A new phenomenon on the surface of FINEMET alloy

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AIM: Analysis of quadratic magneto-optical effects observed in $Fe_{73,5}Si_{13,5}Nb_3Cu_1B_9$ ribbons annealed at temperatures of 733 K and 743 K

Sample preparation

Material: $Fe_{73,5}Si_{13,5}Nb_3Cu_1B_9$

Thermal treatment: annealing in vacuum (10^{-5} Pa) and hydrogen at 733 K, 743 K, and 823 K

Sample dimensions: 20 μm thick and 6 mm wide

Investigated side: shiny - side in contact with air during rapid quenching

Experimental methods

Magneto-optical Kerr effect (MOKE): penetration depth PD ≈ 20 nm, measured longitudinal magnetization component M_L(in the plane of the sample and incident light) proportional to the angle of Kerr rotation θ, wavelength: 670 nm, angle of light incidence: oblique (50°) and almost normal (0.5°), circular laser beam with diameter about 300 μm

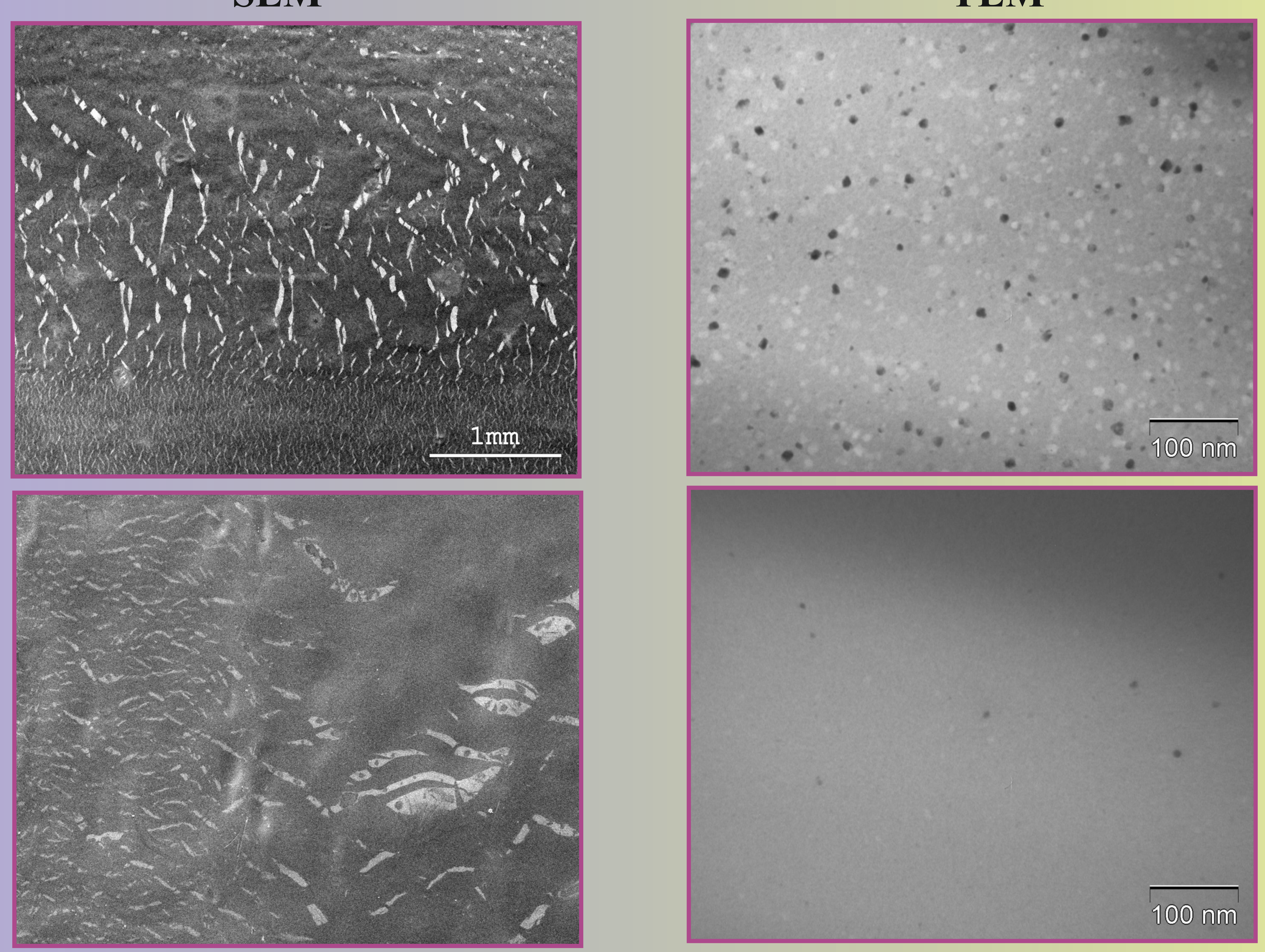
Grazing incidence XRD (GIXRD): grazing angle ≈ 1,5°, CoKα radiation in Bragg-Brentano geometry, PD lower than 100 nm

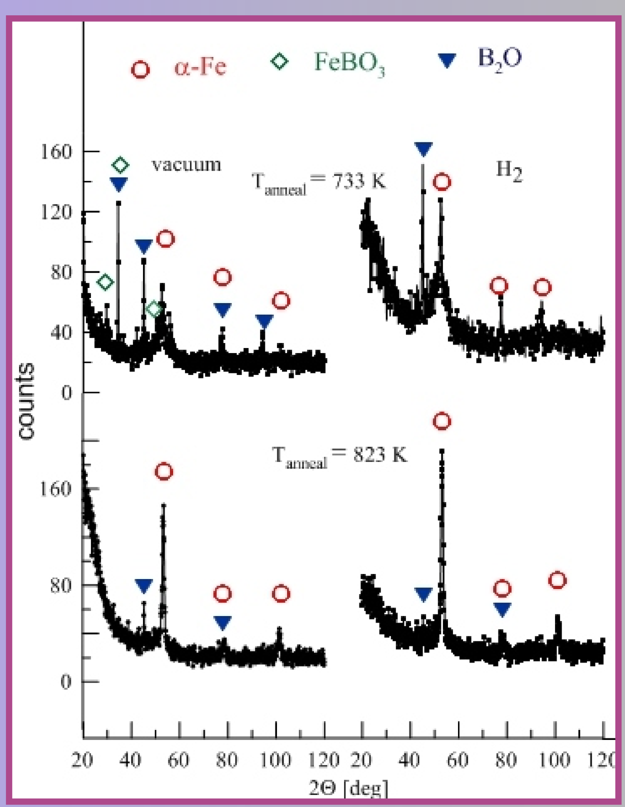
SEM-TEM: JEOL scanning electron microscope (SEM) - Philips CXM12 STEM with an EDAX energy dispersive X-ray analyzer, accelerating voltage 120 kV

Experimental results

Relation between surface microstructure and MOKE

Surface microstructure

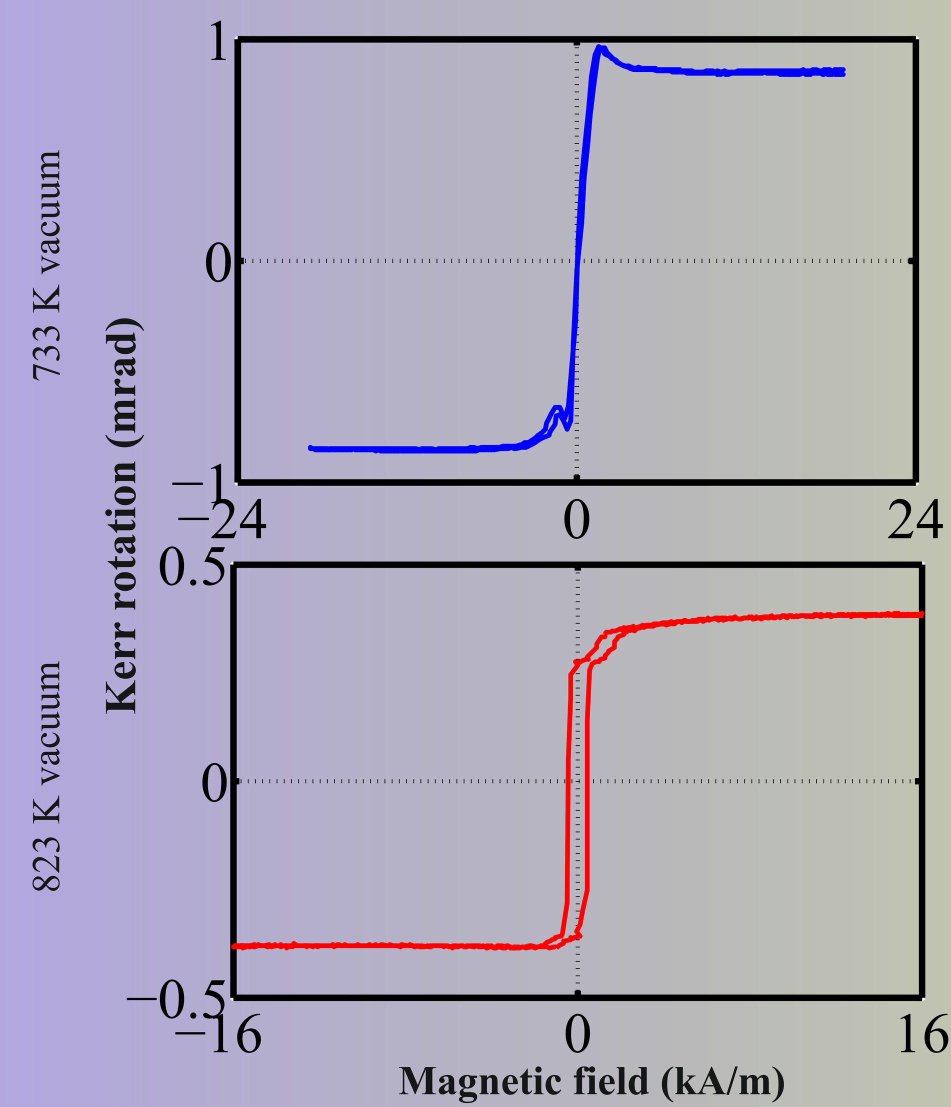




Ta [K]	vacuum α-Fe [%]	vacuum B_2O+ $FeBO_3$ [%]	vacuum d [nm] Fe grains	hydrogen α-Fe [%]	hydrogen B_2O [%]	hydrogen d [nm] Fe grains
733	35	65	5	53	47	4
823	60	40	13	94	6	10

- In surface layers the existence of oxides (B_2O and/or $FeBO_3$) and α-Fe(Si) nanocrystals with the size about 4-5 nm embedded in the amorphous matrix consisting of coherent domains - clusters (size 1-2 nm) was evidenced by GIXRD, SEM, and TEM at temperatures of 733 K and 743 K. Differences between annealing atmospheres are summarized in the Table.
- On the shiny side influence of annealing temperatures gave to arise interesting SEM patterns similar to the „scar-like shapes". Analysis did not show marked difference between dark and bright places.
- With increasing annealing temperatures Fe grains grow and penetrate deeper into the ribbon volume.

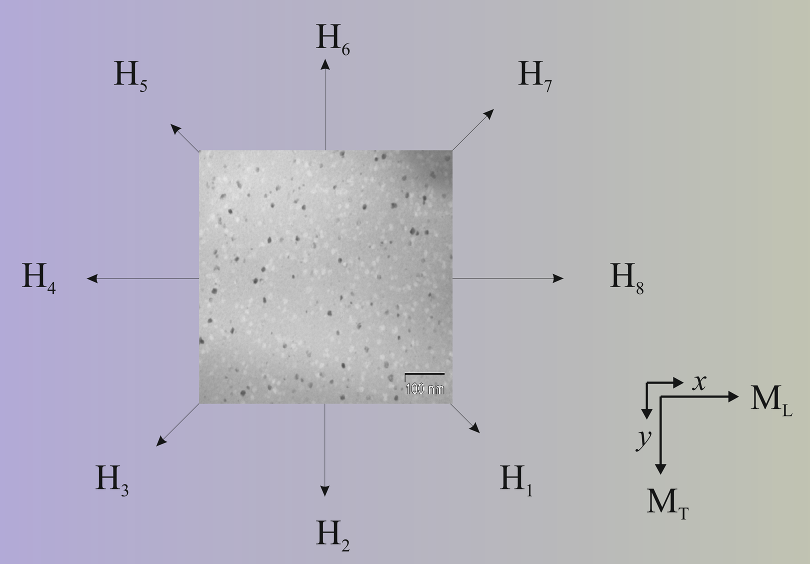
MOKE measurements at oblique incident angle

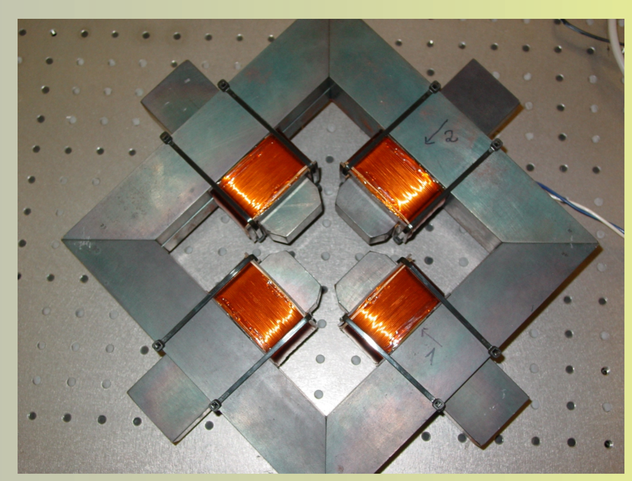


- **(left)** MOKE hysteresis loops measured at the angle of 50°. At annealing temperatures (T_a) of 733 K and 743 K strong asymmetries corresponding to the quadratic magneto-optical effects (QMOKE) were observed in both atmospheres. Wth increasing T_a amplitude of QMOKE decreases.
- **(right)** Magnetic domains observed using the magneto-optical Kerr microscopy. As a consequence of annealing, stresses originating during preparation process relax and magnetization tends to the ribbon plane. Local easy axis randomly change their directions reflecting inhomogeneous surface microstructure. Magnetic domains of nanocrystals cannot be visualized - under resolution of optical microscope.

Analysis of quadratic magneto-optical effects (QMOKE)

8-directional method

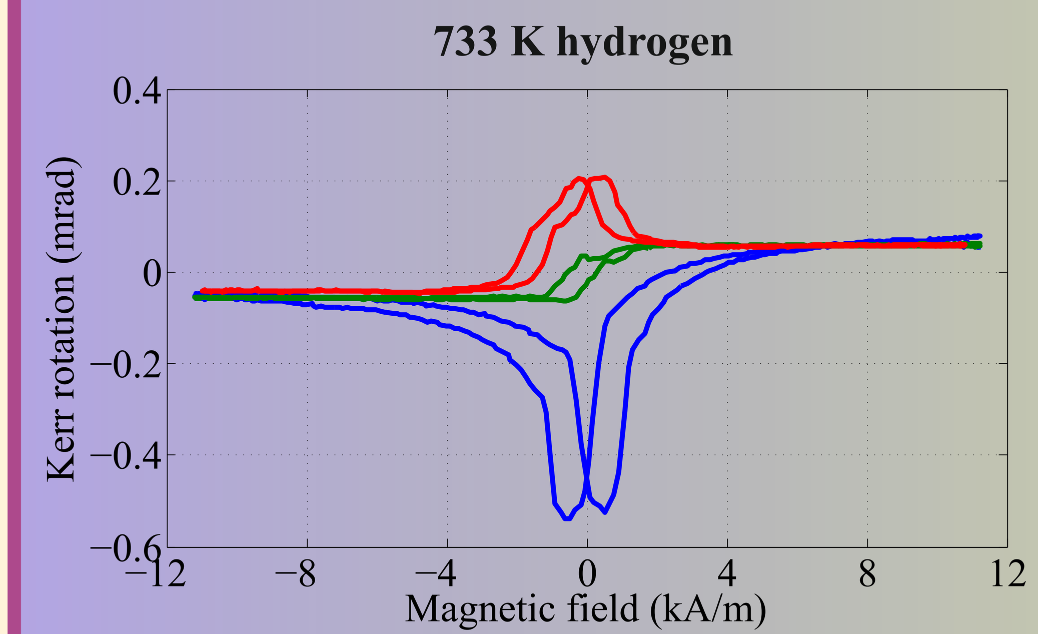




- **(left)** Schematic illustration of 8-directional method for analysis of QMOKE in saturation.
- **(right)** Quadrupole magnet used for generation of magnetic field in all eight directions.

MOKE loops at almost normal incident angle

At almost normal incidence - small linear Kerr effect and the highest QMOKE contributions are observed.



- blue, red, and green loops correspond to the case, when light is focused into the different places on the ribbon surface, magnetic field applied along H_4 direction
- QMOKE loops (red and blue - even in magnetic field) change randomly amplitude of peaks and sign on the sample surface
- in specific places - QMOKE vanish - see green curve odd in magnetic field proportional to the small linear effect M_L
- shape of QMOKE loops - similar to that observed in Co_2FeSi Heusler compounds - reversal process connected with growth and nucleation of magnetic domains

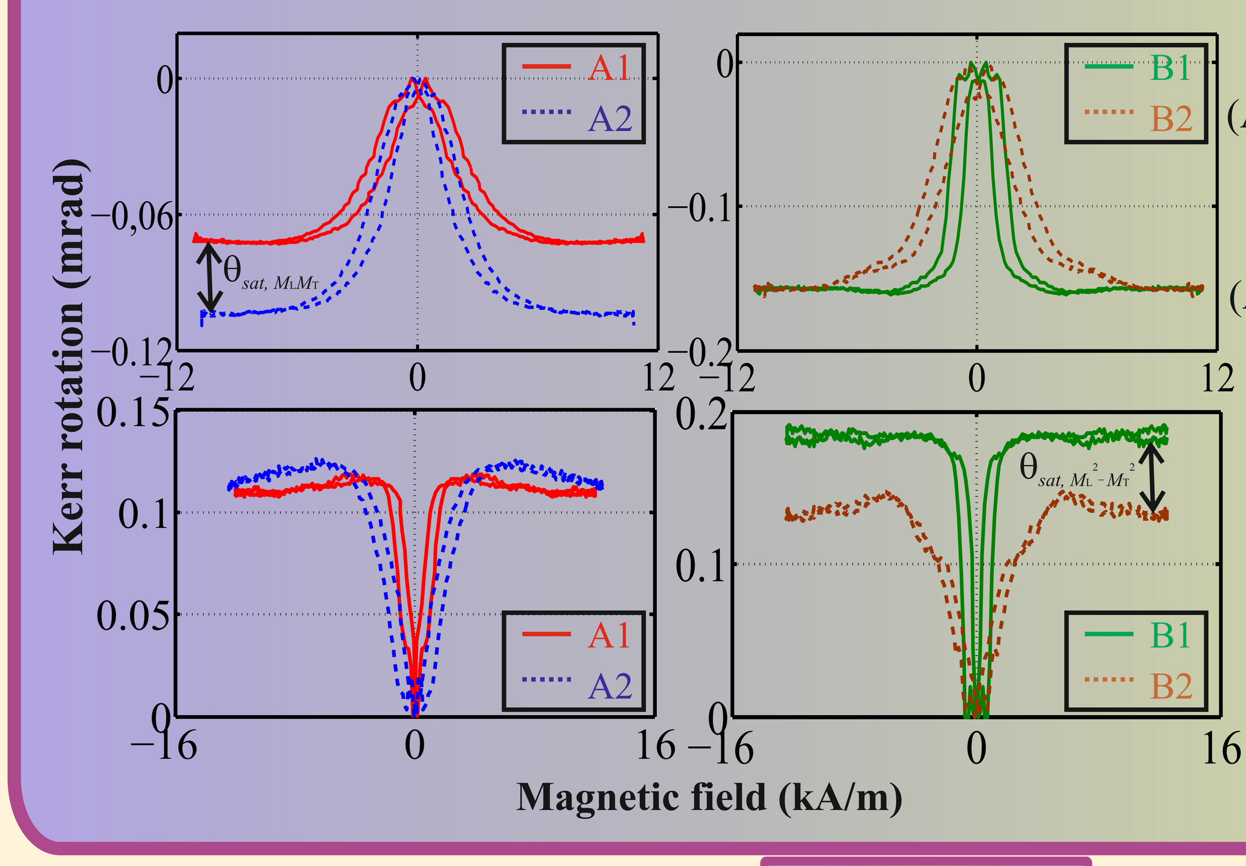
Amplitude of QMOKE in saturation

Magnetization lies in the ribbon plane ⇒ QMOKE consist of two mixed terms M_LM_T and $M_L^2 - M_T^2$. In saturation their contributions can be separated using the relation:

$$\theta_{sat,\,M_LM_T} = [\theta(H_1)+\theta(H_5)]/4 - [\theta(H_3)+\theta(H_7)]/4 = A1-A2$$

$$\theta_{sat,\,M_L^2-M_T^2} = [\theta(H_1)+\theta(H_5)]/4 - [\theta(H_3)+\theta(H_7)]/4 = B1-B2.$$

733 K hydrogen



upper images
prevaling contribution of M_LM_T
(A1 - A2 ≈ 0.036 mrad, B1 - B2 ≈ 0)

lower images
prevaling contribution of $M_L^2 - M_T^2$
(A1 - A2 ≈ 0, B1 - B2 ≈ 0.055 mrad)

most frequent case
combination of both terms

maximal effect in saturation in specific place
0.2 mrad - approximately 3 times lower than maximal QMOKE observed in Co_2FeSi Heusler compounds

Conclusions

The main contribution of present investigations rests in the analysis of QMOKE that have been newly detected in the surface layers of FINEMET-type FeSiNbCuB ribbons. Observed inhomogeneous magnetic behavior is closely related to the surface microstructure. For practical applications it is necessary to homogenize the near-surface region, for example by annealing sample during and/rr after preparation in magnetic field or by applying tensile stress. Such experiments enable us to study also influence of mentioned postpreparation treatment on the QMOKE properties.

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