Kerr Microscopy

L. J. Heyderman

Kerr Effect

1845

Michael Faraday
(1791-1867)

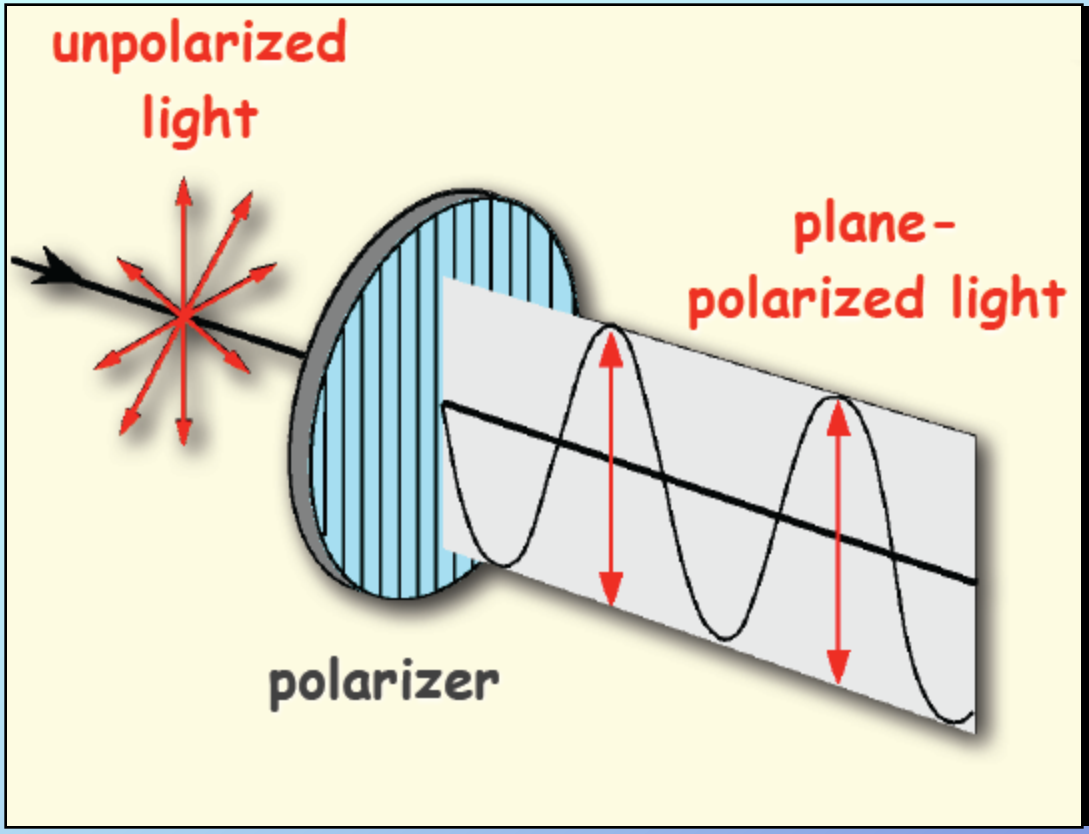
small change of polarization plane due to magnetooptic interaction in transmission, circular birefringence, ~ M

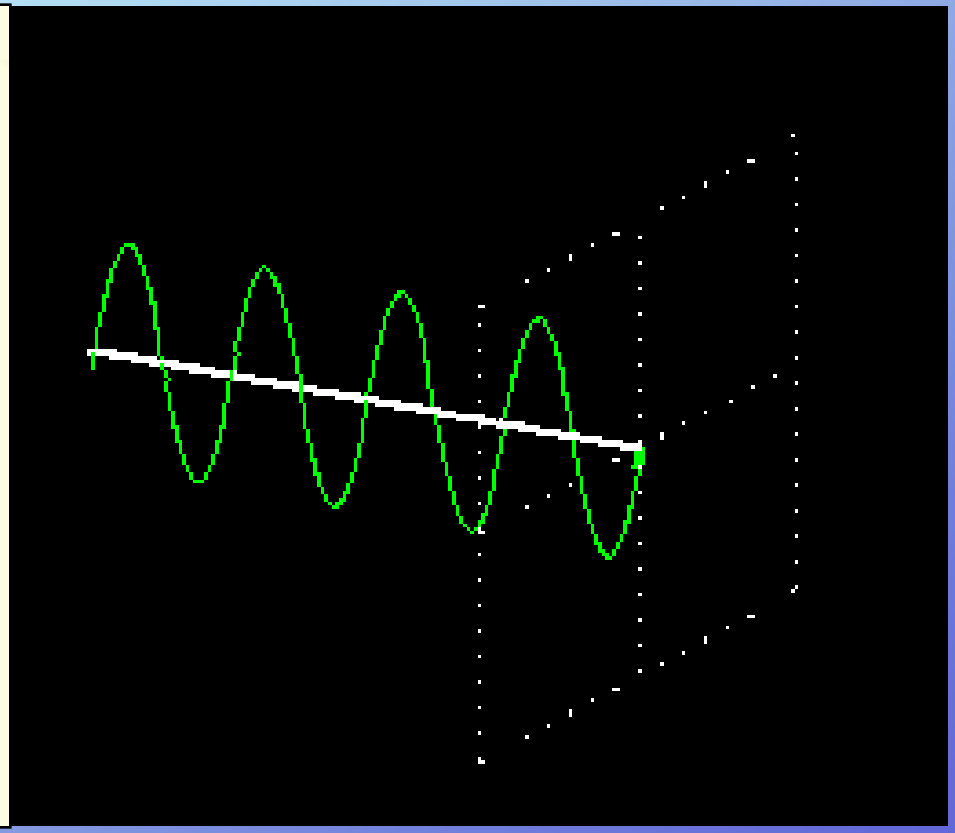
1877

John Kerr
(1824-1907)

small change of polarization plane due to magnetooptic interaction in reflection, circular birefringence, ~ M

Kerr Effect

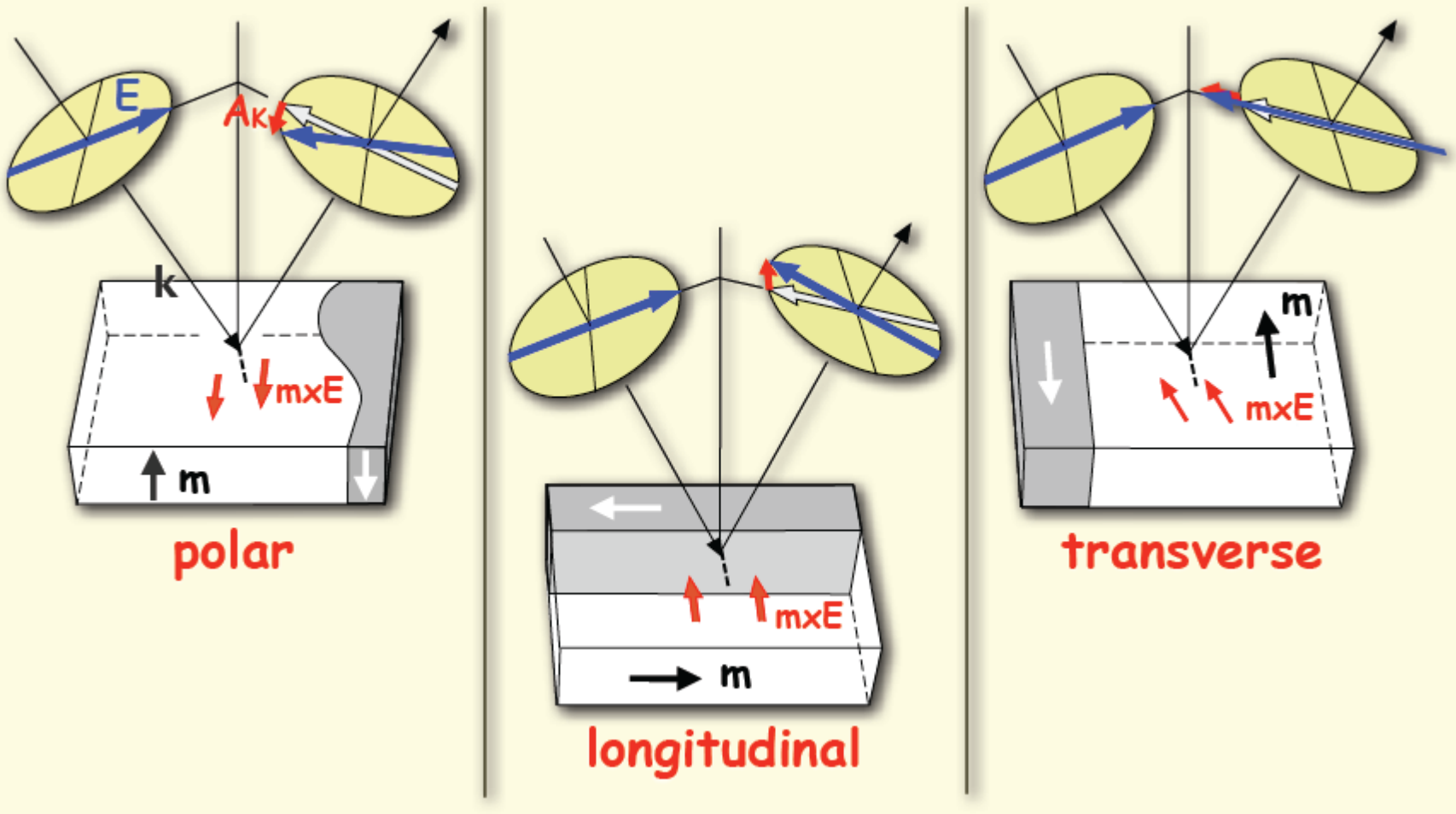




Rudolf Schäfer — IFW Dresden

http://cddemo.szialab.org

Kerr Effect



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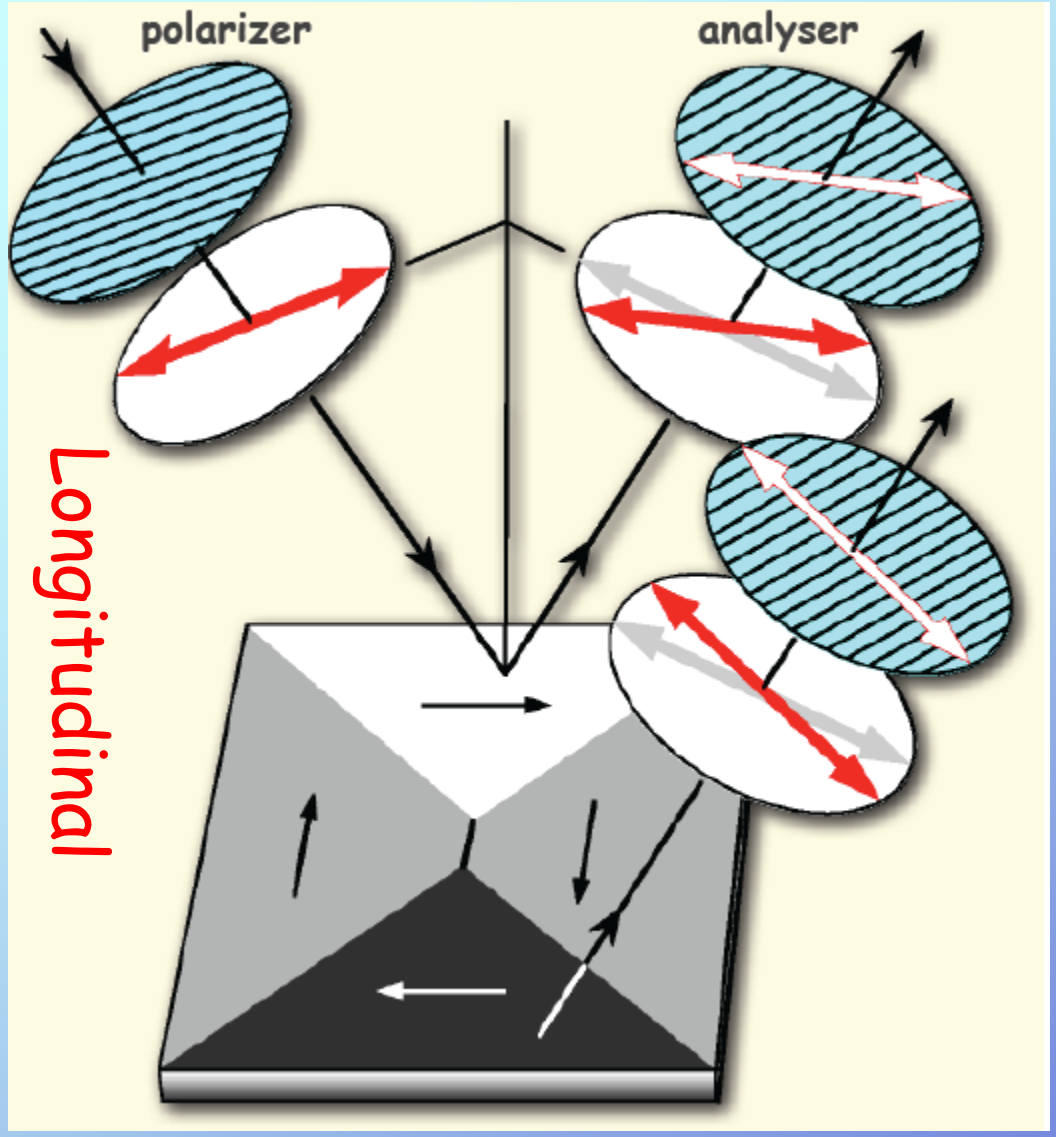
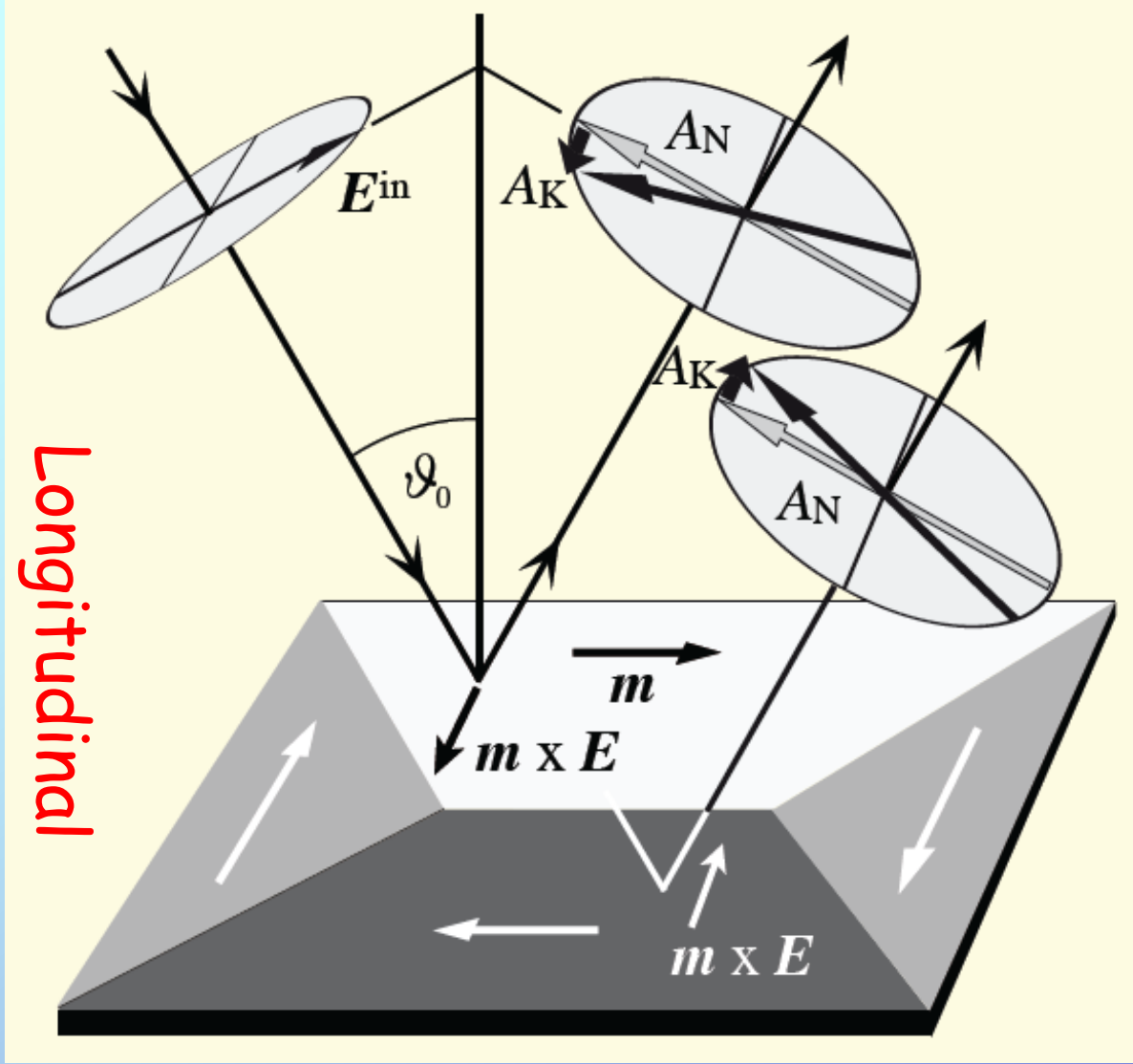
Kerr Effect



Kerr Effect – Lorentz Concept



Linearly polarized light will induce electrons to oscillate parallel to its plane of polarization – the plane of the electric vector E of light

Secondary motion is proportional to –M x E, and generates the Kerr amplitude, A_K, for reflection ➔ rotation of polarisation

Opposite M direction ➔ opposite Kerr rotation

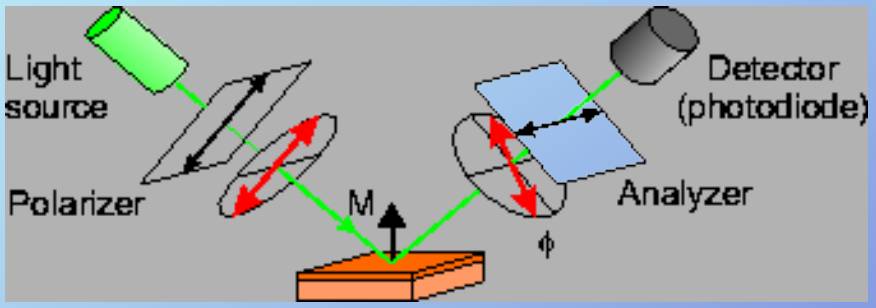
Kerr Microscopy

- Based on small rotations of the polarization plane of light
- Linearly polarized light will induce electrons to oscillate parallel to its plane of polarization – the plane of the electric vector E of light
- Regularly reflected light is polarised in the same plane as the incident light: A_N component
- Spin-orbit interaction induces a small component of vibrational motion perpendicular to original motion and to direction of magnetisation
- Secondary motion which is proportional to –M x E, and generates the Kerr amplitude, A_K, for reflection

Hubert & Schäfer, Magnetic Domains

Image Signal

http://www.physik.fu-berlin.de/~bauer/habil_online/node9.html



If total signal amplitude:

$$A_{TOT} = A_N +/- A_K \text{ (normal \& Kerr)}$$

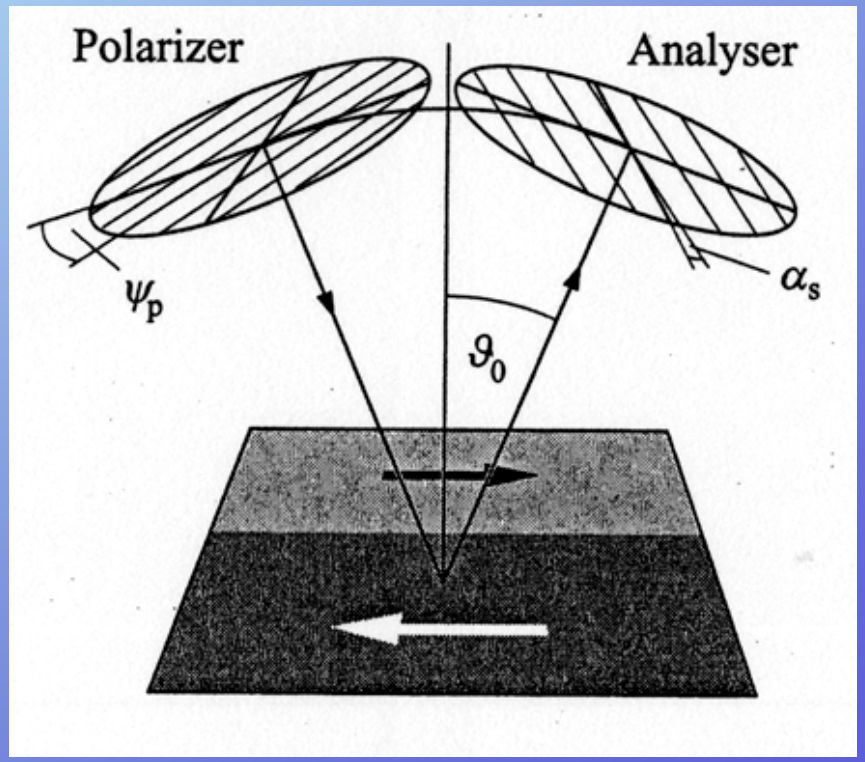
Then Kerr Rotation:

$$\phi_K = A_K / A_N$$

Start with $\alpha_S = \phi_K$; extinguishes light from one domain; one domain appears dark and the other light

Actually better to rotate the analyser beyond the extinction point.

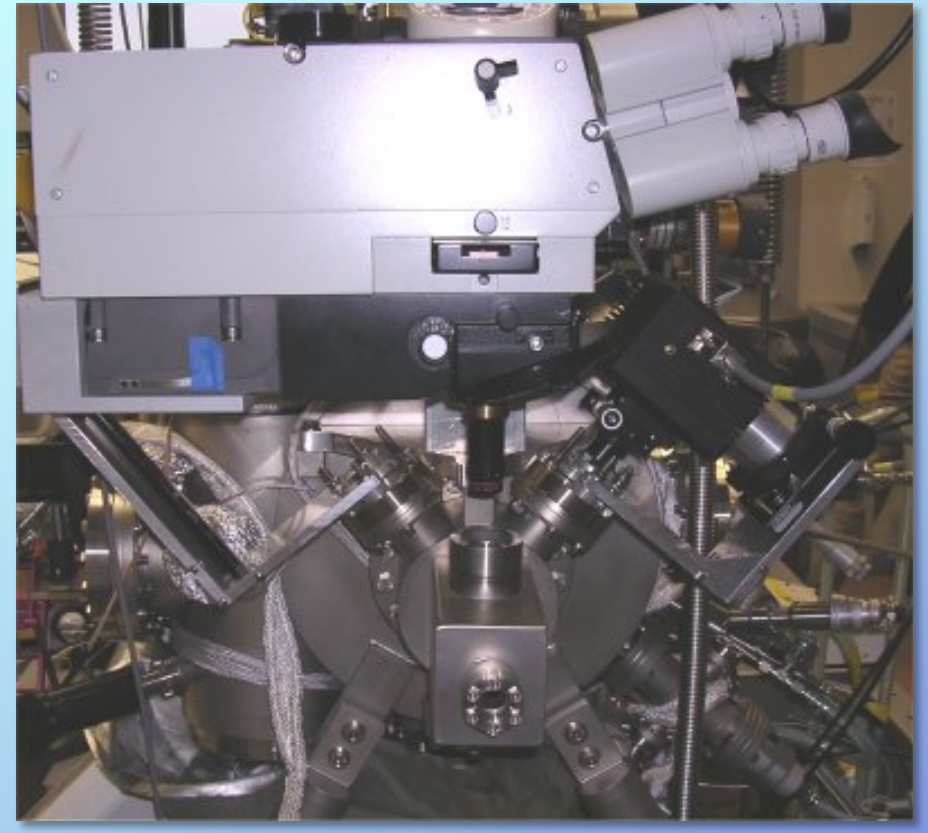
In practice, adjust polarizer and analyser until an image of satisfactory contrast and brightness is obtained.

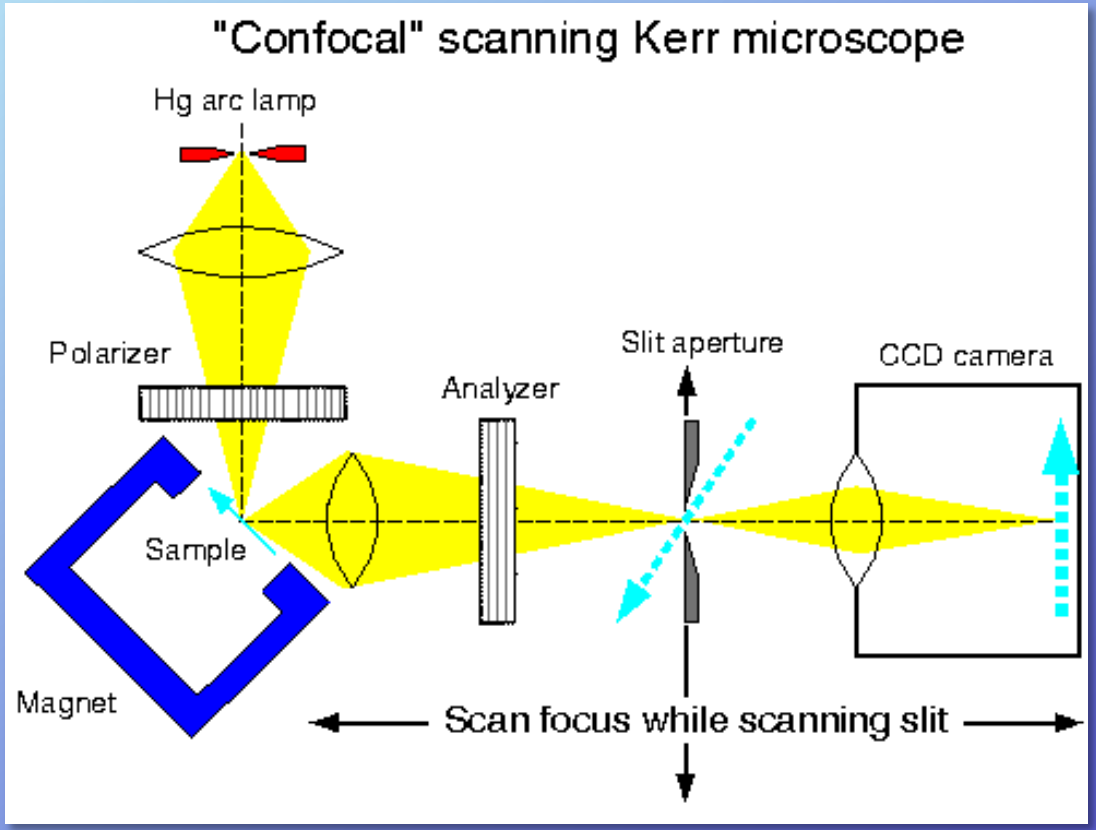


Hubert & Schäfer, Magnetic Domains

Polarising Microsope

http://physics.nist.gov/Divisions/Div841/Gp3/Facilities/kerr.html



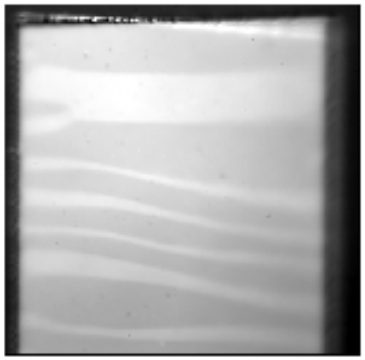


http://www.fkf.mpg.de/kern/facilities/kerr/kerr.html

Digital Image Enhancement

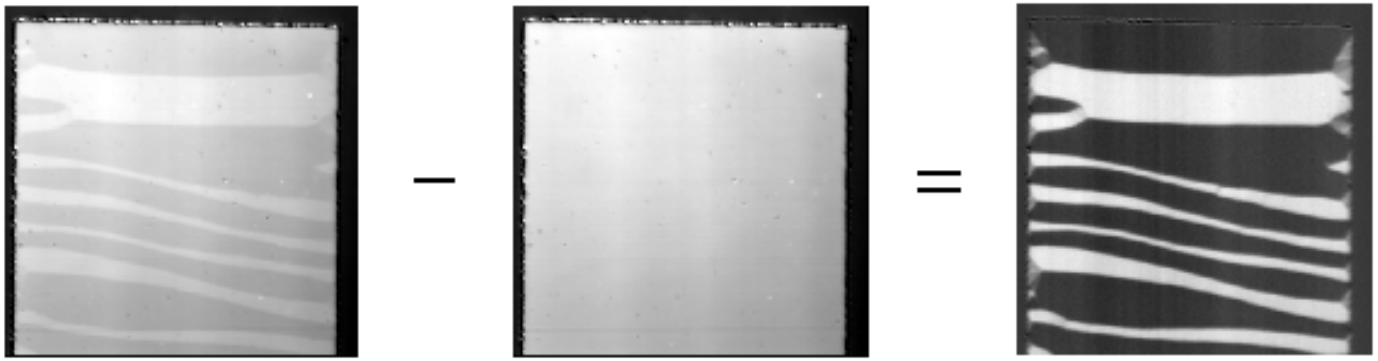
Digital difference technique:
non-magnetic background image is digitally subtracted

Images of 500 μm wide NiFe square



0 Oe field, no scanned slit

with confocal scanned slit

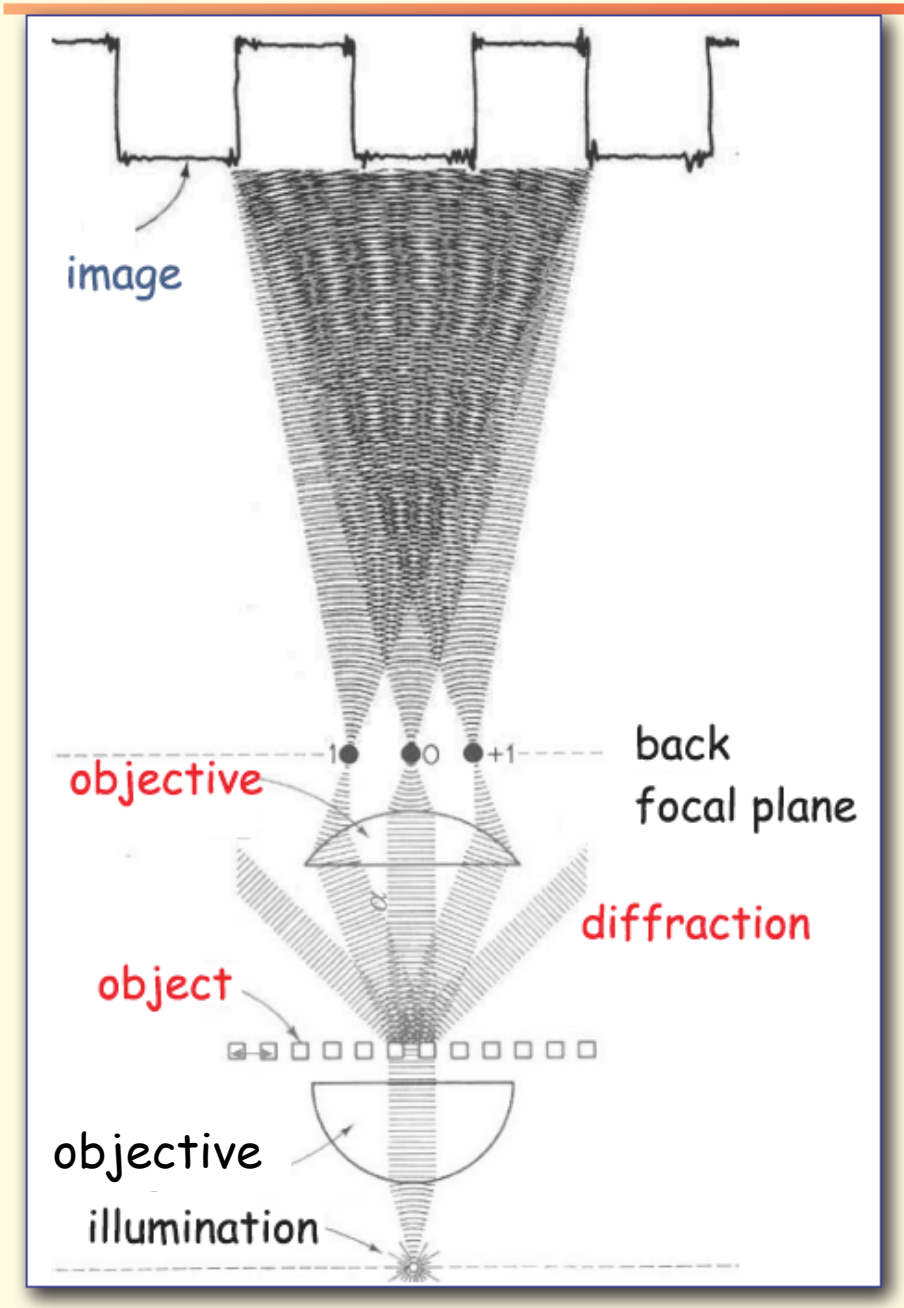


0 Oe field − 100 Oe field = Difference

Spatial resolution: ~200 nm

http://physics.nist.gov/Divisions/Div841/Gp3/Facilities/kerr.html

Resolution of optical microscopy (E. Abbe 1840 - 1905)



Rudolf Schäfer
IFW Dresden

resolution determined by
constructive interference

diffraction limited image formation

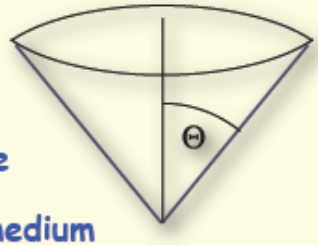
Rayleigh equation: $d = \frac{0.5\,\lambda}{NA}$

d = separation between particles,
still allowing to see them

λ = wavelength

NA = numerical aperture of objective

$NA = n \sin\theta$



θ = half the cone angle of
light accepted by objective

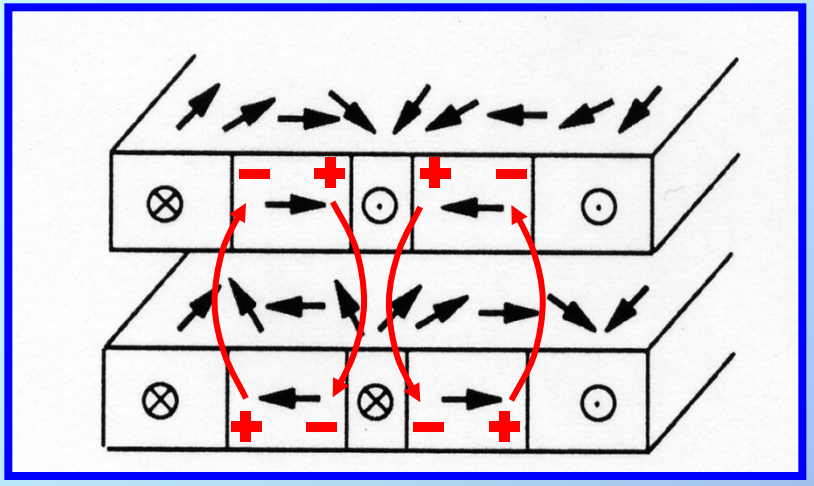
n = referaction index of medium
between sample and objective

↓

best around 200 nm

Observation of Quasi-domain Walls

Twin Walls

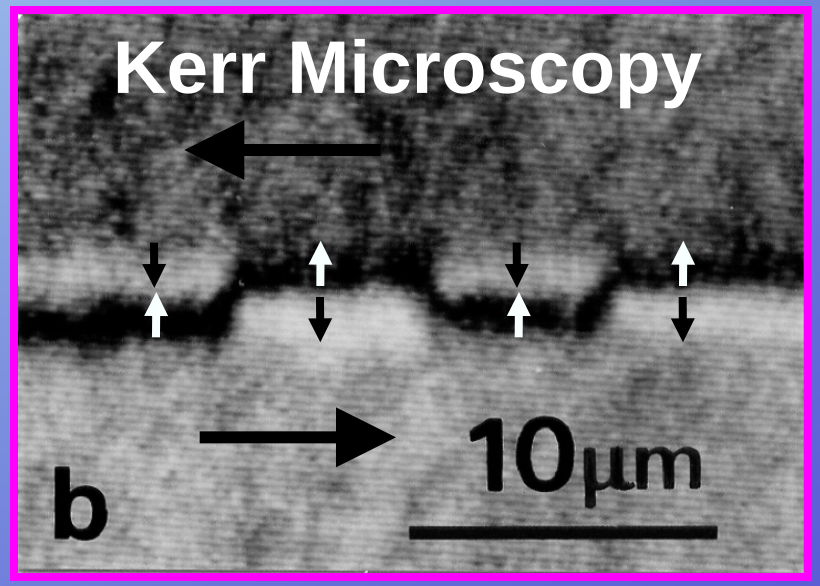


Ferromagnetic Thin Film

Non-magnetic Spacer Layer

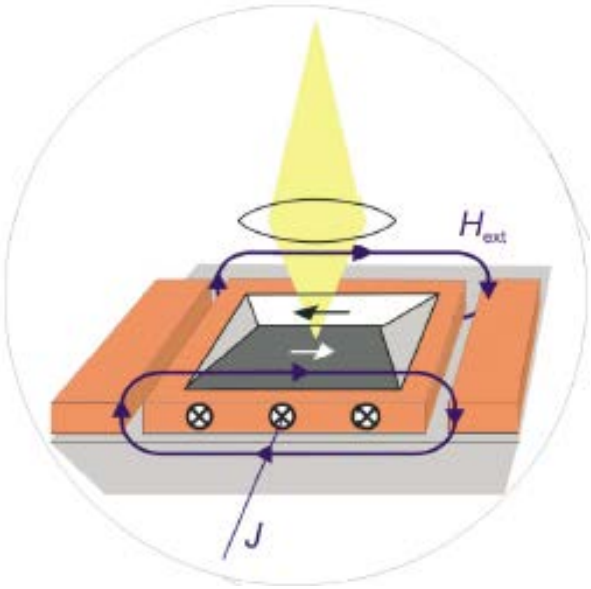
Ferromagnetic Thin Film

Image shows domain wall (black line) and quasi-domain wall (white line) in top layer of sandwich film



L. J. Heyderman

Time-Resolved Kerr Microscopy



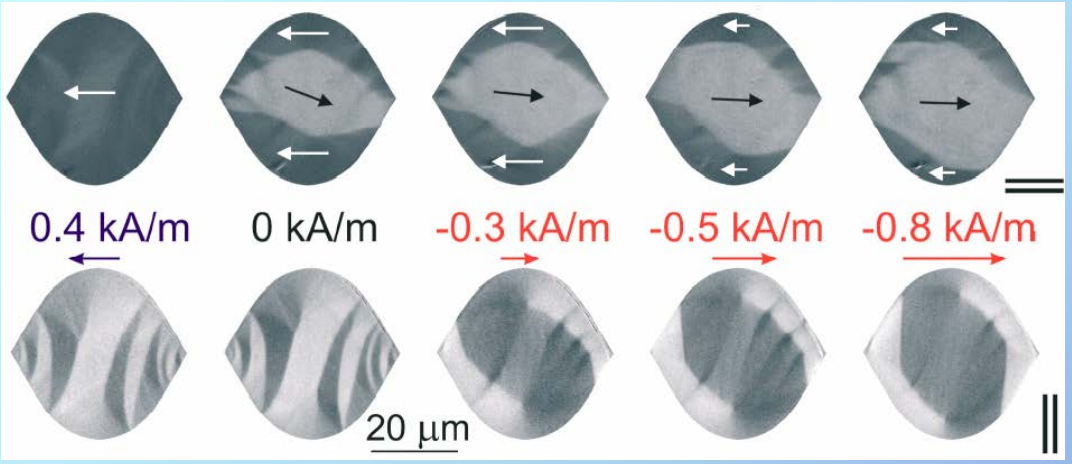
Stroboscopic technique:

- Short field pulses (e.g. 20 ns, 10 kA/m) with copper microstrip line
- With a defined time delay, the magnetization is probed
- Reasonable signal-to-noise ratio by integrating the optical signal
- Accumulation over repeatable magnetization processes is required.
- Gated & intensified CCD camera providing temporal resolution down to 200 ps

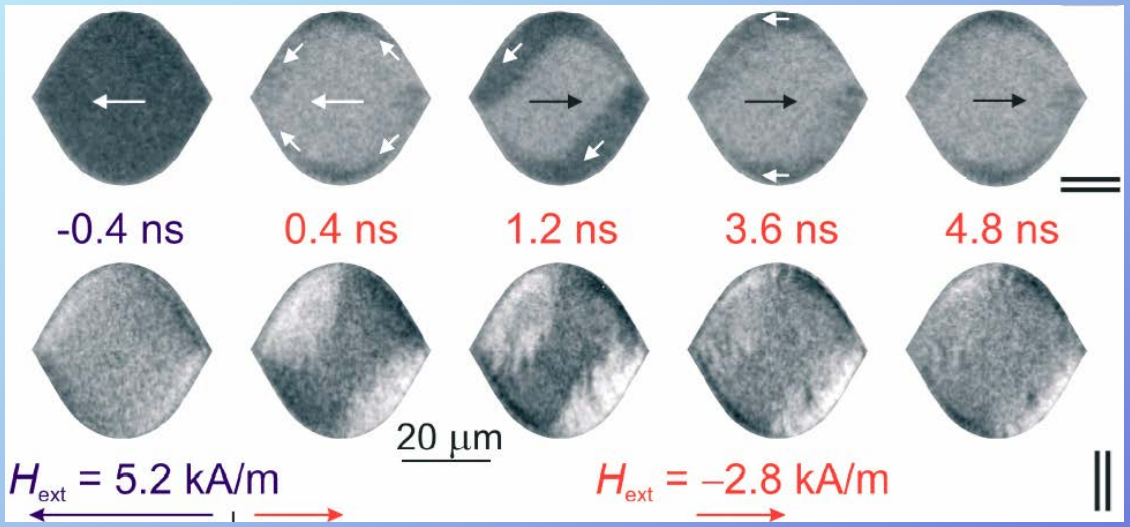
Chumakov, McCord, Schäfer, Schultz

Time-Resolved Kerr Microscopy

Applied Field: quasi-static reversal



Applied Field Pulse: time-resolved



Applying a field pulse: magnetization not able to instantaneously follow magnetic field.

To reach new magnetization direction, will have to spin about the field axis: precessional motion that is gradually opposed by damping.

Reversal looks very different!

Chumakov, McCord, Schäfer, Schultz

Kerr Microscopy Summary

- Flat and smooth surface
- Spatial resolution ~ 200 nm
- Magnetization can be observed directly
- Quantitative measurements possible but need to take care with calibration
- Observation does not influence magnetization
- Dynamic processes can be observed at high speed
- Sample may be easily manipulated: fields, high or low temperature, mechanical stress
- Surface magnetization: penetration depth of 10-20 nm
- Can look at back and front of sample

Hubert & Schäfer, Magnetic Domains