


Transmission electron microscopy (TEM)




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Levels of investigation of structures


- Atomic level (*X-ray diffraction XRD, transmission electron microscope TEM, atomic force microscope AFM*)
- Microstructure (*scanning electron microscope SEM, X-ray spectroscopy*)
- Macrostructure (*classical metallography – „materialography”, non-destructive methods*)



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
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Resolution




$$d = \frac{\lambda}{2n \cdot \sin \alpha}$$

10 mm



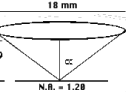
N.R. = 0.75

10 mm




N.R. = 1.20

18 mm



N.R. = 1.20



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Transmission electron microscope (TEM)

$$d = \frac{\lambda}{2n \sin \alpha}$$

$$\lambda_{\text{light}} = 360 - 720 \text{ nm}$$

$$\lambda_{\text{electron}} = 1 \dots 3 \text{ pm}$$

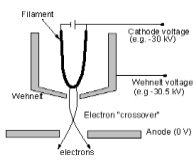

100 keV electron energy: $\lambda = 3,89 \text{ pm}$, theoretical resolution $d = 1,95 \text{ pm} \rightarrow$ atomic resolution!



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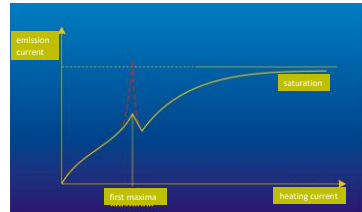

Thermoemission electron gun

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Emission current vs. heating current

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Electromagnetic lenses

$$\vec{F} = -q \cdot (\vec{E} + \vec{v} \times \vec{B})$$

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Electromagnetic lenses

- Lorentz-law: $\vec{F} = -q \cdot (\vec{E} + \vec{v} \times \vec{B})$

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Focus and rotation

$$\frac{1}{f} = \frac{\eta}{8V} \int_{-\infty}^{\infty} B_z^2(z) dz$$


$$\Phi = \sqrt{\frac{\eta}{8V}} \int_{-\infty}^{\infty} B_z(z) dz$$

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Operating modes of TEM

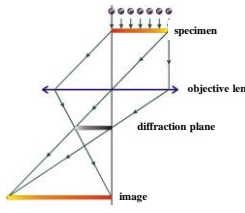
- Image formation (*grains, grain boundaries, crystal defects, dislocations, precipitations, inhomogenities*)
- Electron diffraction (*crystal structure, crystallographic orientation*)




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Operating modes

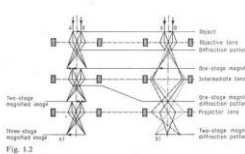





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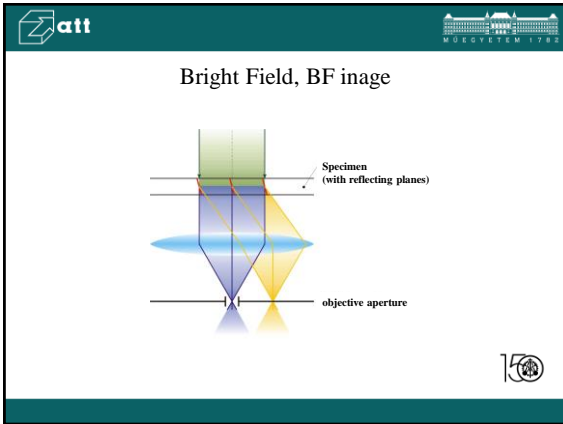
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Projecting system

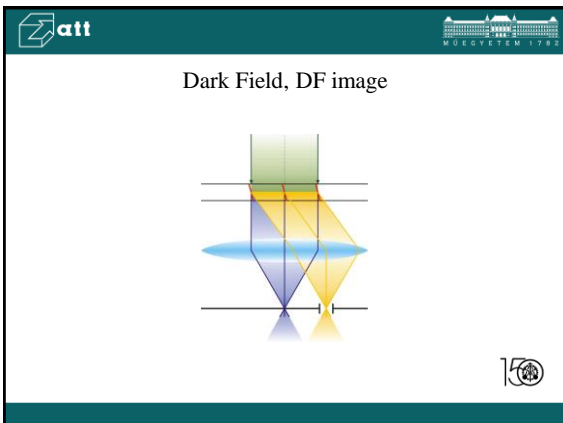




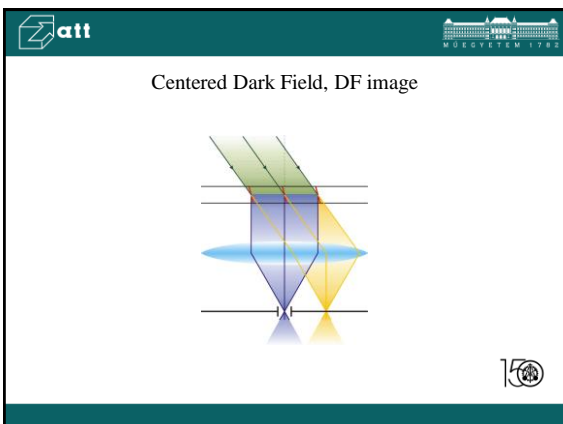
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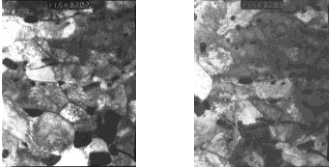
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Bright field images

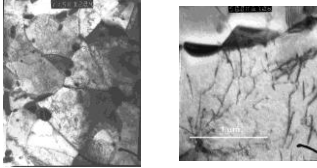





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Bright field images

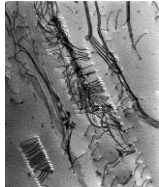





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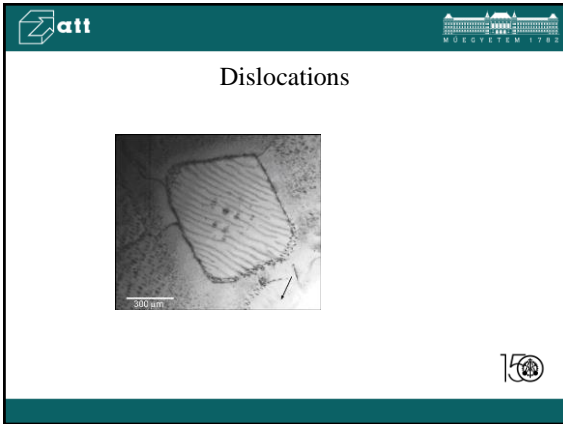
 

Dislocations

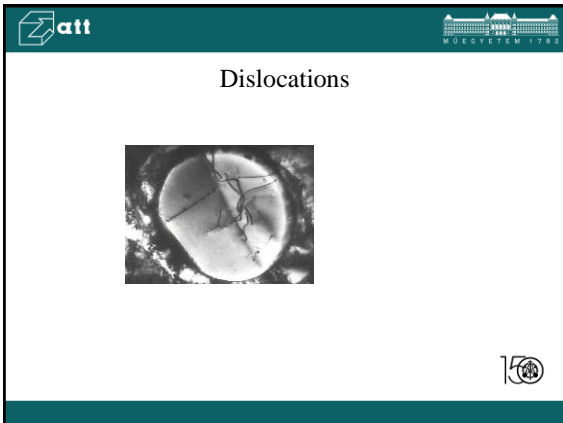




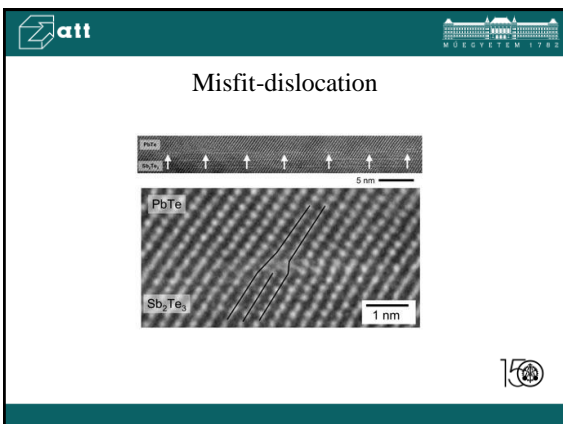
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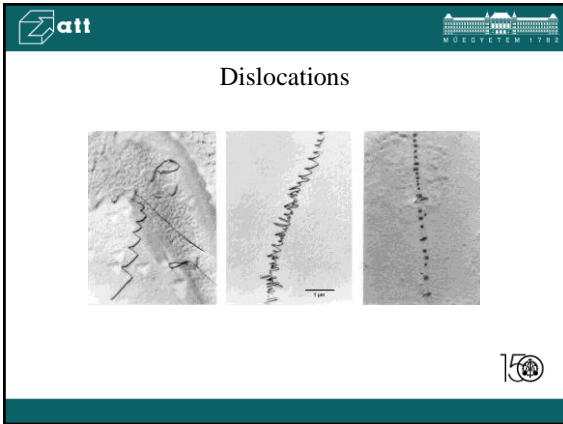
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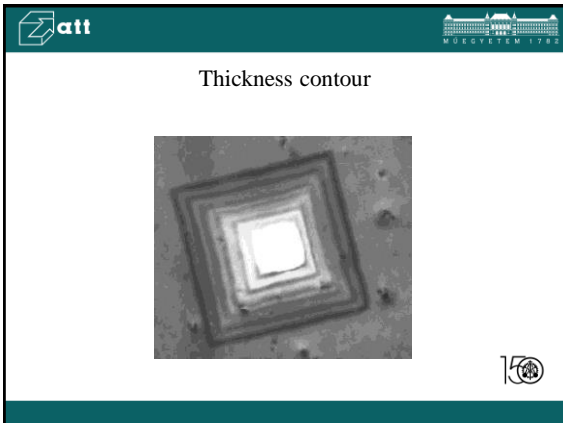
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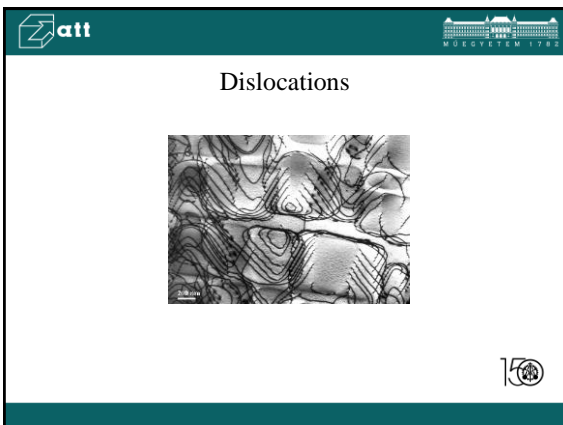
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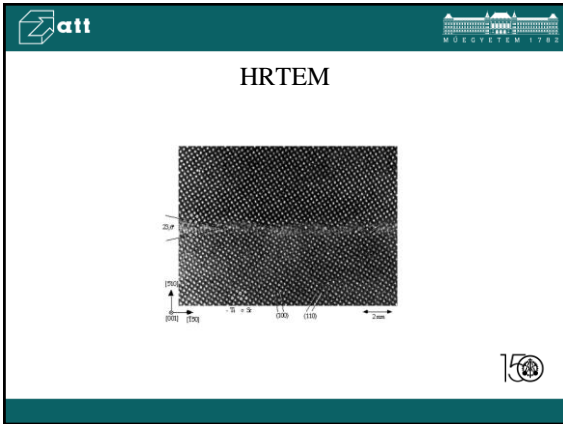
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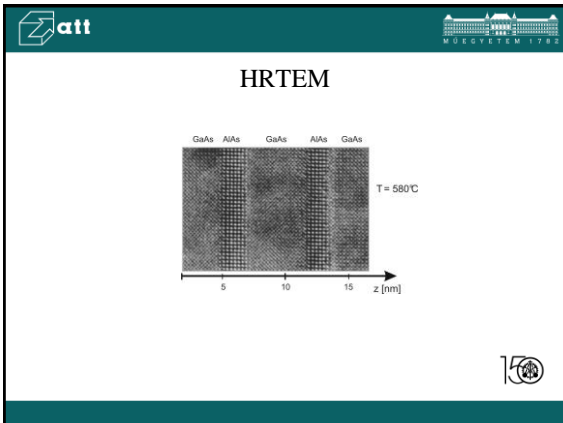
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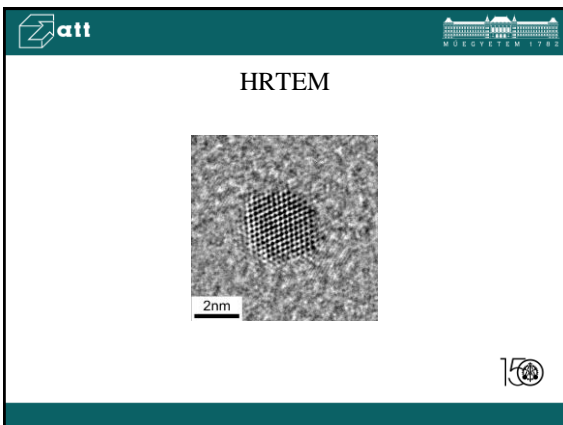
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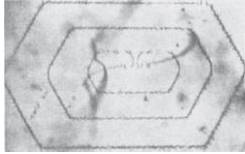
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Frank-Read source

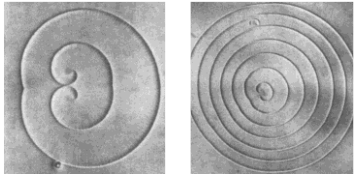





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Frank-Read source

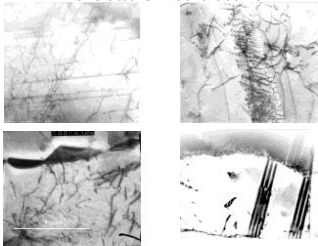





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Dislocation structure

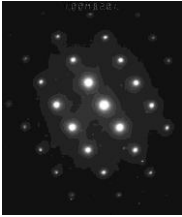





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Electron diffraction






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Sample preparation

- Thin foils are needed
- $d_{\max} = 100 \text{ nm!}$
- Electrolytic etching
- Uncertain area of investigation

- Ionic bombardment



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