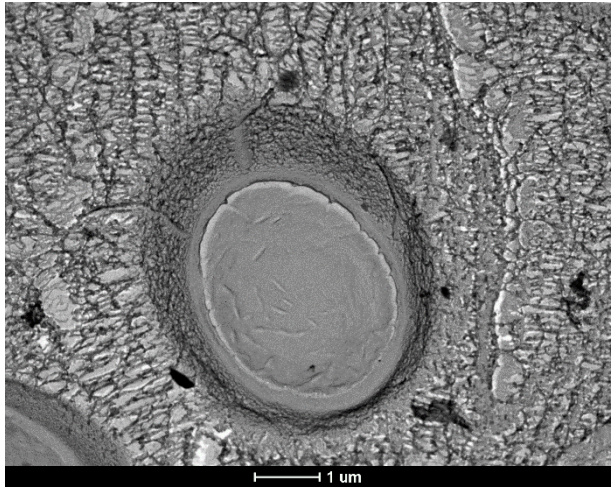

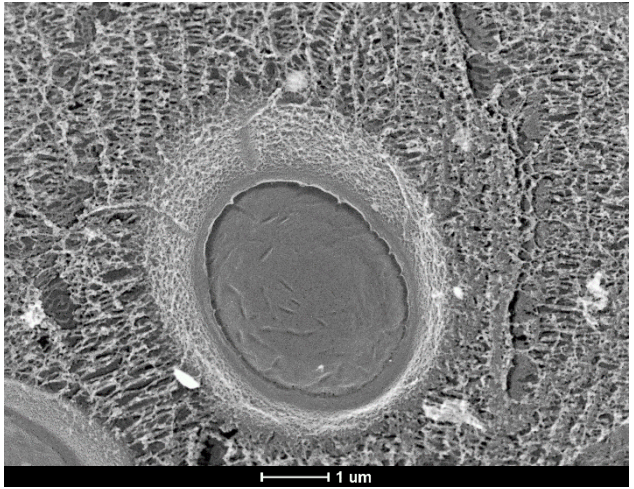

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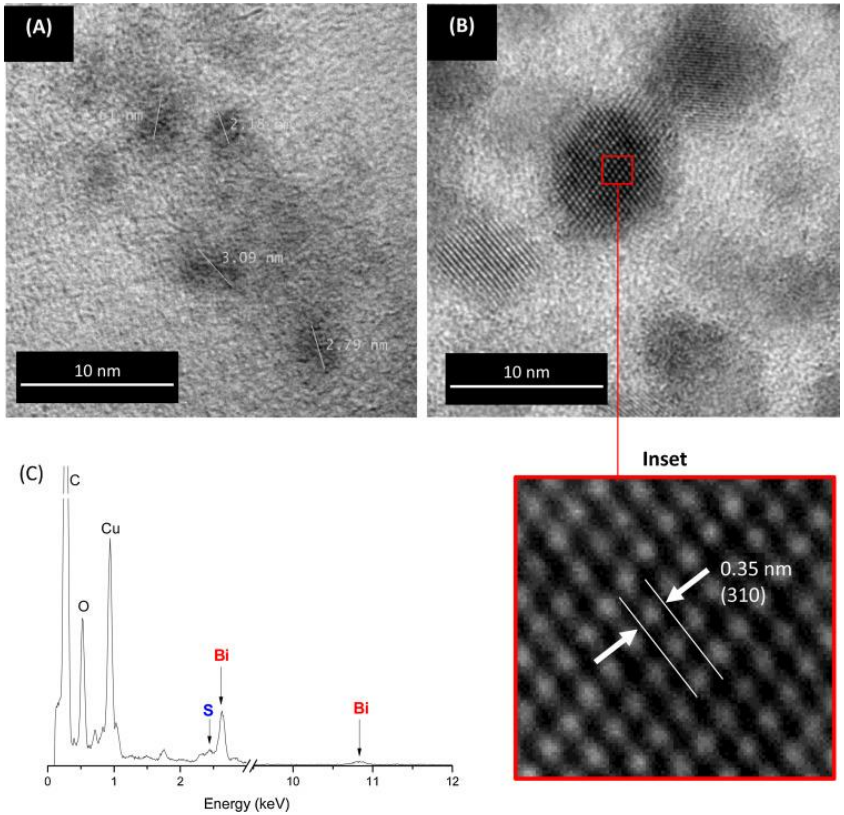
Quantum dots



A.A.P. Mansur et al. / Carbohydrate Polymers 146 (2016) 455–466

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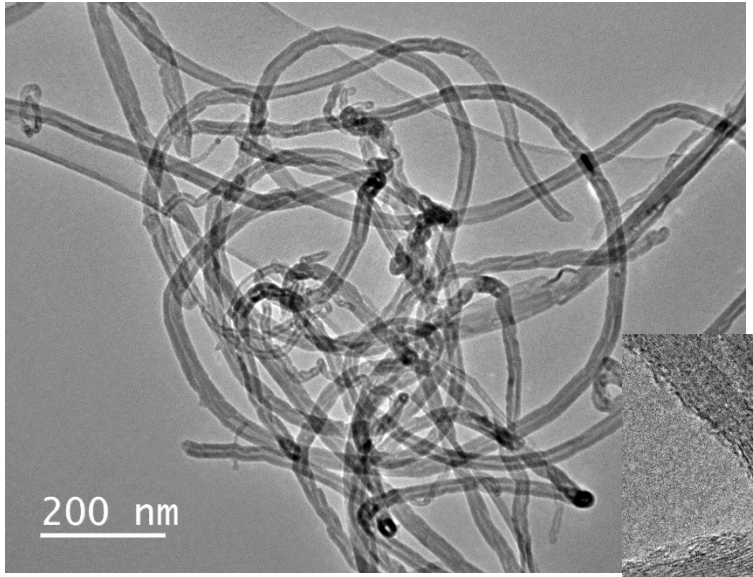
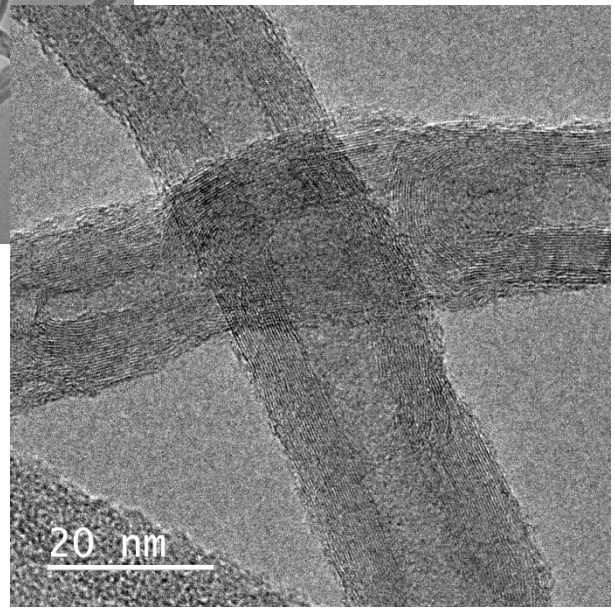


Carbon Nanotubes



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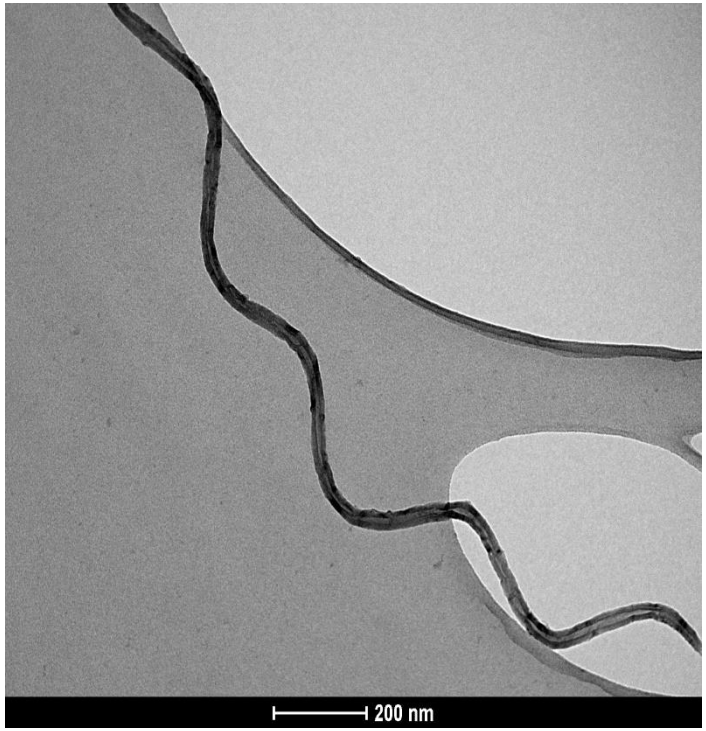

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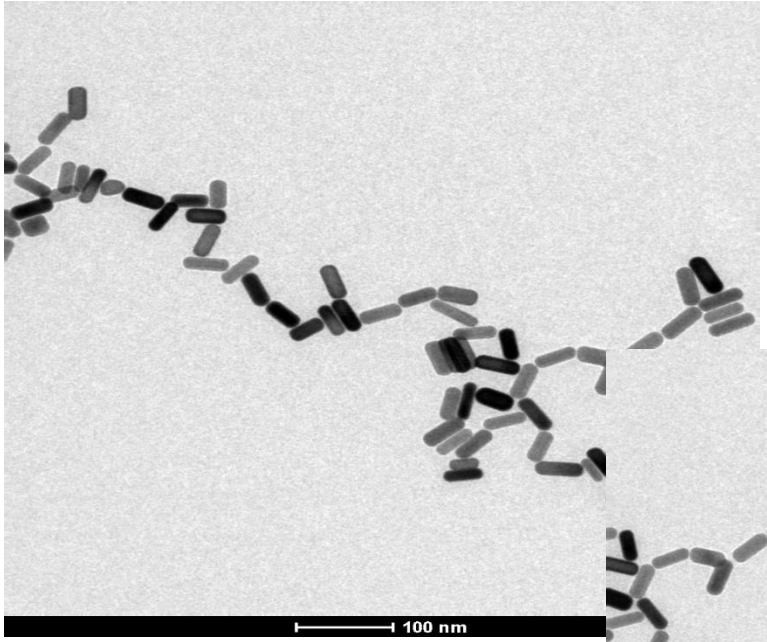
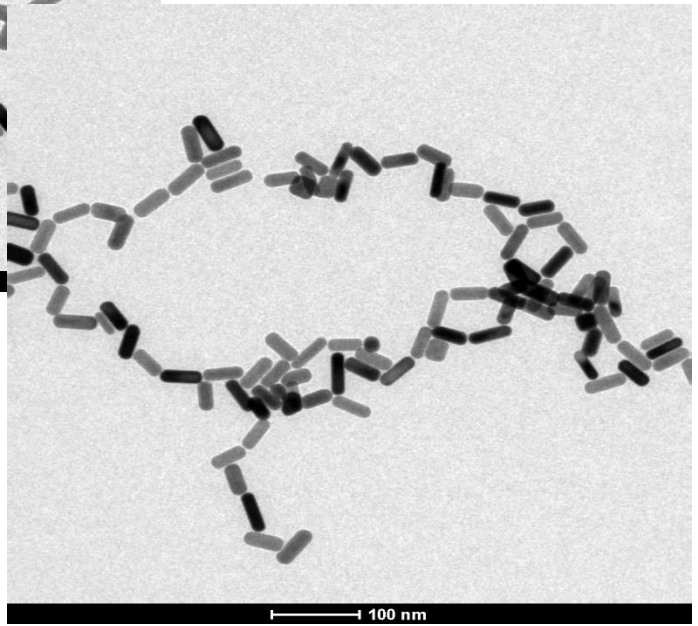


Gold Nanoparticles



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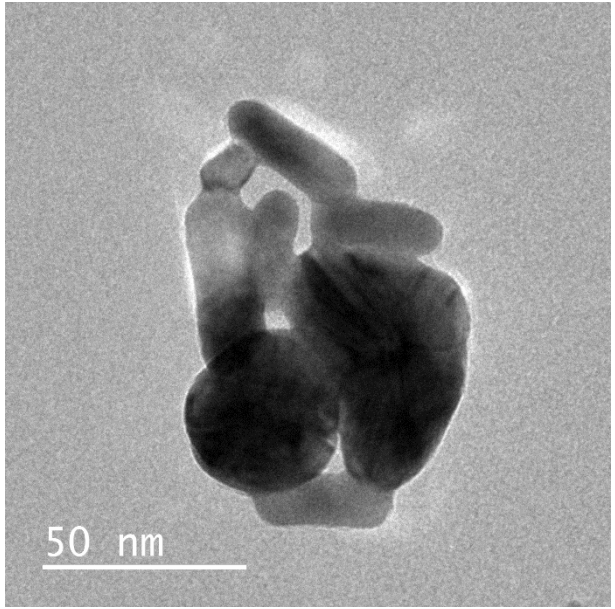

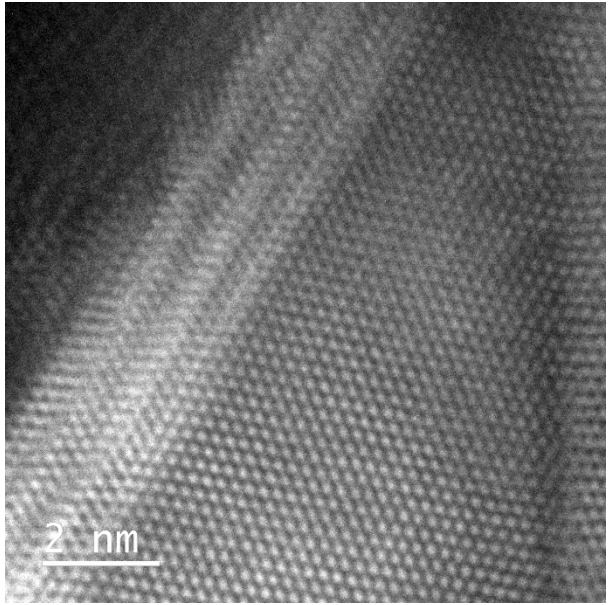

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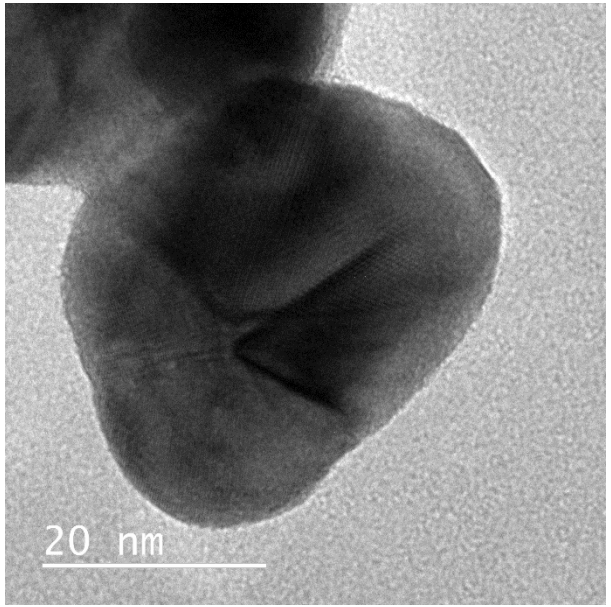

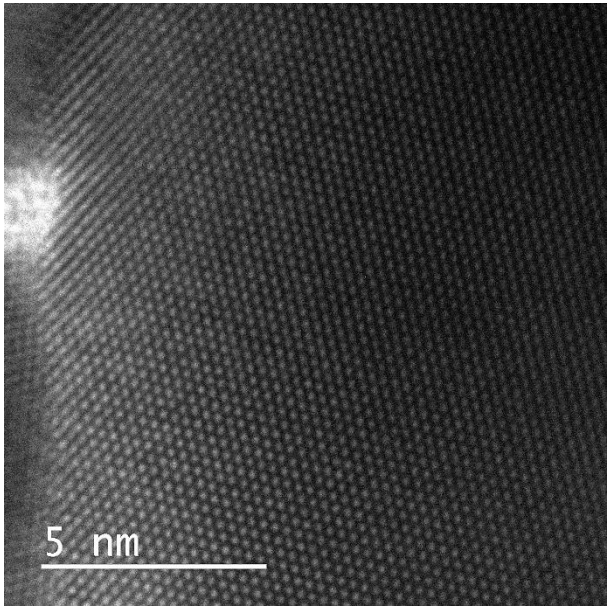

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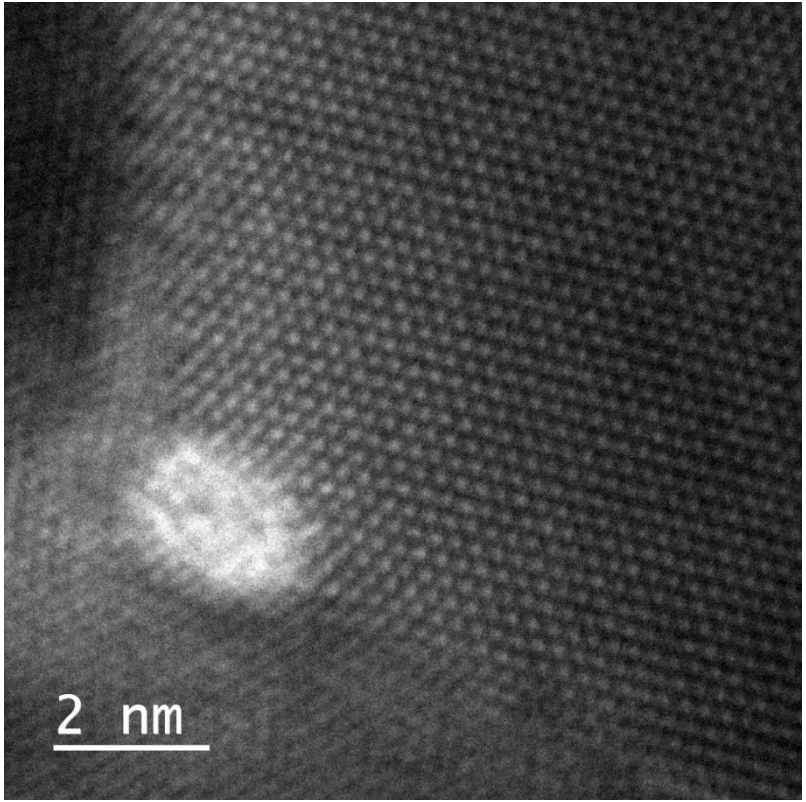
Gold Nanoparticles- HRTEM



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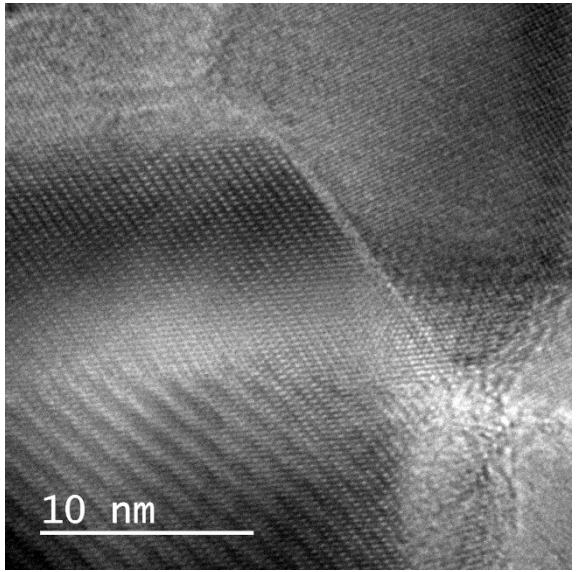
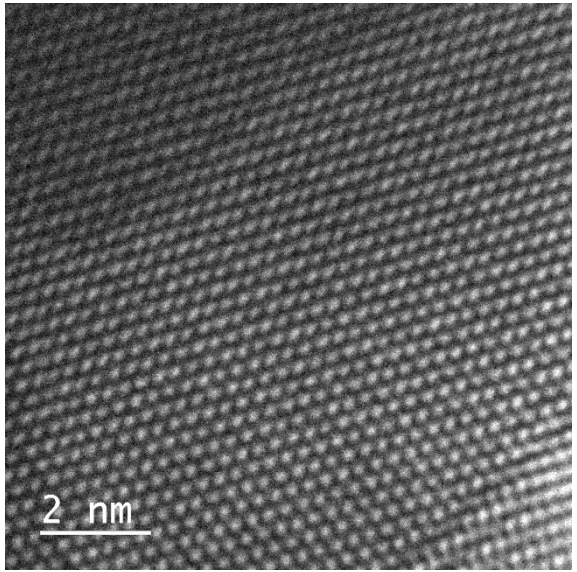
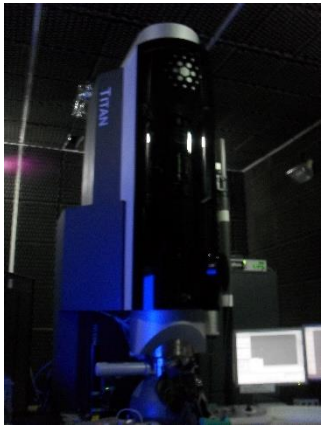
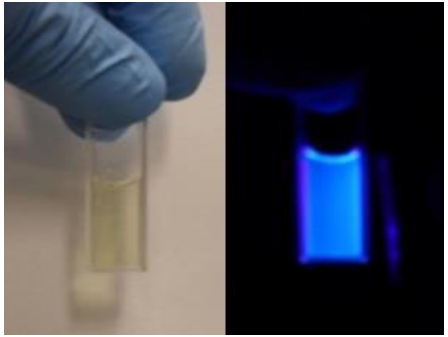
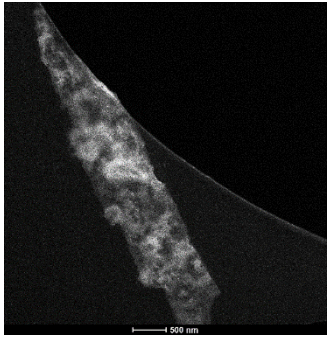


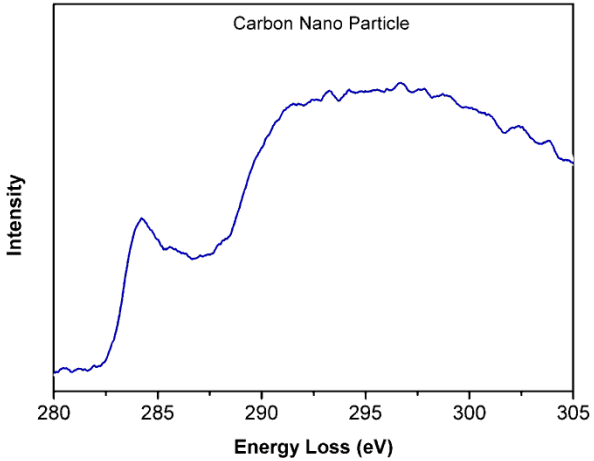


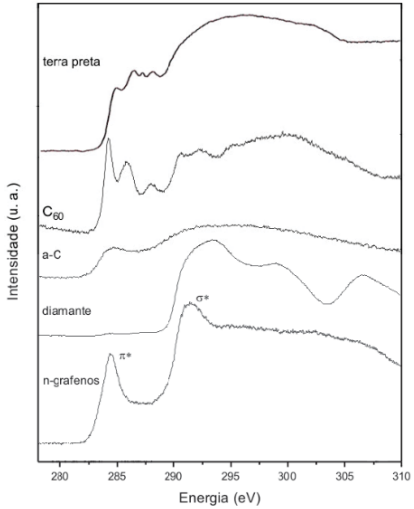
Carbon


TITAN



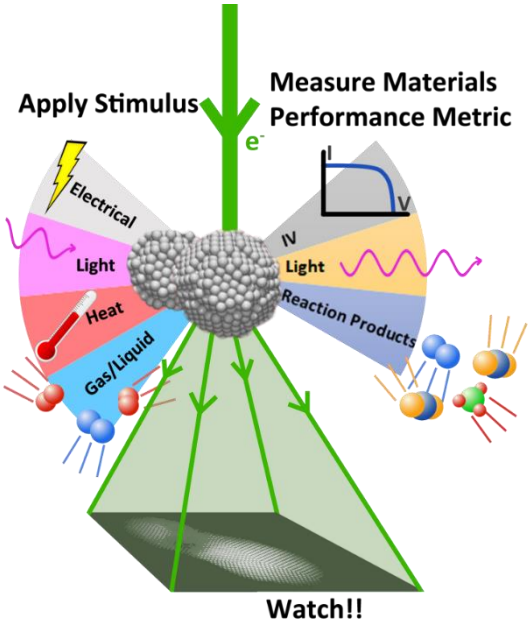

500 nm

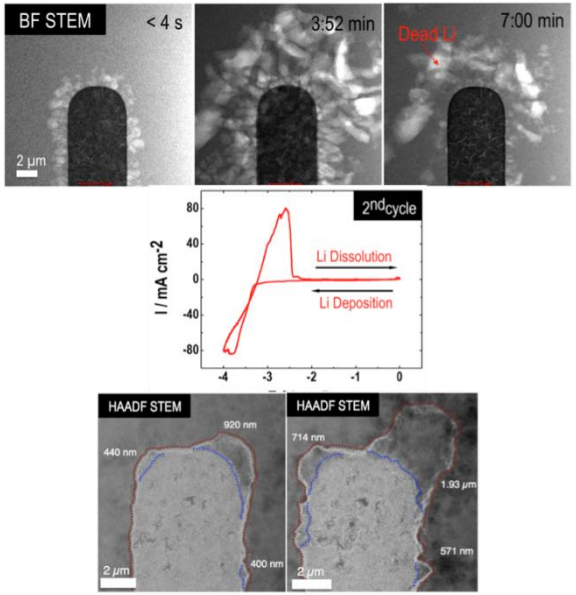

Carbon Nano Particle
Intensity
280
285
290
295
300
305
Energy Loss (eV)


terra preta
C60
a-C
diamante
n-grafenos
σ*
π*
Intensidade (u. a.)
280
285
290
295
300
305
310
Energia (eV)

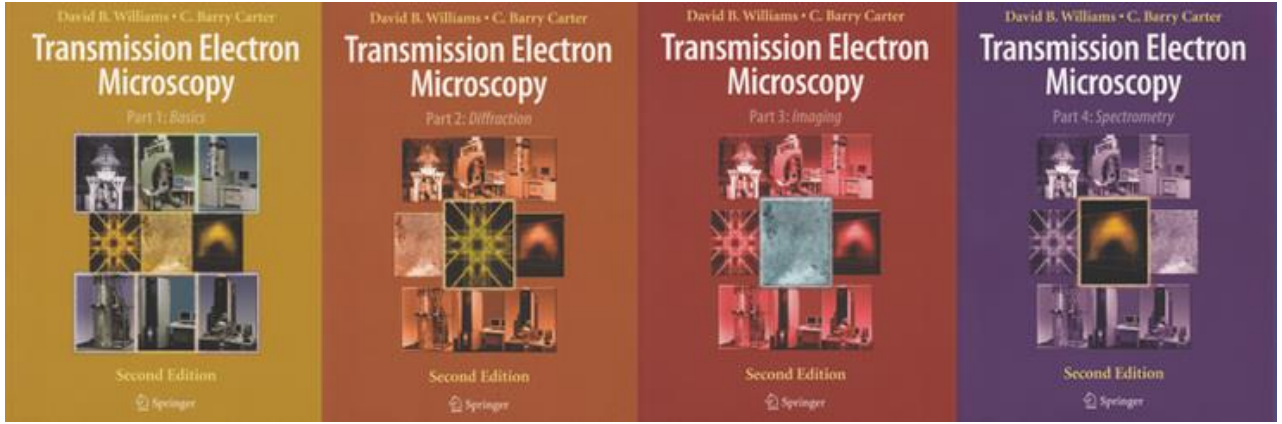
“Operando”

“Operando” Transmission Electron Microscopy





Electron Microscopy for Energy and the Environment Group at Arizona State University
http://crozier.faculty.asu.edu/research/transmission-electron-microscopy/operando-transmission-electron-microscopy/
http://www.jcesr.org/direct-observation-of-sei-and-dendrite-dynamics-by-operando-electrochemical-scanning-transmission-electron-microscopy/



D.B. Williams, C.B. Carter; Transmission Electron Microscopy – A Textbook for Materials Science, 2nd Edition, Springer Publisher, 2009.

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