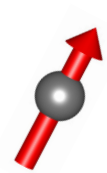
Ferromagnets: domains and anisotropy

coercive field, Bloch and Néel domain walls

ferromagnetic resonance spectroscopy

ferromagnetic materials

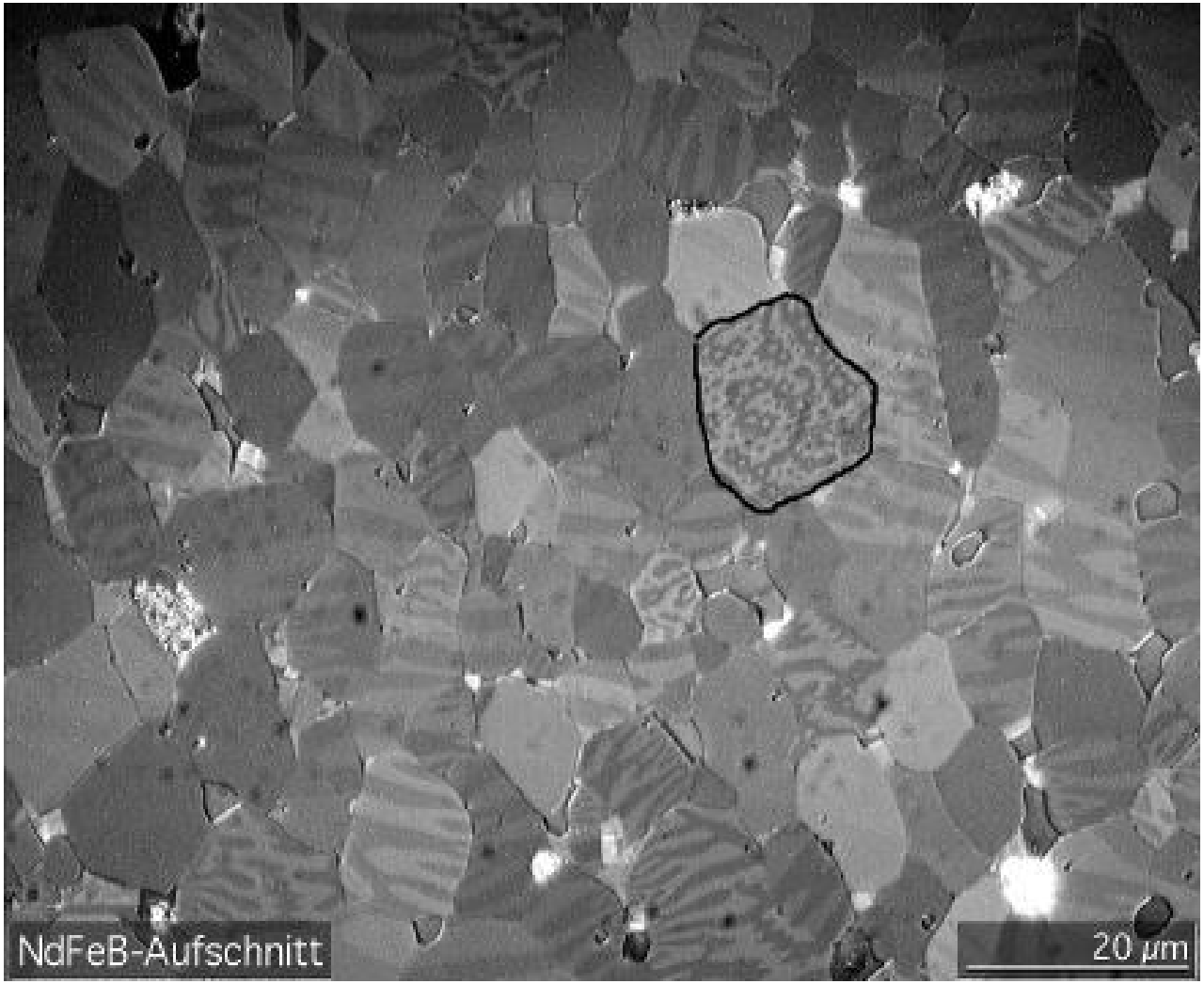


by Alexander Tsirlin, Leipzig University

Lecture 9: January 13, 2025

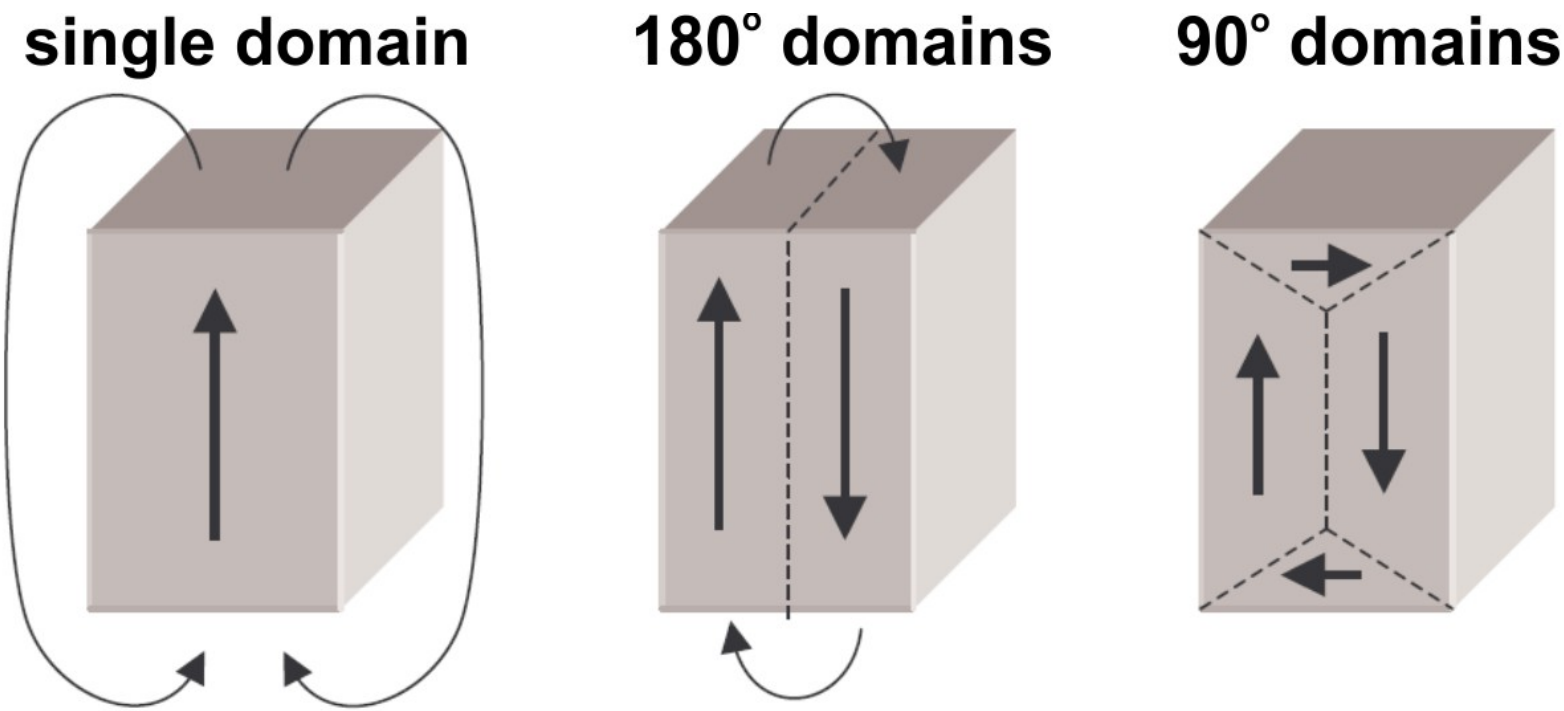
Magnetic domains

Image credit: Gorchy (CC-BY-SA)



Nd–Fe–B magnet

Light and dark regions within each grain are magnetic domains



Domains serve to minimize magnetostatic energy

Image credit: Zureks (public domain)

Magnetization process

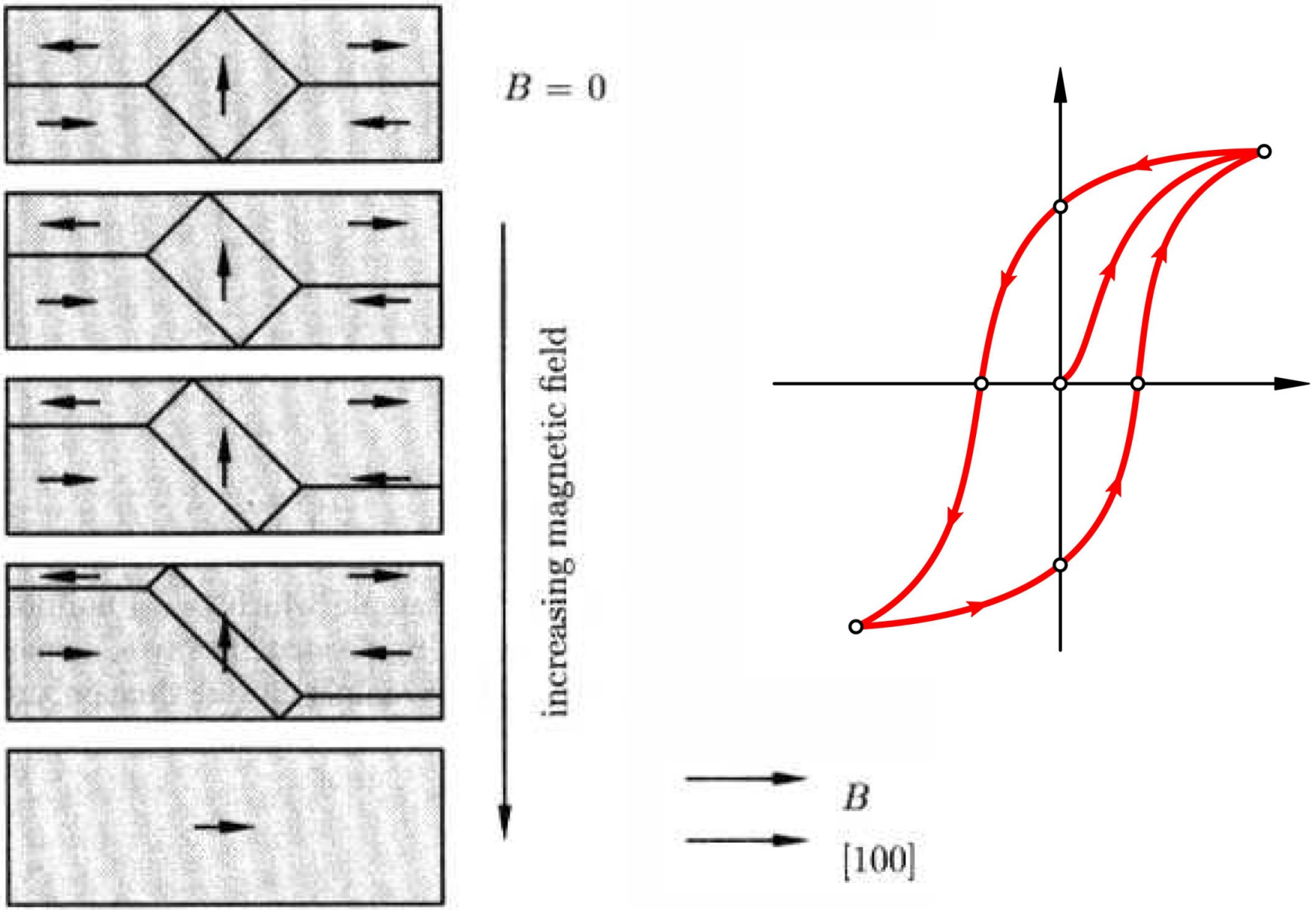
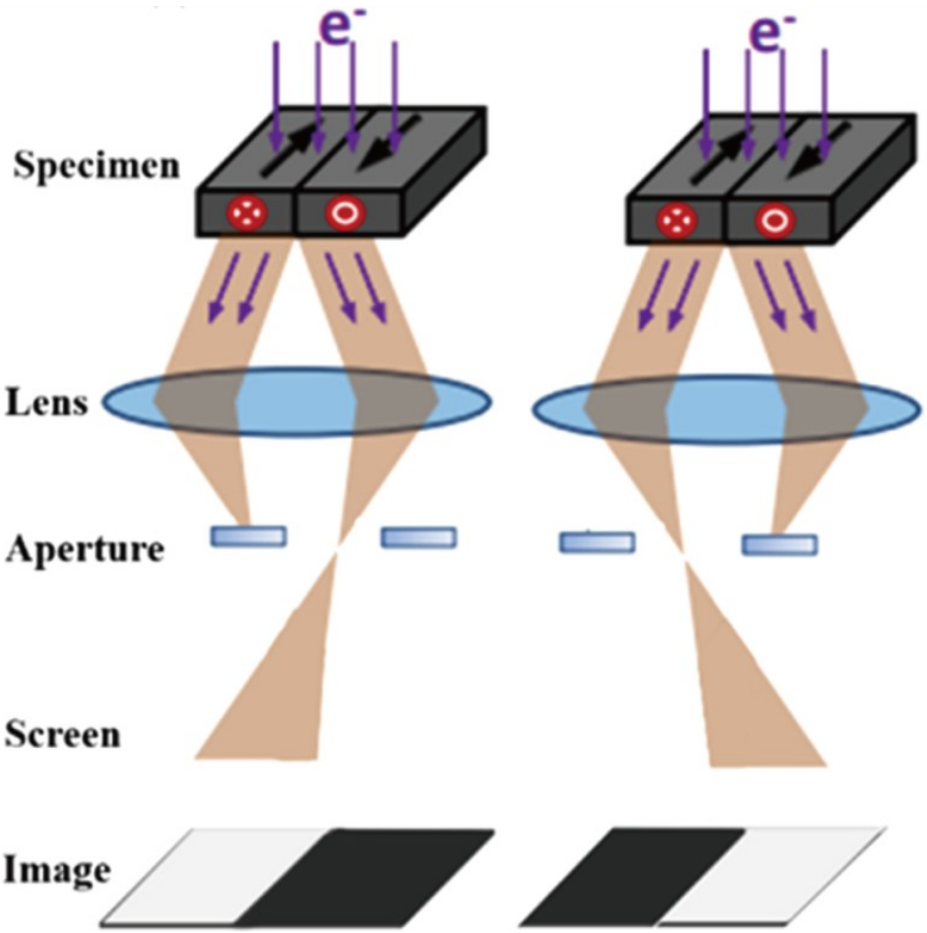


Image credit:
S. Blundell, Magnetism in Condensed Matter



Electrons influenced by the Lorentz force

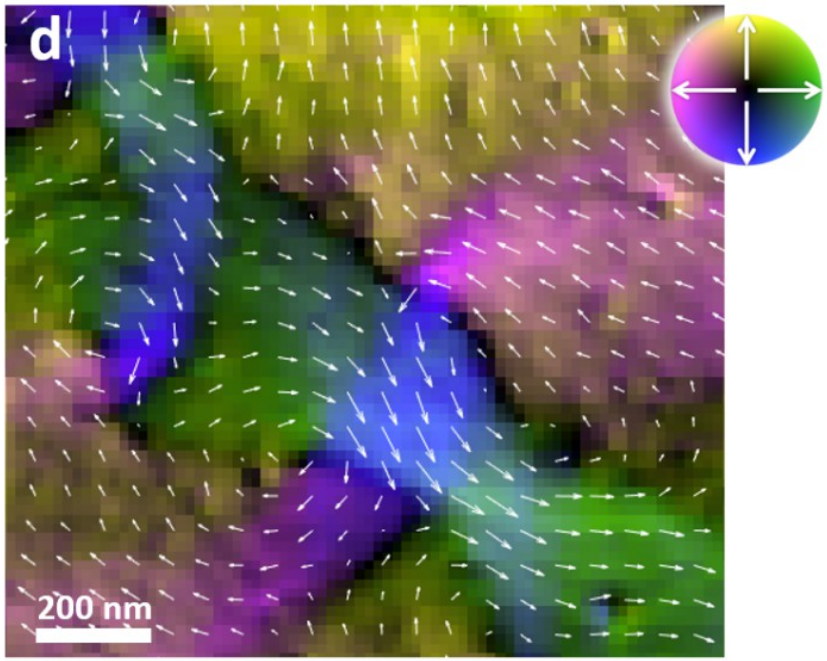


Image credit: Chinese Phys. B 27, 066802 (2018) and Xiaoke Mu (KIT)

MFM = magnetic force microscopy

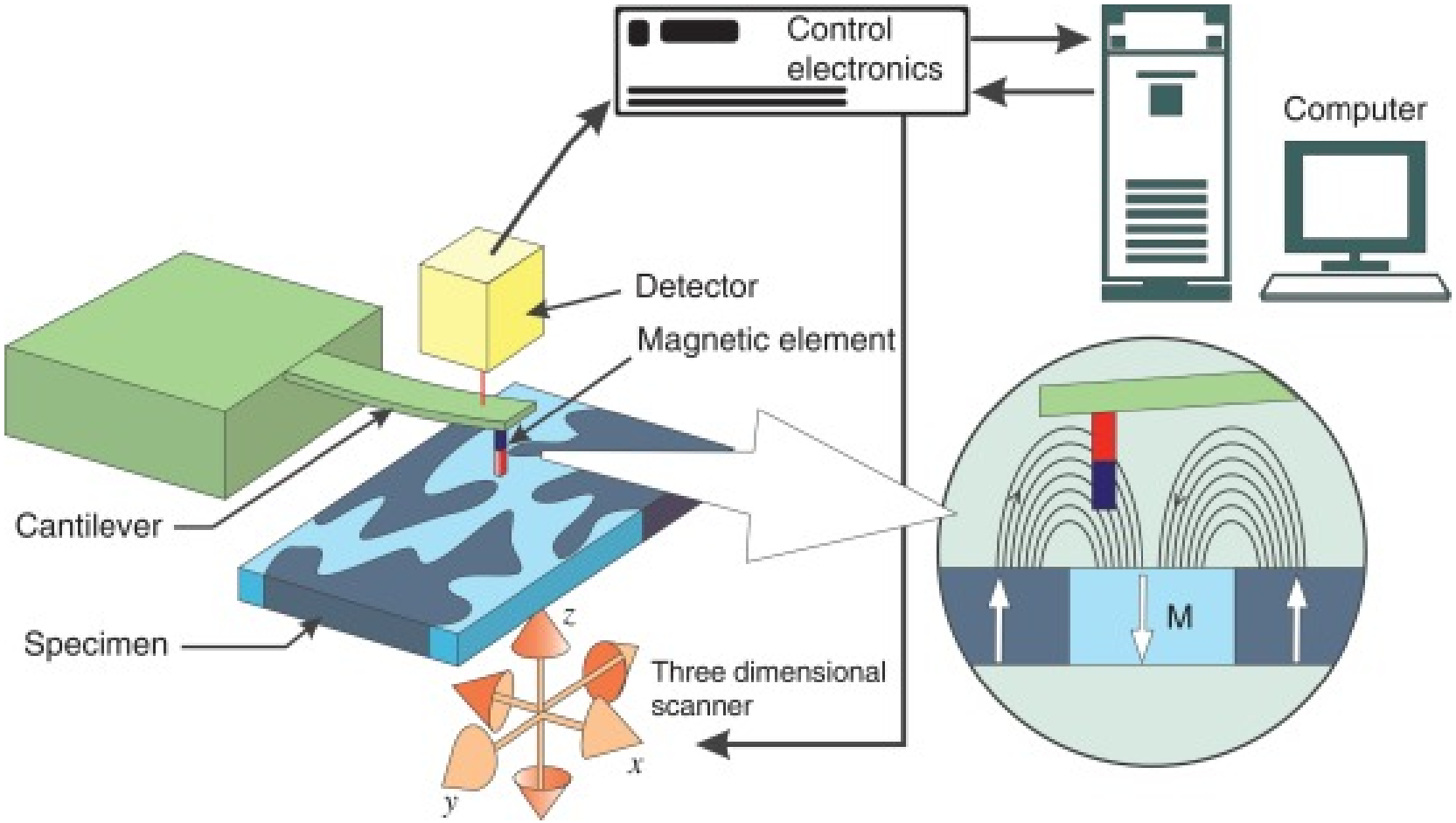


Image credit: Encyclopedia of Spectroscopy and Spectrometry

Optical detection (MOKE)

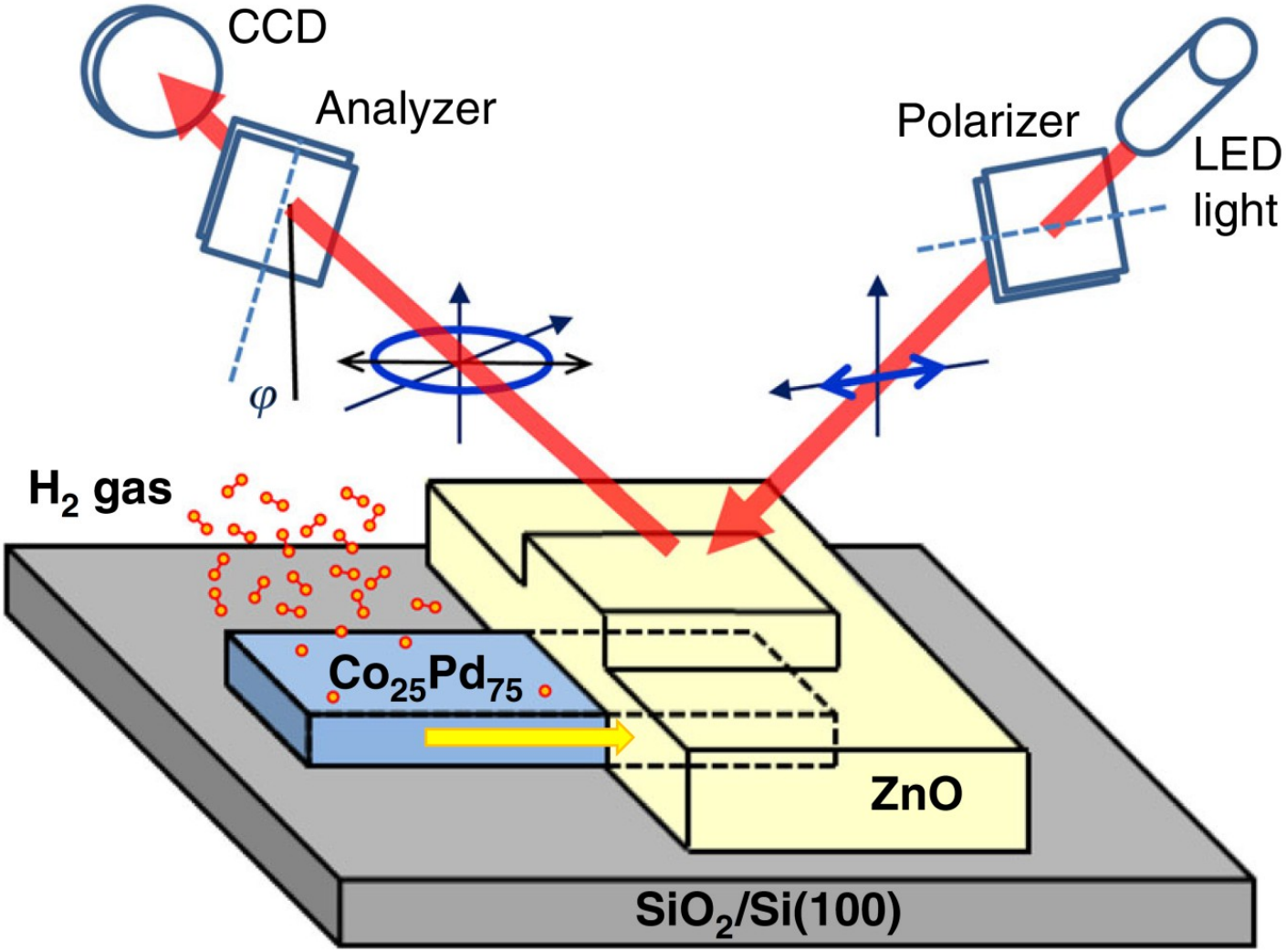


Image credit: Comm. Chem. 2, 89 (2019)

Imaging example

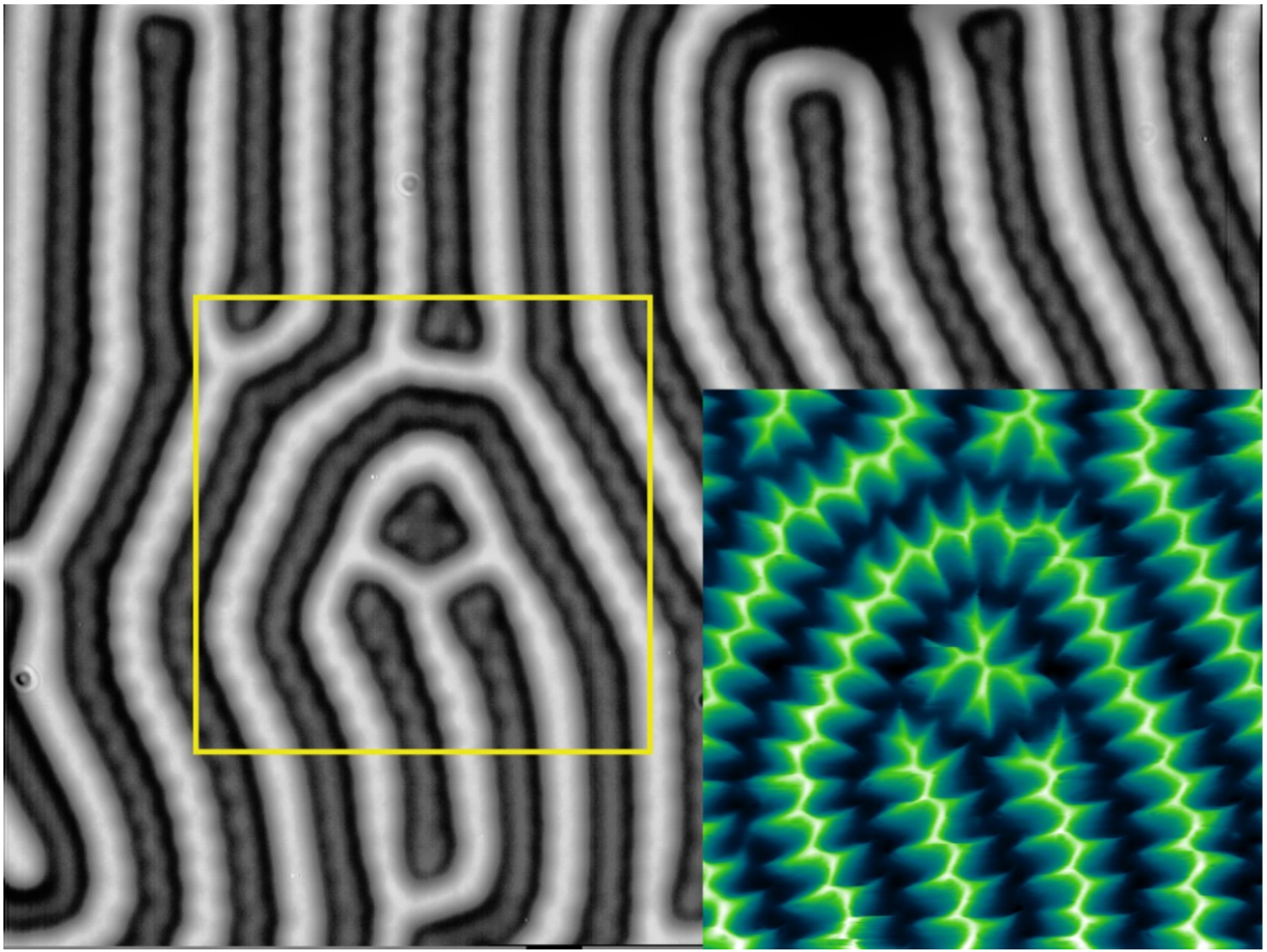
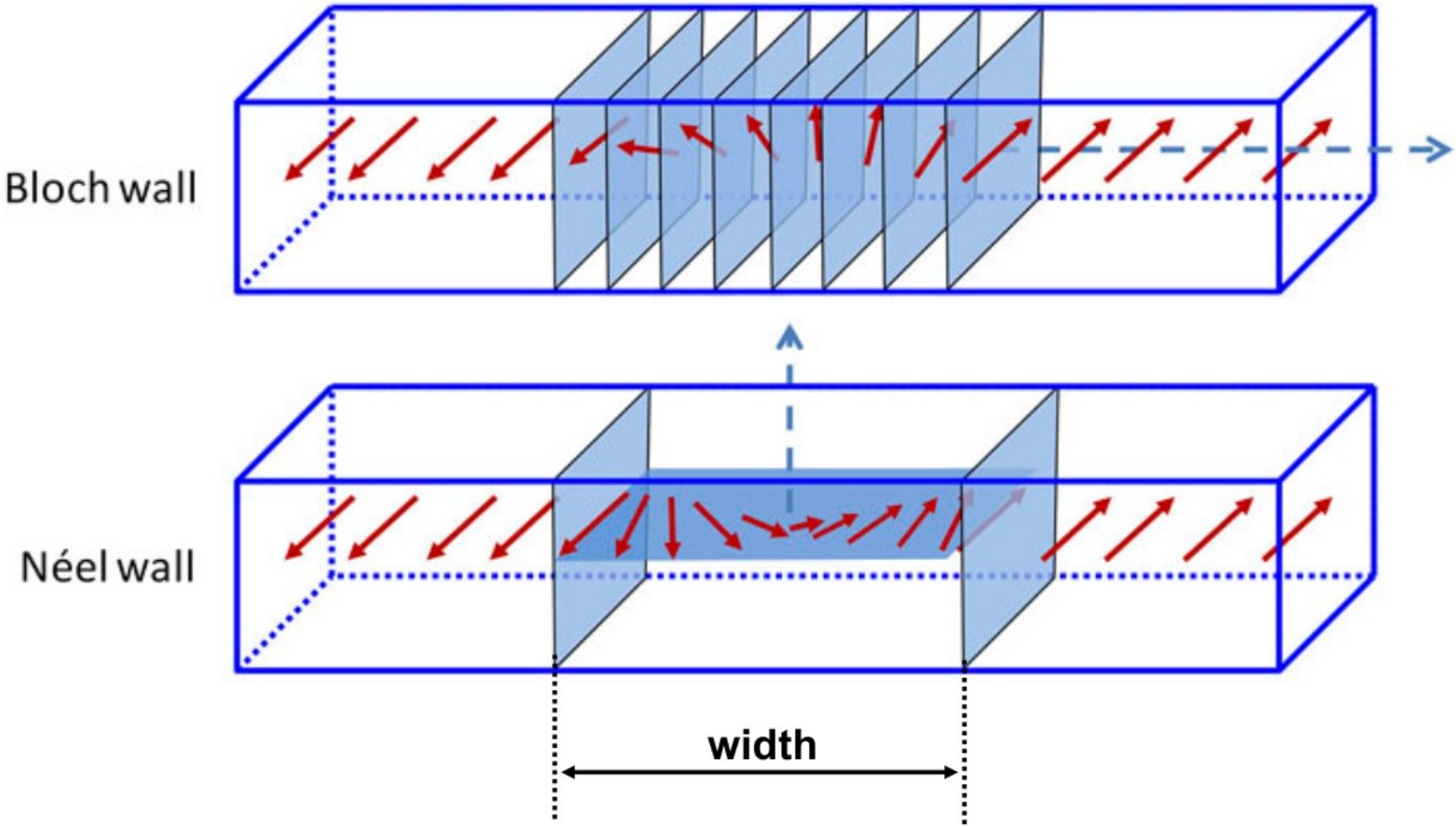


Image credit: Temiryazev (CC-BY-SA)

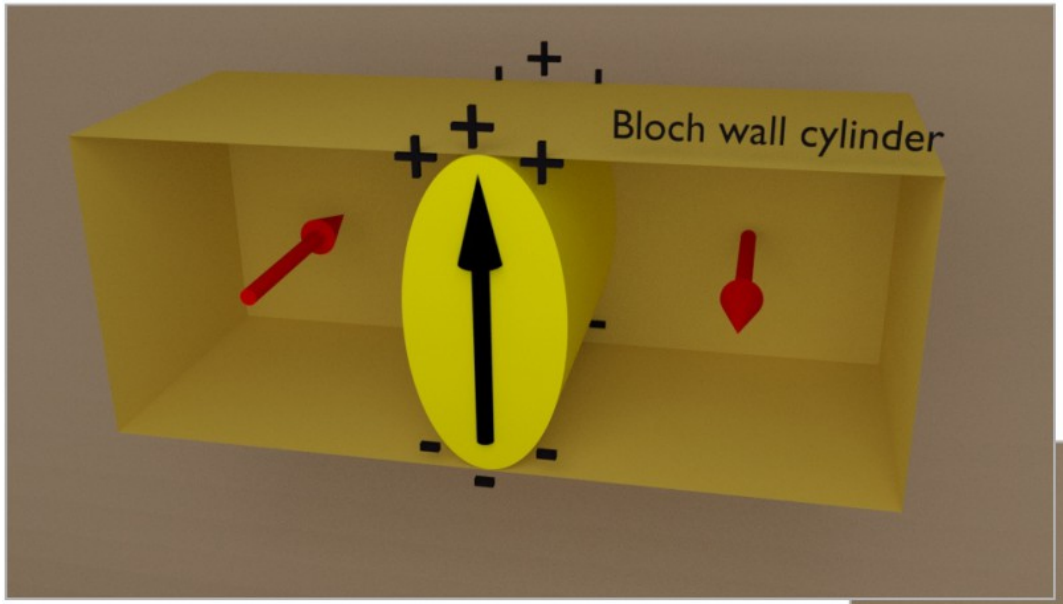


Width of the domain wall $N \sim \sqrt{J/K}$

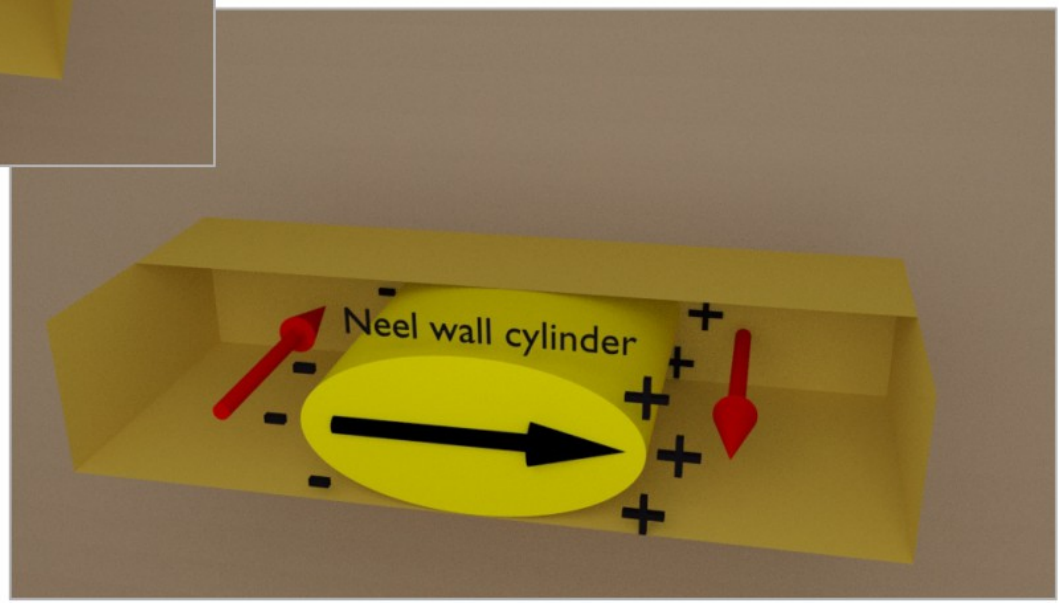
(J – exchange, K – anisotropy)

AIP Advances 9, 045107 (2019)

Bloch vs. Néel

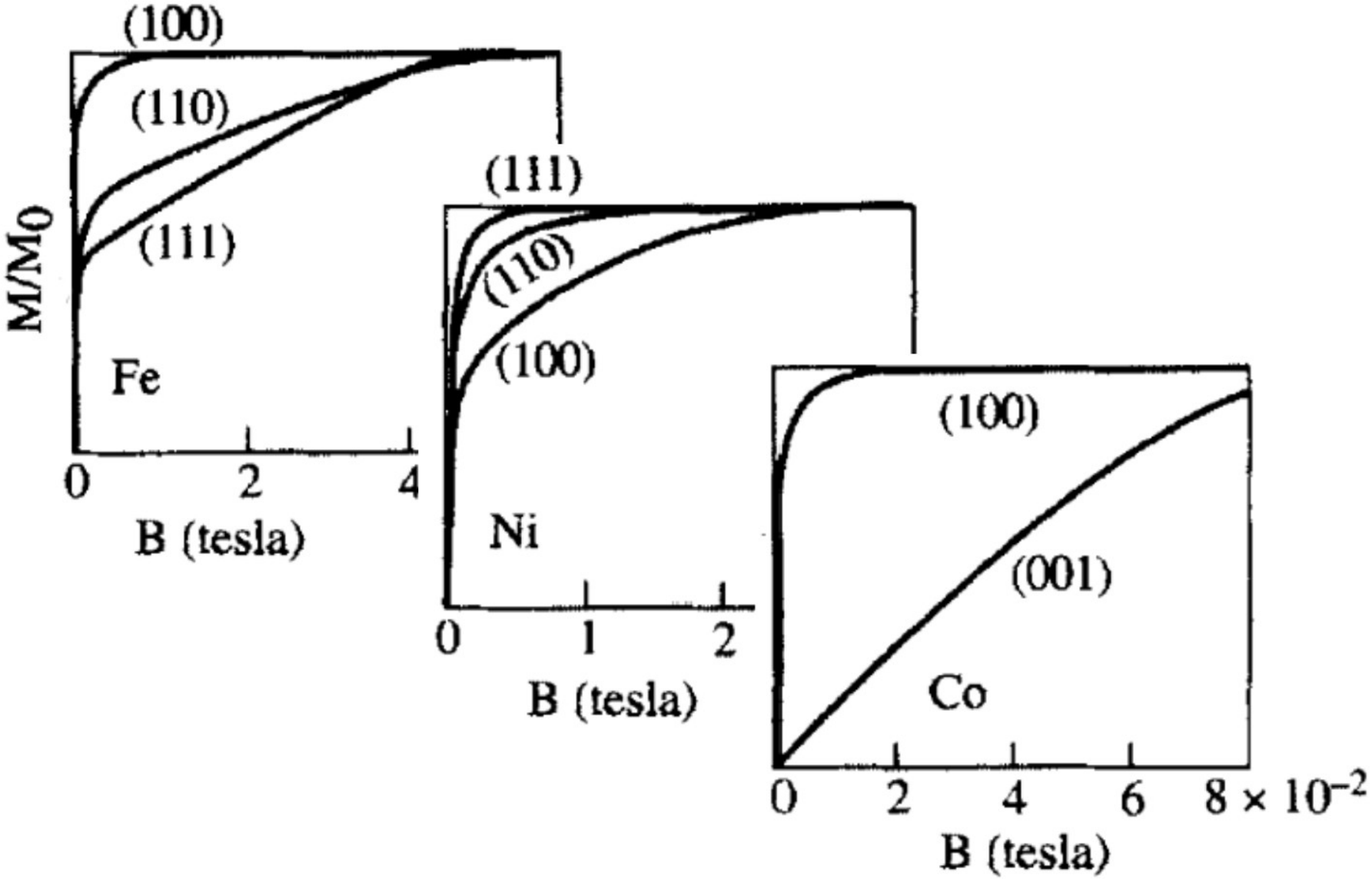


more stable in bulk



more stable in thin films

Image credit: Maciej Urbaniak (Poznań)



S. Blundell, Magnetism in Condensed Matter

Material / Technology

ferromagnetic materials

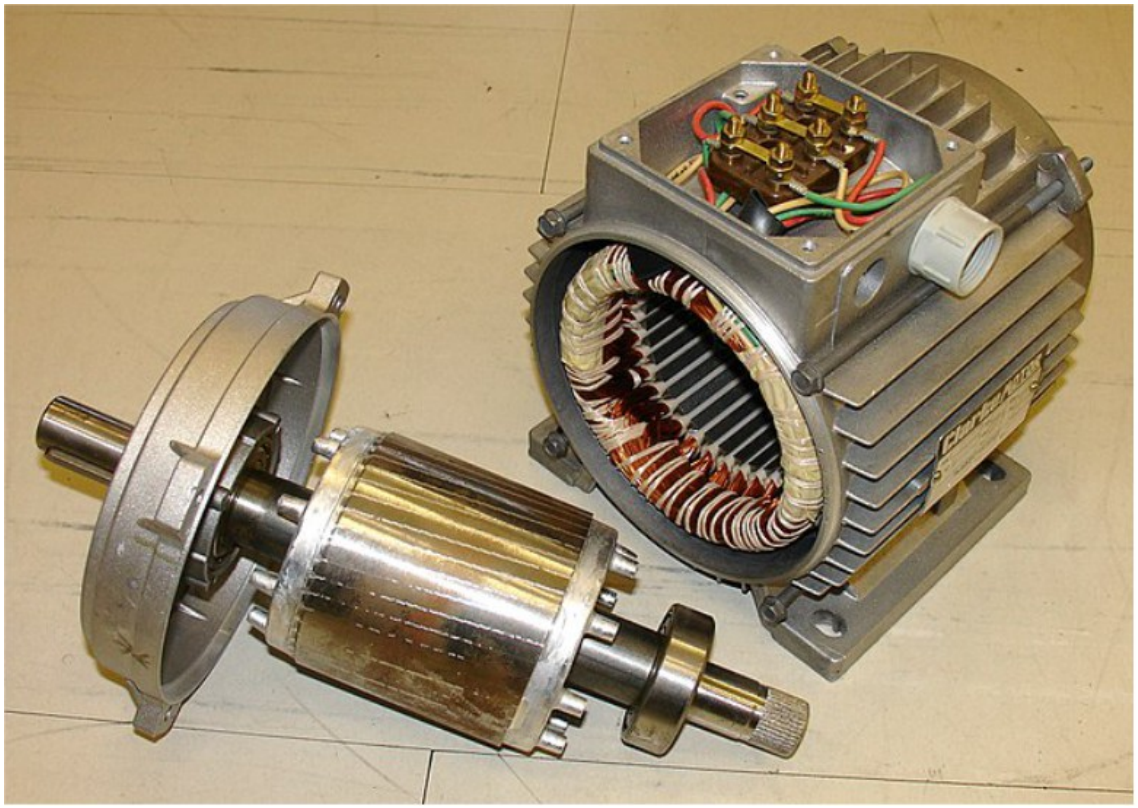
Soft ferromagnets

DC-field: magnetic cranes

AC-fields: electrical transformers, relays, and such

iron and Fe-based alloys

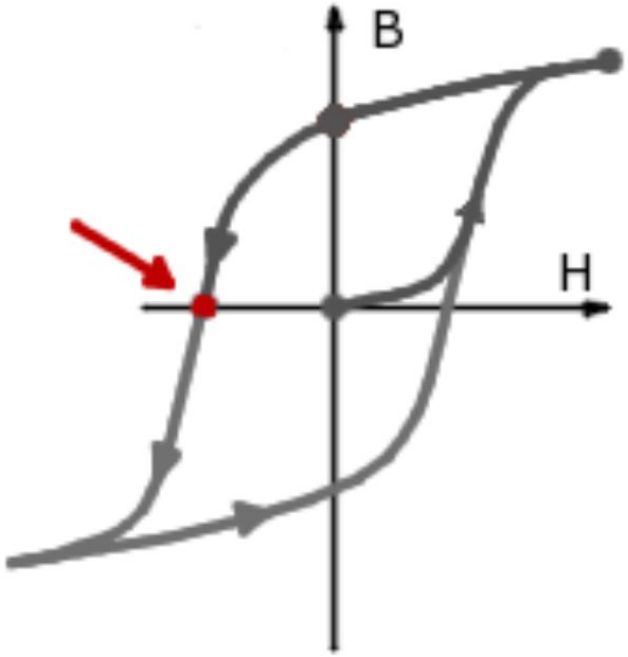
Hard ferromagnets

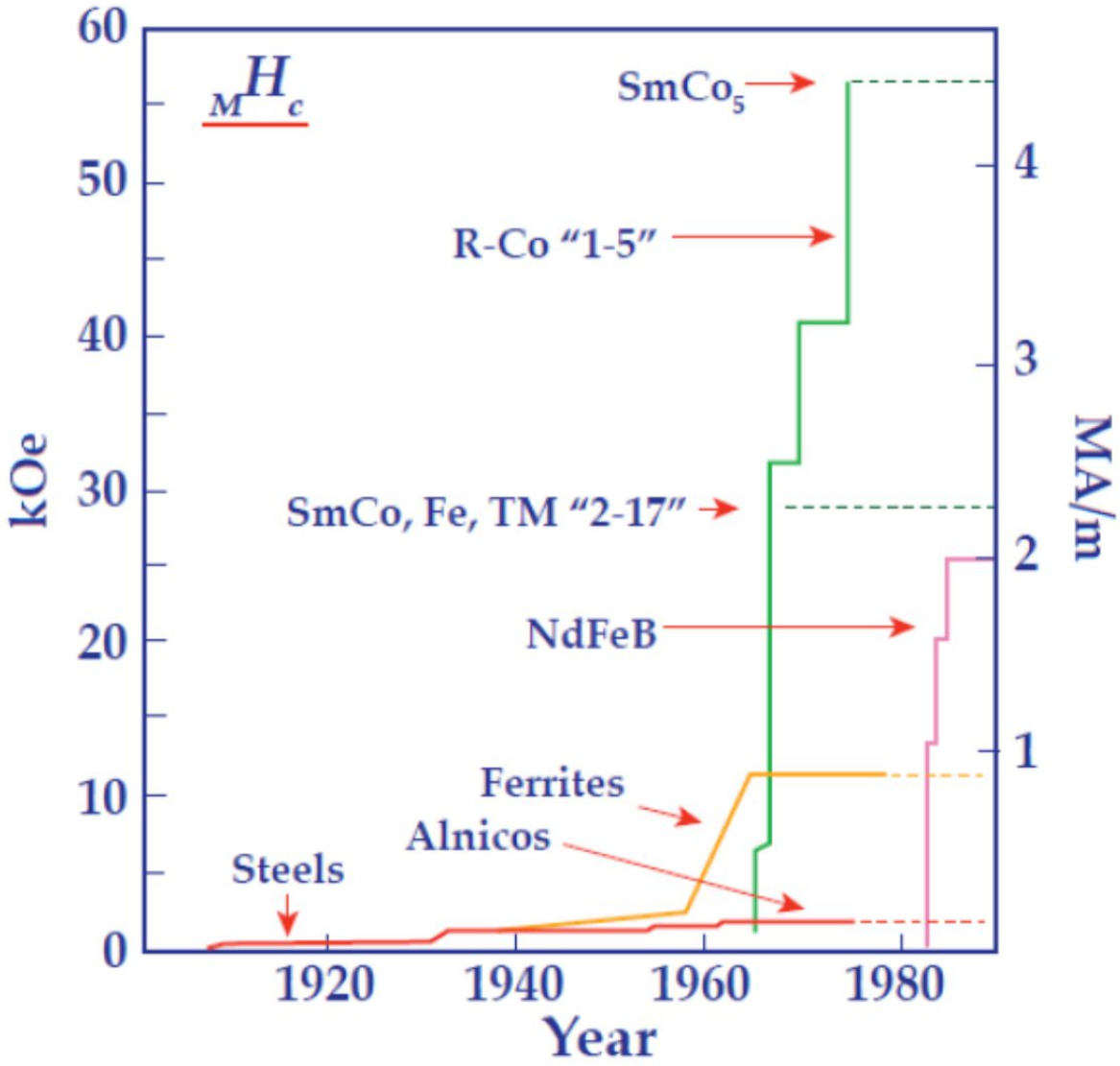


Motors, microphones, magnetic tapes and other data storage

Ferrites and 4f materials ($SmCo_5$, $Nd_2Fe_{14}B$)

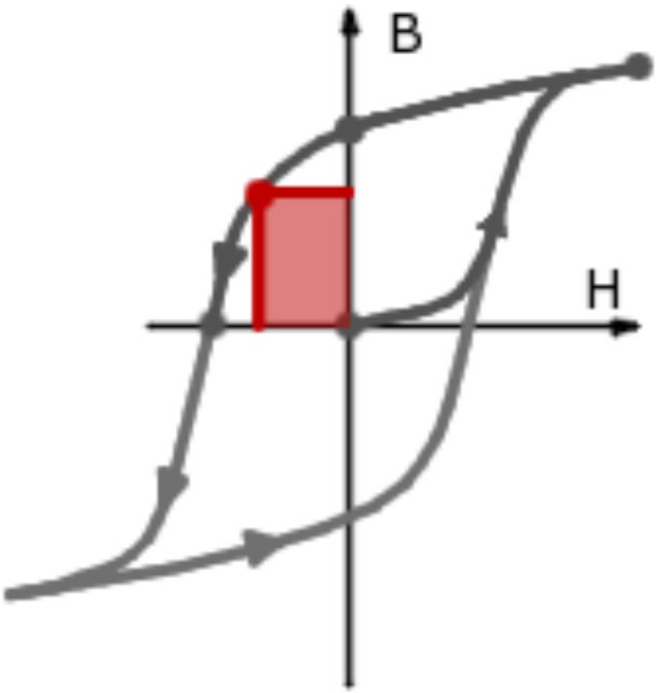
Materials: Coercive field

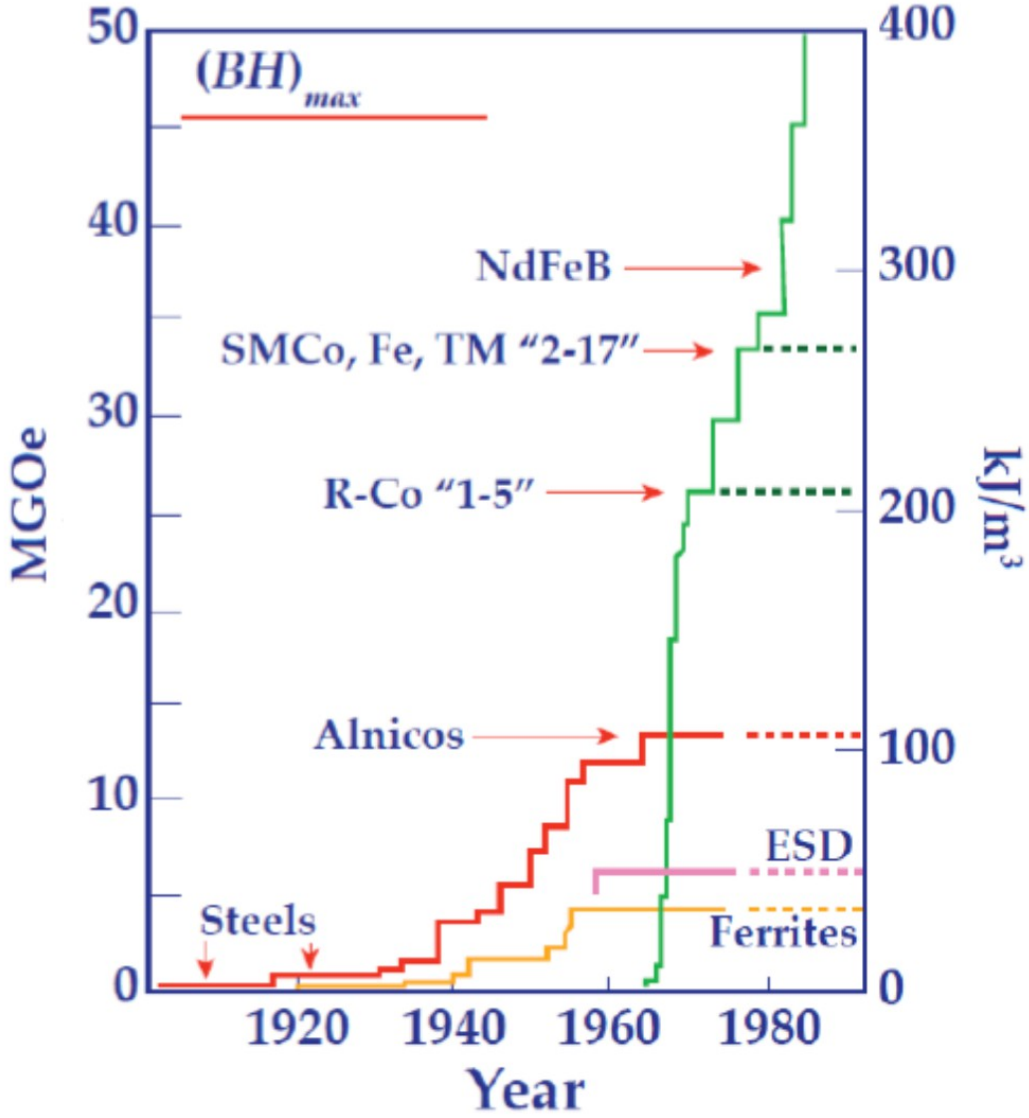




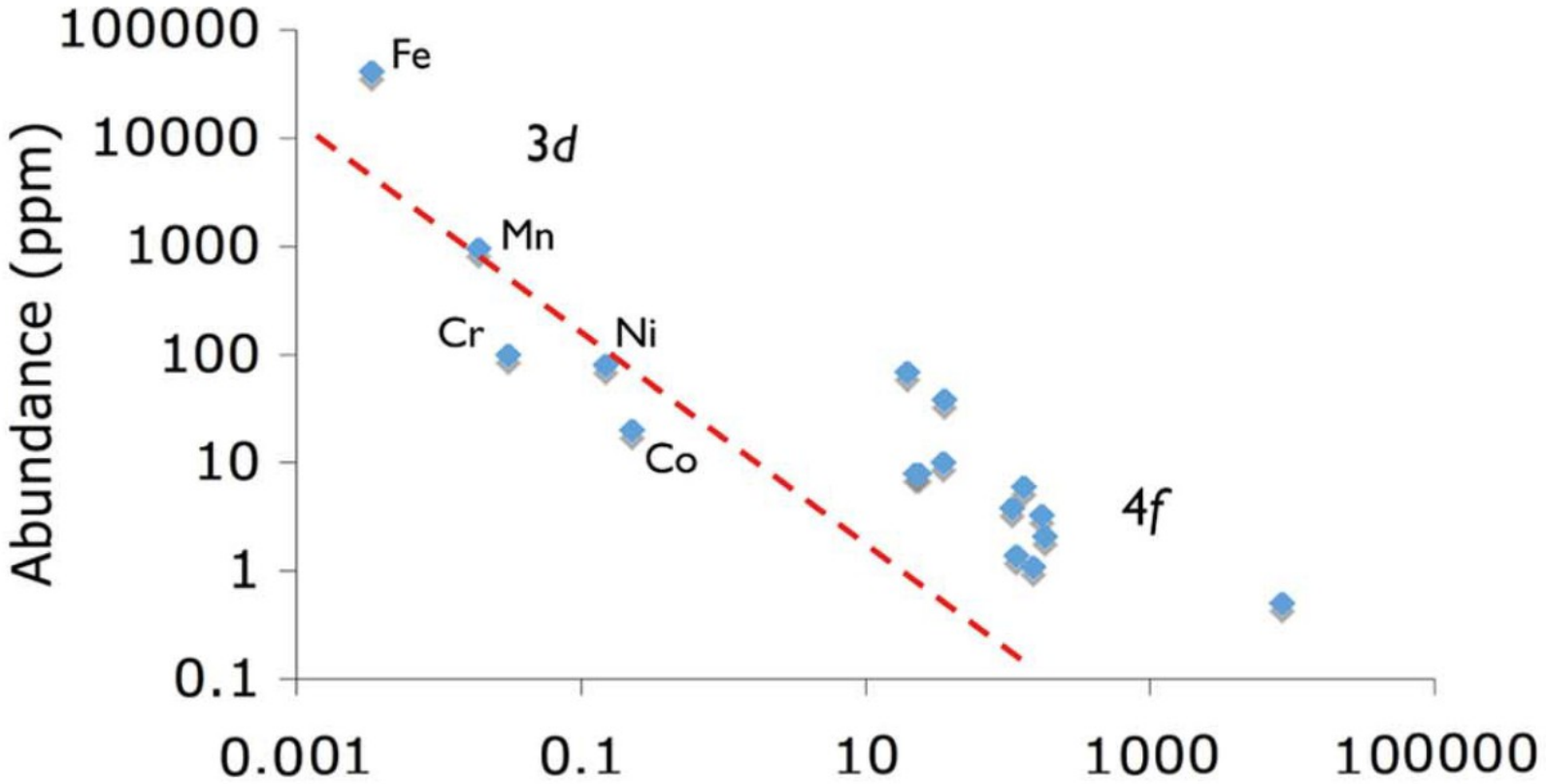
Proc. IEEE 78, 923 (1990)

Materials: Energy product

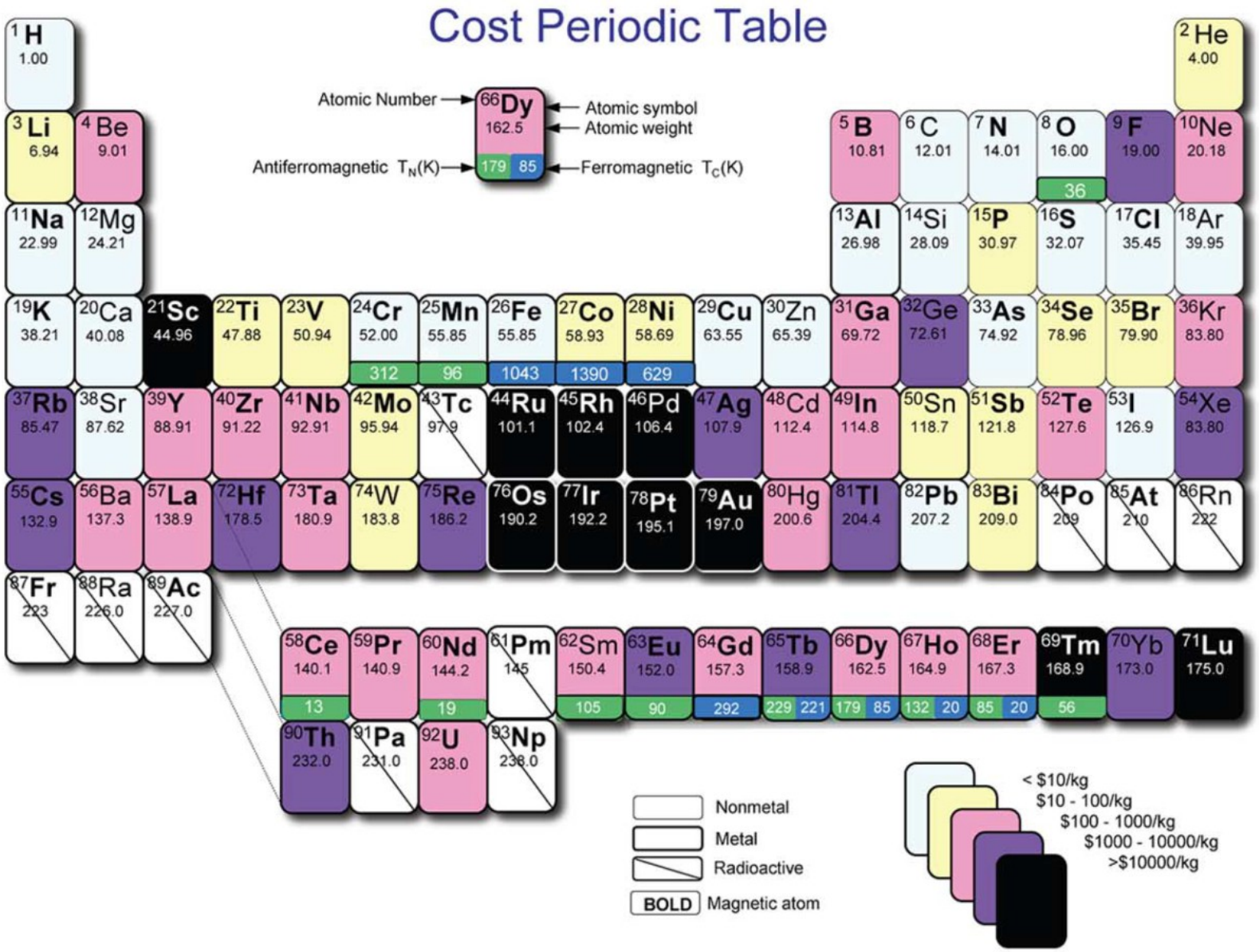




Proc. IEEE 78, 923 (1990)

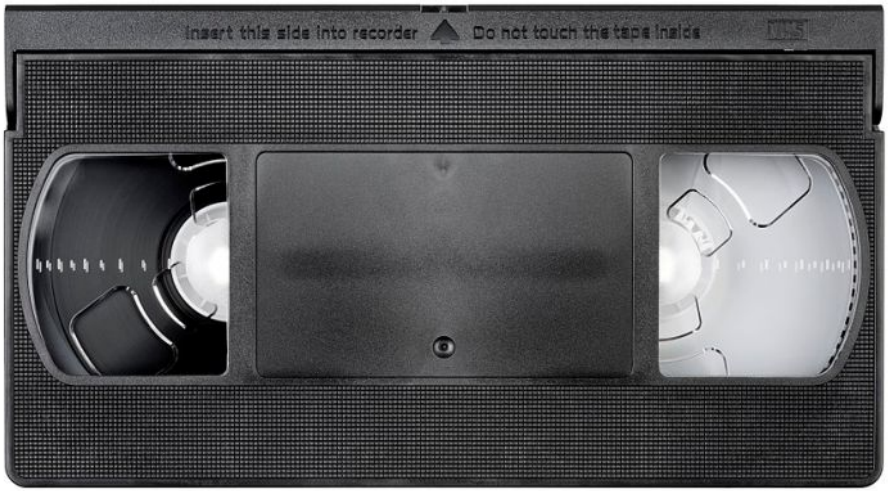


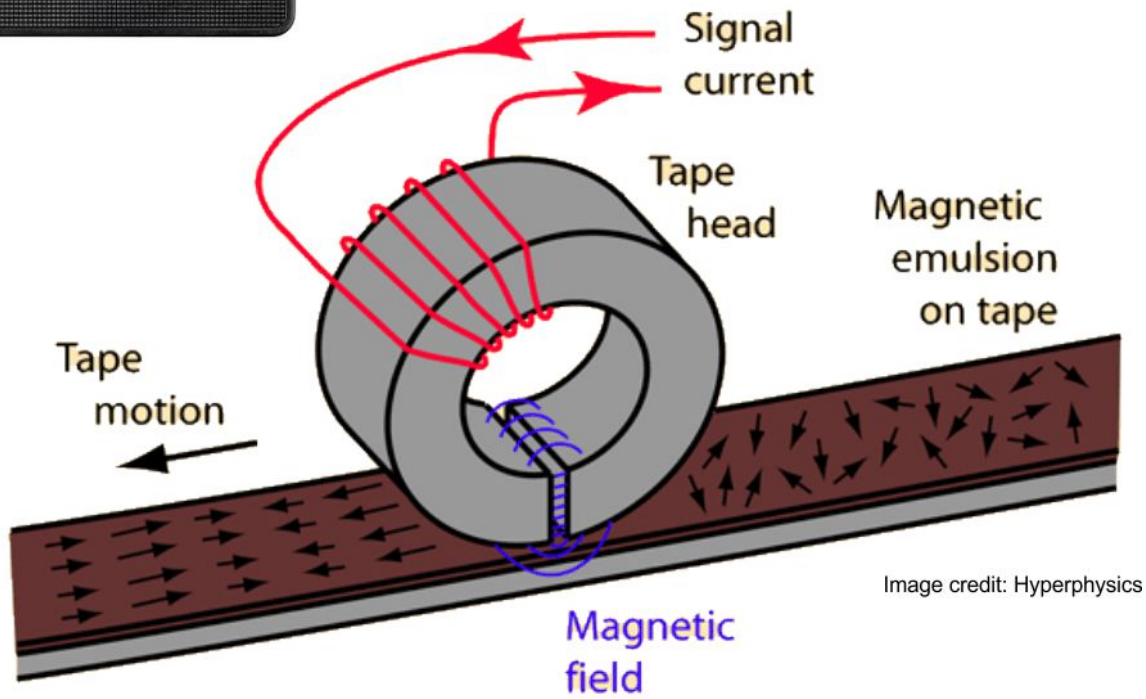
IEEE Trans. Magn. 47, 4671 (2011)



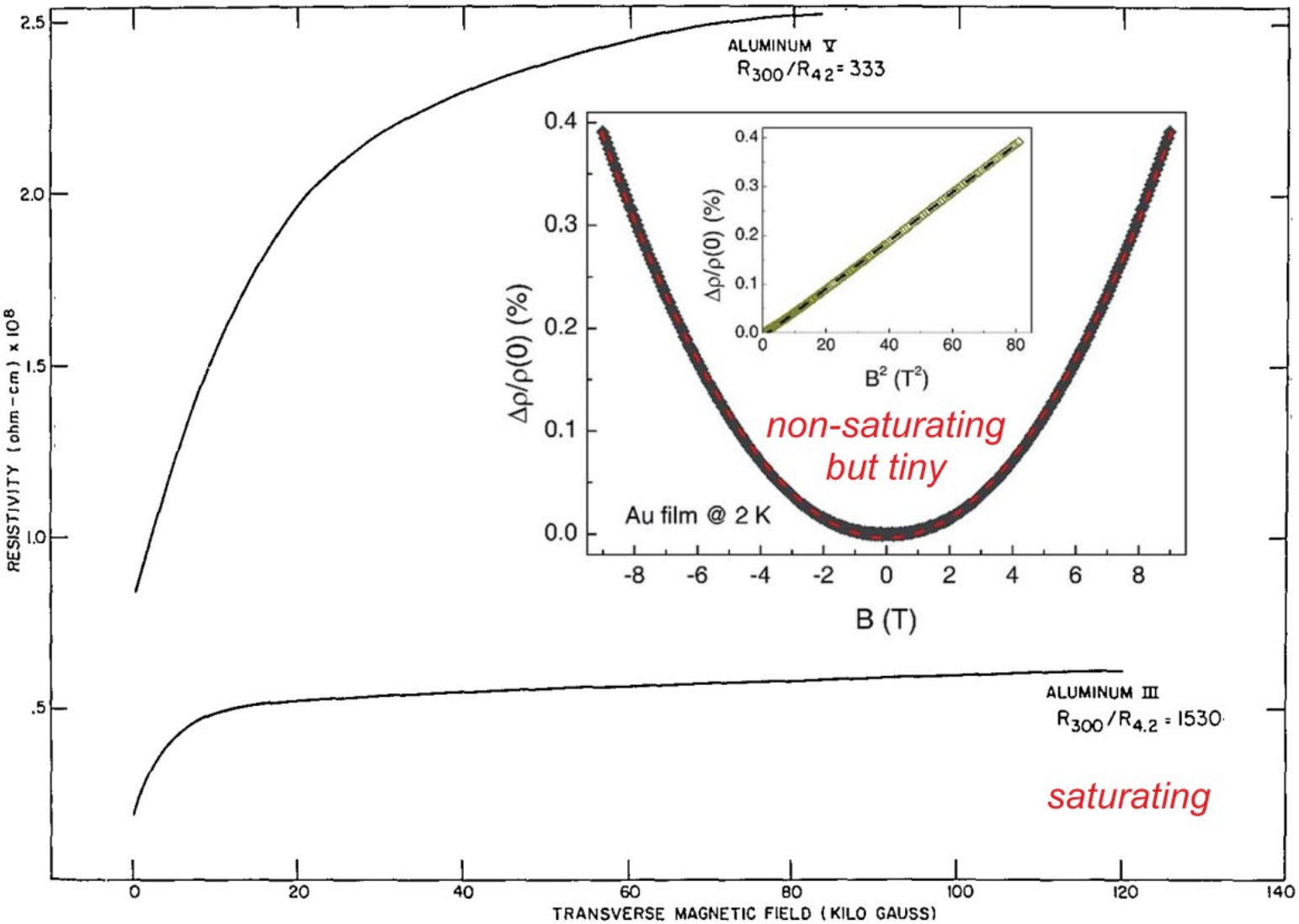
IEEE Trans. Magn. 47, 4671 (2011)

Old memories



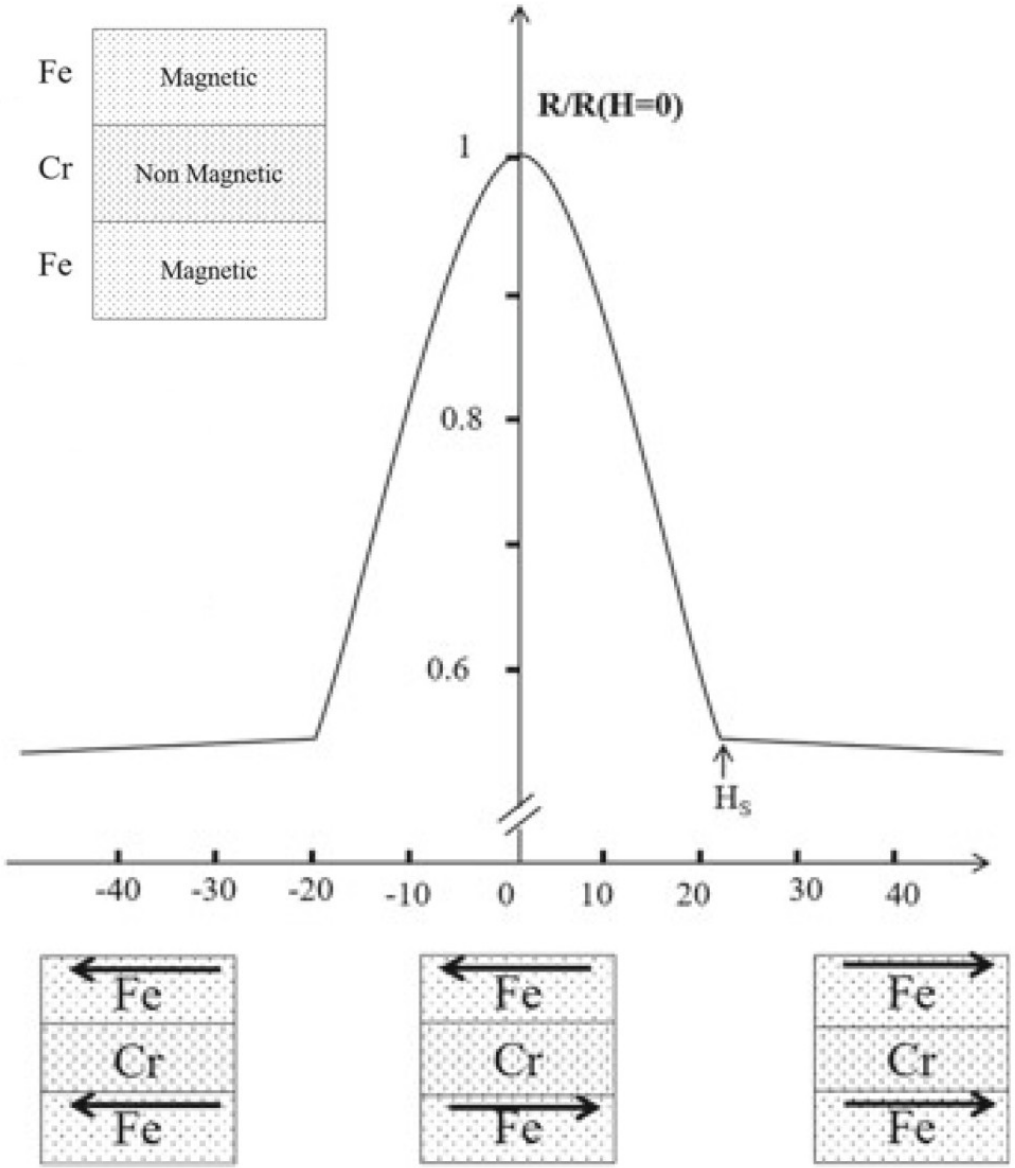


Magnetoresistance: simple metals



U.S. Naval Research Lab, AD 405879 and RSC Advances 7, 26434 (2017)

Giant magnetoresistance (GMR)



Albert Fert

born 1938

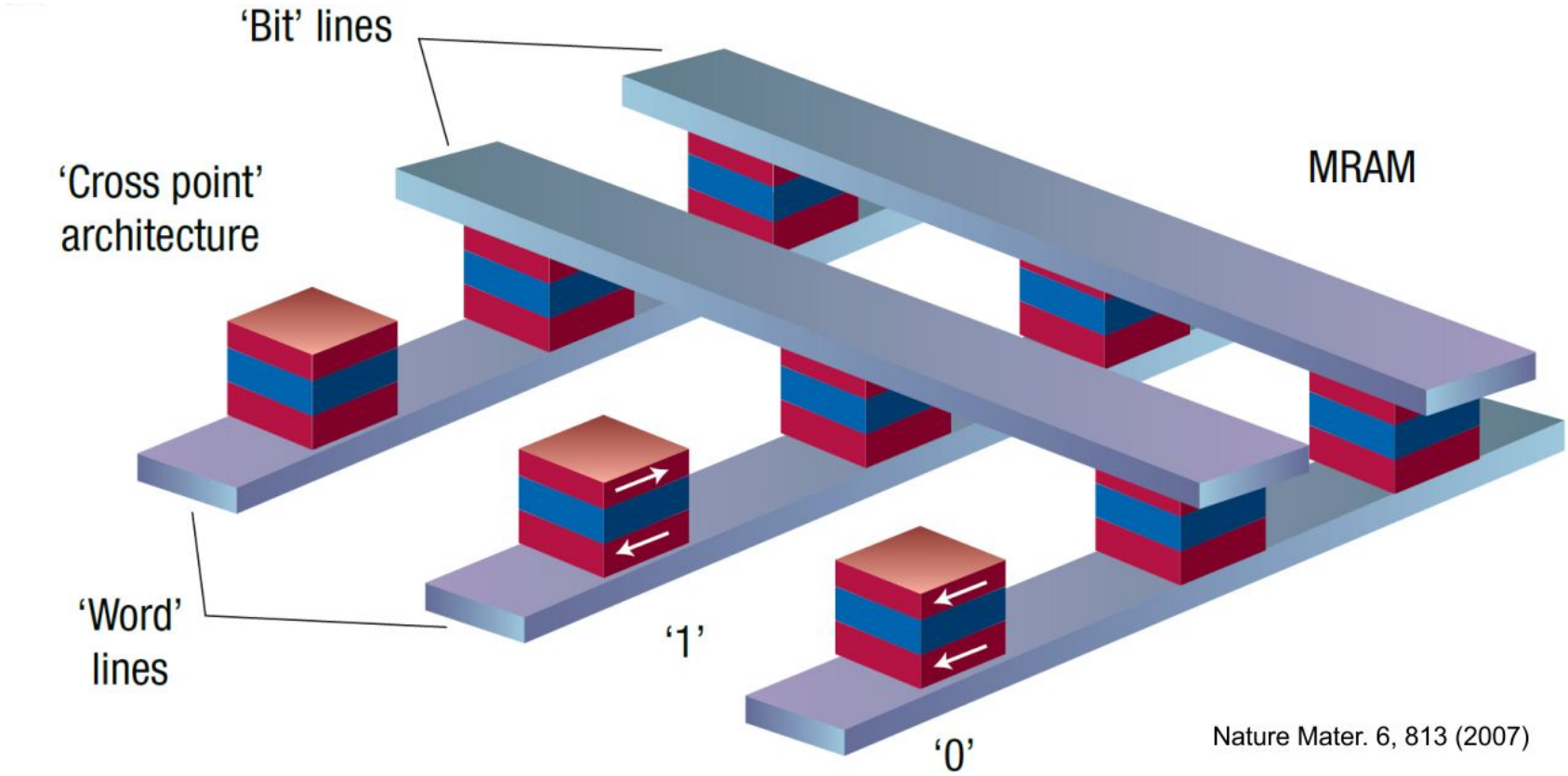
Peter Grünberg

born 1939

Nobel prize in physics 2007

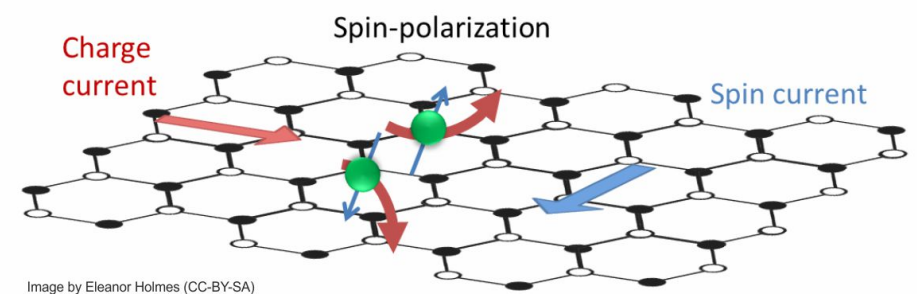
Image credits: Phys. Rev. Lett. 61, 2472 (1988); Spintronics (2021); Jevillegas and Armin Kübelbeck (CC-BY-SA)

Concept of MRAM



readout: magnetoresistance
writing: spin Hall effect

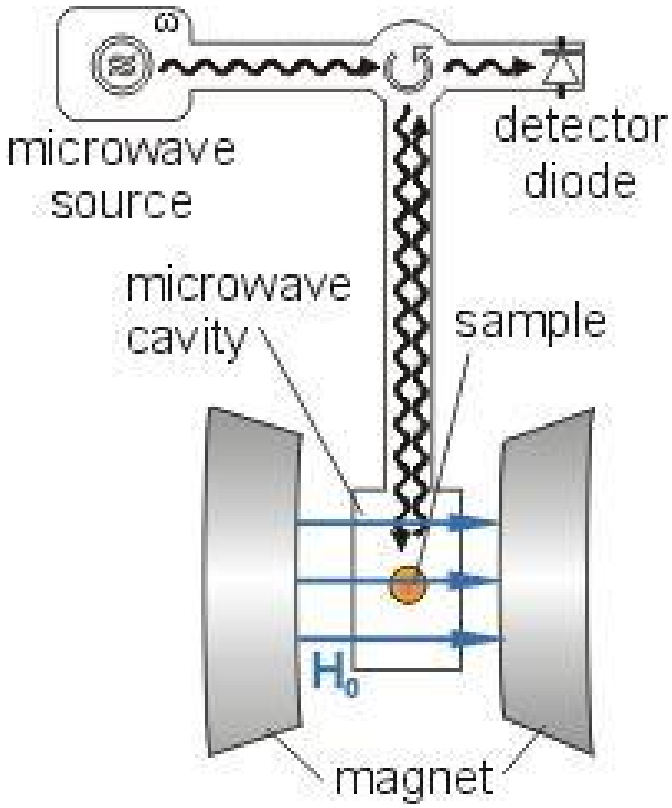
problems: stray fields, heating

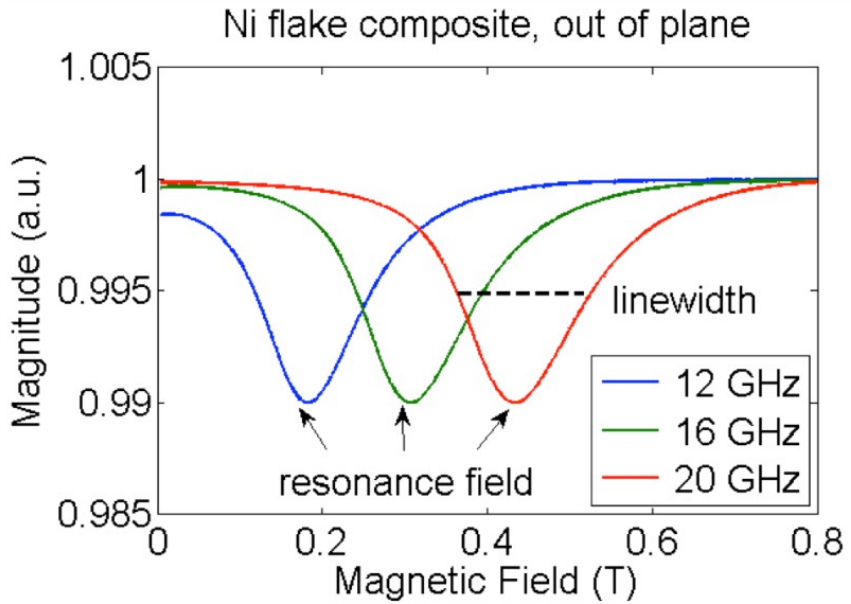


Experiment

ferromagnetic resonance spectroscopy

Resonance spectroscopy





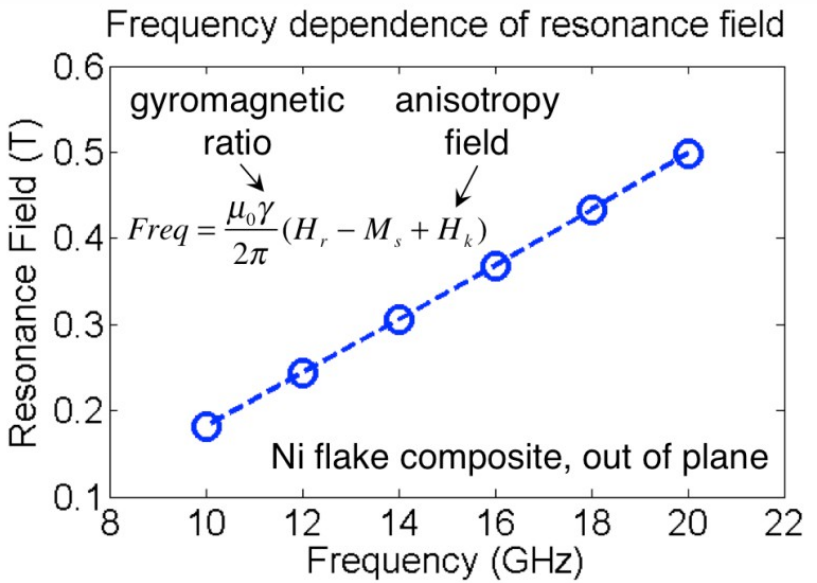


Image credits: AG Kuch at FU Berlin and Applied Magnetics Lab at Oregon State University