

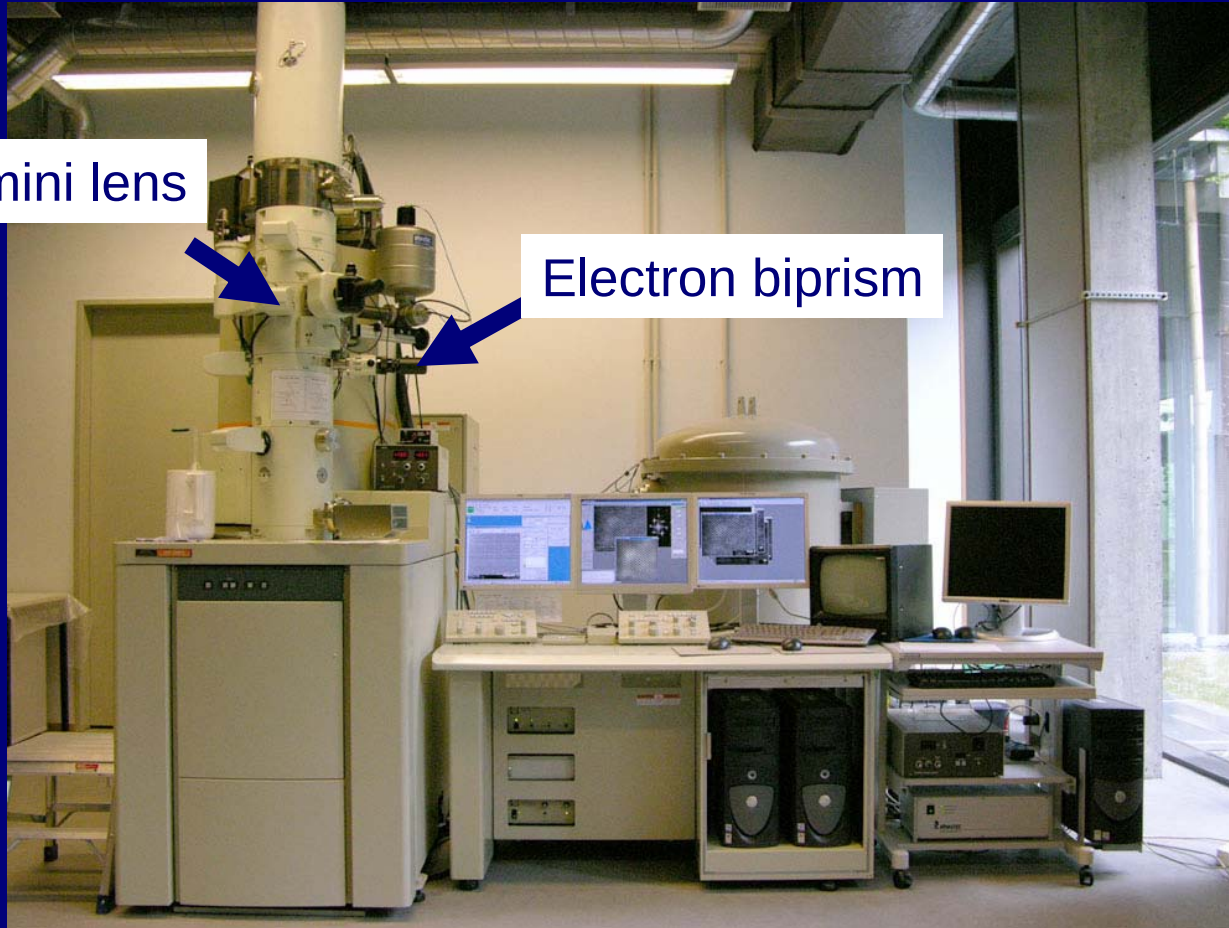
**Characterization of magnetic materials
by
Lorentz microscopy
and
electron holography**

JEOL JEM-2200FS transmission electron microscope @HU-Berlin



Objective mini lens

Electron biprism



Structure and chemical composition
(CTEM, STEM, EDX, EELS)

Magnetic properties
(Lorentz microscopy, electron holography)

FeCo based alloys:



HITPERM: (Fe,Co)-M-B-Ge-Cu

M:Nb, Zr, Hf

Carnegie Mellon University
(USA)

NANOPERM



FINEMET

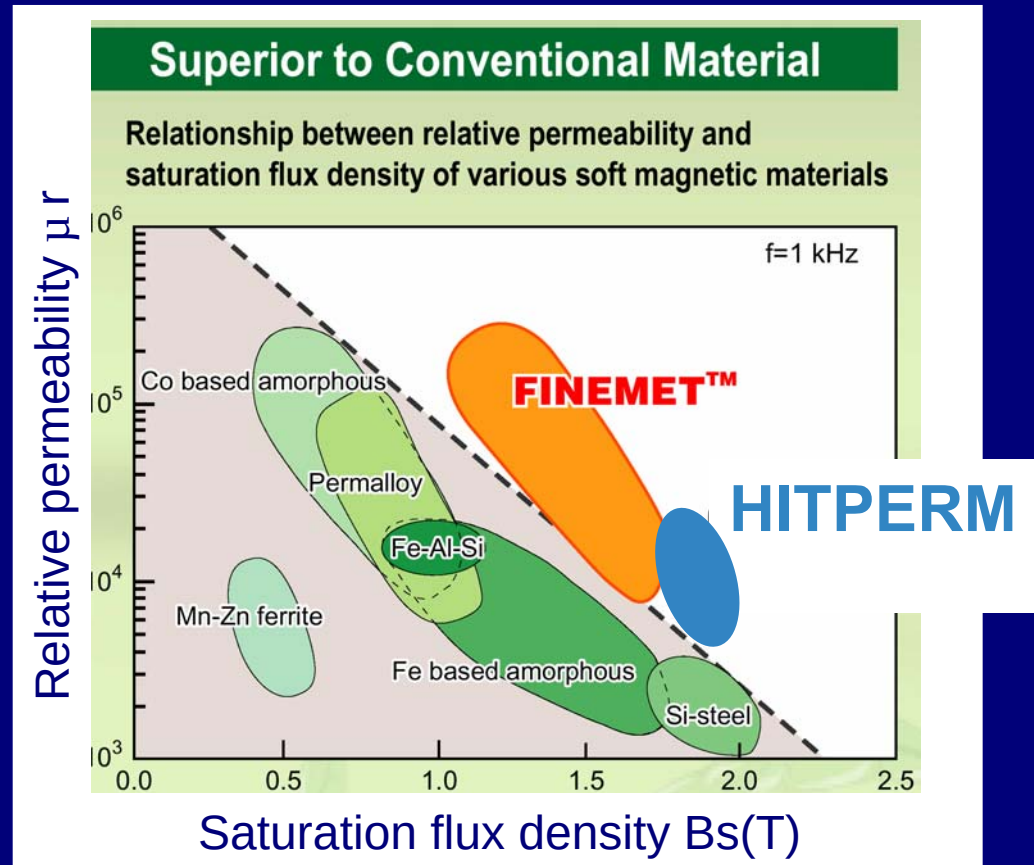
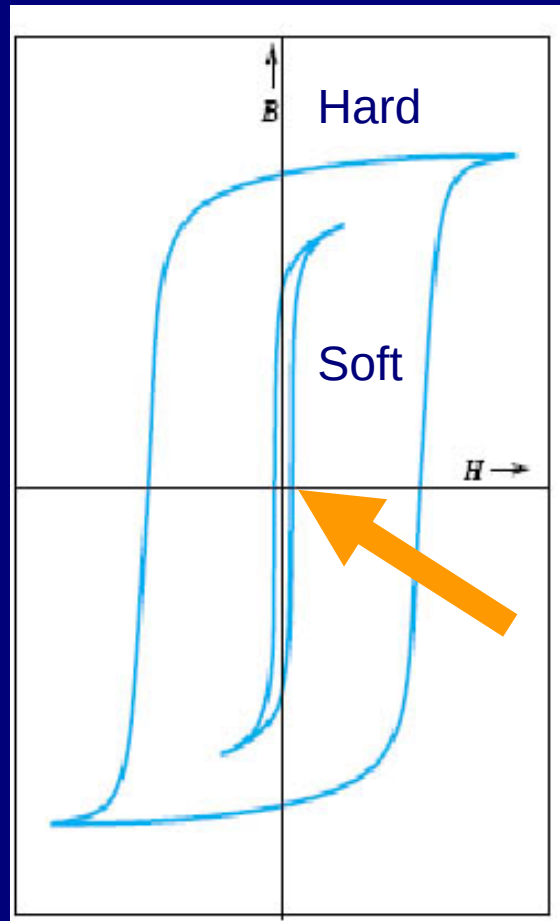


Image : Hitachi metal company

Introduction to softmagnetic materials



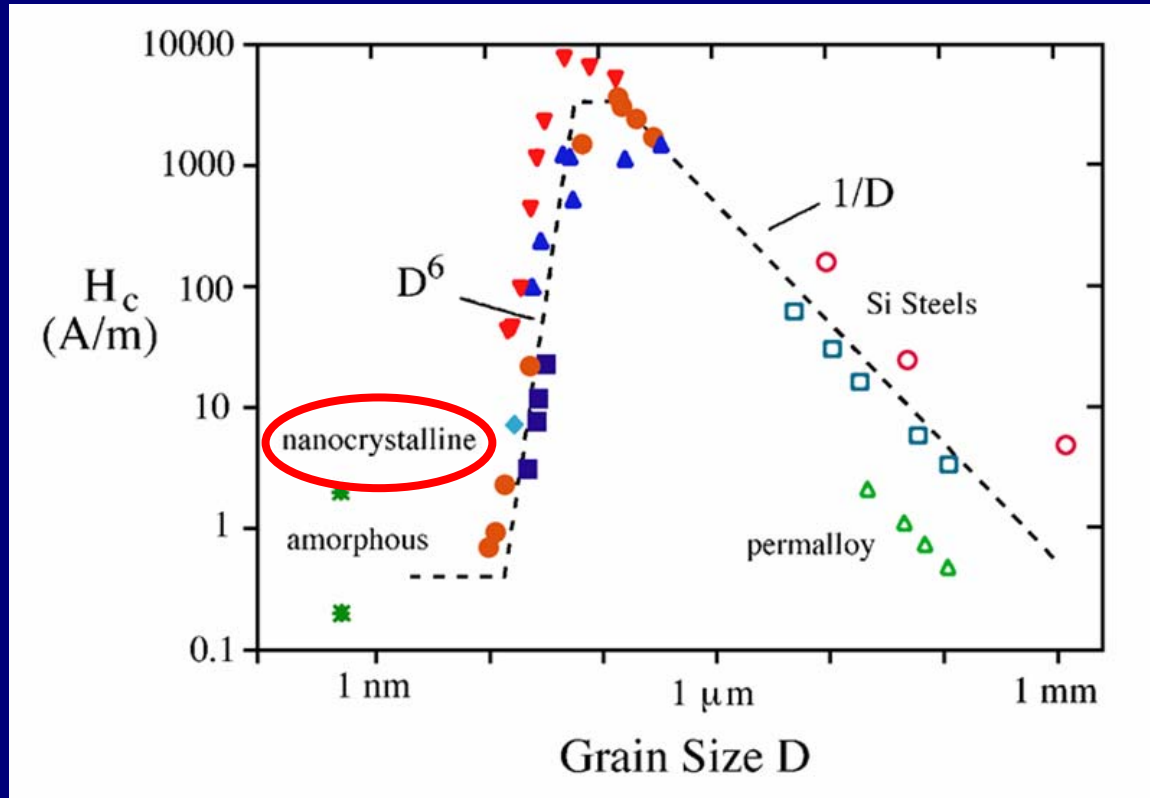
Low coercivity

Applications

- Power Transformers
- Data communication
- Sensors
- Magnetic heads

Easily Magnetized and demagnetized. (Easily moving domain walls).

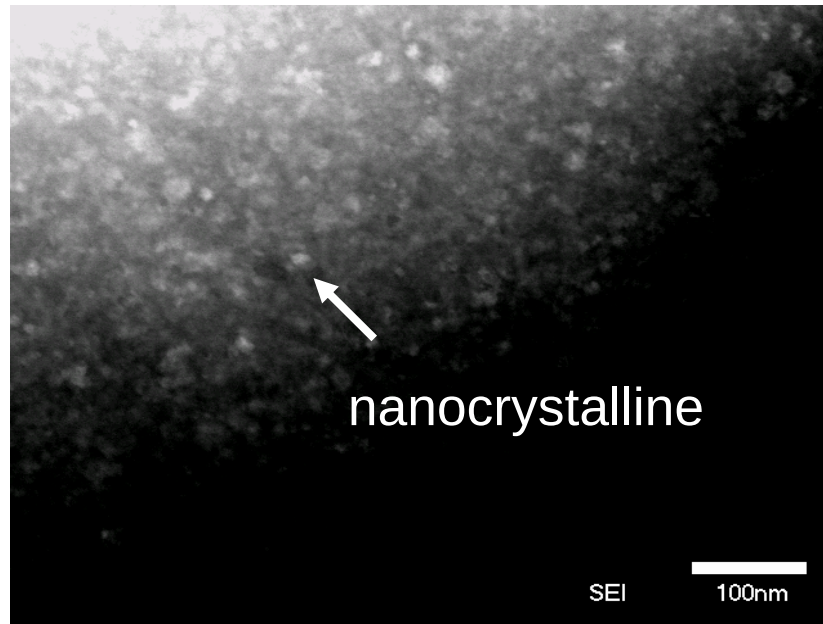
Why we use nanocrystalline materials?



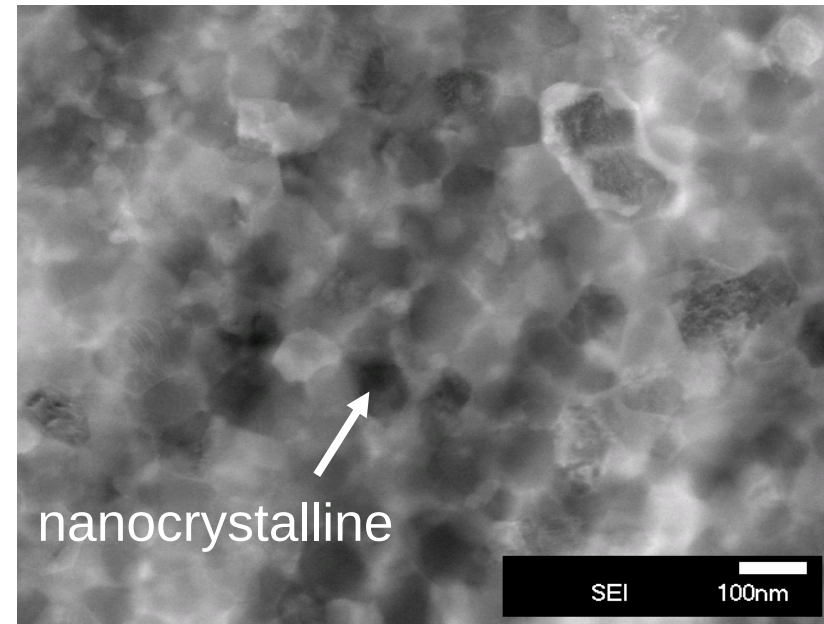
Relationship between structure and magnetic properties

Herzer G. In: Buschow KHJ, editor. Handbook of magnetic materials, vol. 10. Amsterdam:Elsevier Science, 1997. p. 415 [chapter 3].

HAADF images

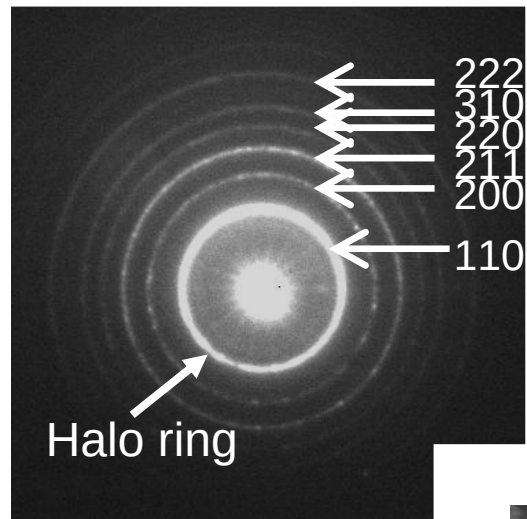


Annealed at 550°C for 1 hour



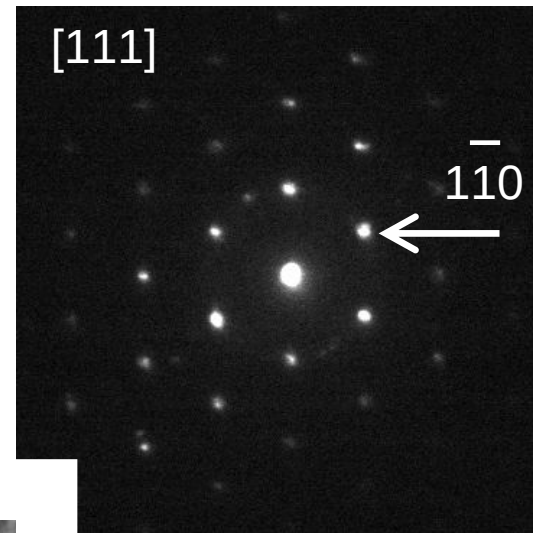
Annealed at 610°C for 1 hour

Electron diffraction

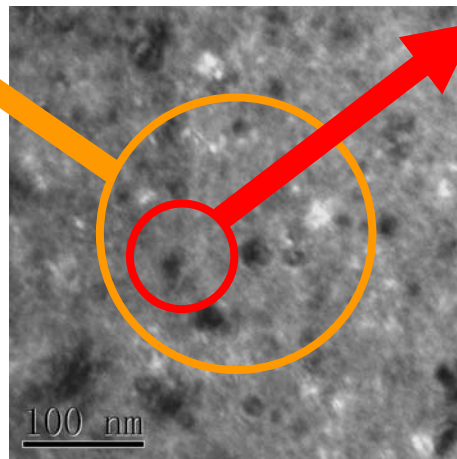


SAED

bcc structure



Nano beam diffraction (NBD)

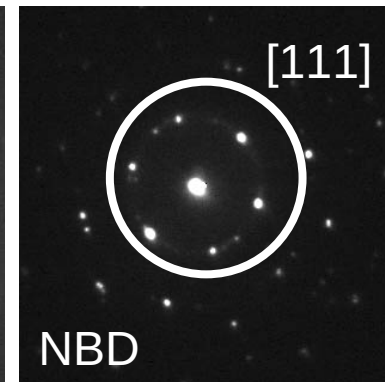
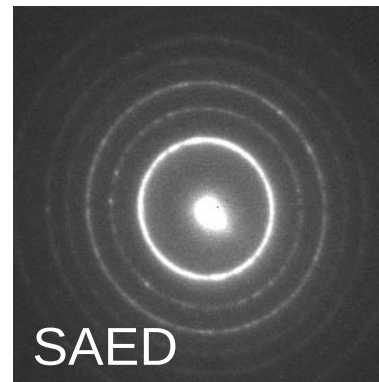
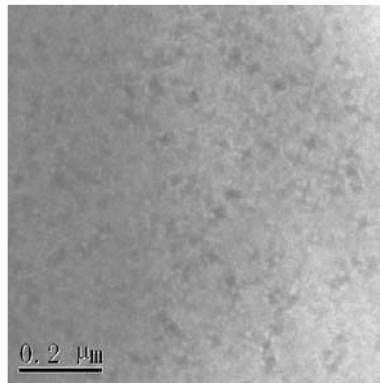


$(\text{Fe}_{0.5}\text{Co}_{0.5})_{80}\text{Nb}_4\text{B}_{13}\text{Ge}_2\text{Cu}_1$
Annealed at 550°C for 1 hour

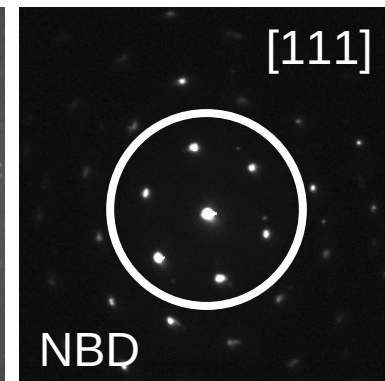
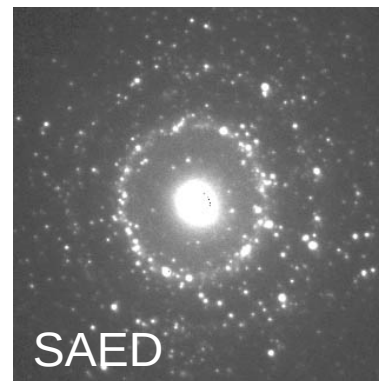
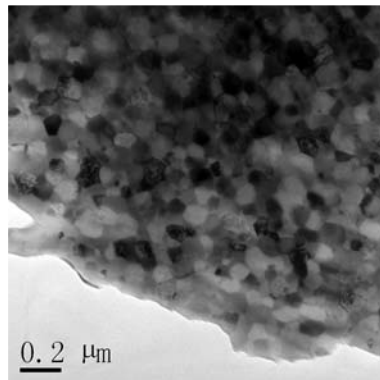
Electron diffraction



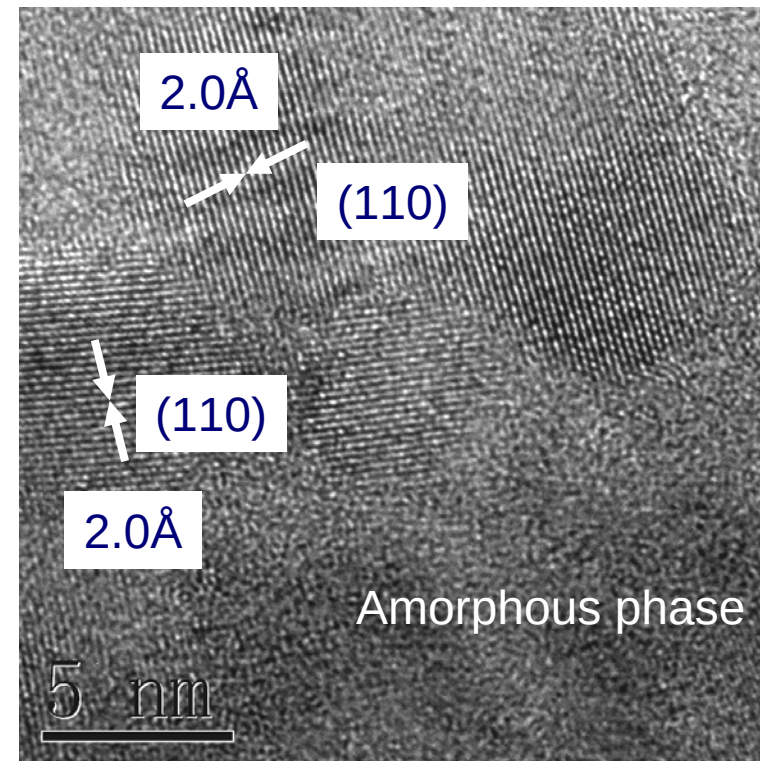
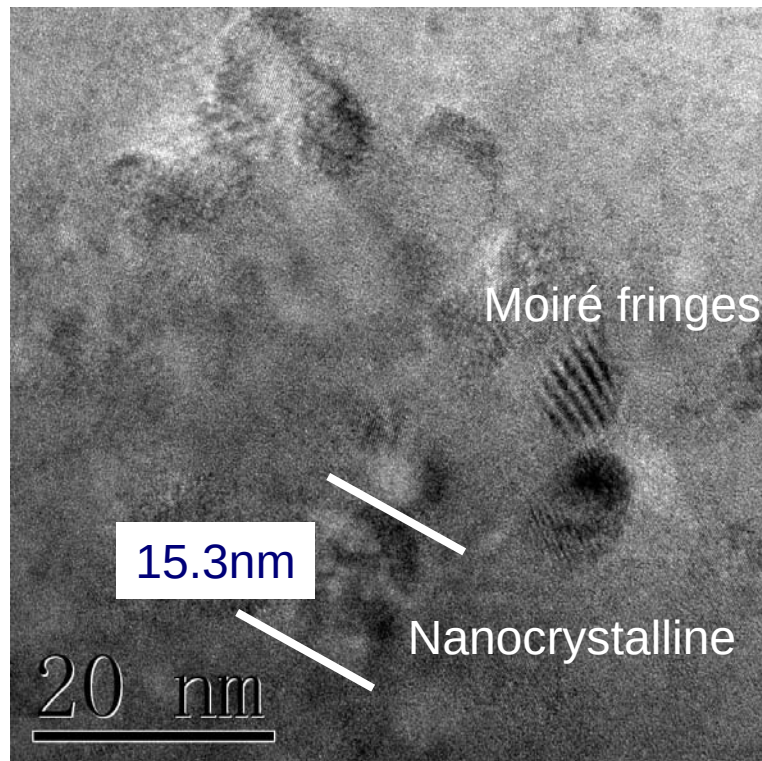
550°C
1 hour



610°C
1 hour

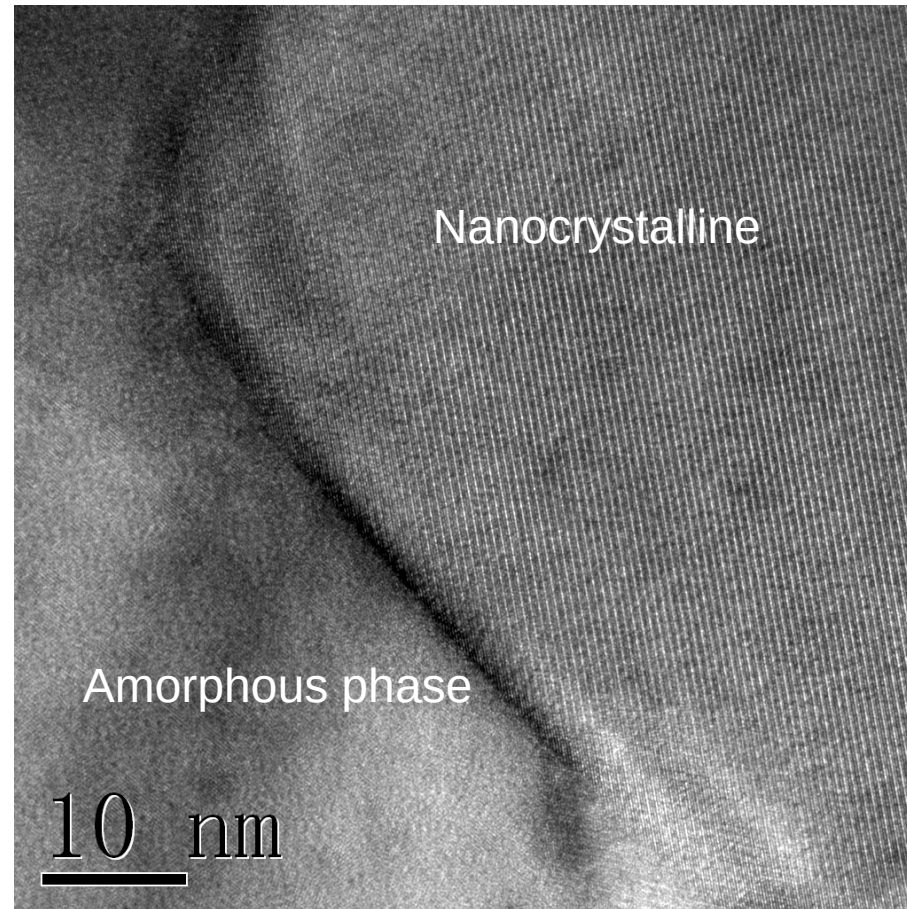


HRTEM images



Annealed at 550°C for 1 hour

HRTEM images

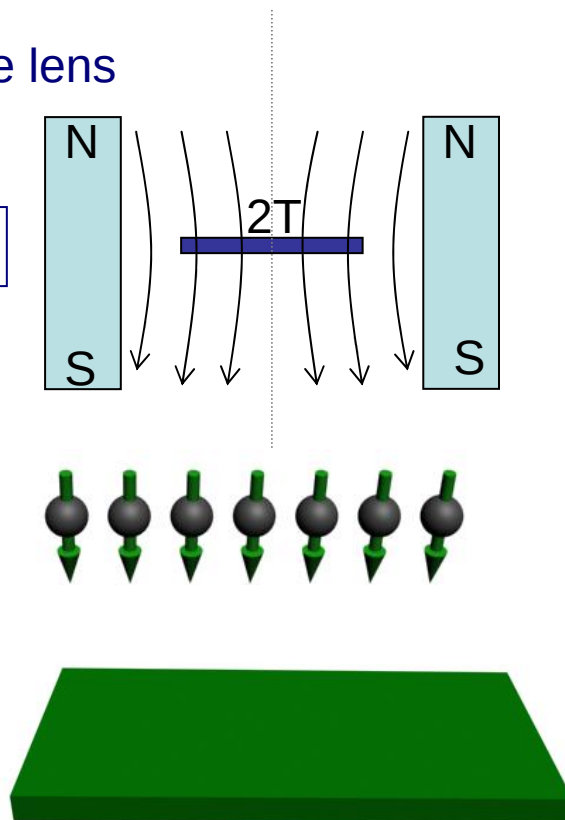


Annealed at 610°C for 1 hour

Lorentz microscopy

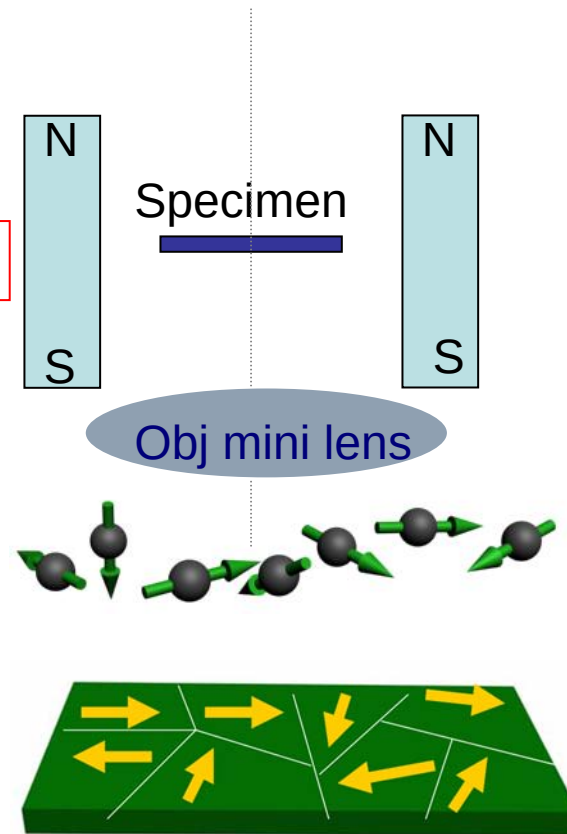
Objective lens

ON



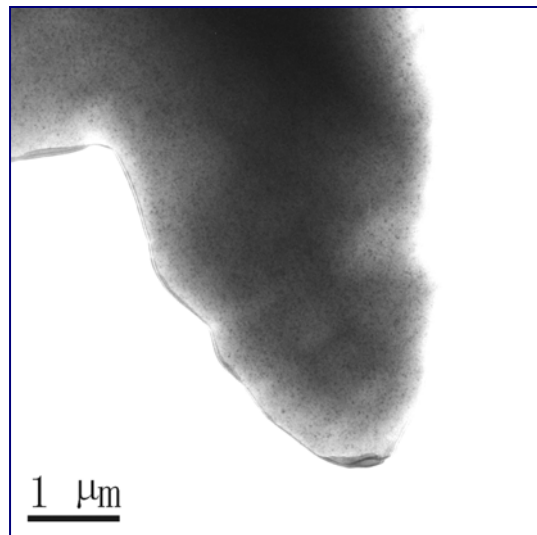
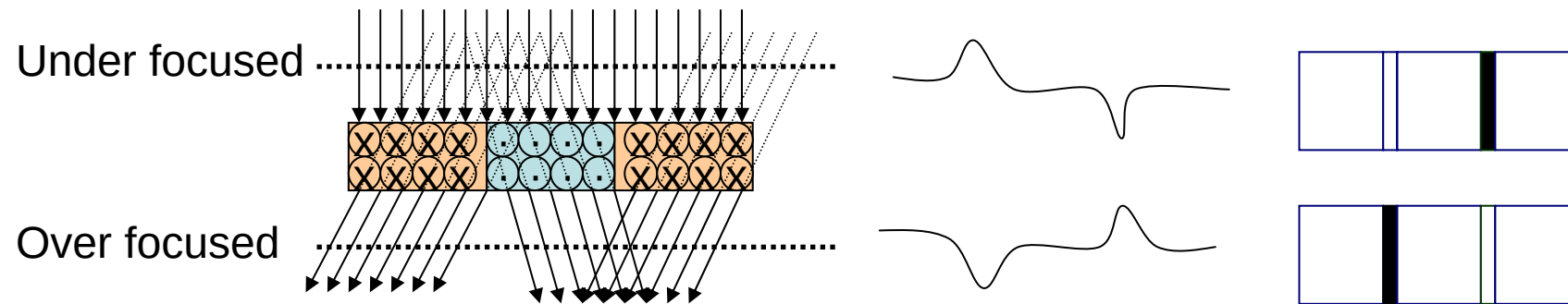
CTEM mode

OFF

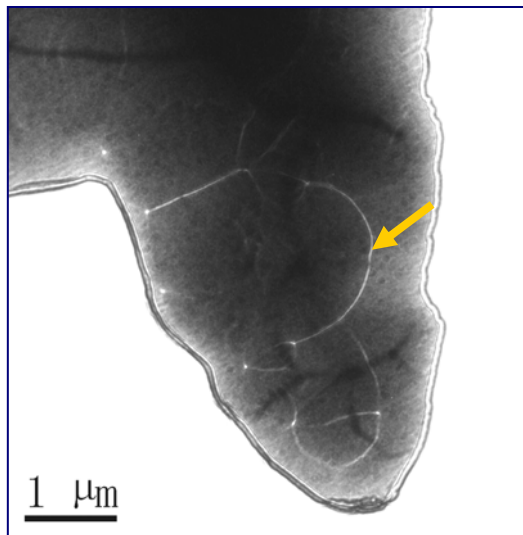


Lorentz mode

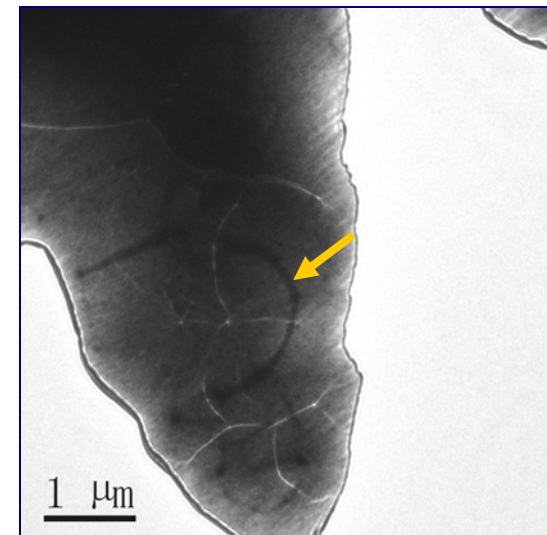
Lorentz microscopy



In focus



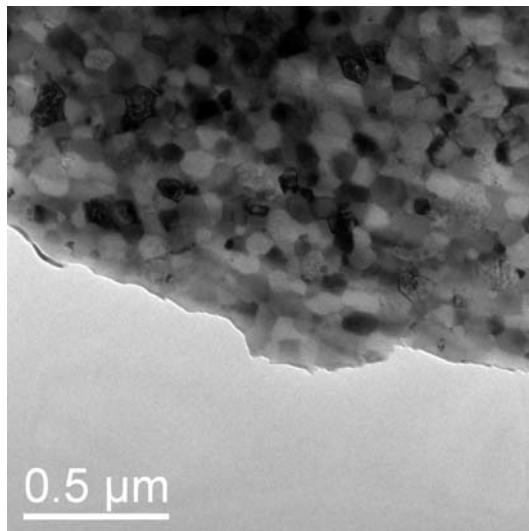
Over focused



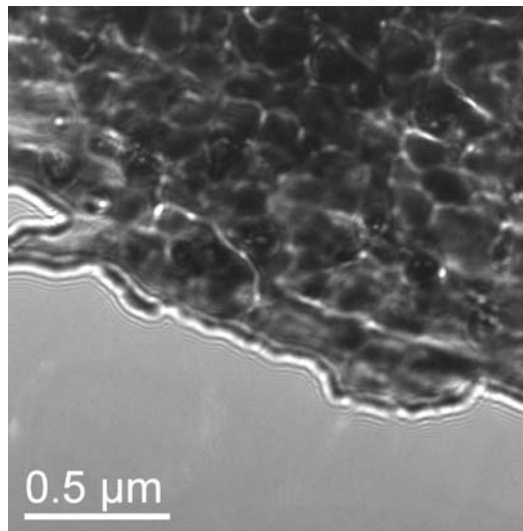
Under focused

Annealed at 550°C for 1 hour

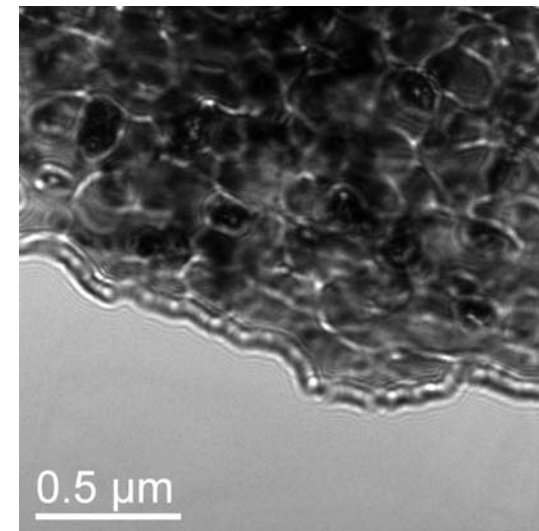
Lorentz microscopy



In focus



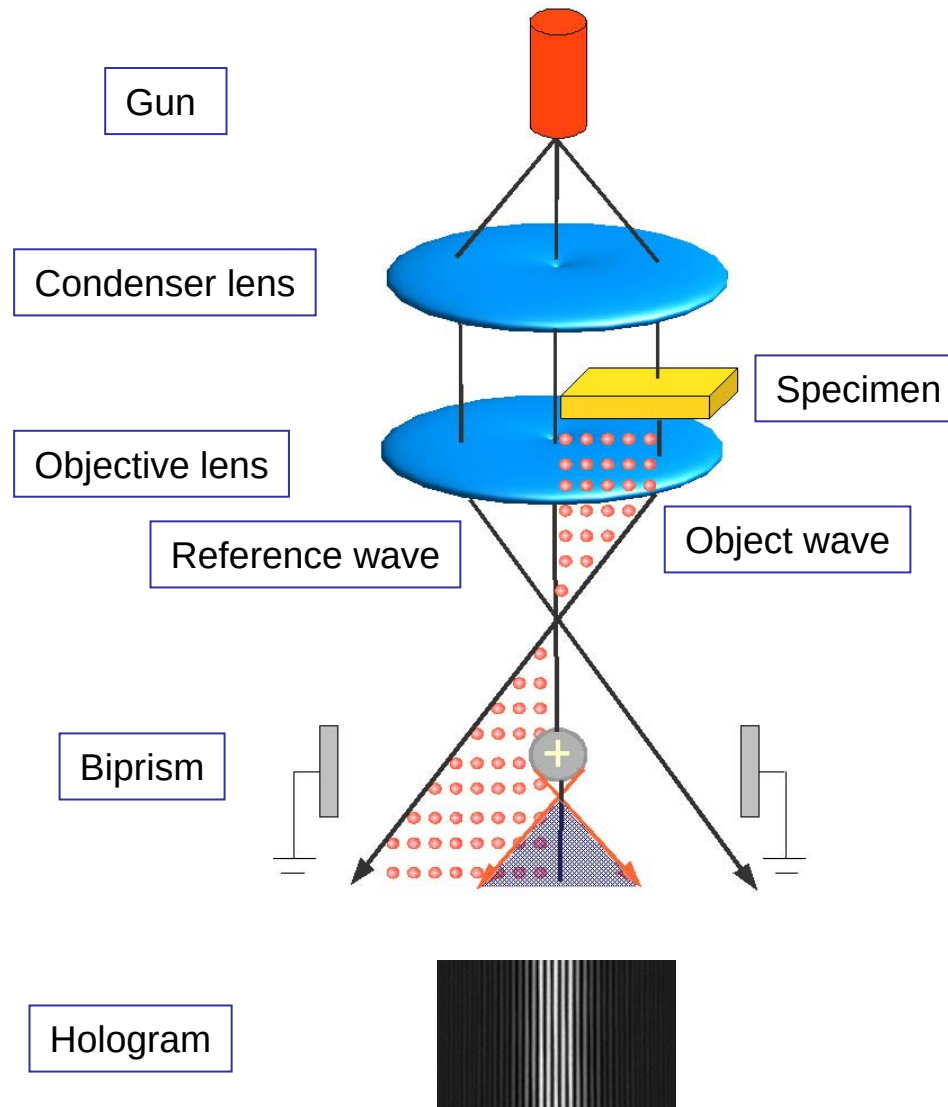
Over focused



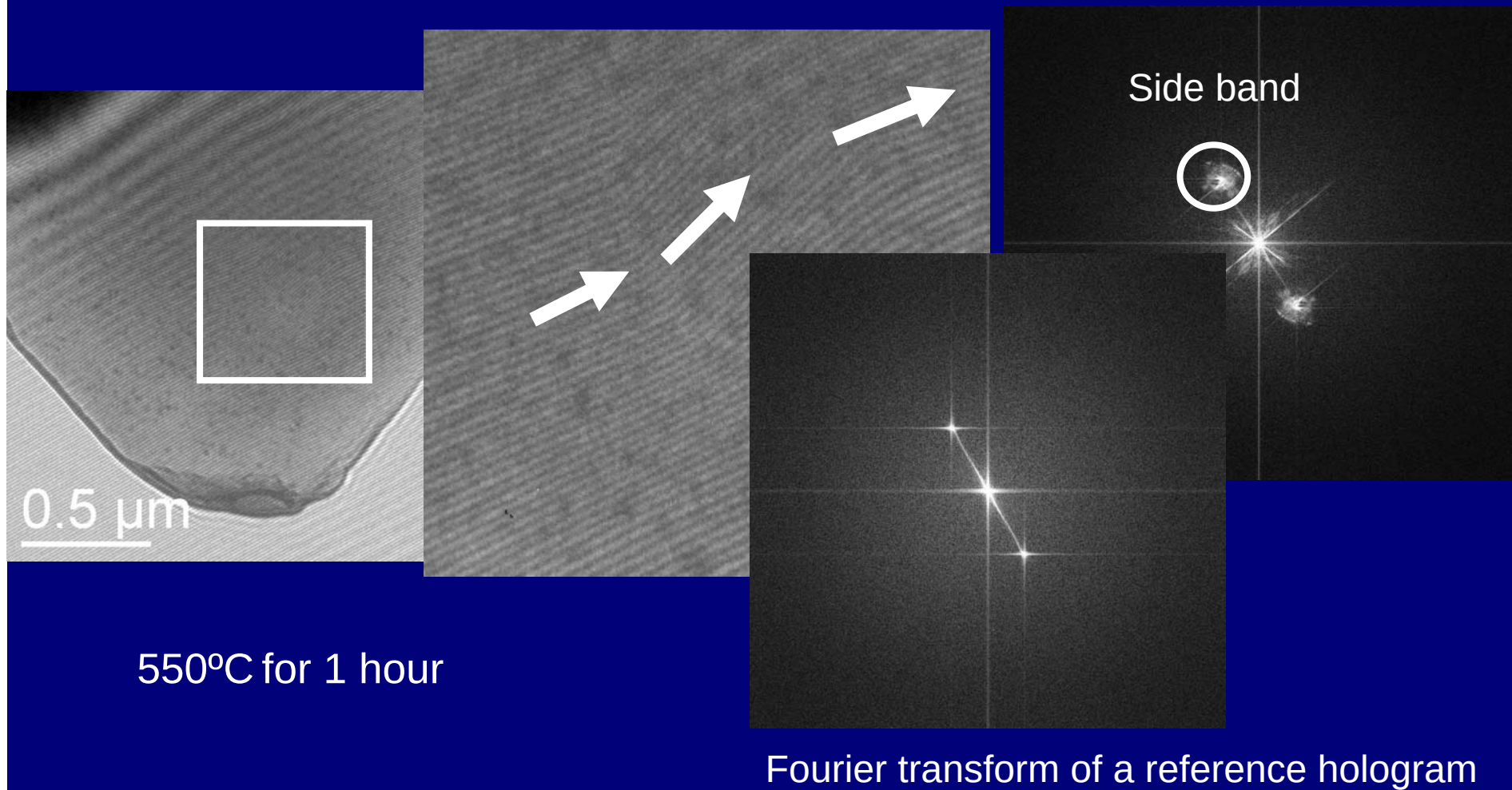
Under focused

Annealed at 610°C for 1 hour

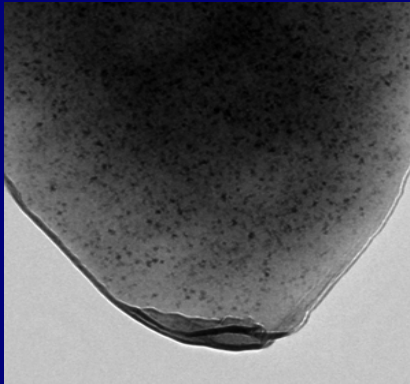
Electron holography



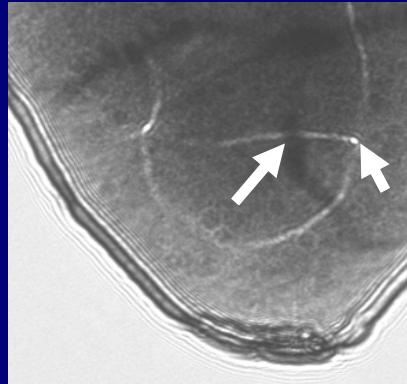
Electron hologram and it's Fourier transform



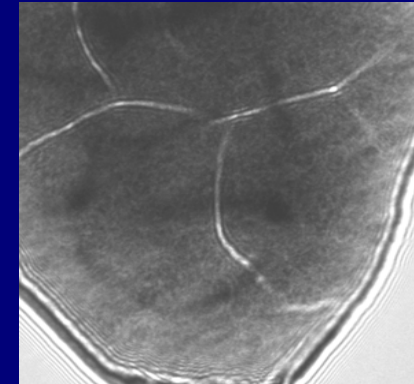
Reconstructed phase and amplitude compared to Lorentz mode image



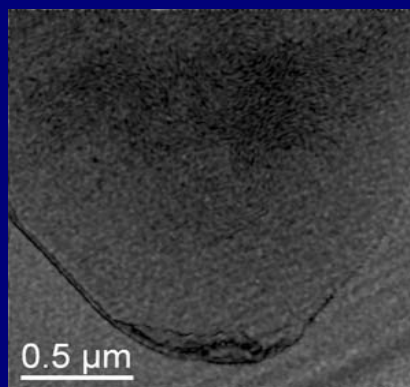
In focus



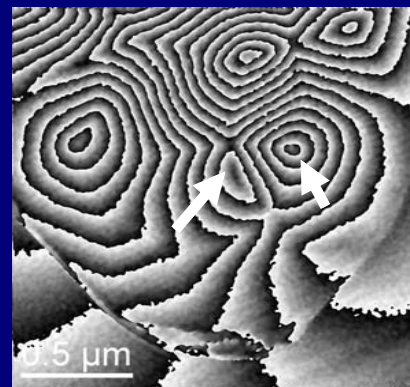
Over focused



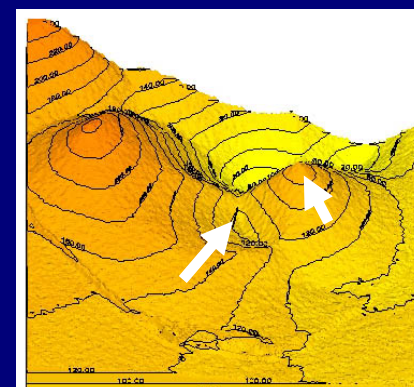
Under focused



Amplitude



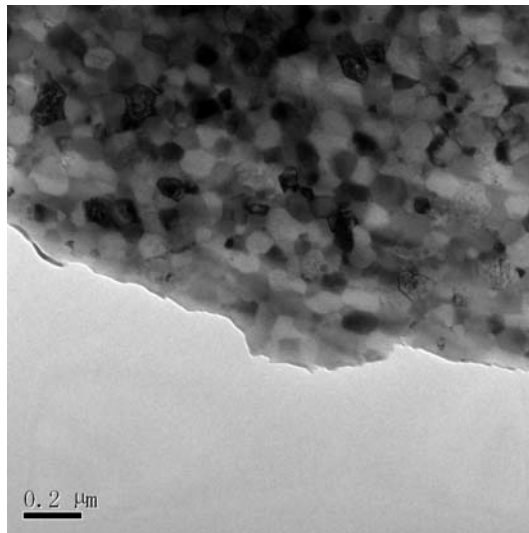
Phase



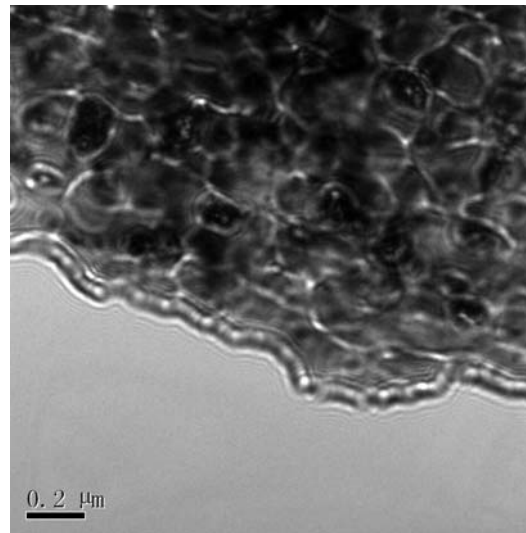
Surface plot of phase

550°C for 1 hour

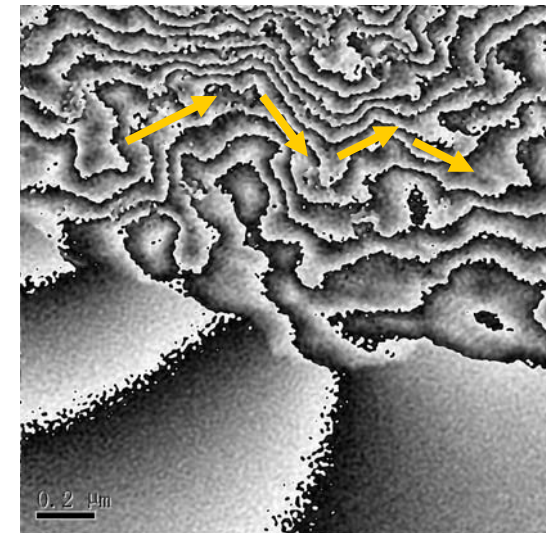
Reconstructed phase compared to Lorentz mode image



In focus



Under focused



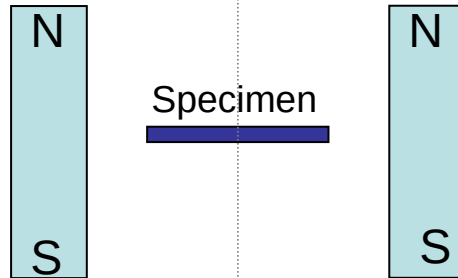
Phase

Annealed at 610°C for 1 hour

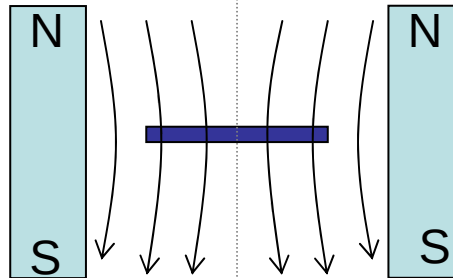
Change of applied field by tilting sample



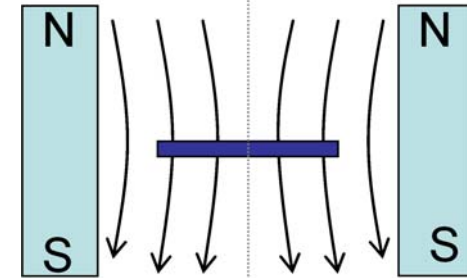
Objective lens



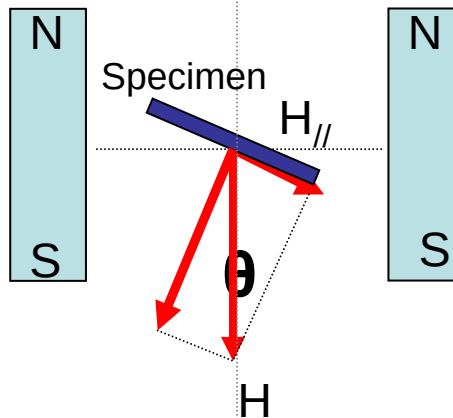
Objective lens off



Objective lens slightly active

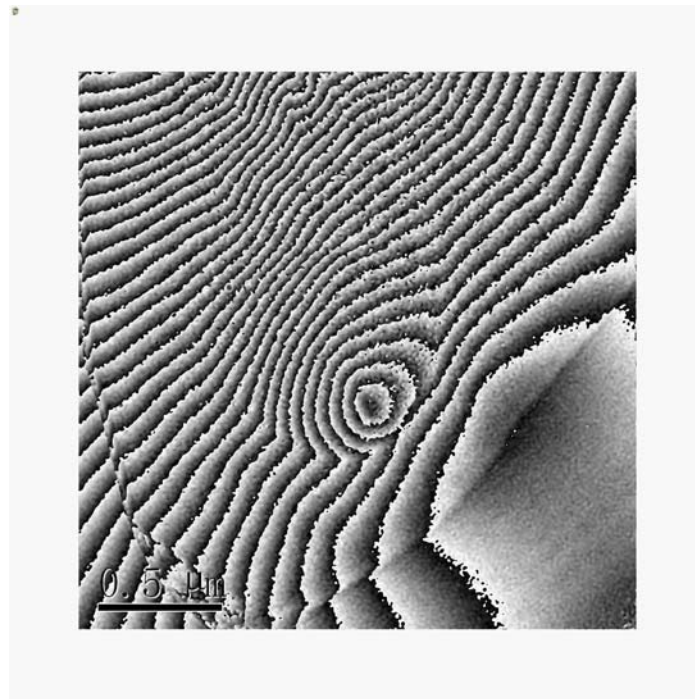


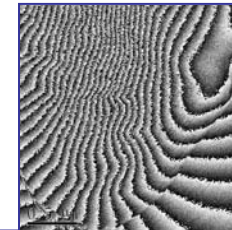
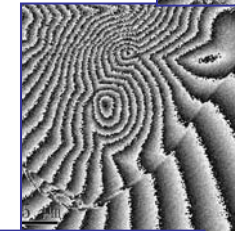
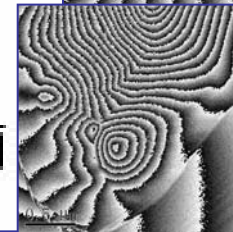
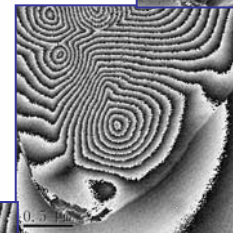
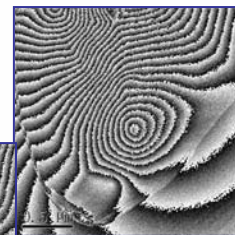
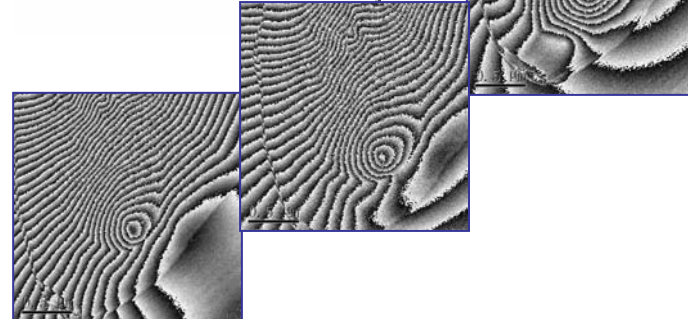
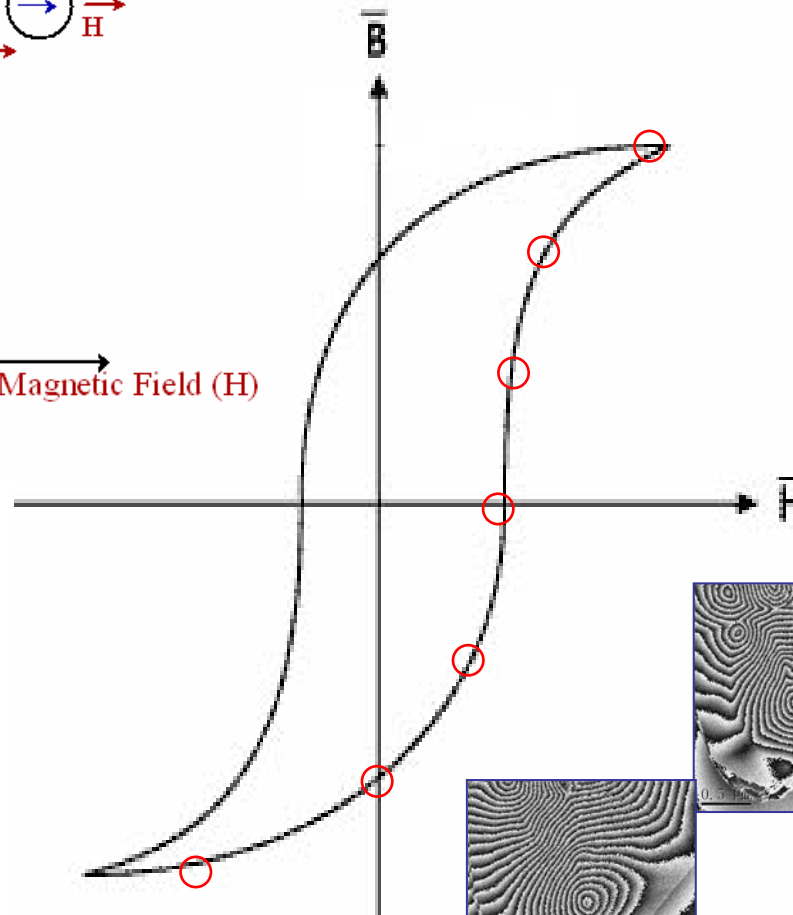
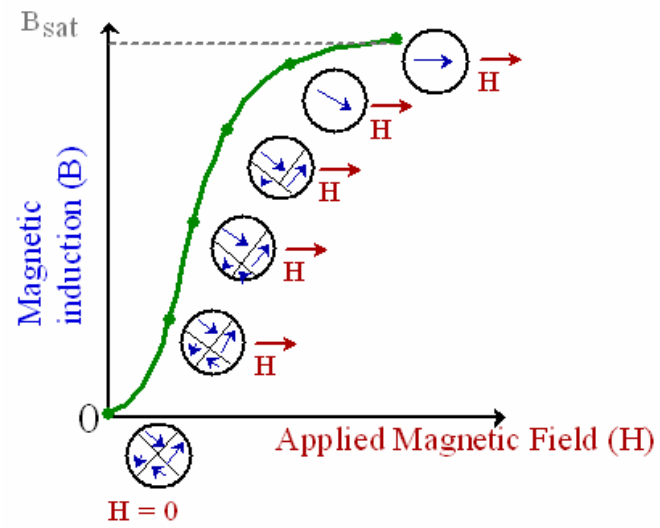
Tilt specimen



In-plane magnetic field

$$H_{//} = H \cdot \sin \theta$$

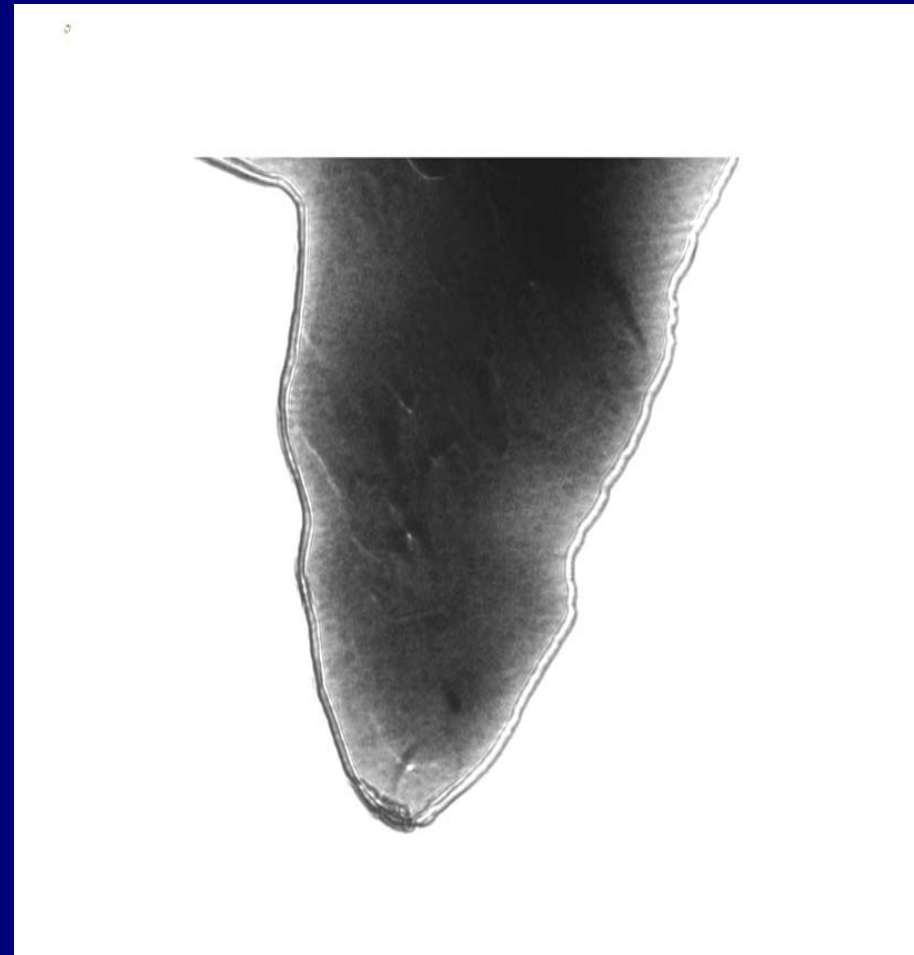
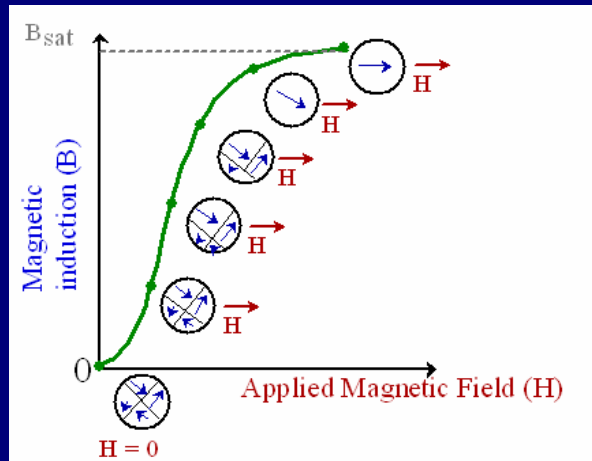




$(\text{Fe}_{0.5}\text{Co}_{0.5})_{80}\text{Nb}_4\text{B}_{13}\text{Ge}_2\text{Cu}_1$
Annealed at 550°C for 1 hour

Applied field

Domain walls' motion in Lorentz mode



550°C for 1 hour

Conclusion

Large magnetic domain and few pinning sites in sample annealed at 550°C for 1 hour were observed by Lorentz microscopy and electron holography. This kind of domain configuration is easy to move in small magnetic field.

Domain configuration becomes more complicated and more pinning sites exist when the annealing temperature was elevated to 610°C . This means domain walls in sample need more energy to overcome these barriers. In other words, the coercivity of sample becomes large.