



Kristalle in Farben

Einblick in das Innere der Metalle

Stefan Zaefferer

100 μm

- Was sind Kristalle? Atomare Struktur, Symmetrie.
- Wie kann man die atomare Struktur sichtbar machen?
Mit Licht geht's nicht!
- Sehen mit Elektronen. Was ist (Raster) Elektronenmikroskopie? Die Bragg'sche Gleichung und Elektronenbeugungsmuster.
- Graphische Darstellung von Kristallen. Kristallographie für alle.
- Endlich: Farbige Kristalle aus dem Elektronenmikroskop!



WAS SIND KRISTALLE?

Was sind Kristalle?



trigonal



orthorhombisch

[https://www
/Mineralien](https://www.Mineralien)



[https://www.mineralienatlas.de/lexikon/index.php/
MineralData?mineral=Schwefel](https://www.mineralienatlas.de/lexikon/index.php/MineralData?mineral=Schwefel)

(C) Chinglieto Matteo 2007

kubisch



[https://www.mineralienatlas.de/lexikon/index.php/
/MineralData?mineral=Granat](https://www.mineralienatlas.de/lexikon/index.php/MineralData?mineral=Granat)

hexagonal



[https://www.mineralienatlas.de/lexikon/index.php/
MineralData?min](https://www.mineralienatlas.de/lexikon/index.php/MineralData?mineral=Emerald)

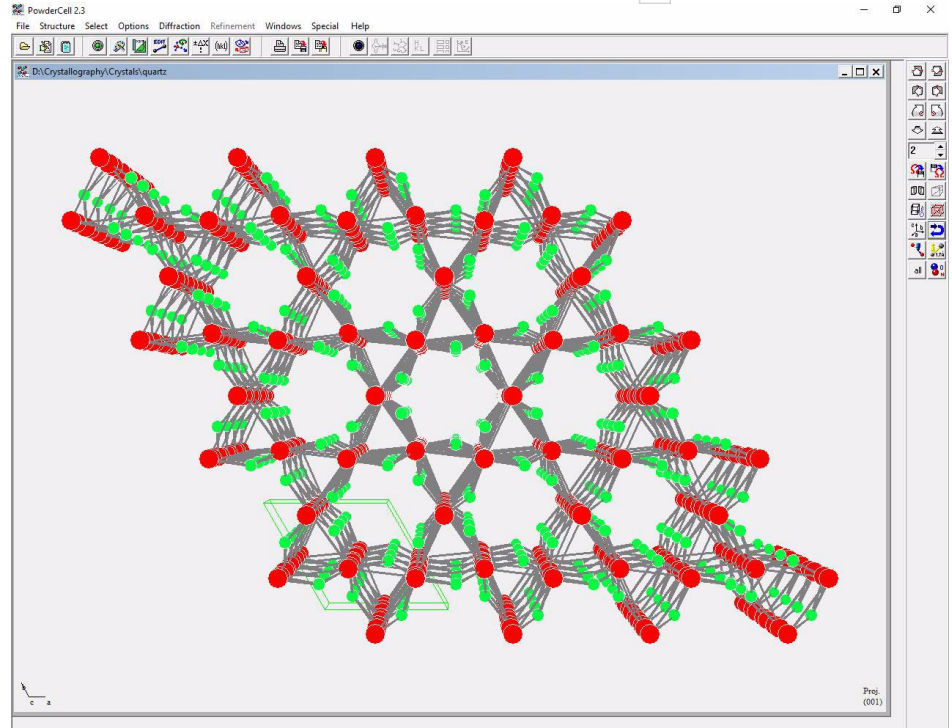
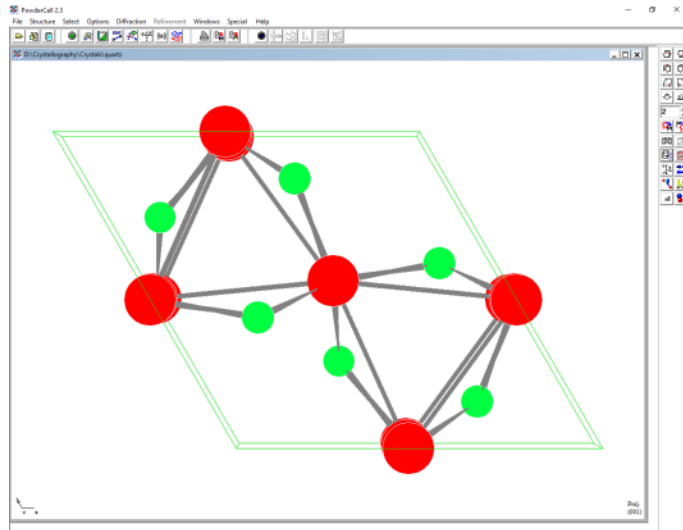
monoklin



[https://www.mineralienatlas.de/lexikon/index.php/
MineralData?mineral=Gips](https://www.mineralienatlas.de/lexikon/index.php/MineralData?mineral=Gips)



Quarz mit trigonaler Kristallsymmetrie



Bestehen Metalle denn auch aus Kristallen?



100
YEARS 1917-2017

Goldkristalle



Goldnuggets



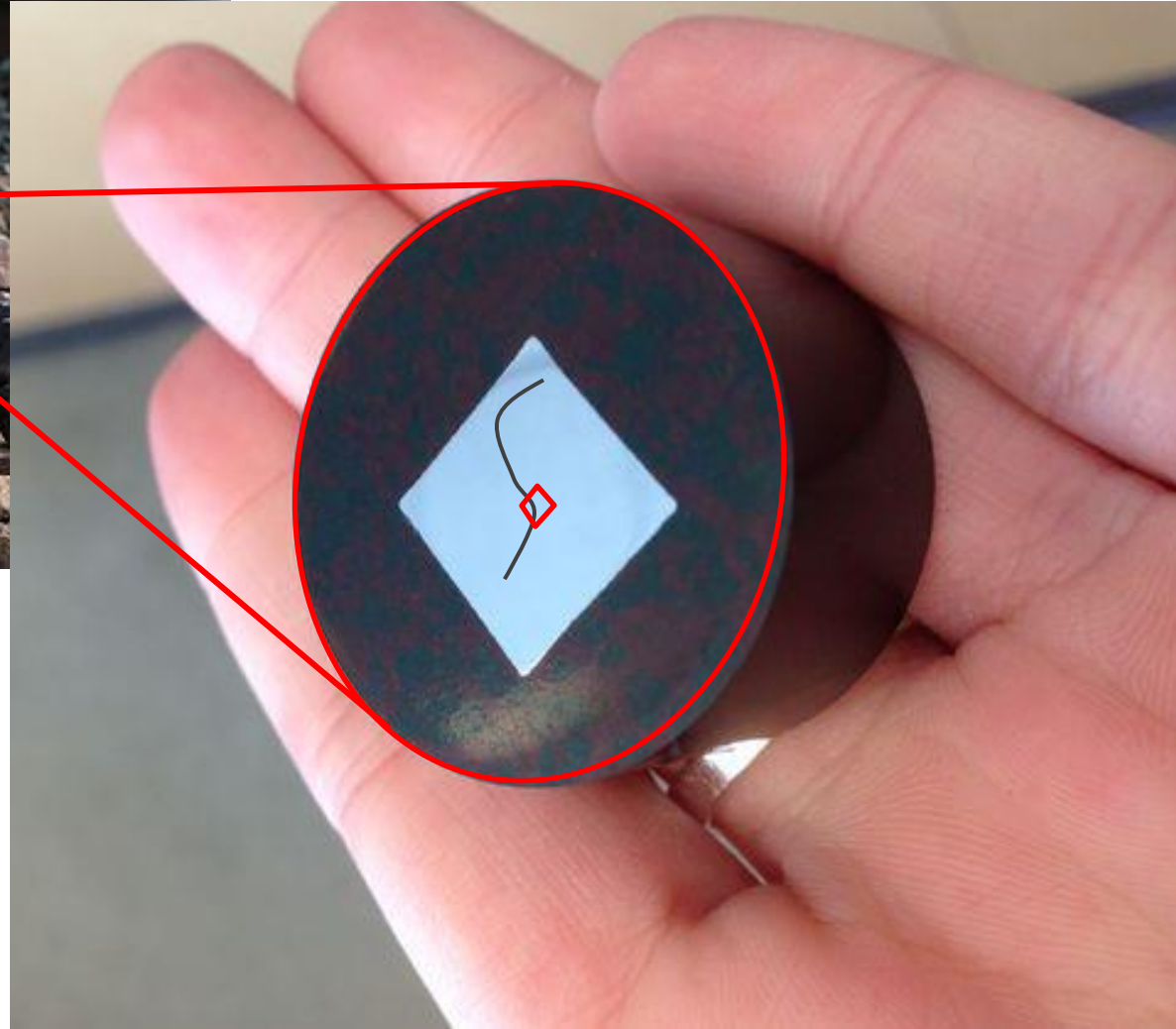
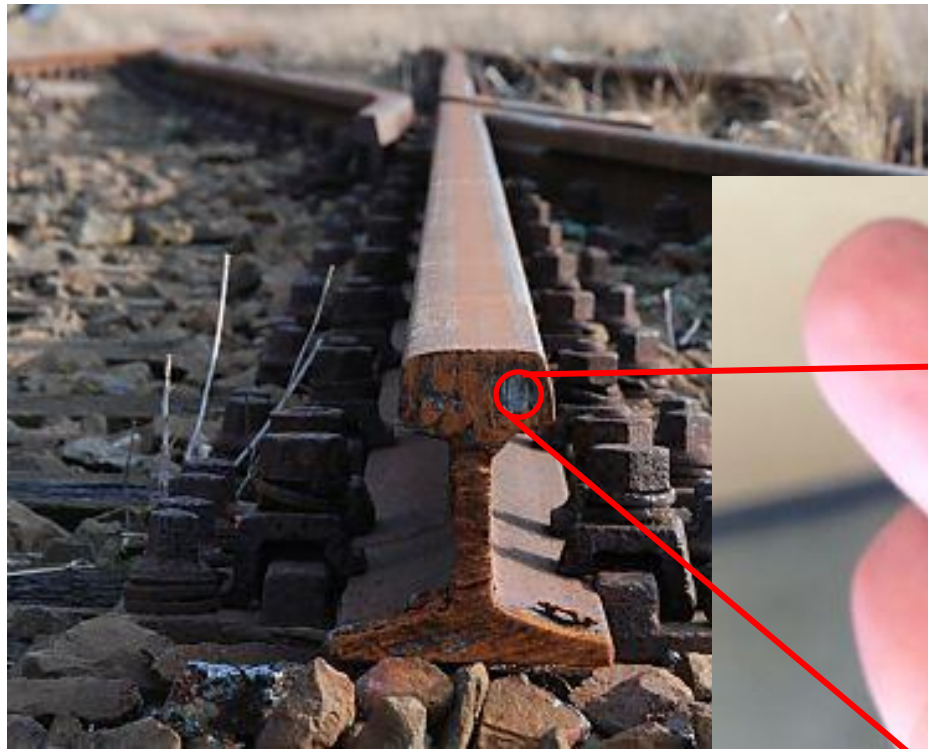
Eisenkristalle

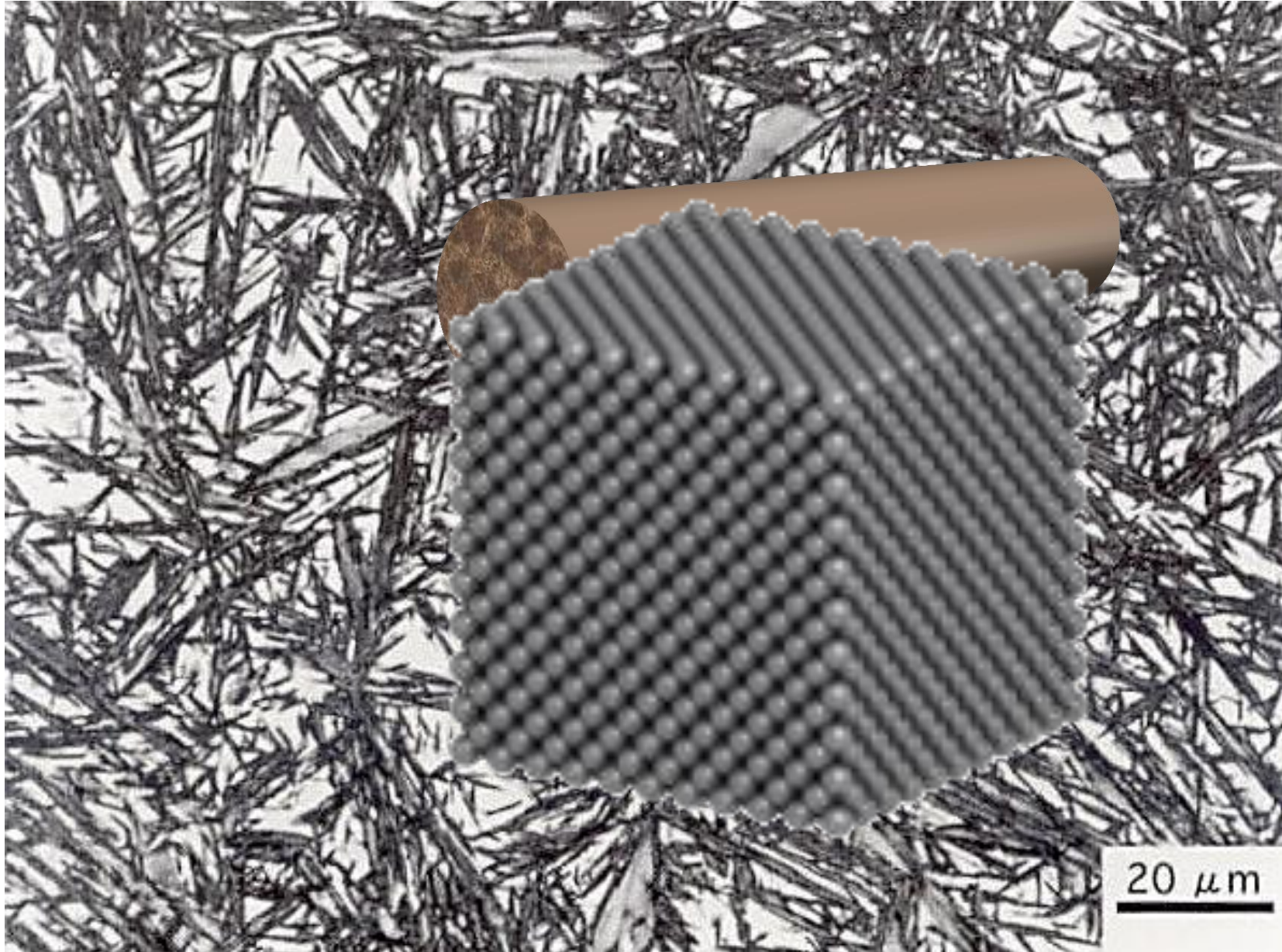


Eisenkristalle in Meteoriten

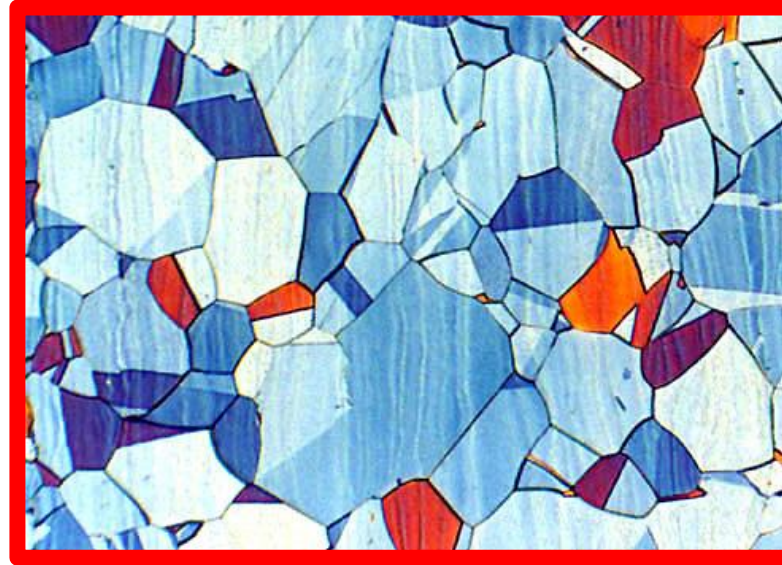


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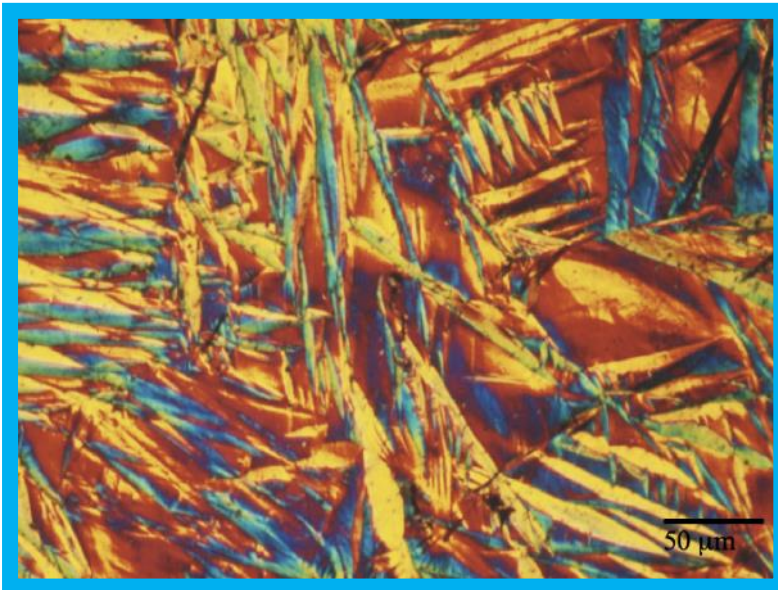




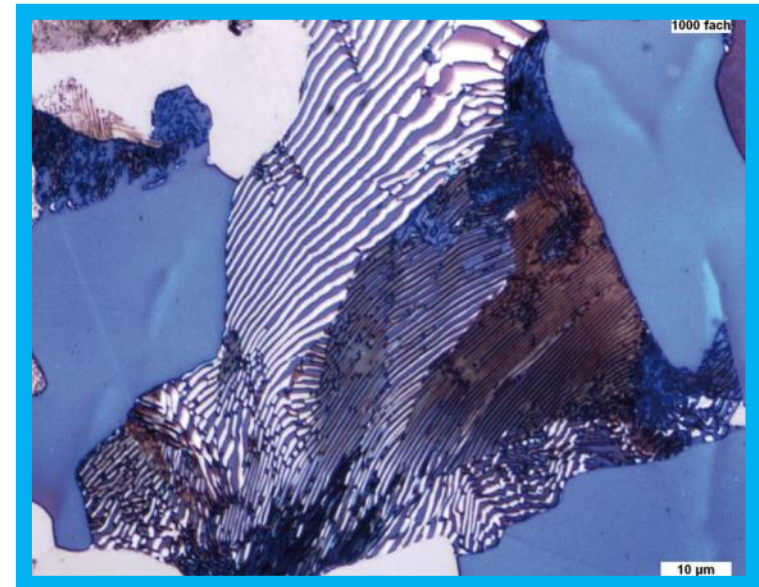
hohe
Temperatur



niedrige
Temperatur

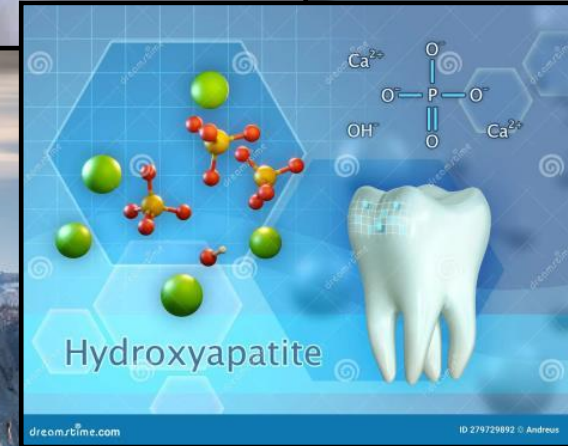


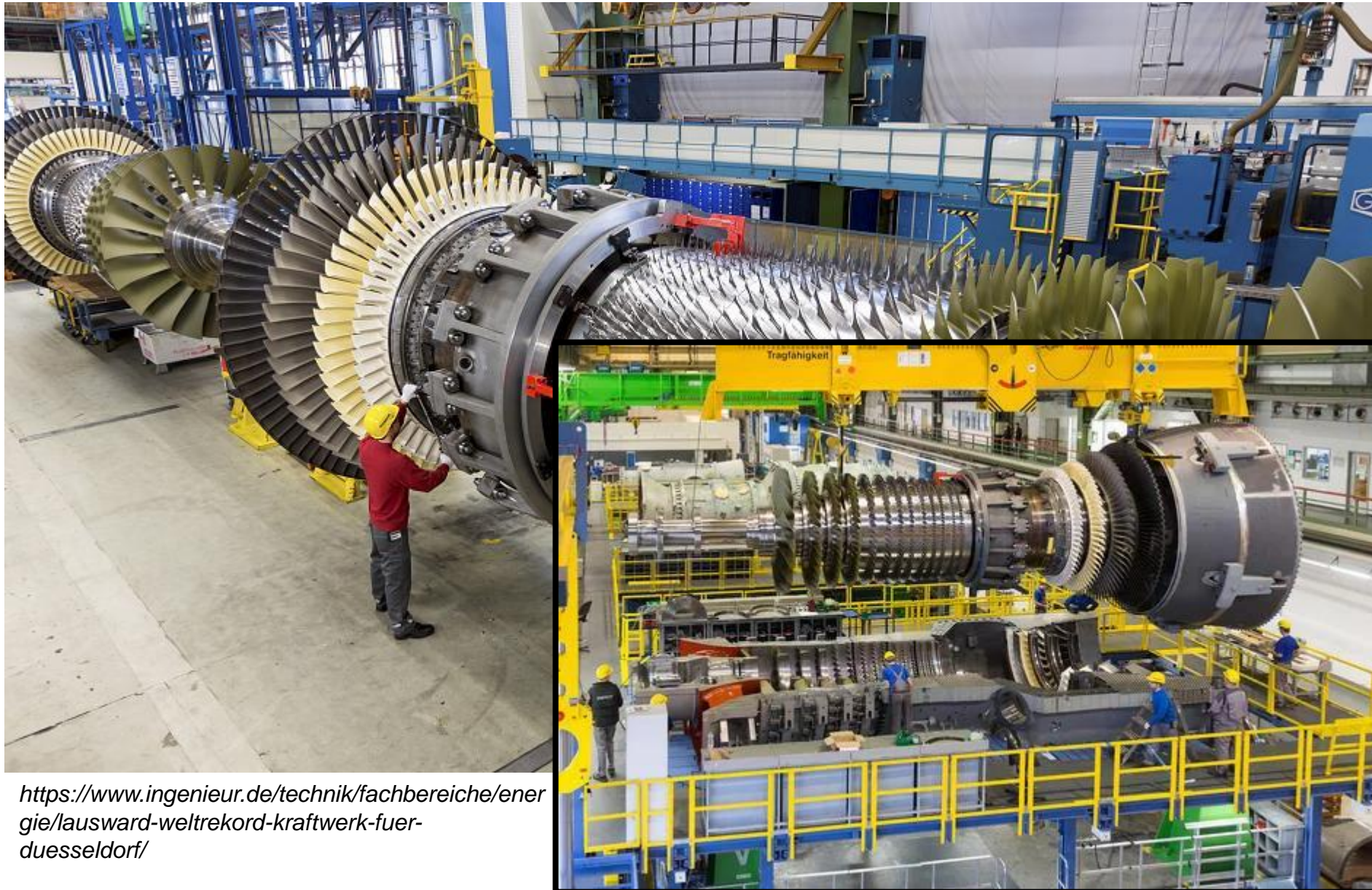
schnell abgekühlt



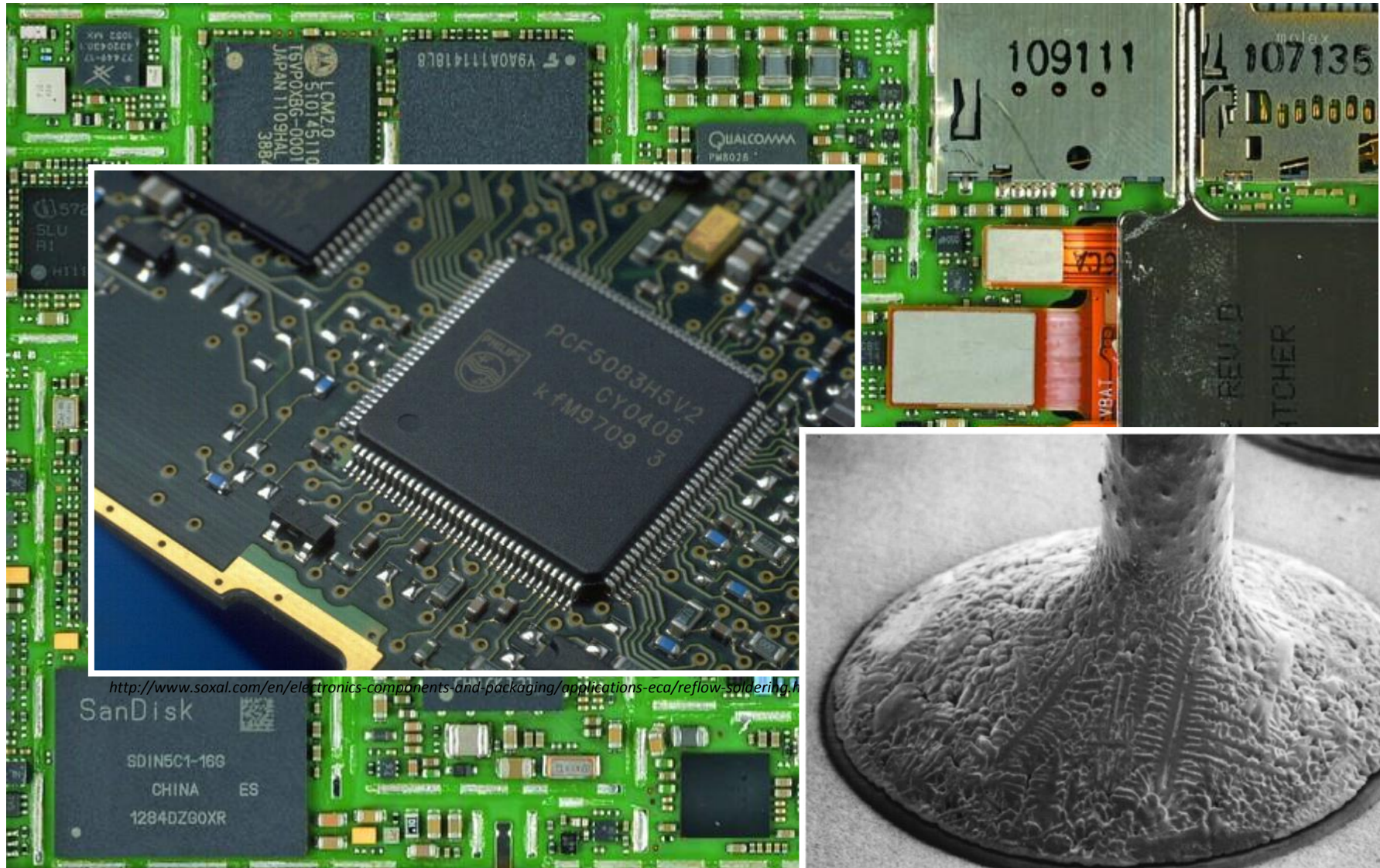
langsam abgekühlt

Kristalle sind überall





<https://www.ingenieur.de/technik/fachbereiche/energie/lausward-weltrekord-kraftwerk-fuer-duesseldorf/>

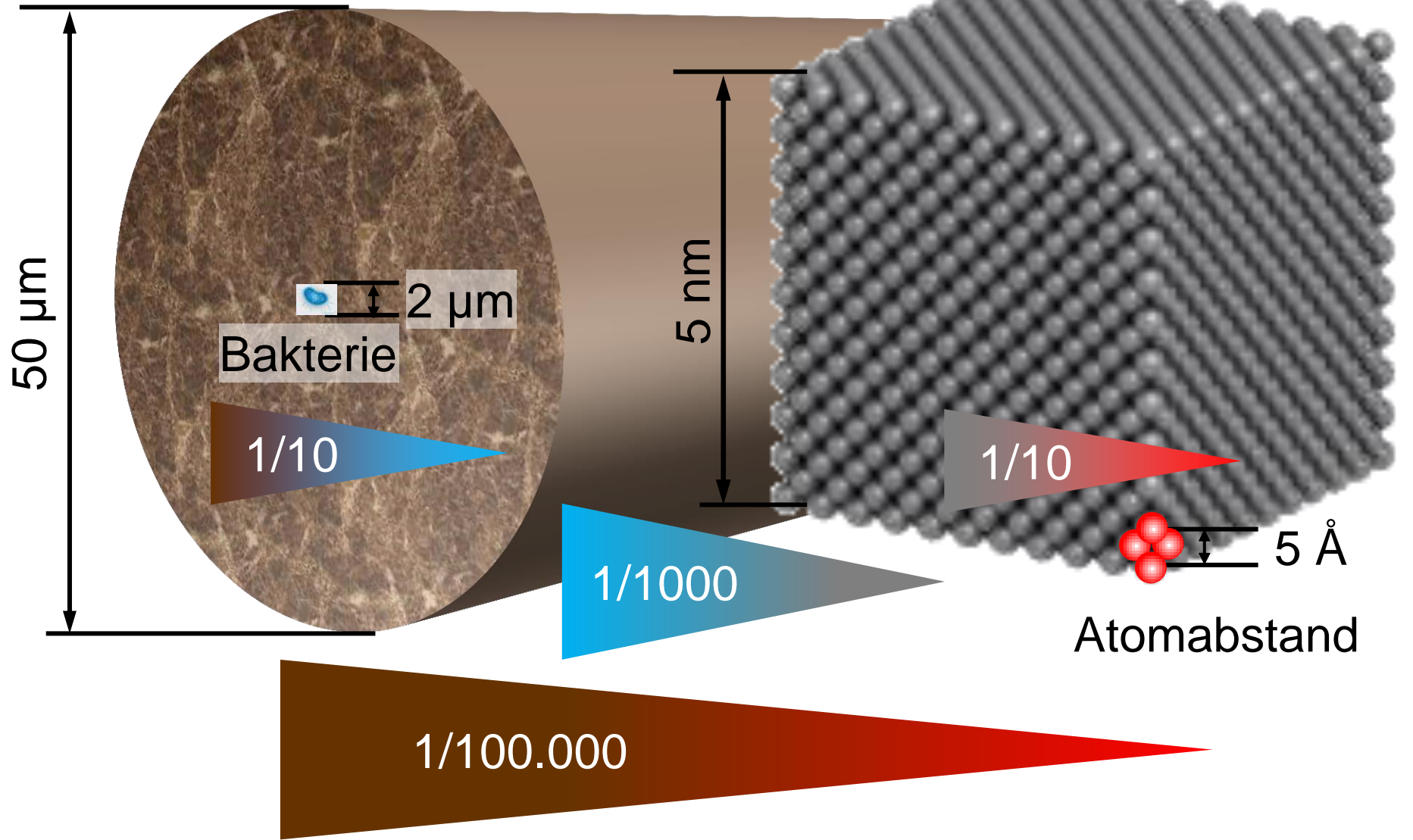


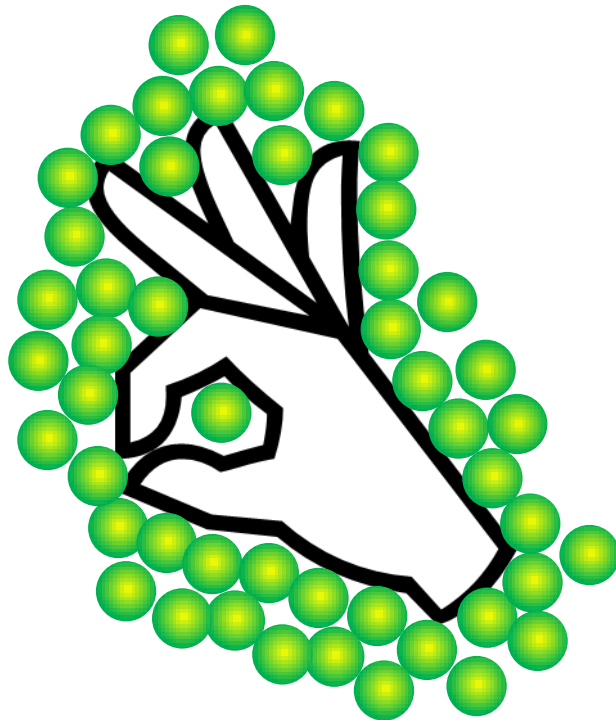
<http://www.soxal.com/en/electronics-components-and-packaging/applications-eca/reflow-soldering>

(WIE) KANN MAN DIE KRISTALLSTRUKTUR SEHEN?

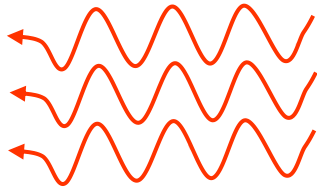
menschliches Haar

Atomgitter

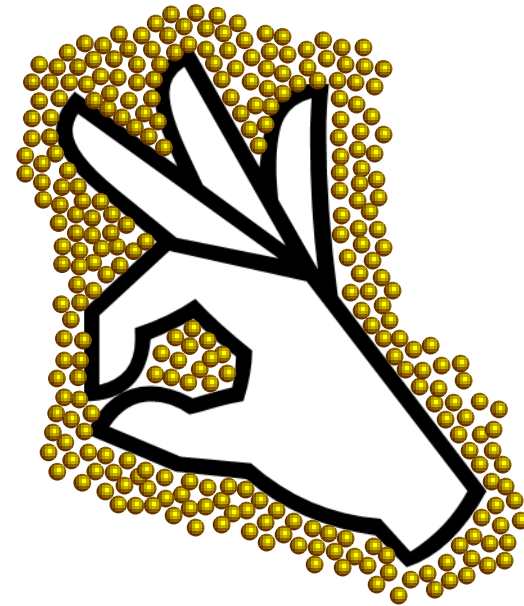




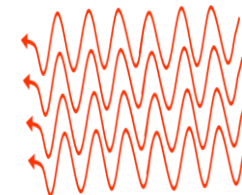
Licht



Wellenlänge: ~ 500 nm

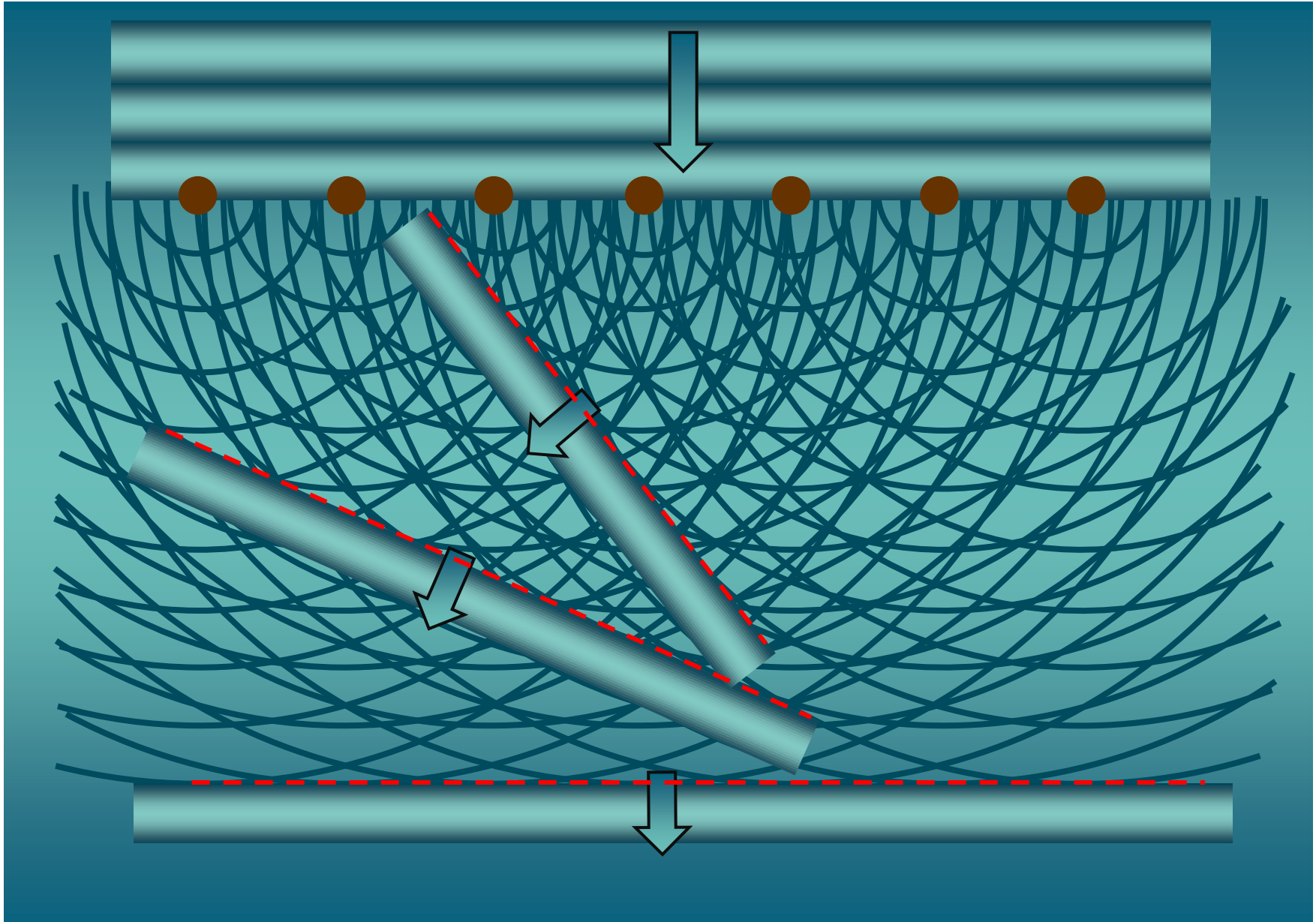


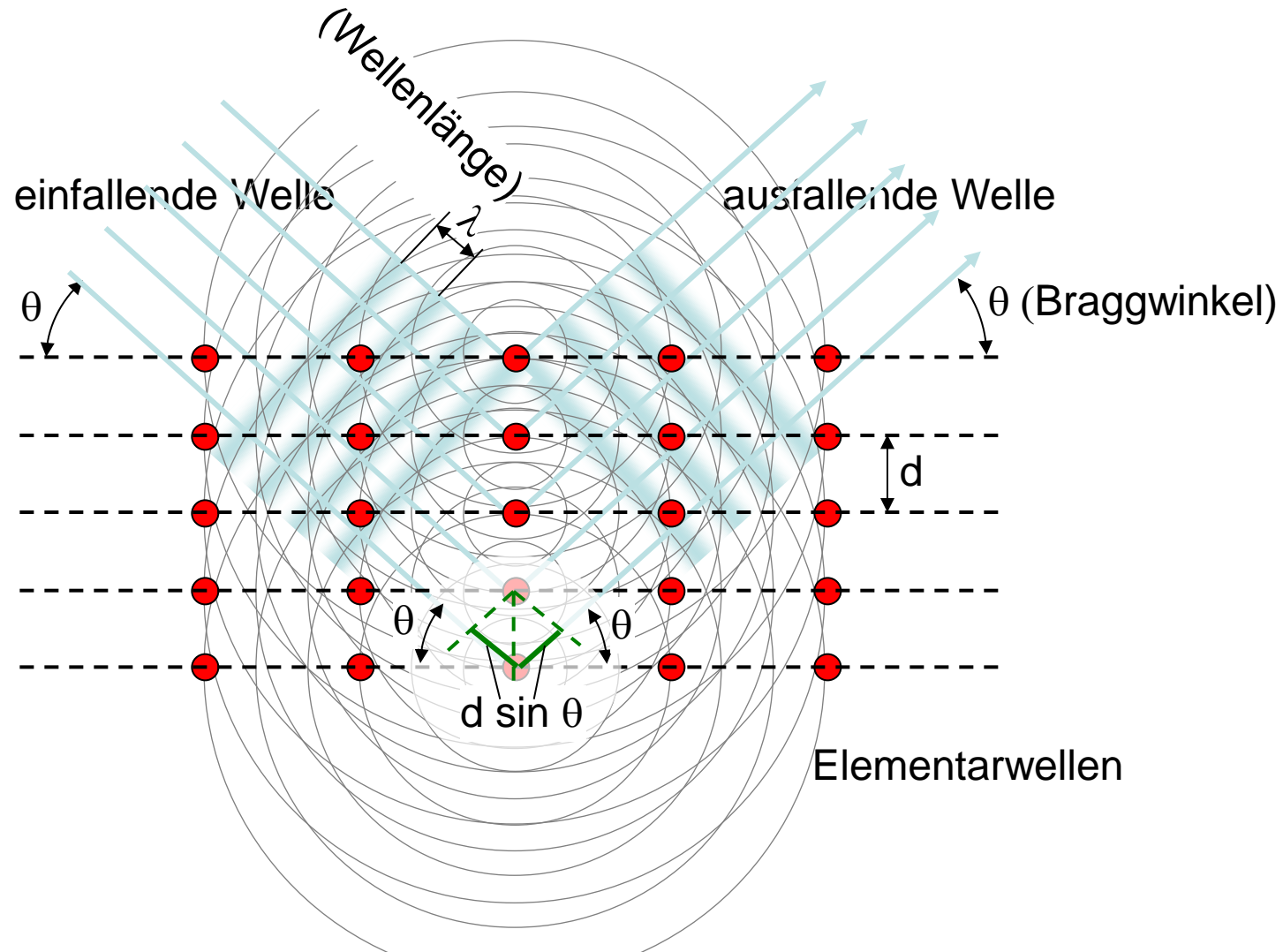
Elektronen



Wellenlänge: ~ 5 pm

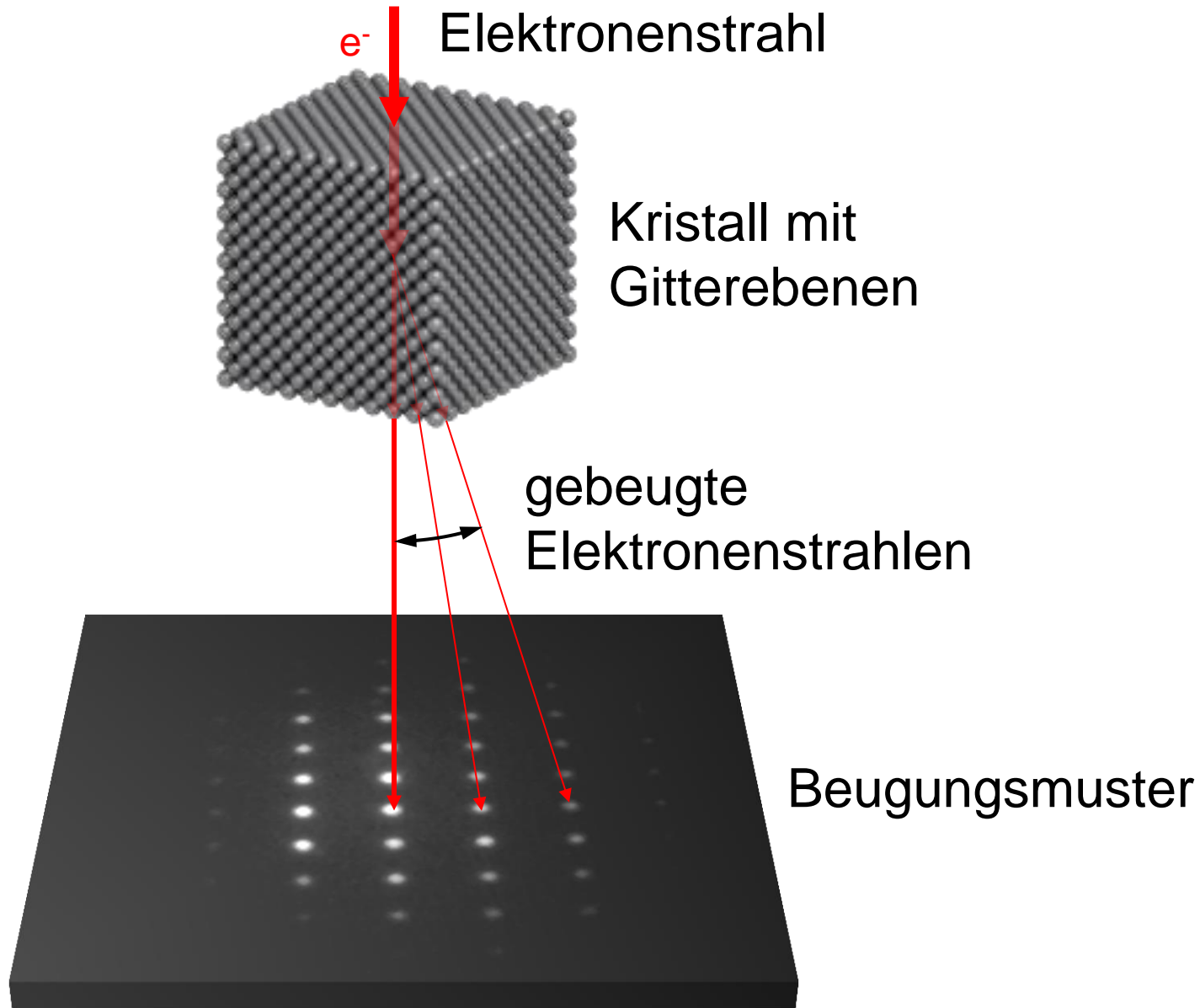
Elektronen haben 10.000-fach kleinere Wellenlänge!

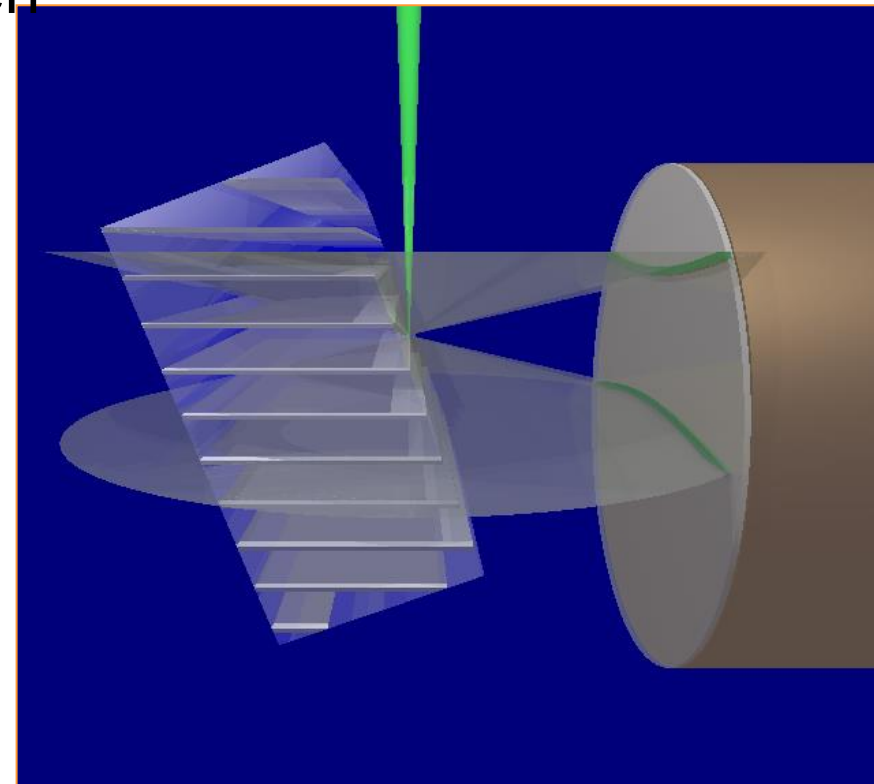
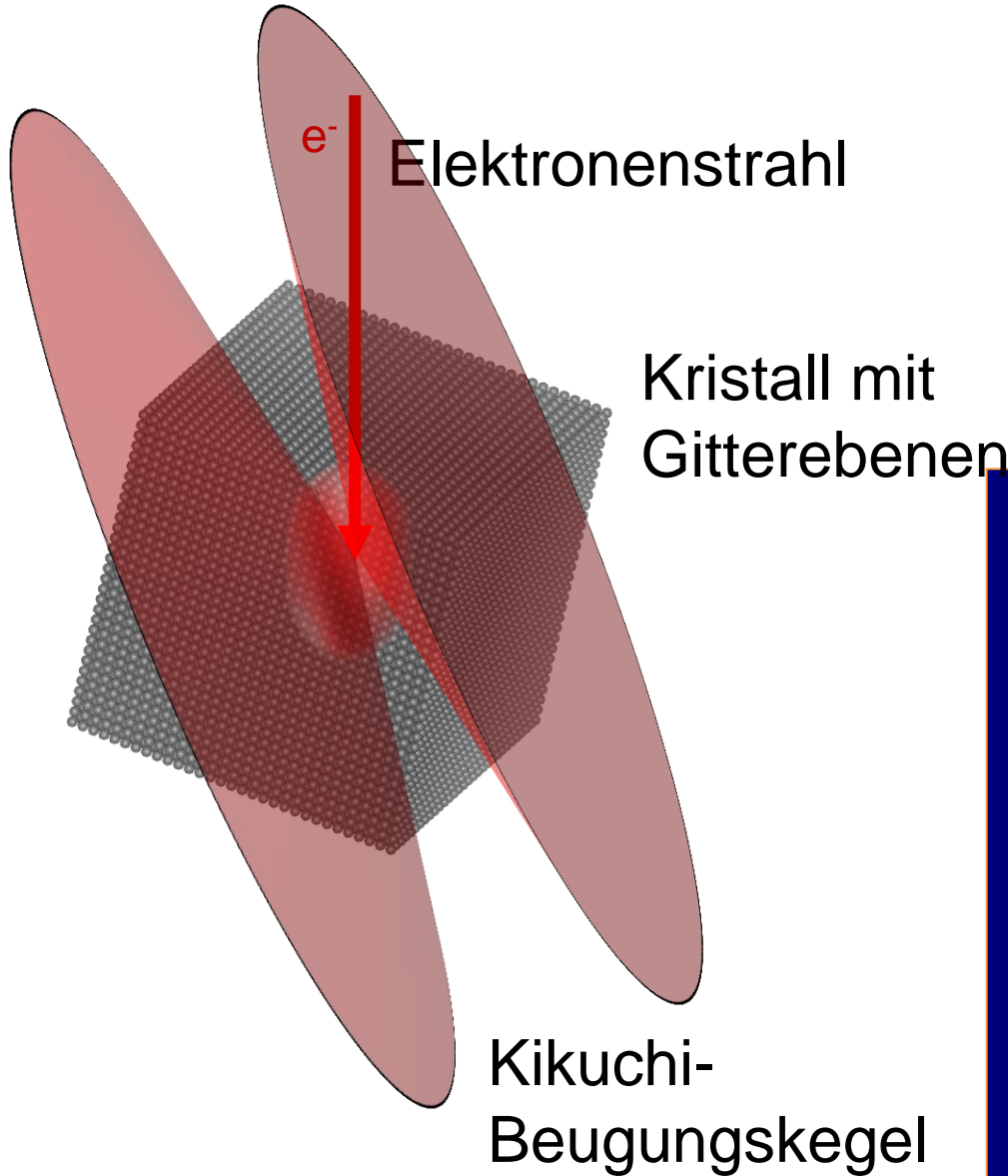


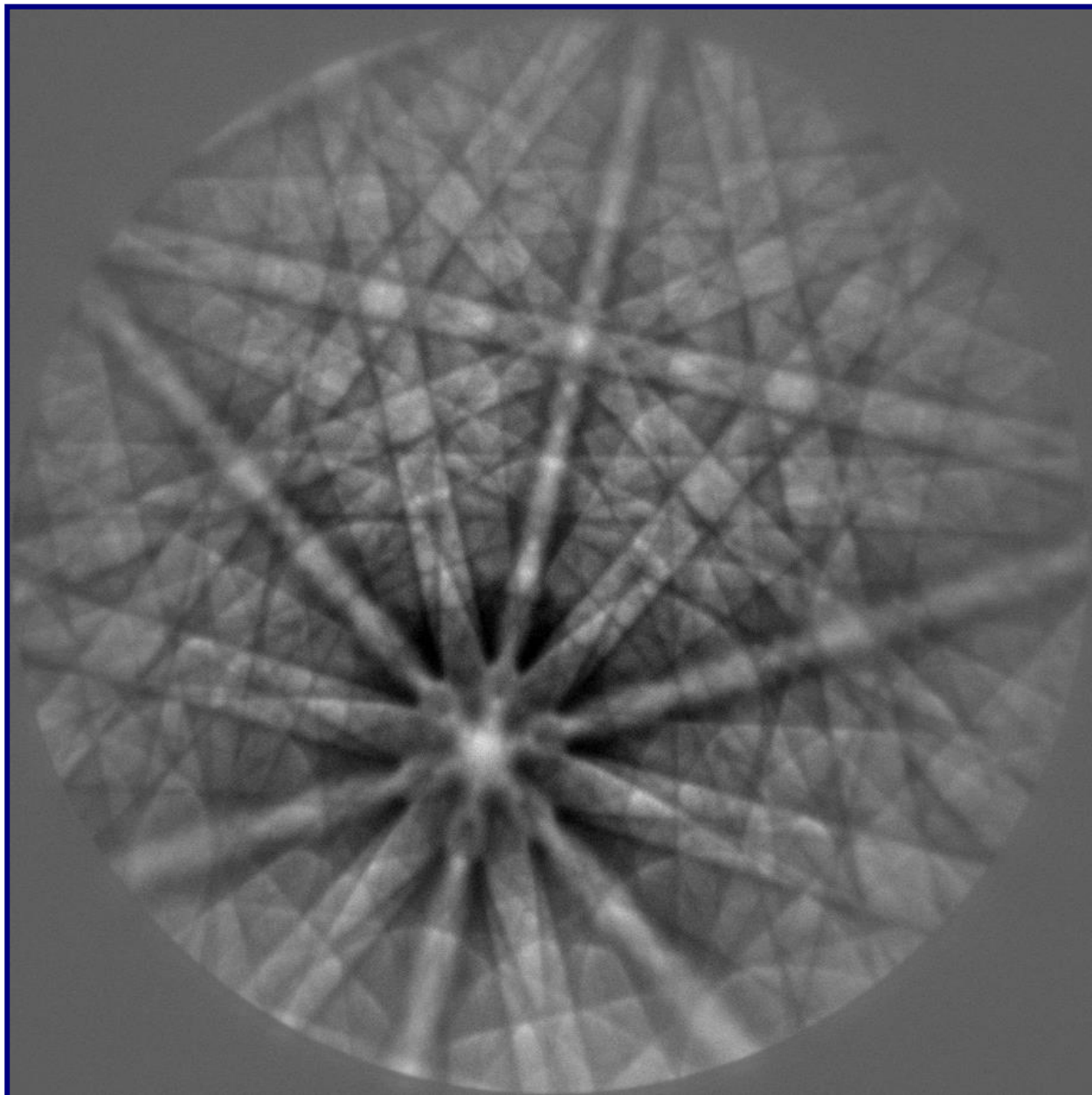


neue Wellen entstehen (konstruktive Interferenz) wenn:

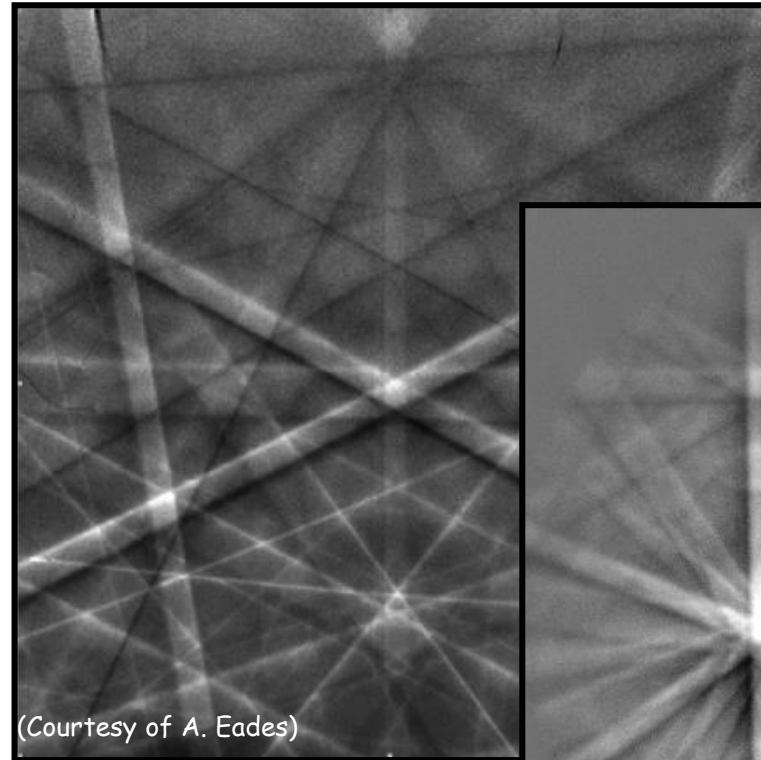
$$n \lambda = 2 d \sin \theta \quad (\text{Bragg'sche Gleichung})$$





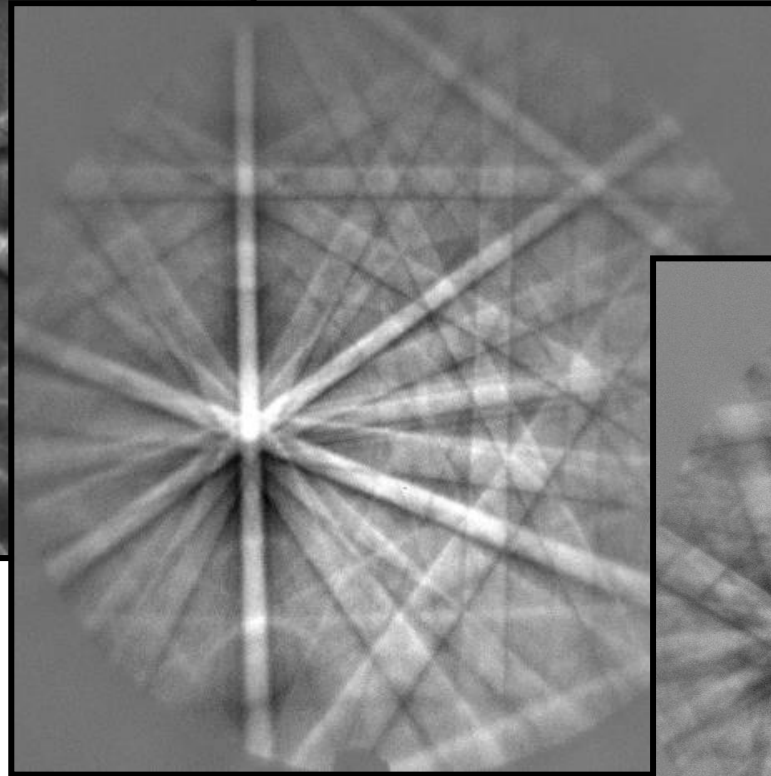


TOCA

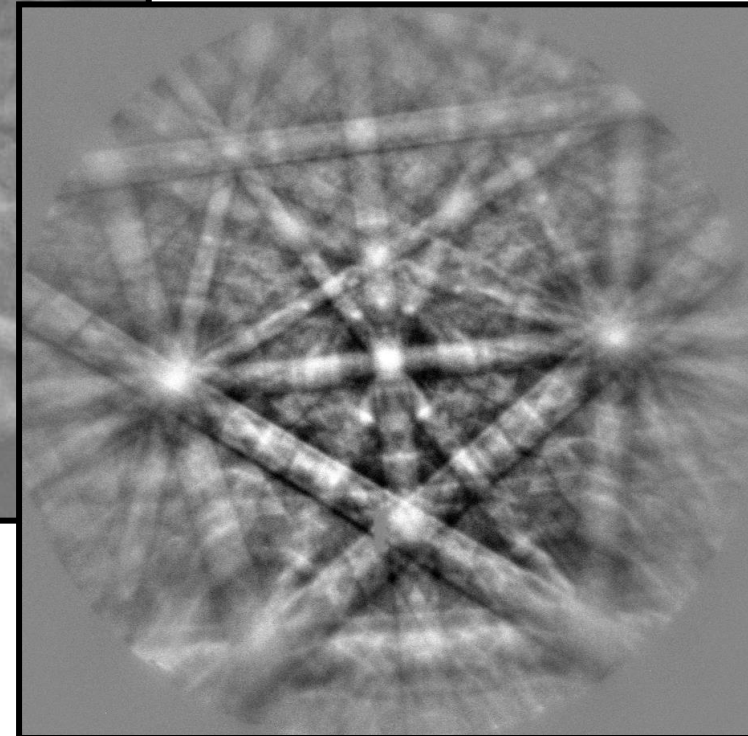


(Courtesy of A. Eades)

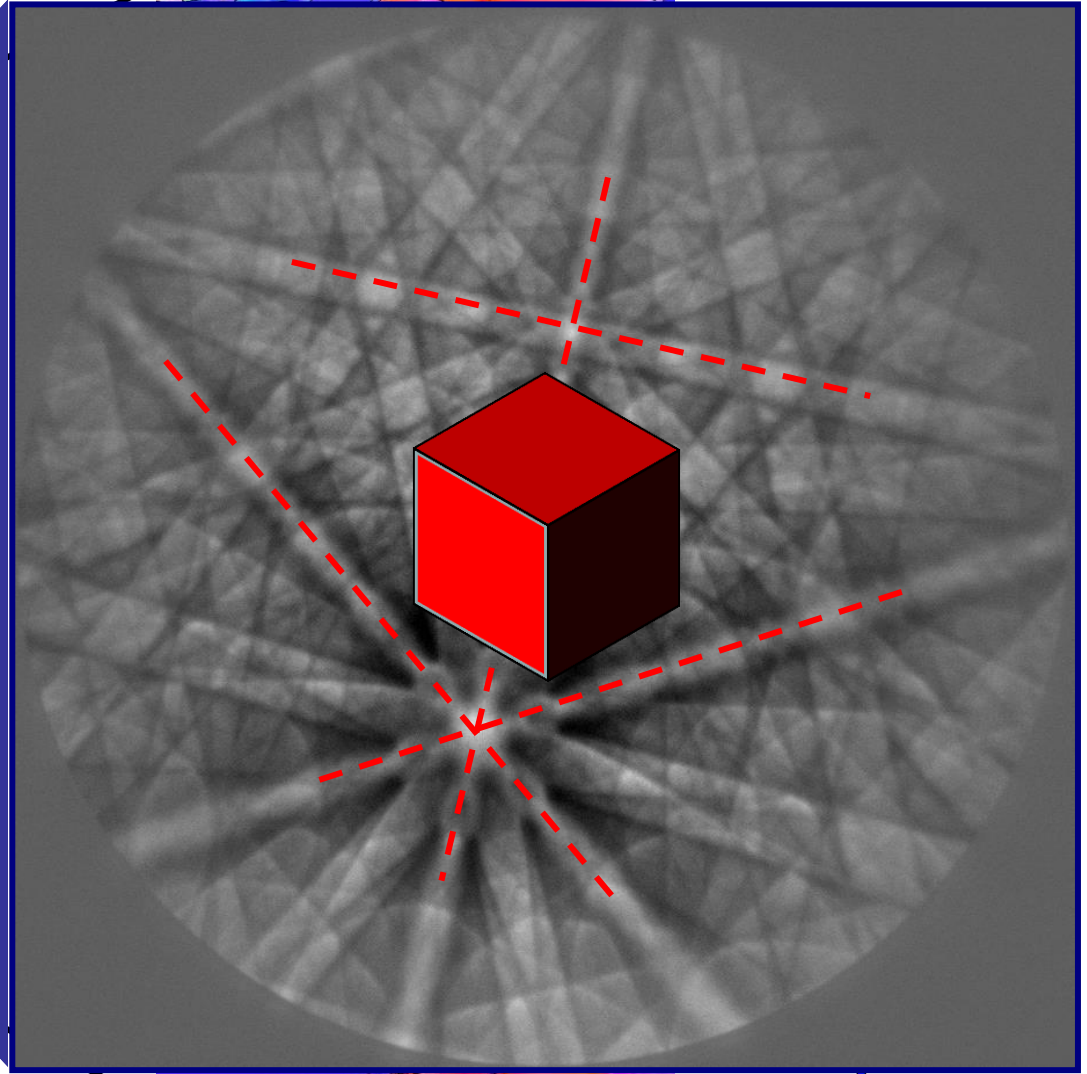
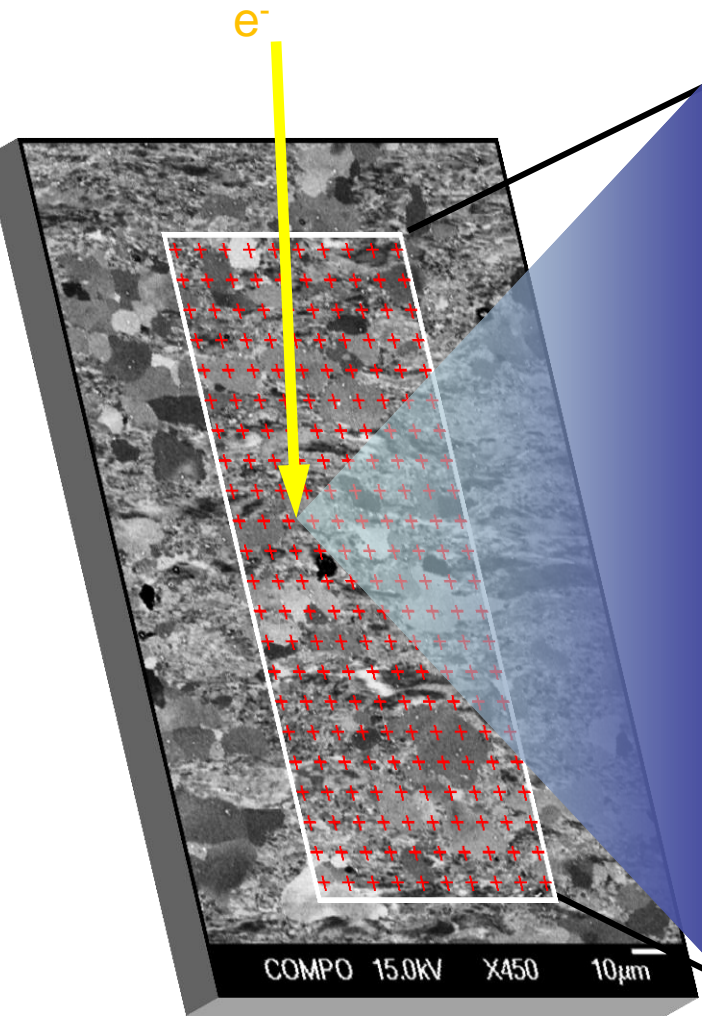
Beryllium (Z=4), 30 kV



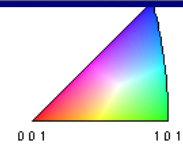
Magnesium (Z=12), 15 kV



TiCr Laves phase (Z=22...24), 15 kV

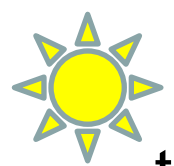


10.00 µm = 100 steps

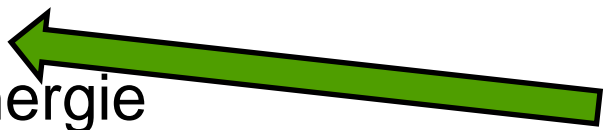
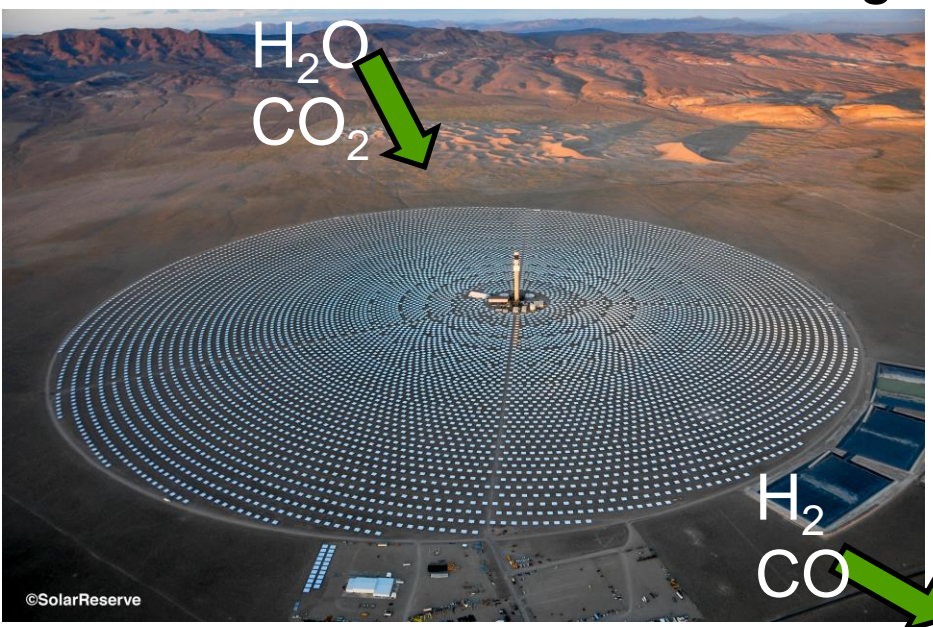


BEISPIEL: WASSERSTOFF-BASIERTE REDUKTION VON EISENOXID

- Nachhaltige Energie-Bereitstellung

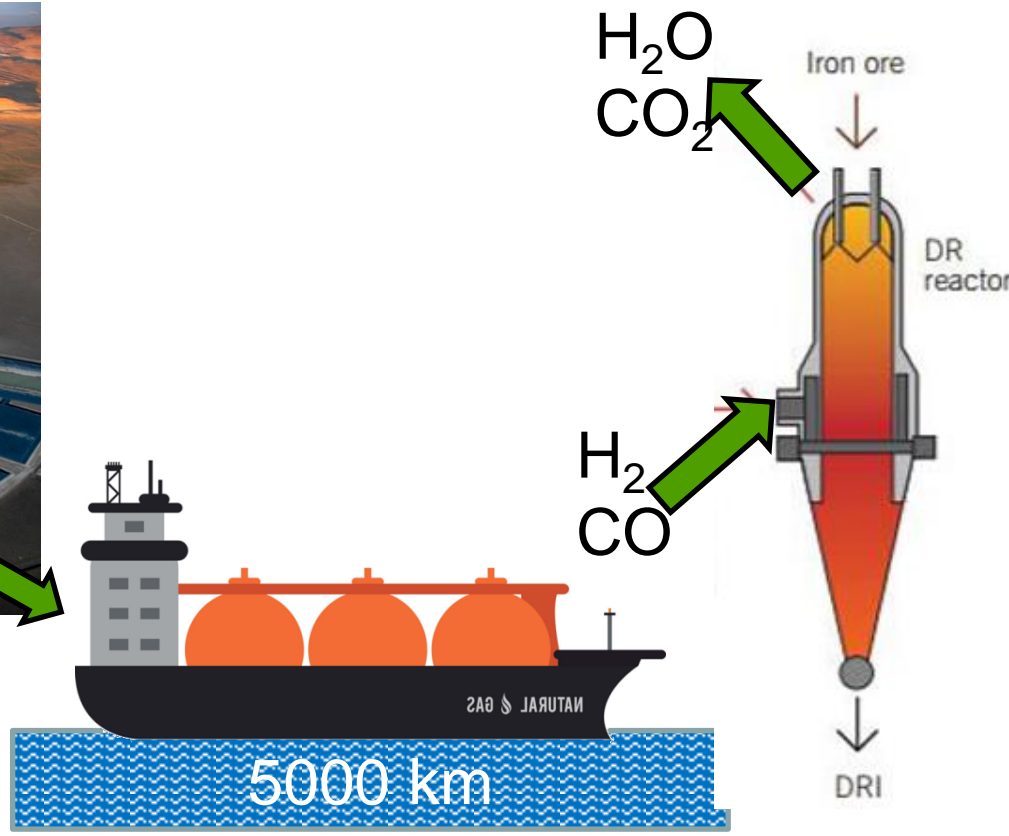


thermische Solarenergie



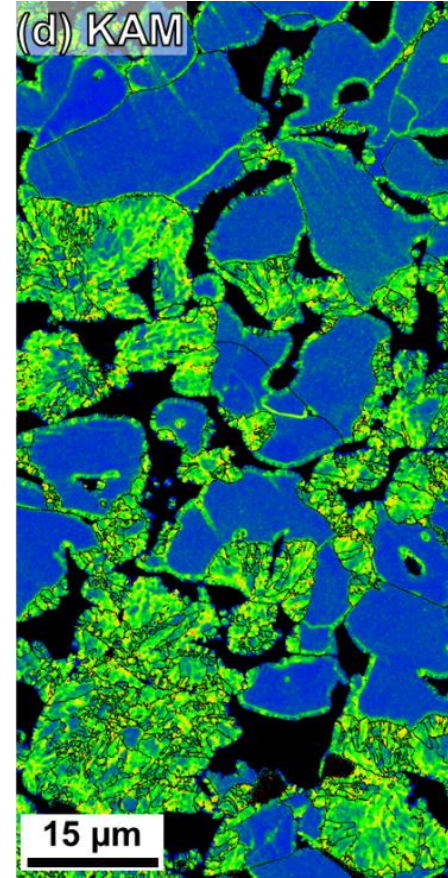
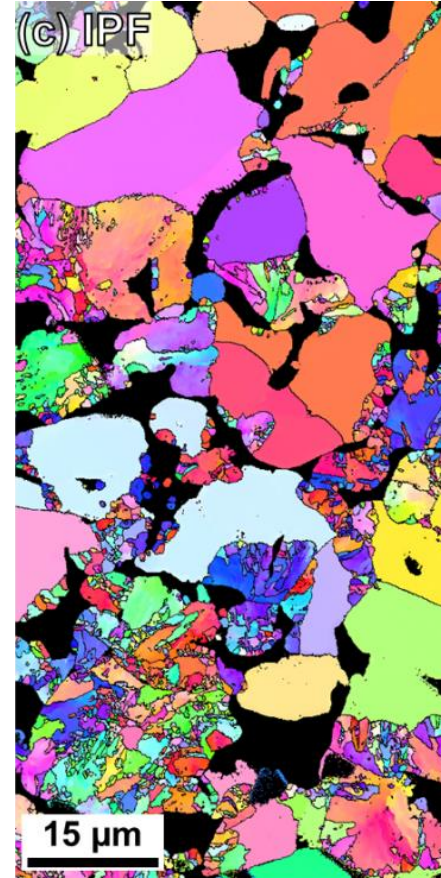
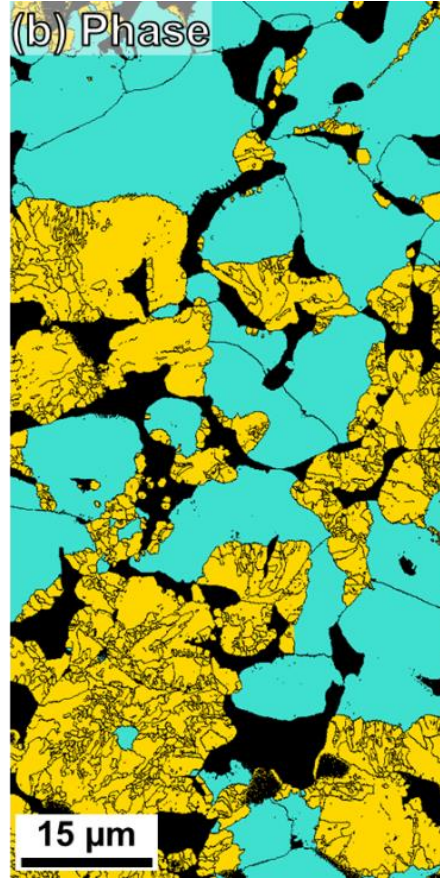
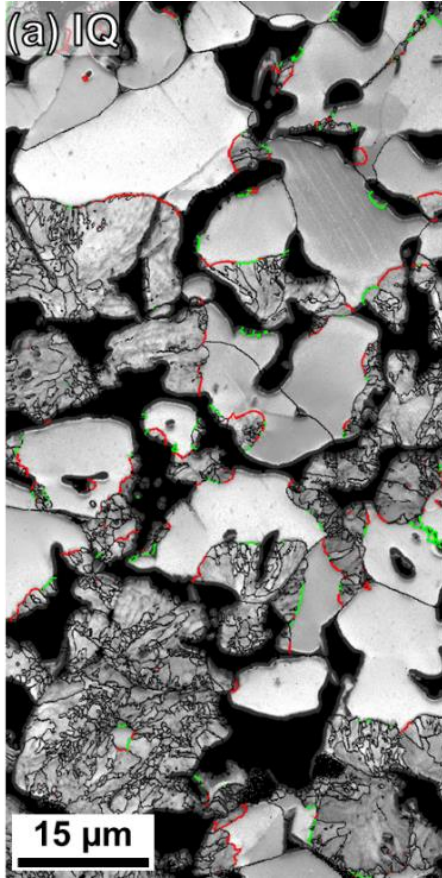
Abwärme

H₂O
CO₂



Hematite to magnetite transition during direct H-based reduction (700 °C for 1 min)

2 mm below pellet surface

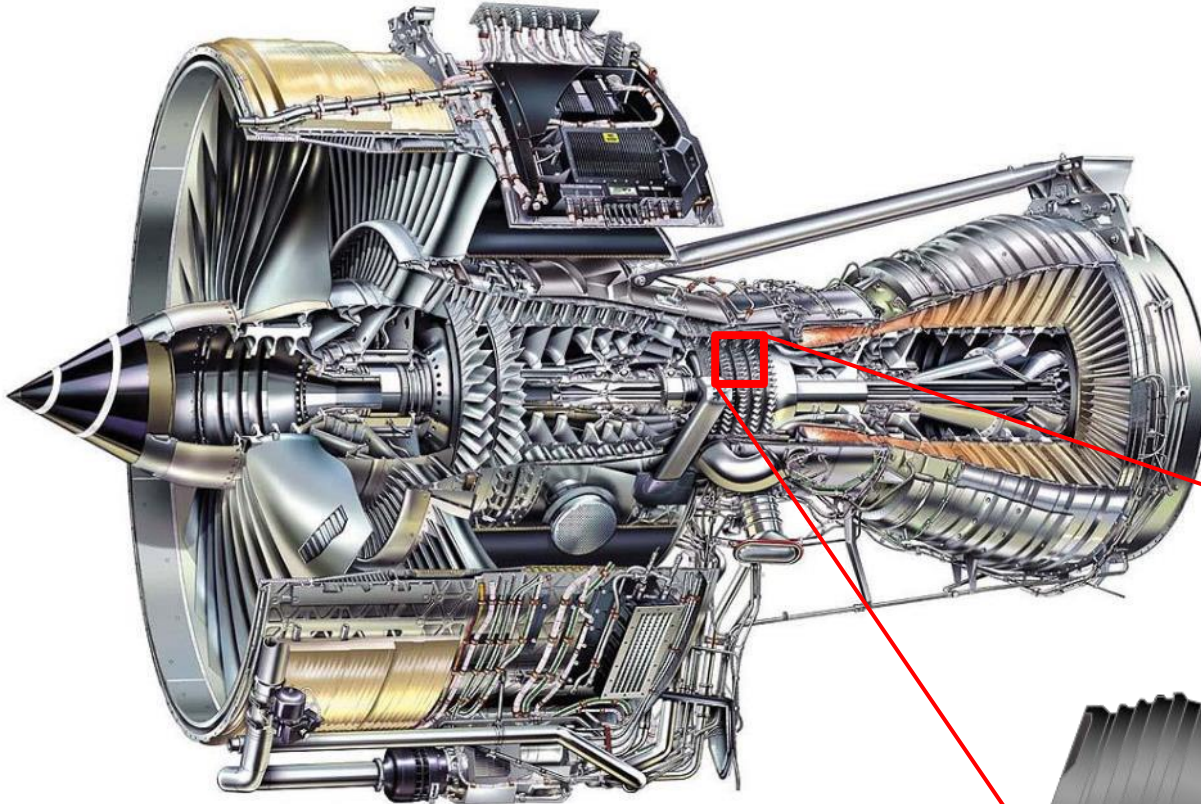


| | |
|--|--|
| OR1 (0001) _h // (111) _m [10 $\bar{1}$ 0] _h // [1 $\bar{1}$ 0] _m (deviation < 5°) | OR2 (0001) _h // (121) _m [10 $\bar{1}$ 0] _h // [10 $\bar{1}$] _m (deviation < 5°) |
|--|--|

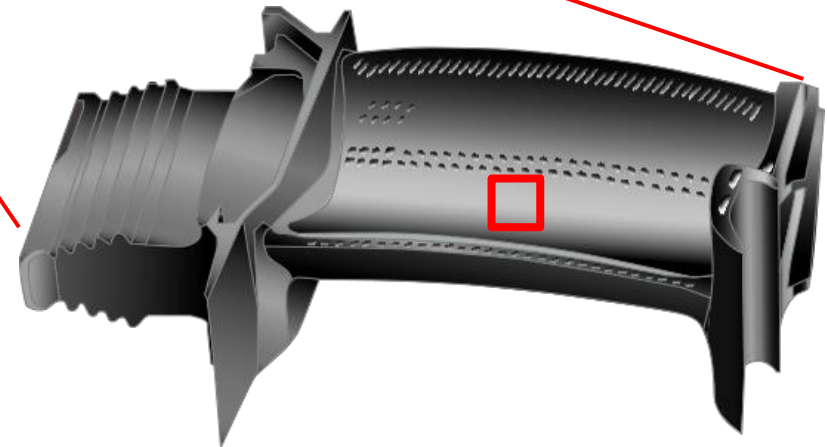
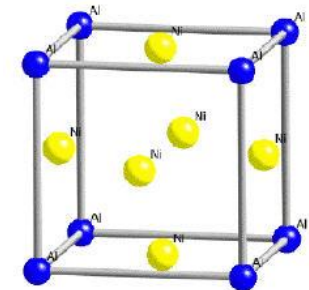
| Phase | |
|----------|-----------|
| Hematite | Magnetite |

courtesy Yan Ma, MPIE

BEISPIEL: TURBINENSCHAUFELN



Legierung aus Nickel und Aluminium – mit Zusätzen aus Cr, Co, W, Re, Ta, etc.

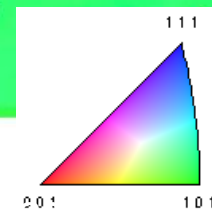


- Hohe Temperaturen
- Hohe mechanische Last
- Starker Oxidationsangriff



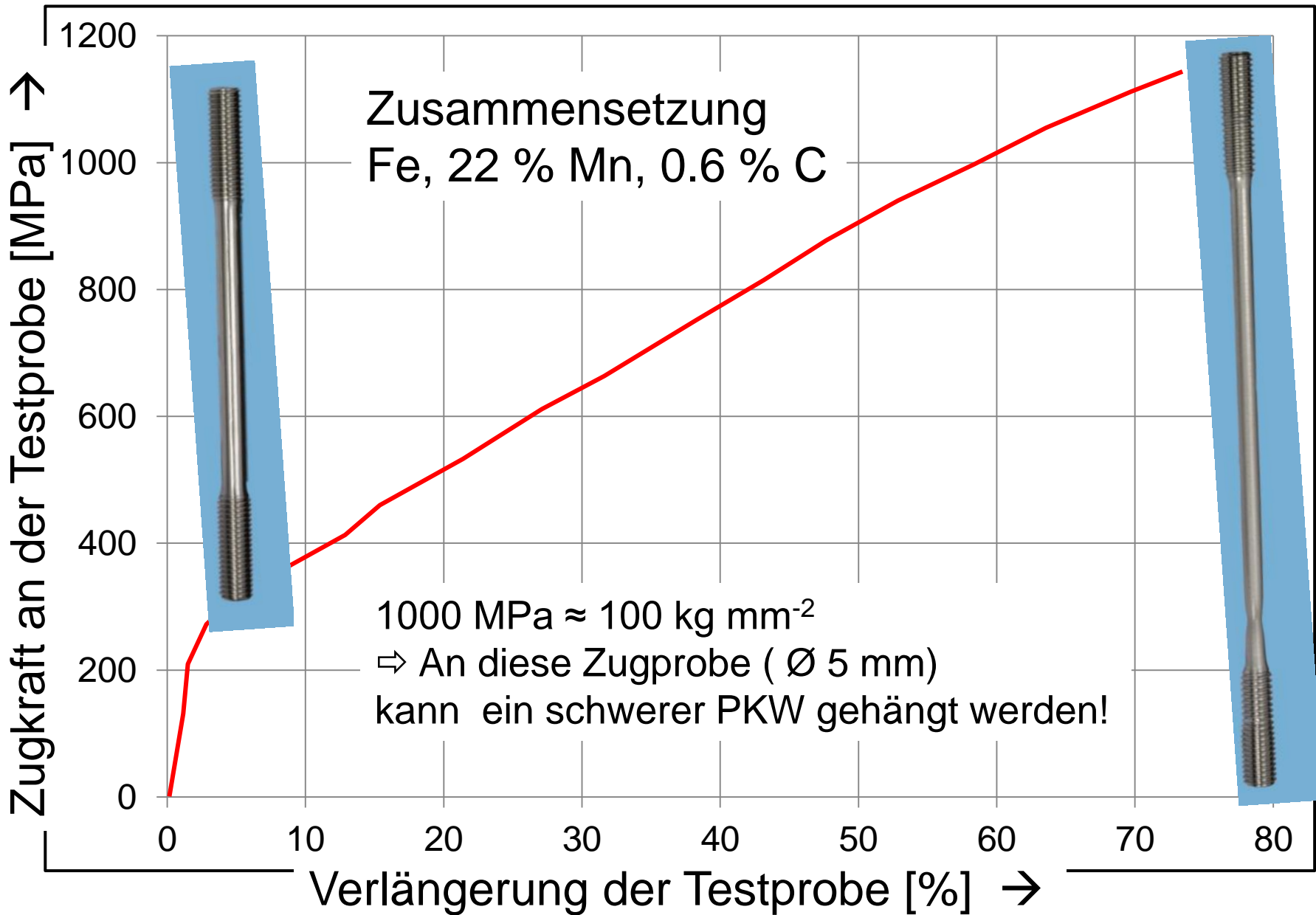
10.00 μm = 100 steps

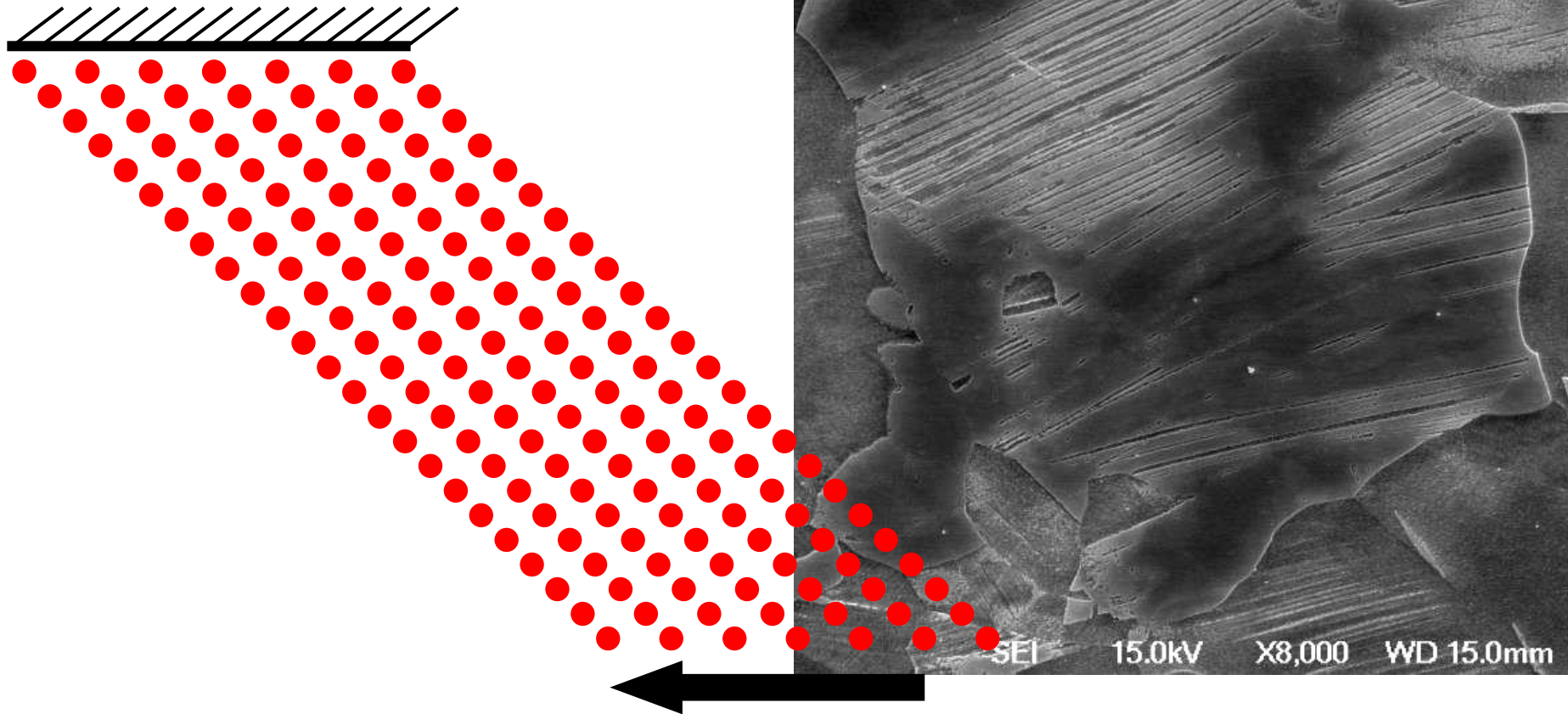
Boundary levels: 15°
IPF [001]



BEISPIEL: HOCHFESTER MANGAN-STAHL



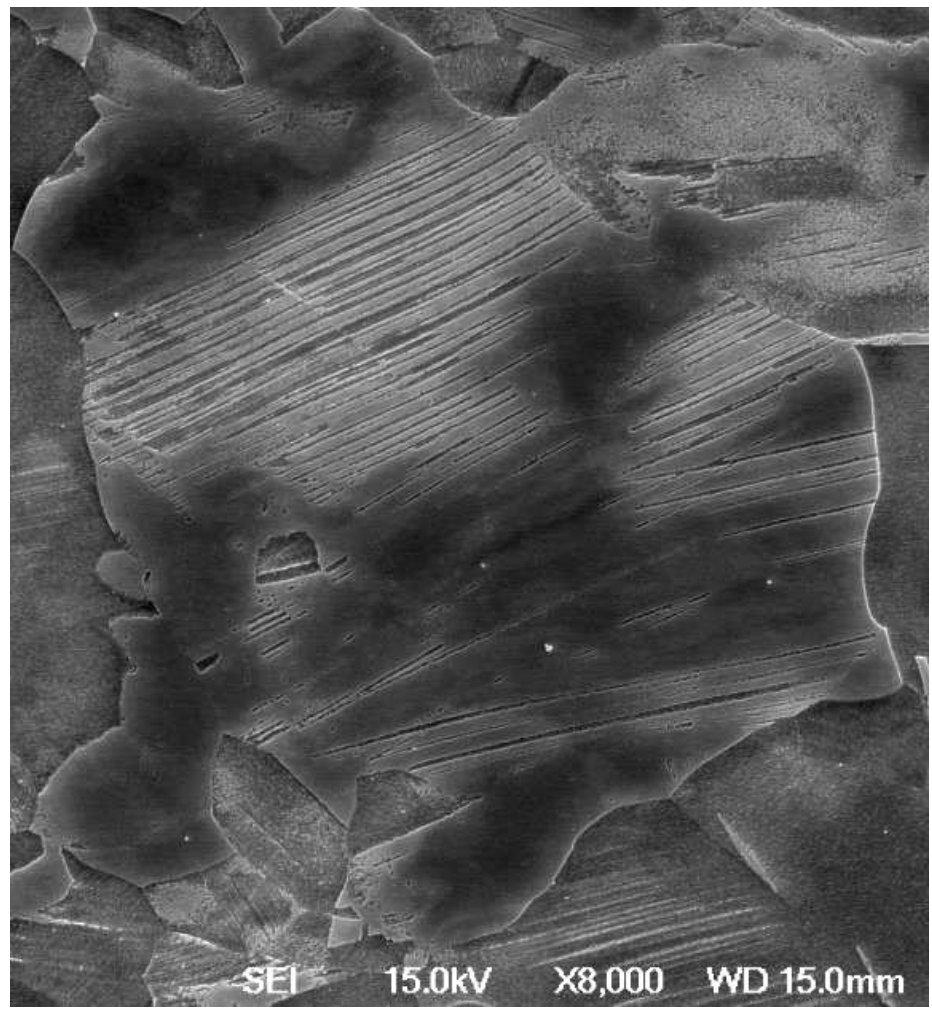
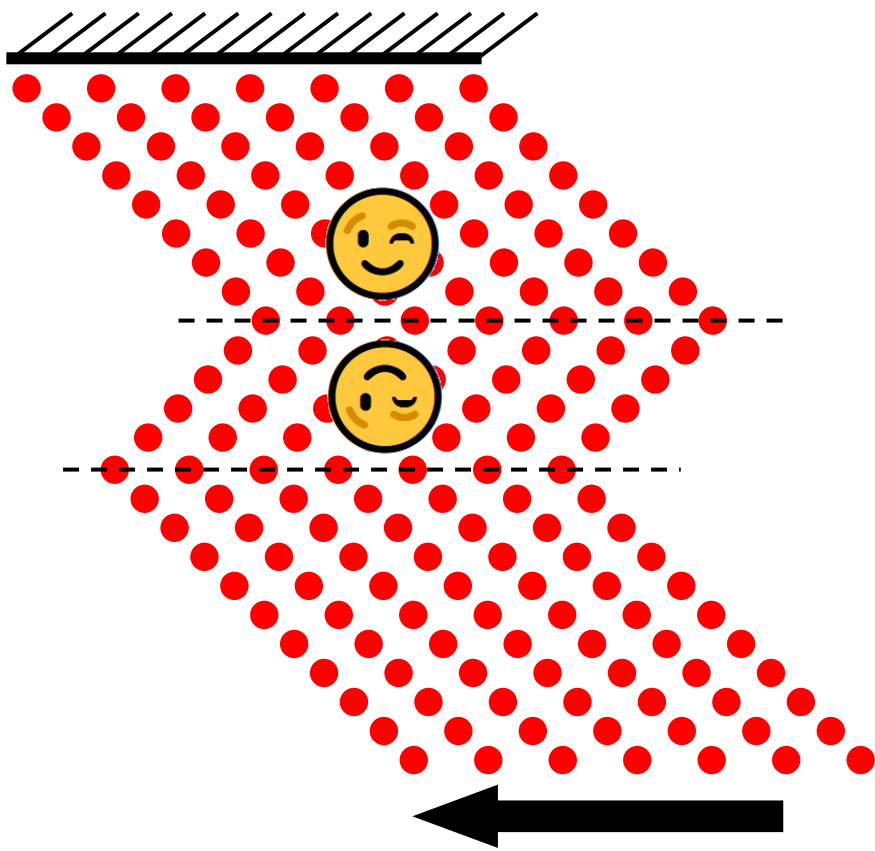




Zwillinge im Metall?



100 YEARS 1917-2017

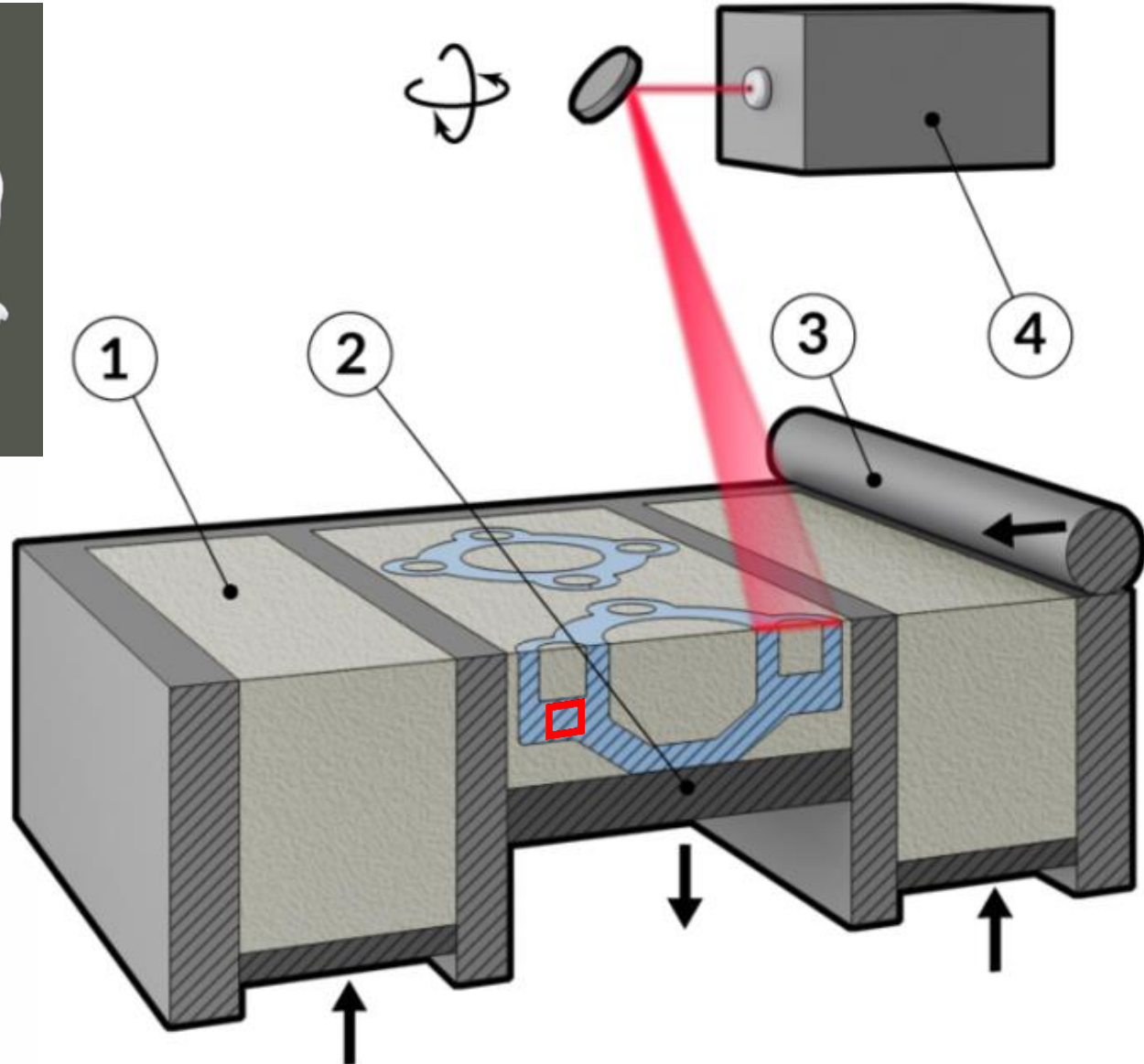


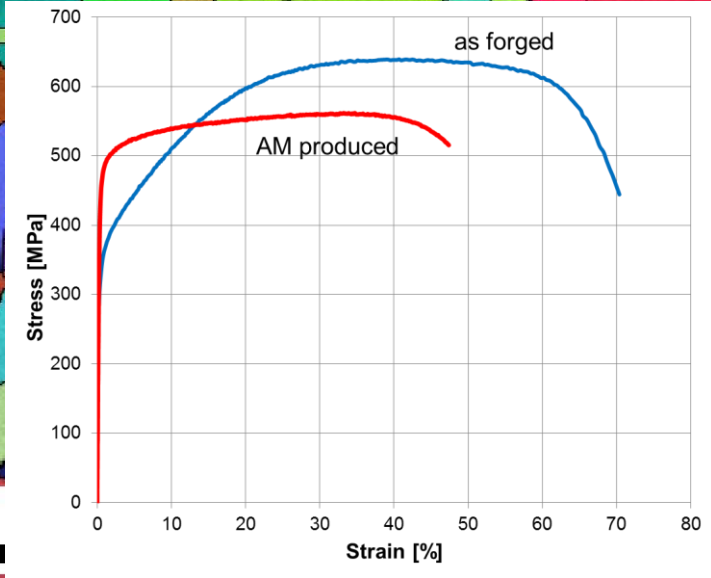
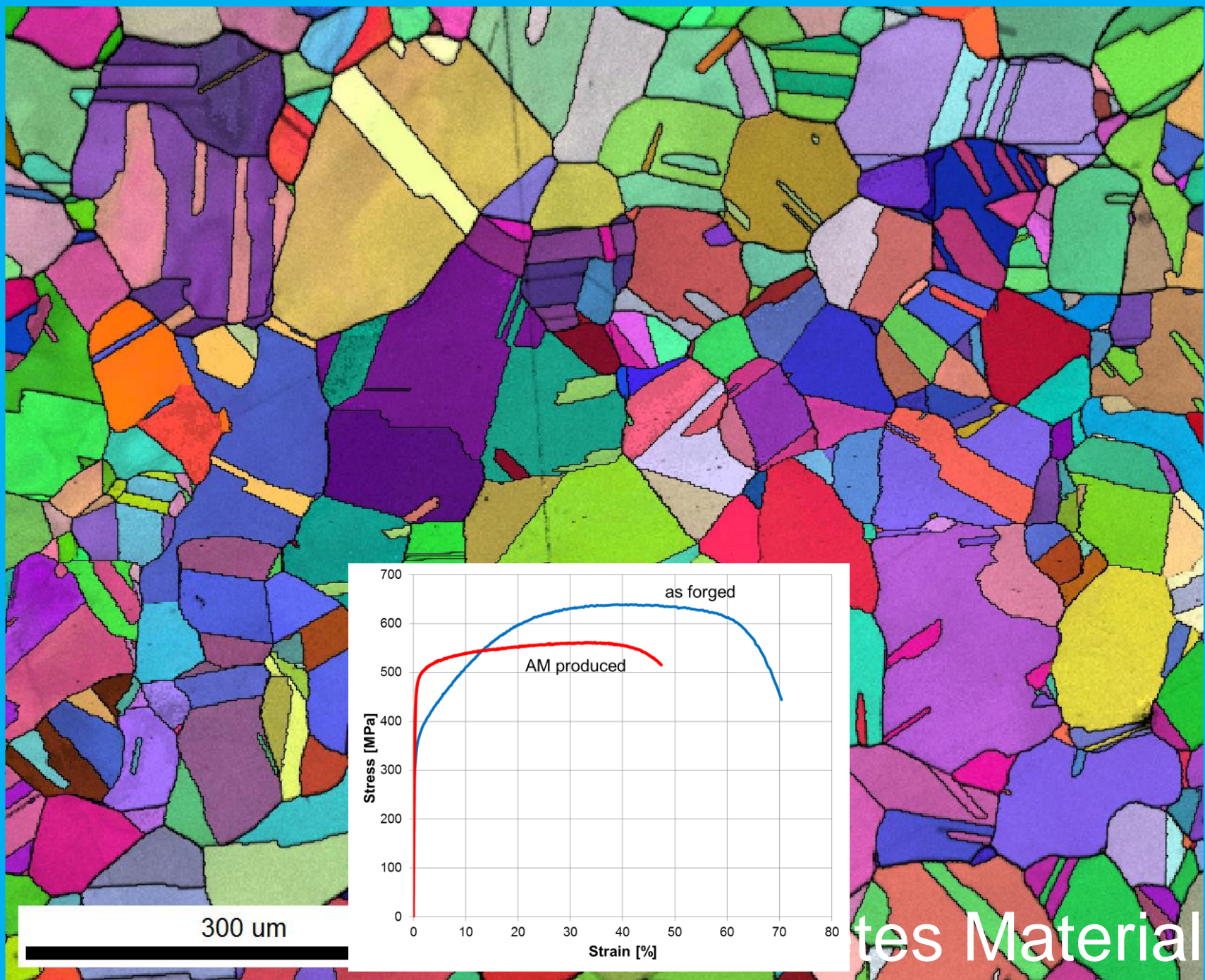


20 µm

BEISPIEL: 3D DRUCKEN VON METALLEN

<https://www.manufacturingguide.com/en/selective-laser-melting-slm>

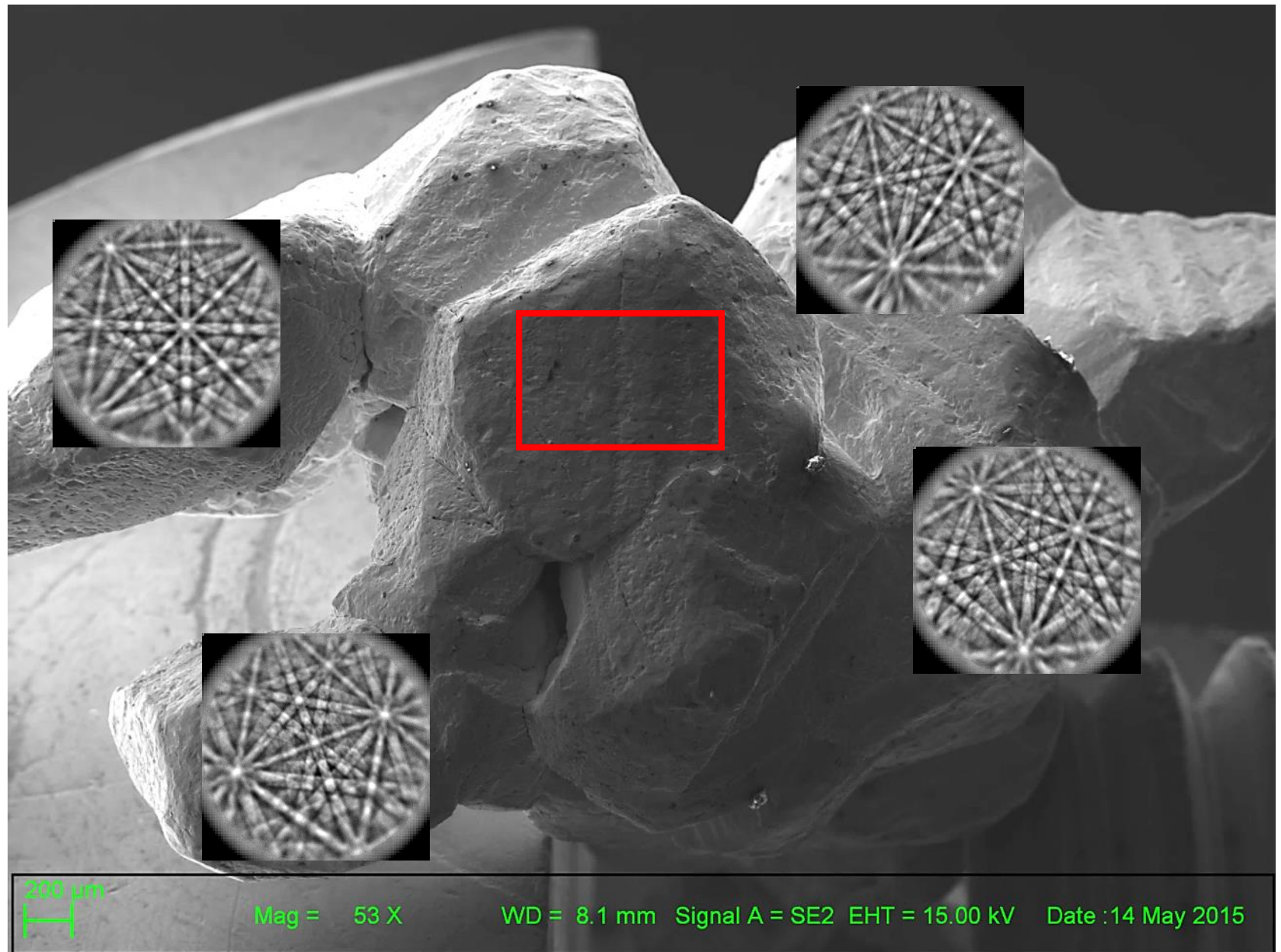


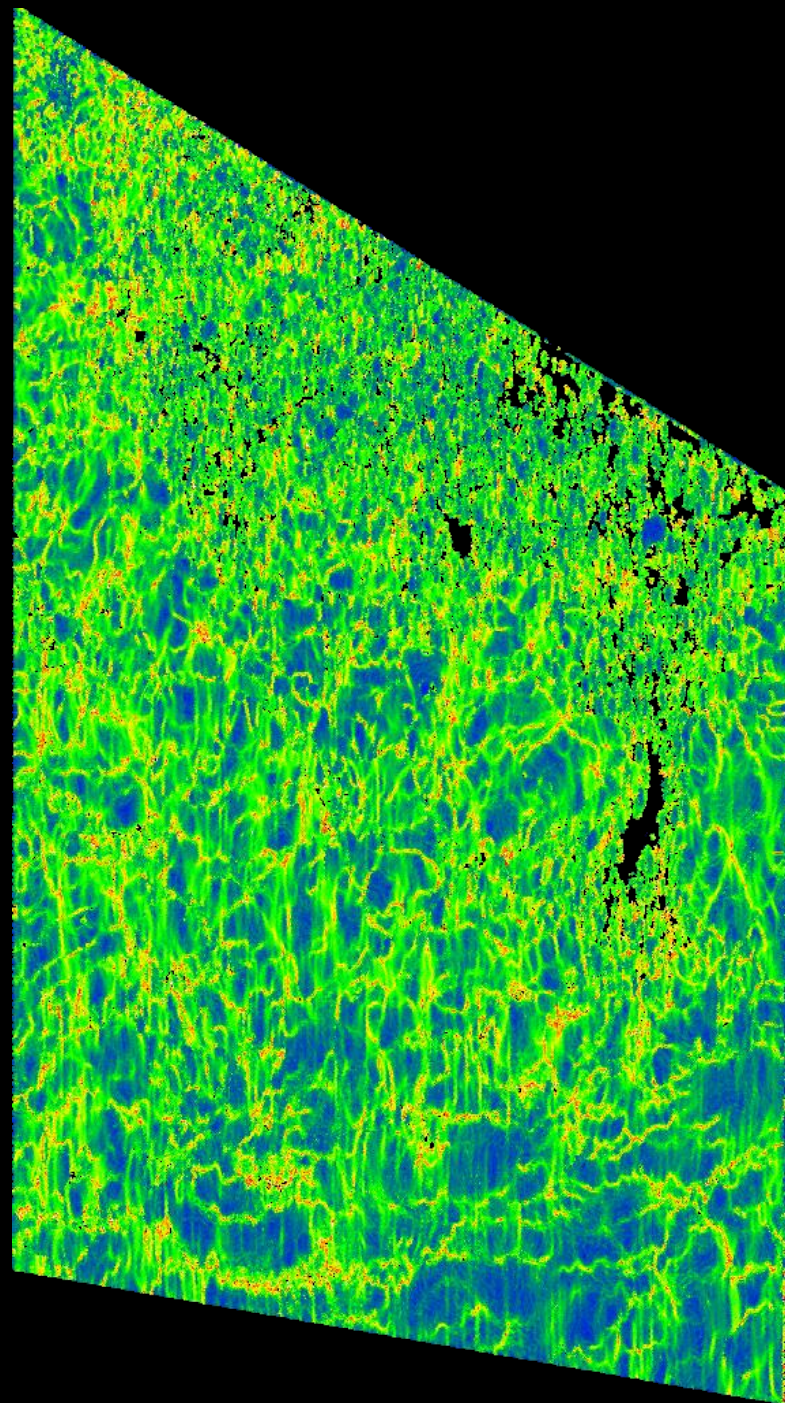
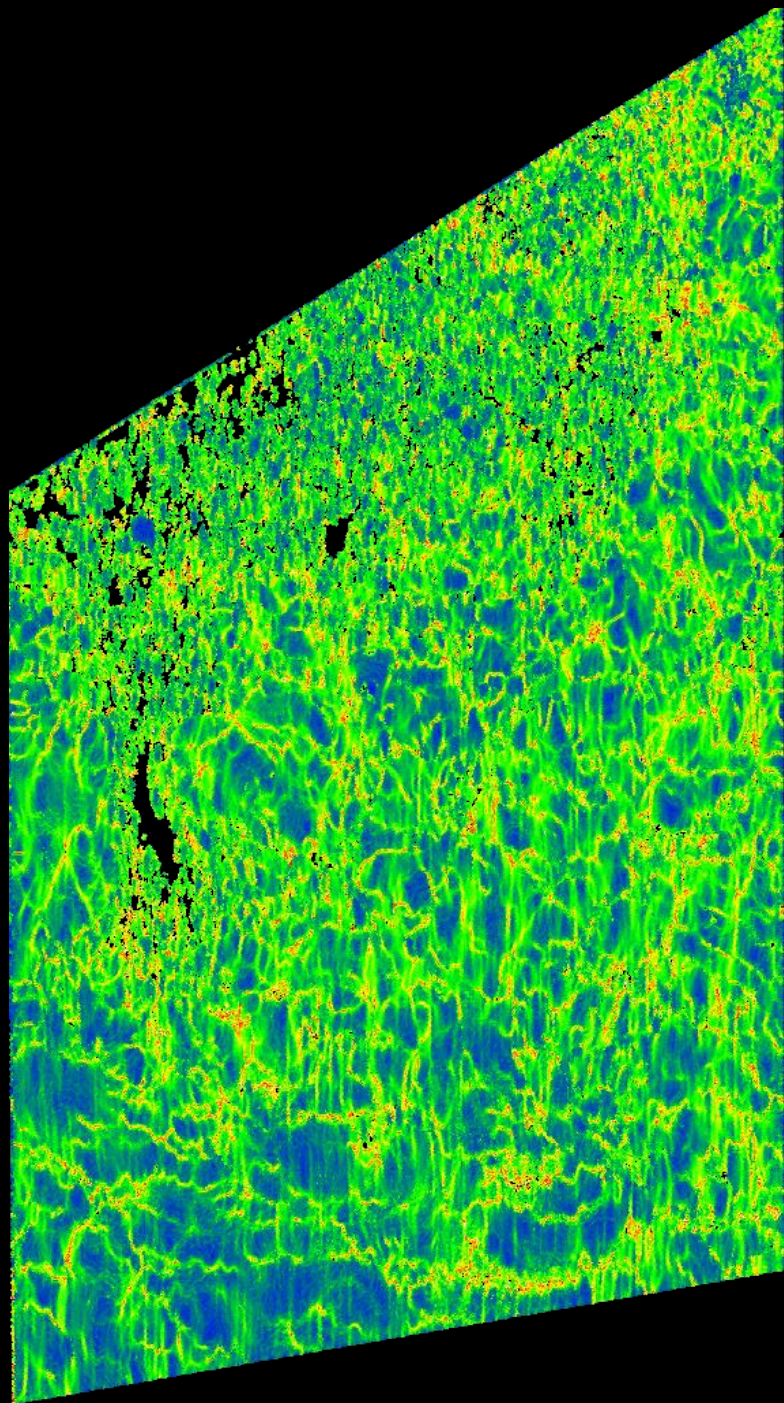


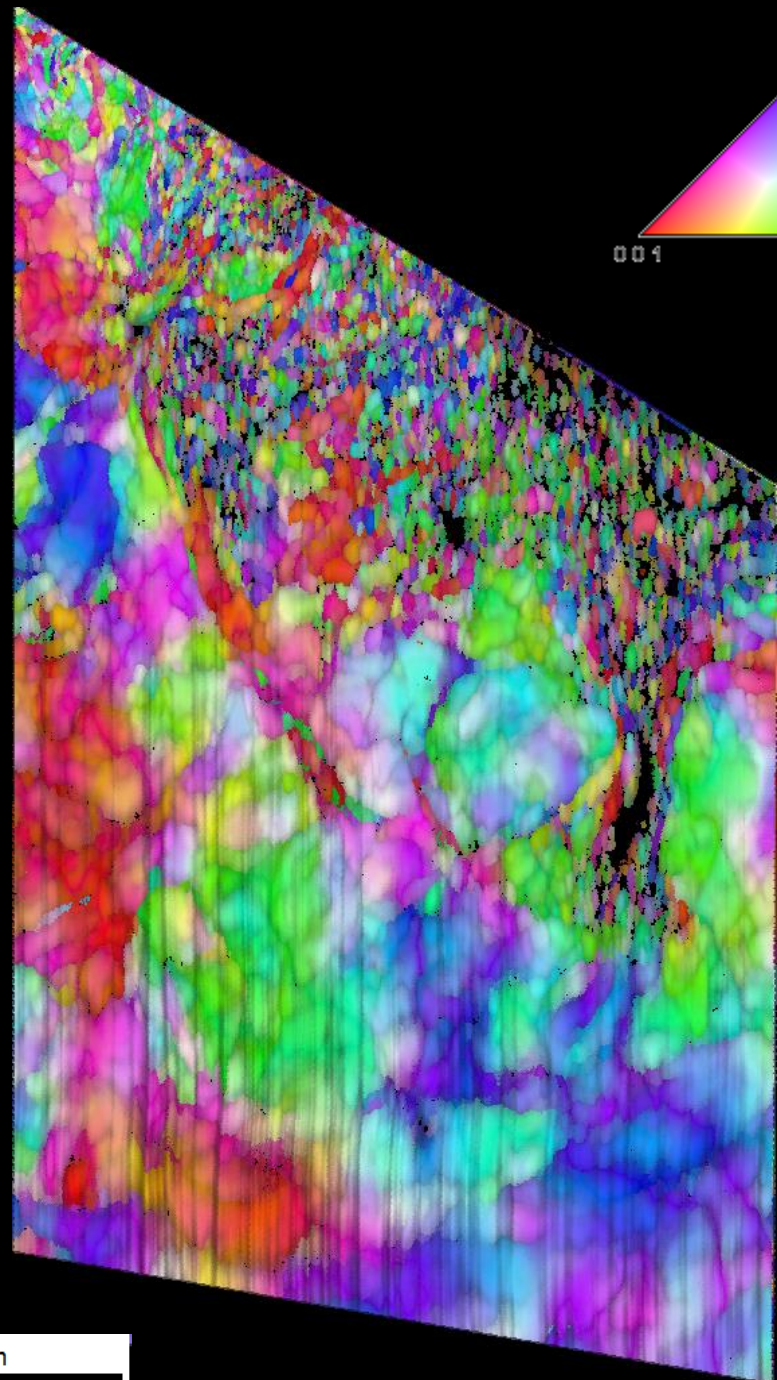
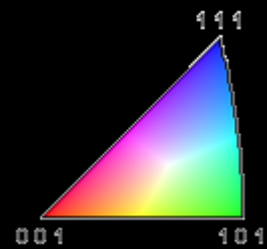
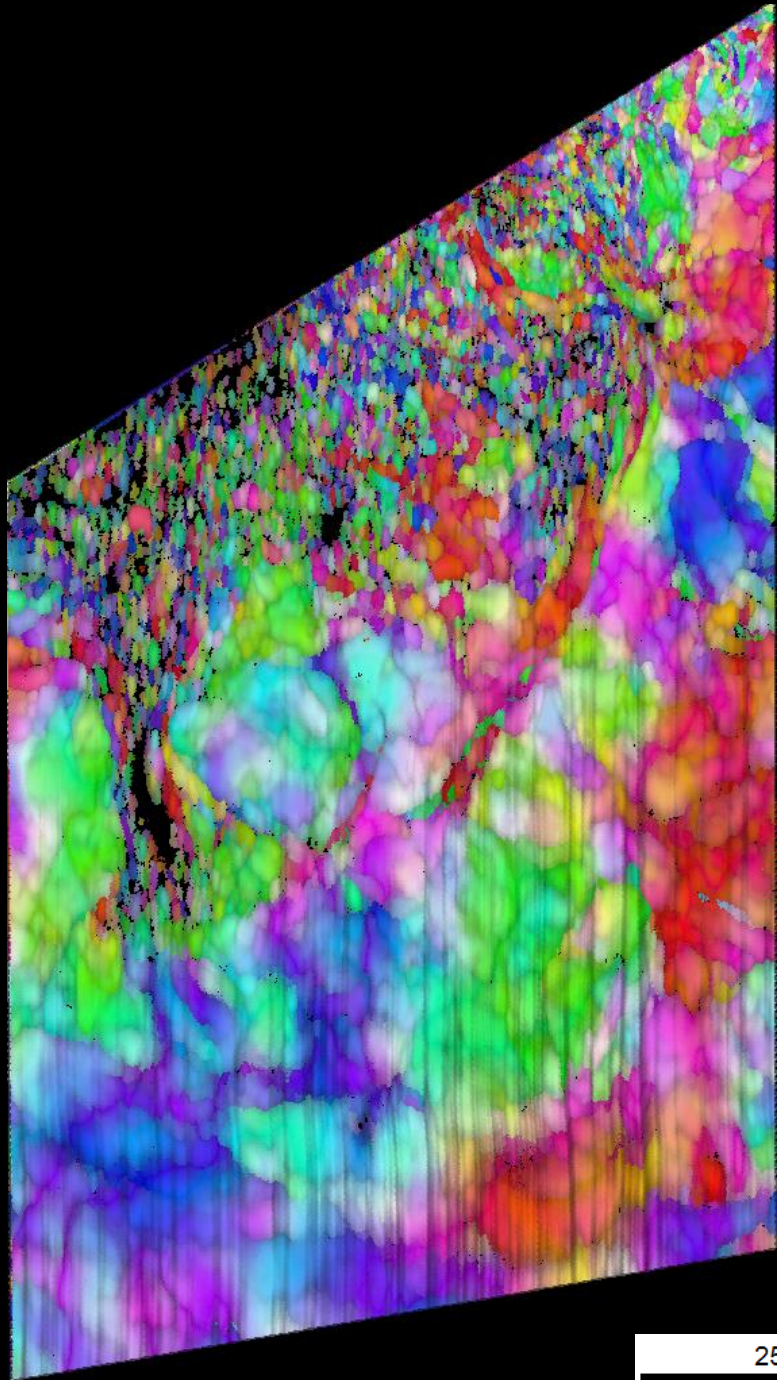
tes Material

BEISPIEL: NATÜRLICHES GOLDNUGGET



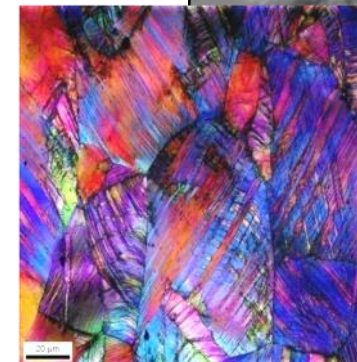
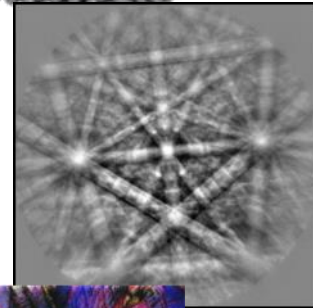
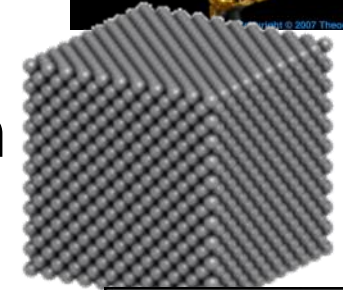
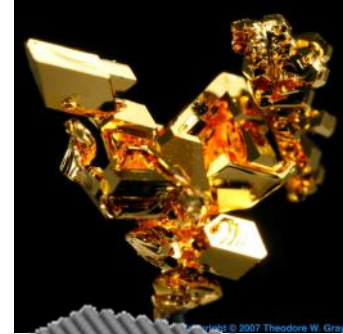






25 μm

- viel Materialien sind kristallin
- Die Art, Größe und Anordnung der Kristalle bestimmt die Eigenschaften, insbesondere die Duktilität
- Kristalle bestehen aus einer regelmäßigen Anordnung von Atomen
- Die Atomordnung kann mit Elektronenbeugung sichtbar gemacht werden
- Die Ergebnisse der Elektronenbeugung werden in Form von Farben dargestellt
- Phasen, Kristallorientierungen, Korngrenzen, Kristalldefekte...



Thanks
for your
attention!



MAX-PLANCK-INSTITUT FÜR EISENFORSCHUNG