THE TRANSMISSION ELECTRON MICROSCOPE:
ITS EARLY DEVELOPMENT AND RECENT ACHIEVEMENTS

Stan Konings
First electron microscope

Ernst Ruska and Max Knoll (1928-1931)

First commercial electron microscope (Siemens 1939)
1-stage “microscope”

2-stage microscope

Platina grid

13 x Platina grid

Bronze grid

4.8 x Bronze grid

17 x Platina grid

4.8 x Bronze grid

1929

1931
1933: Das übermikroskop

Magnification: up to 12000x

Wing of a house fly
M=2200x

Driest and Müller: Z. Wiss. Mikroskopie 52, 53-57 (1935)

Bacteria culture
M=2000x

Krause: Naturwissenschaften 25, 817-825 (1937)
Scanning TEM

1938: The *scanning* transmission electron microscope invented by Manfred von Ardenne
Early adopter in the Netherlands: Willy Burgers

• First to build a “low magnification” electron microscope in the Netherlands: 1935 (Philips Research lab)

• Alpha-gamma transition in iron at high temperature
Jan le Poole: founding father of electron optics in the Netherlands

1941: build his first electron microscope
1957: prof. of electron optics group (Delft)

X-ray projection microscope
SEM with quadrupole lenses
Microprobe x-ray analyzer
Compact 1 MV microscope

Stigmators
Intermediate lens
Twin lens configuration
TEM / STEM switch
The quest for better resolution

Why use electrons?

\[ R = 0.612 \frac{\lambda}{n \sin \alpha} \]

\[ \lambda = \frac{\hbar}{\sqrt{2m_0eU}} \sqrt{\frac{1}{1 + \frac{eU}{2m_0e^2}}} \]

Accelerating voltage

At 75 kV and an opening angle of 20 mrad: \( R = 264 \) pm
At 3000 kV and an opening angle of 20 mrad: \( R = 20 \) pm
3 MV transmission electron microscope Osaka
Lens aberrations limit spatial resolution

Spherical aberration $Cs$

Chromatic aberration $Cc$

Picture from: JARA
Aberation correction for TEM and STEM

60-300 kV

Hexapole lenses for spherical aberration correction

Dodecapole lens for chromatic aberration correction

See beyond at FEI.com

CEOS Corrected Electron Optical Systems GmbH
Aberation-corrected TEM and STEM show the atomic arrangement at high quality.
Grab all signals!
Energy-dispersive X-ray spectroscopy (EDX)

Most important components for mapping at atomic level

- Silicon Drift Detector
- High brightness gun (X-FEG)
- Probe corrector

(Cs corrector for STEM imaging)

Super-X setup
EDX of several perovskite materials

SrTiO$_3$

LaAlO$_3$

DyScO$_3$

Raw data (top) averaged map (lower left) and simulation (lower right)

Trend in X-ray microanalysis and STEM resolution over the last 60 years

Castaing’s Microprobe

1/2 every 5 yrs

1/2 every 15 yrs

EDX resolution

STEM resolution

Castaing’s Microprobe

FEG 30kV

0.1sr

Crewe’s

0.3sr

FEG 100kV

300kV

Cs correctors

~1sr

0.1sr

0.1

0.01


year
In-situ TEM

- STM
- Conductivity
- Nano-indentation
- EBID
- Light
- Gas environment
- Heating/annealing
Environmental TEM: gas + heat

Differential pumping system
Gas flow through microscope

Nanoreactor with thin electron transparent windows
Gas flow integrated on holder
Catalysts are often in the form of nanoparticles (1-10 nm)

- Structure of metal species is non uniform
- Metal - support interaction
- Deactivation due to coalescence
- Where are the active sites? the role of defects (vacancies, dislocations), steps and edges

Typical gases: \( \text{H}_2, \text{O}_2, \text{H}_2\text{O}, \text{CO}, \text{CO}_2, \text{C}_2\text{H}_2, \text{CH}_4 \) ......
Typical temperatures: 500-800 °C

Nanoparticles change shape under the influence of gas

**CO oxidation by gold nanoparticles on CeO\(_2\)**

**Growth of carbon nanotubes**

Nikkel catalysts with \( \text{CH}_4/\text{H}_2 @ 2.1 \text{ mbar} \) and heated to 536 °C
Time scale 2 frames/sec

Thank you!