The University of the Basque Country
Faculty of Chemistry
Department of Material Physics
Magnetism Research Group

Tuning of Magnetic Properties of Magnetic Microwires by Post-Processing

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Outline

1. INTRODUCTION

1.1. STATE OF THE ART

1. 2.MOTIVATION.

2. MEASUREMENTS METHODS

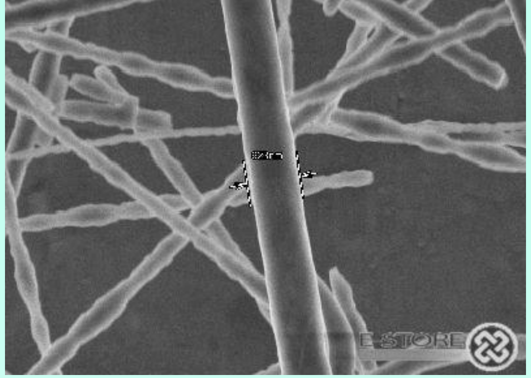
3. TUNNING OF MAGNETIC PROPERTIES

3.1 MAGNETIC PROPERTIES OF AS-PREPARED MICROWIRES

3.1. TUNNING OF HYSTERESIS LOOPS BY POST-PROCESSING

4. CONCLUSIONS

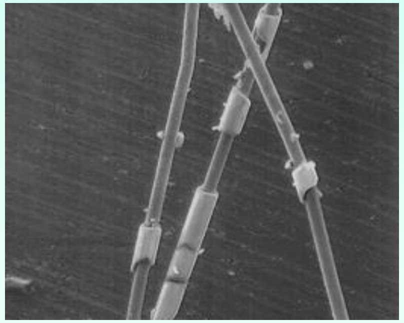
Magnetic wires:

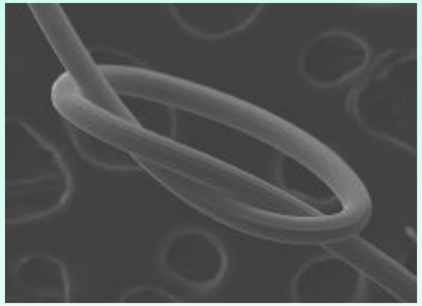


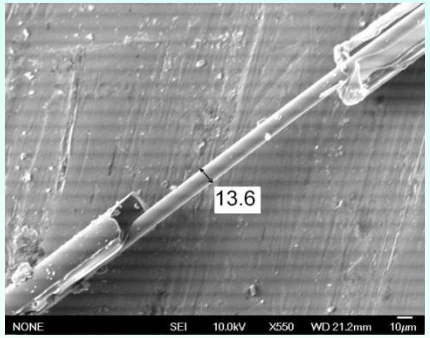
-Iron whiskers
-Wiegan magnetic wires
(CoVFe,1970-th)

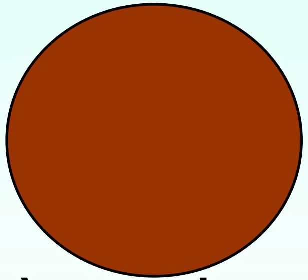
Amorphous: milli
(since 80-th) micro
nano

wires



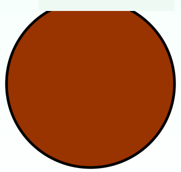




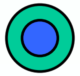


In-rotating water wires
(can be drawn to 20-30 µm) – rough surface

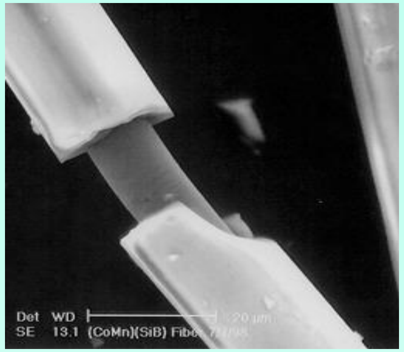
Melt extracted (40-50 µm)- not perfectly cylindrical cross section



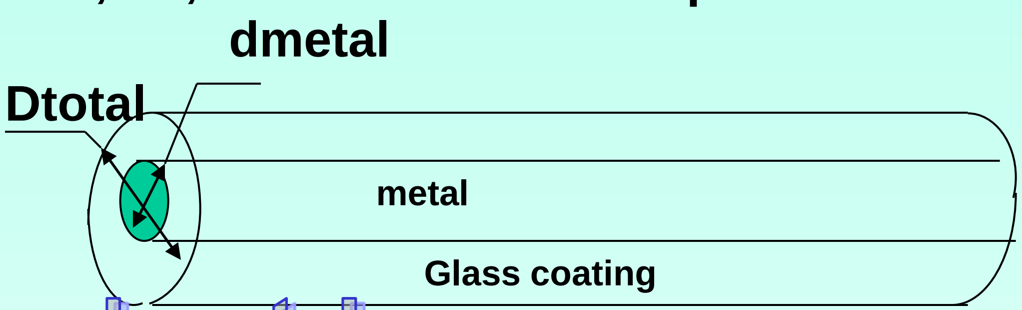
Glass coated (0.1-50 µm)- glass coating (stresses)

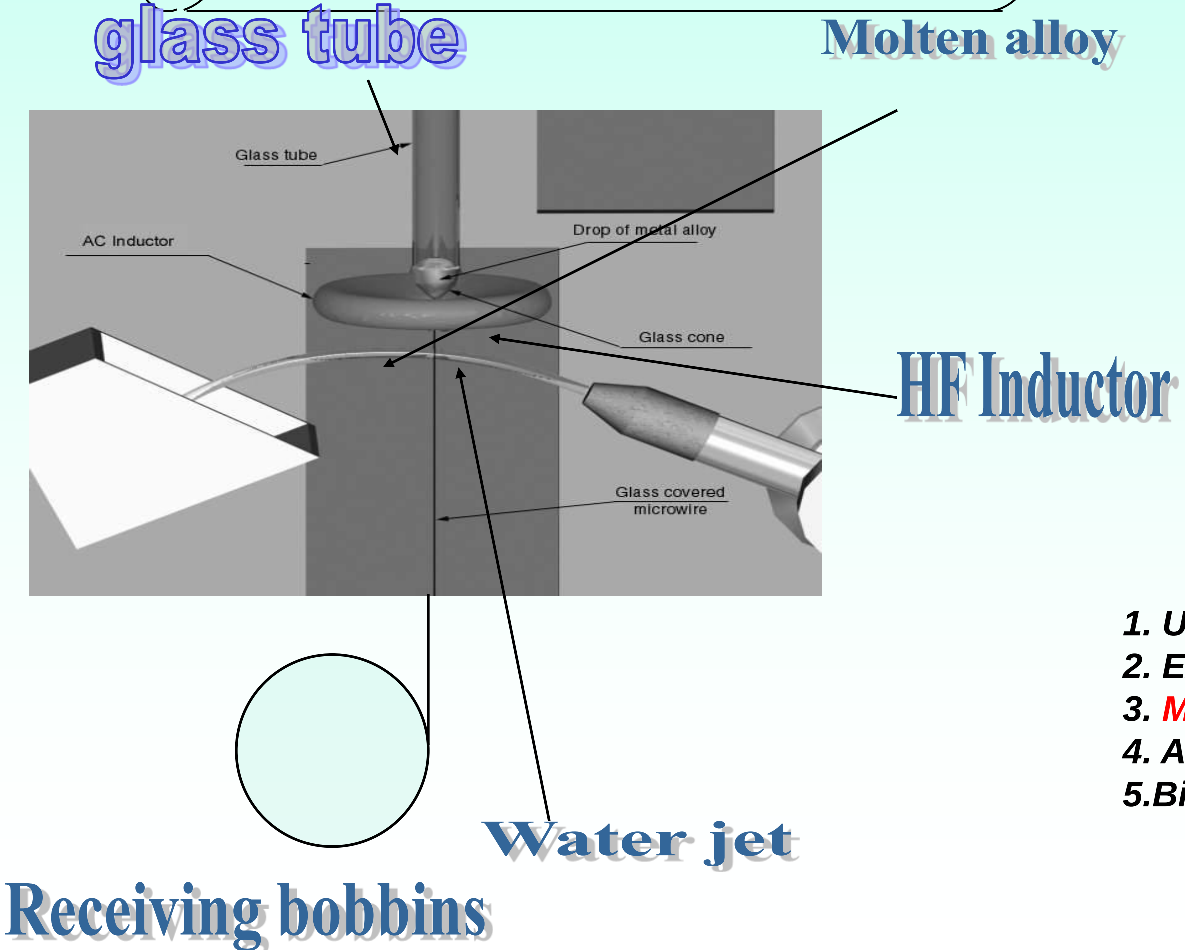


Glass coated microwires



- Co, Ni , Fe and Cu rich compositions





Total diameter 3-40 microns
Metallic nucleus diameter 1-30 microns
Glass coating thickness 1-10 microns
Length - few km (up to 10 in 1 bobbin)

Advantages:

1. *Unexpensive and simple fabrication method*
2. *Excellent soft magnetic properites and GMI effect*
3. *Magnetic bistability and Fast DW propagation*
4. *Also recently Heusler-type and granular microwires*
5. *Biocompatibility (glass-coating)*

Engineering of magnetic properties of magnetic microwires

Wire based sensors

Tuneable Parameters

Non-reversible

First step

- Composition
- Geometric ratio, ρ
- Conditions of thermal treatment (crystallization)

Reversible

Second step: fine tuning

- Local heating
- Mechanical stress
- Axial-circular crossed magnetic field
- Conditions of thermal treatment (crystallization)

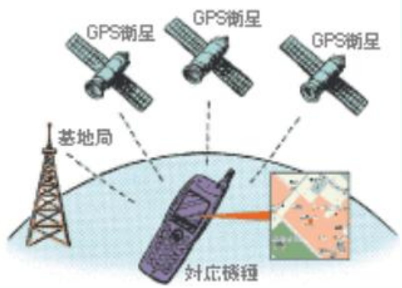
Optimal magnetic properties

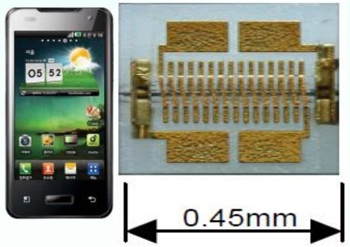
APPLICATIONS

Magnetic microelectronics

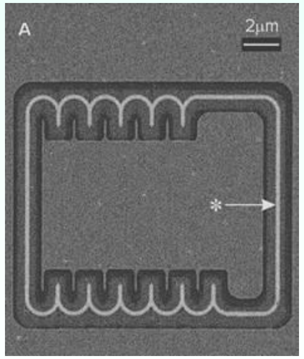
CASIO 2013.June 68250yen

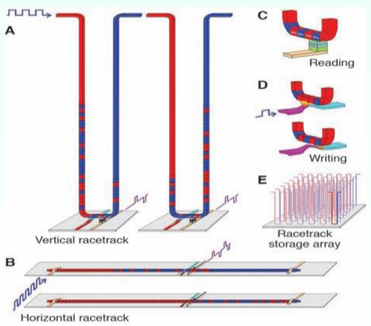
Provided by Prof. K. Mohri





Source: Aichi Micro Intelligent Corporation





S S. P. Parkin, *et al. Science* **320**, 190 (2008)

Magnetoelastic energy

$K_{me} \approx 3/2\, \lambda_s \sigma_i$, :

Internal stresses in composite microwires

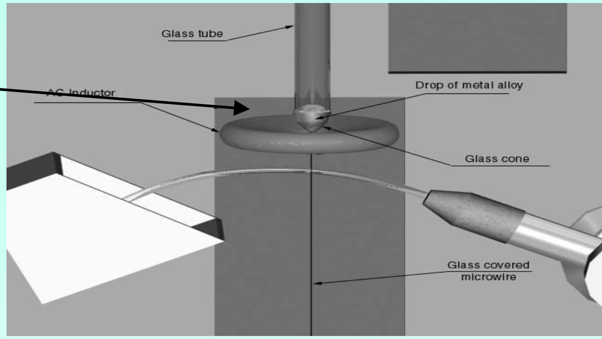
Magnetostriction λ_s -determines by the chemical composition

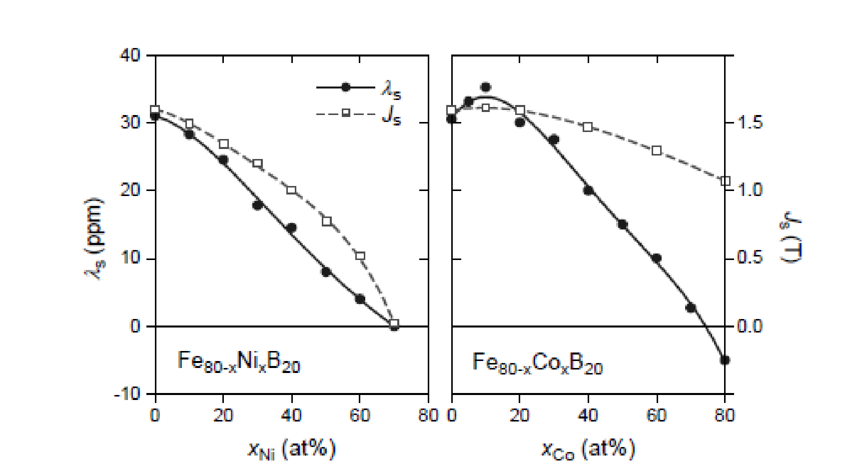
$\sigma = \sigma_{i} + \sigma_{a}$

σ_a- applied stresses

σ_i -determines by the ratio $\rho = d/D$

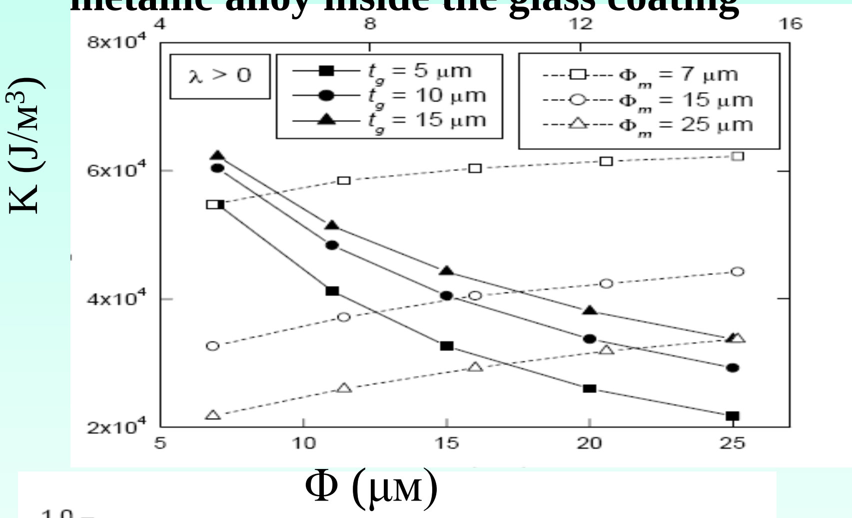
Stress appears at simultaneous solidification of metallic alloy inside the glass coating

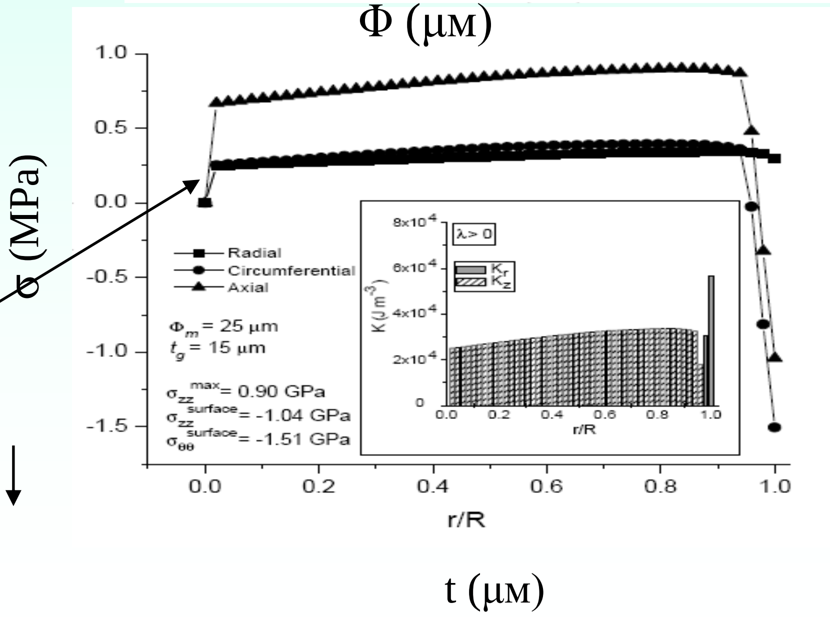


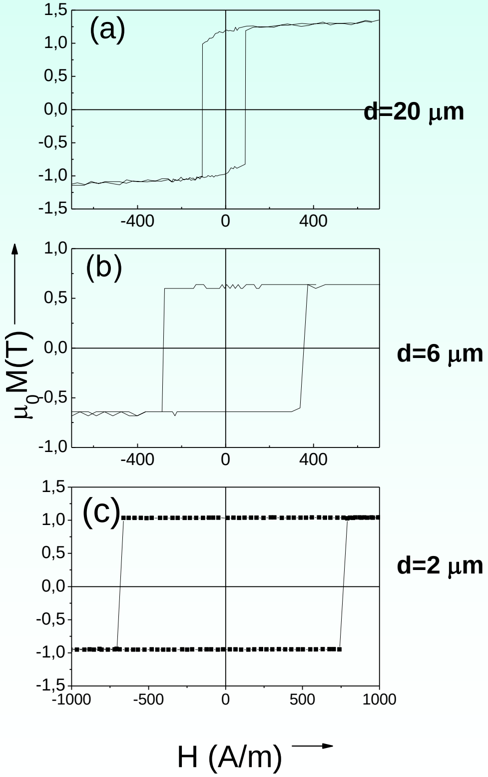


AMORPHOUS AND NANOCRYSTALLINE SOFT MAGNETS

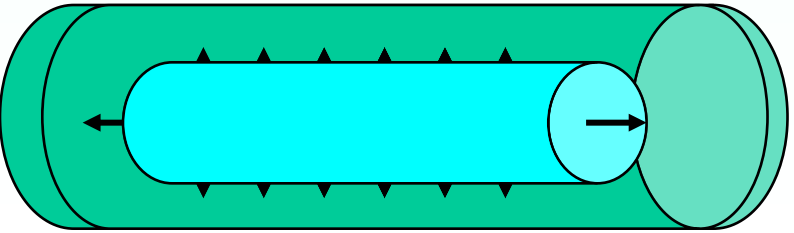
G.Herzer
Vacuumschmelze GmbH & Co KG







$\sigma = f(\rho)$, $\rho = d\,/D$



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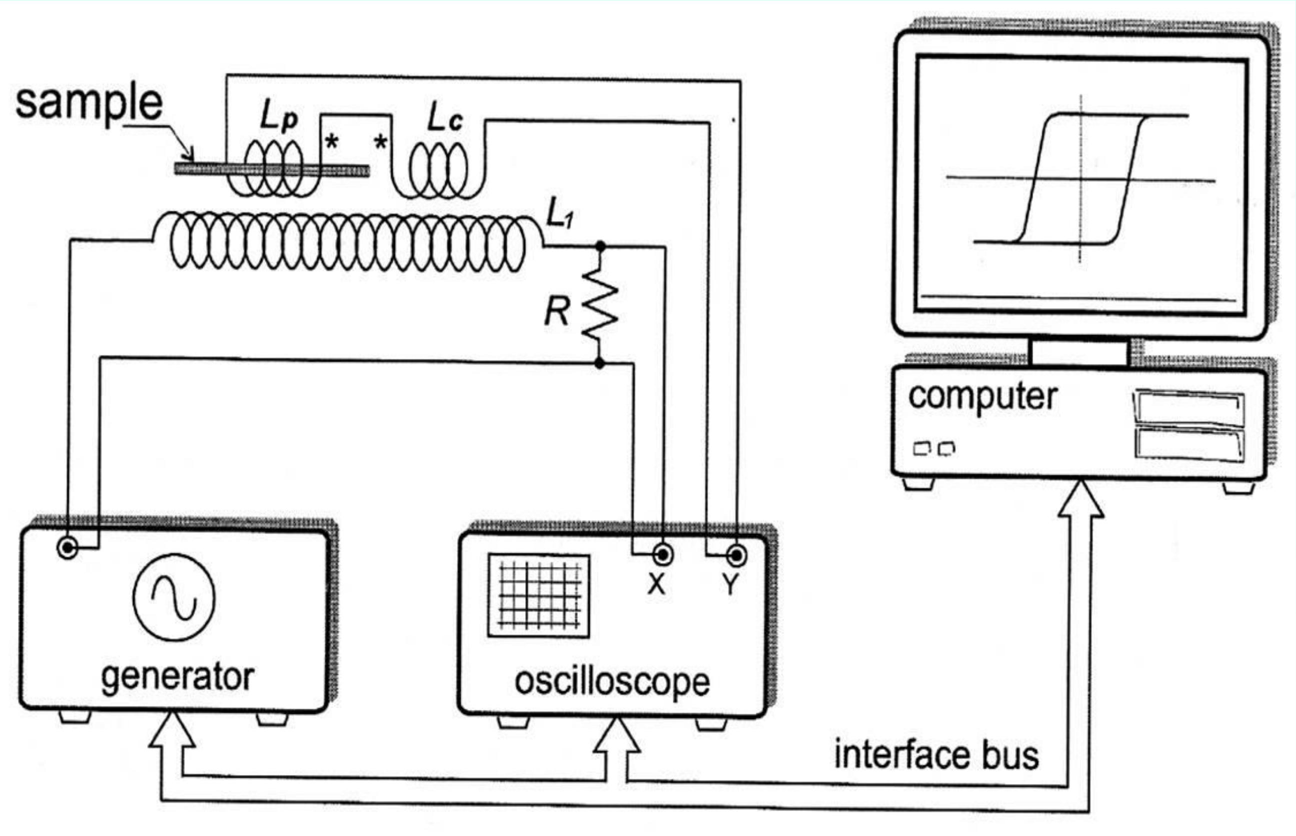
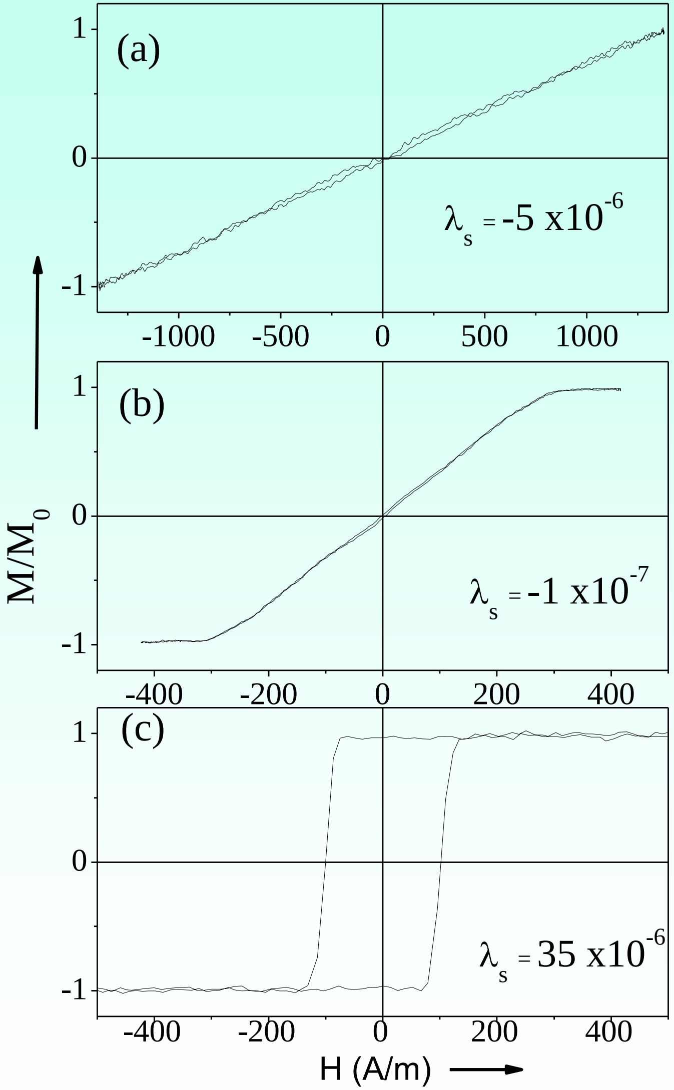
H. Chiriac, T.-A. Ovari, A. Zhukov, J. Magn. Magn. Mater. 254–255 (2003) 469–471

1. Hysteresis loops



Magnetic properties of magnetic microwires



$\lambda s \approx -5 \times 10^{-6}$

$Co_{77.5}Si_{15}B_{7.5}$ (a),

$\lambda s \approx -1 \times 10^{-7}$

$Co_{67}Fe_4Ni_{1.4}Si_{14.5}B_{11.5}Mo_{1.7}$ (b)

$\mu = \Delta M / \Delta H$

High μ, low Hc

Good magnetic softness

and

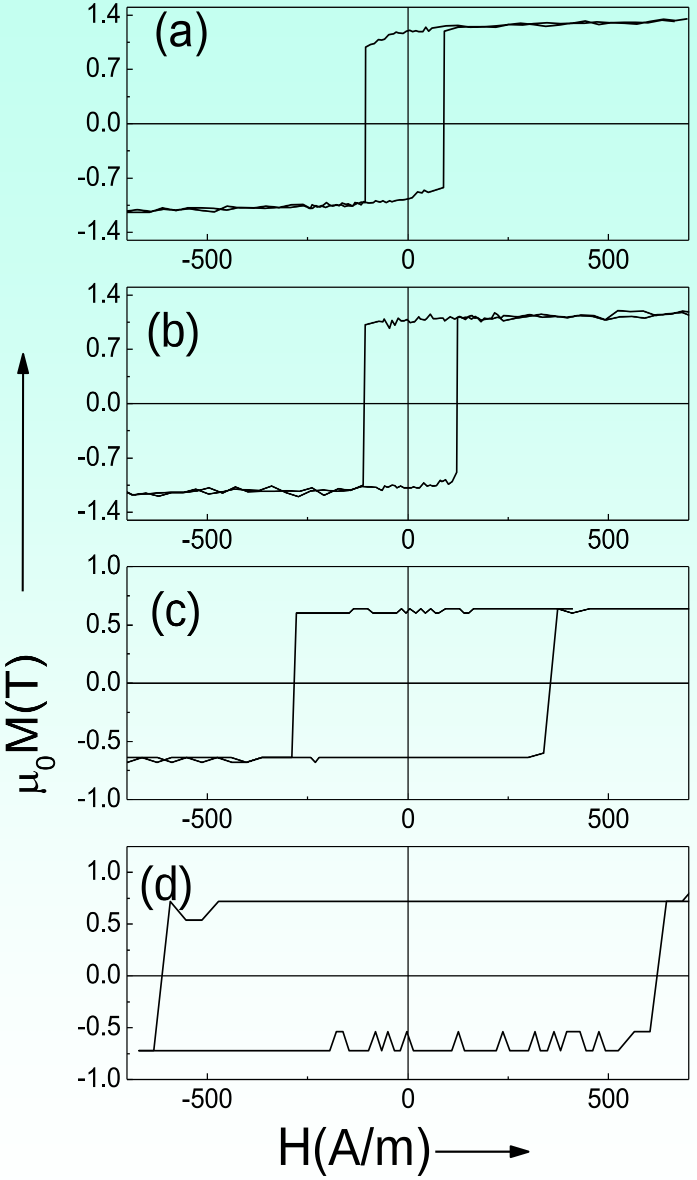
$\lambda s \approx 35 \times 10^{-6}$

$Fe_{75}B_9Si_{12}C_4$ (c) microwires

Magnetic bistability

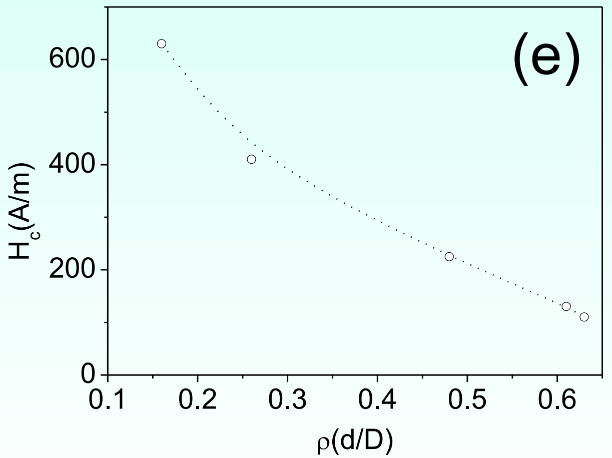
Hysteresis loops, shape and value of GMI ratio are different

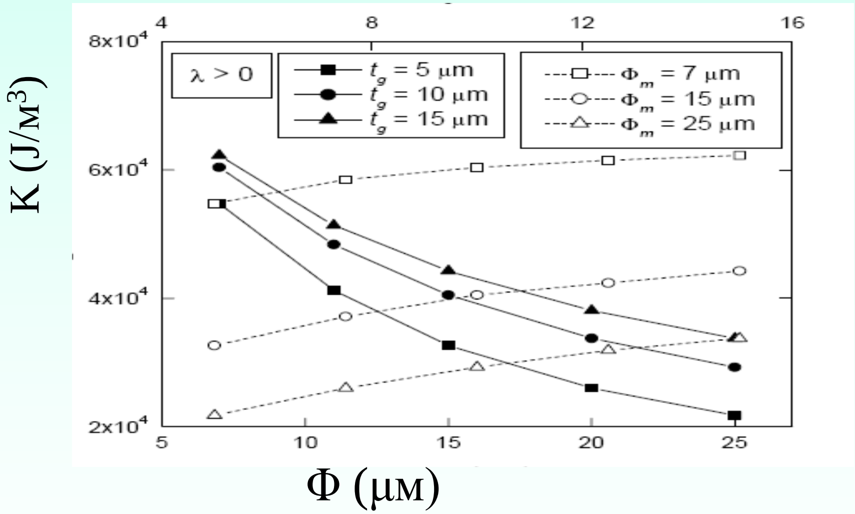
Effect of internal stresses on properties of as-prepared microwires



$\lambda s \approx 35 \times 10^{-6}$

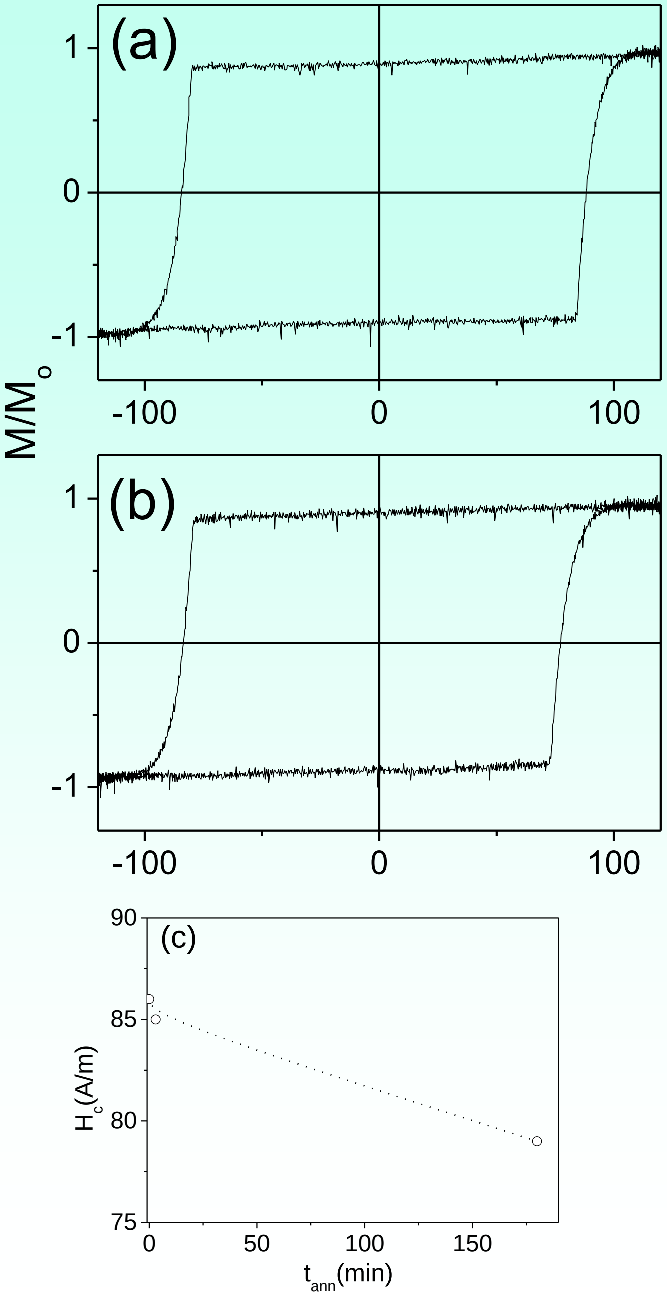
Hysteresis loops of $Fe_{70}B_{15}Si_{10}C_5$ amorphous microwires with different metallic nucleus diameter *d* and total diameters *D*: with ρ = 0.63; *d* = 15 μm (a); ρ = 0.48; *d* = 10.8 μm (b); ρ = 0.26; *d* = 6 μm (c); ρ = 0.16; *d* = 3 μm (d) and *Hc(ρ)* dependence of the same microwires(e).





Low diameters: low signals

Effect of internal stresses relaxation on properties of Fe-based microwires



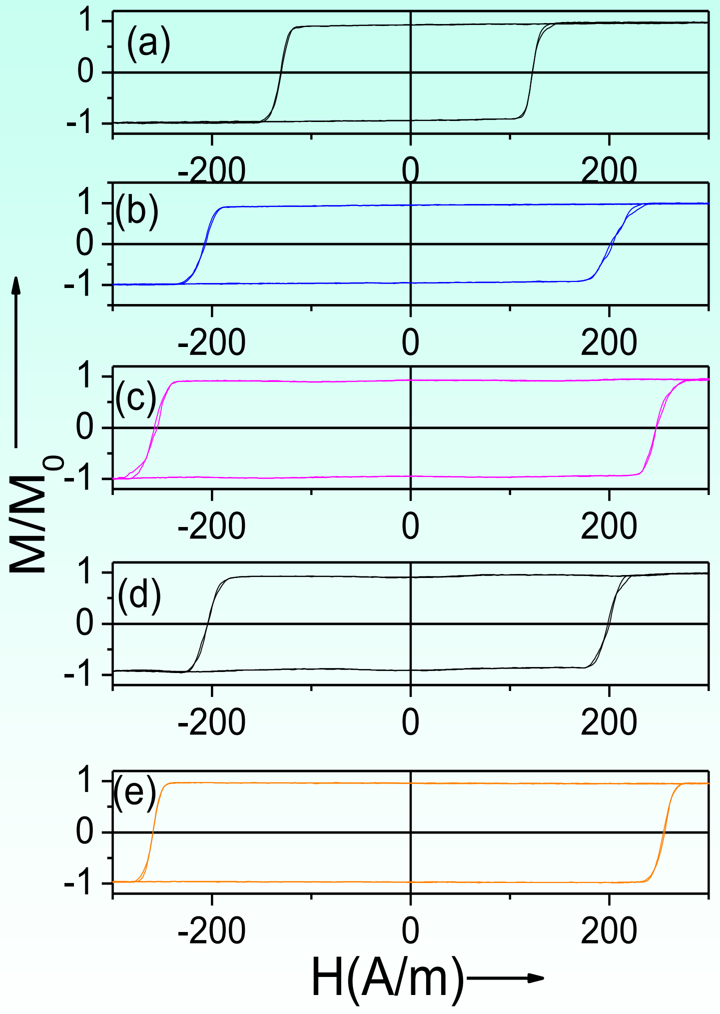
$\lambda s \approx 35 \times 10^{-6}$

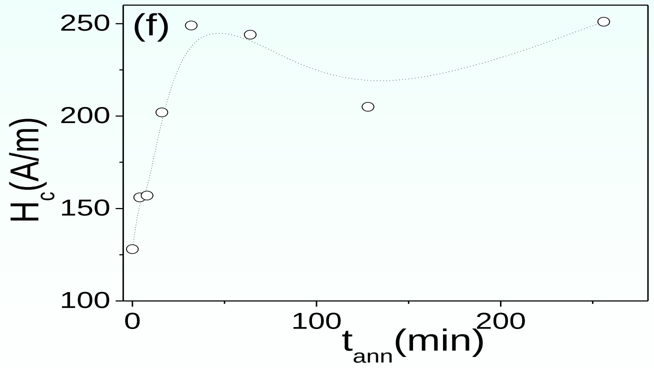
Hysteresis loops of as-prepared (a), and annealed at *Tann* = 400 °C for 180 min (b) $Fe_{75}B_9Si_{12}C4$ microwires and dependence of coercivity on annealing time (c).

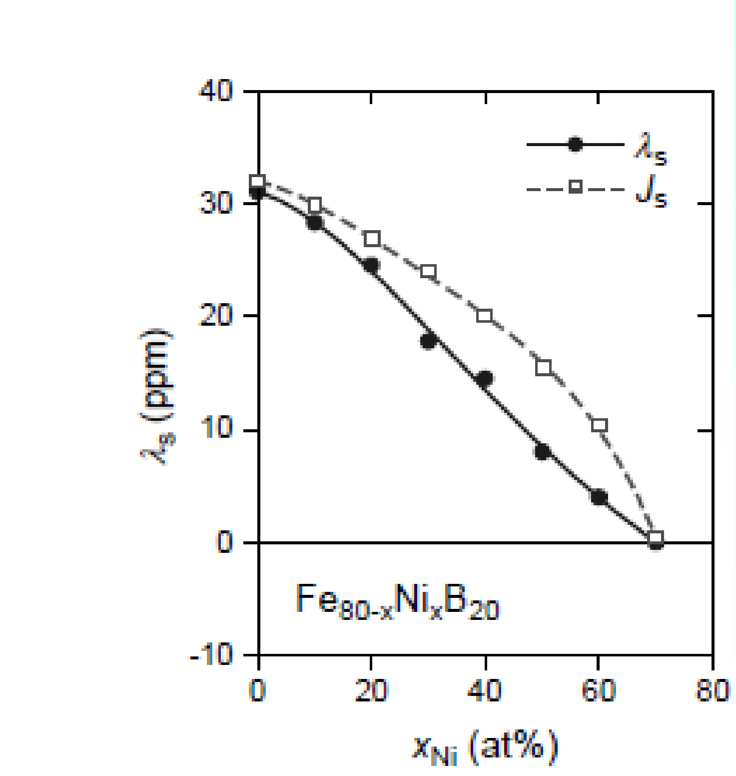
Effect of annealing on properties of Fe-Ni based microwires

$\lambda s \approx 28 \times 10^{-6}$

Hysteresis loops of as-prepared (**a**) and annealed at T_{ann} = 410 °C for 16 min (**b**) 32 min (**c**), 128 min (**d**), and 256 min (**e**) $Fe_{62}Ni_{15.5}Si_{7.5}B_{15}$ microwires and $H_c(t_{ann})$ dependence of the same microwire.

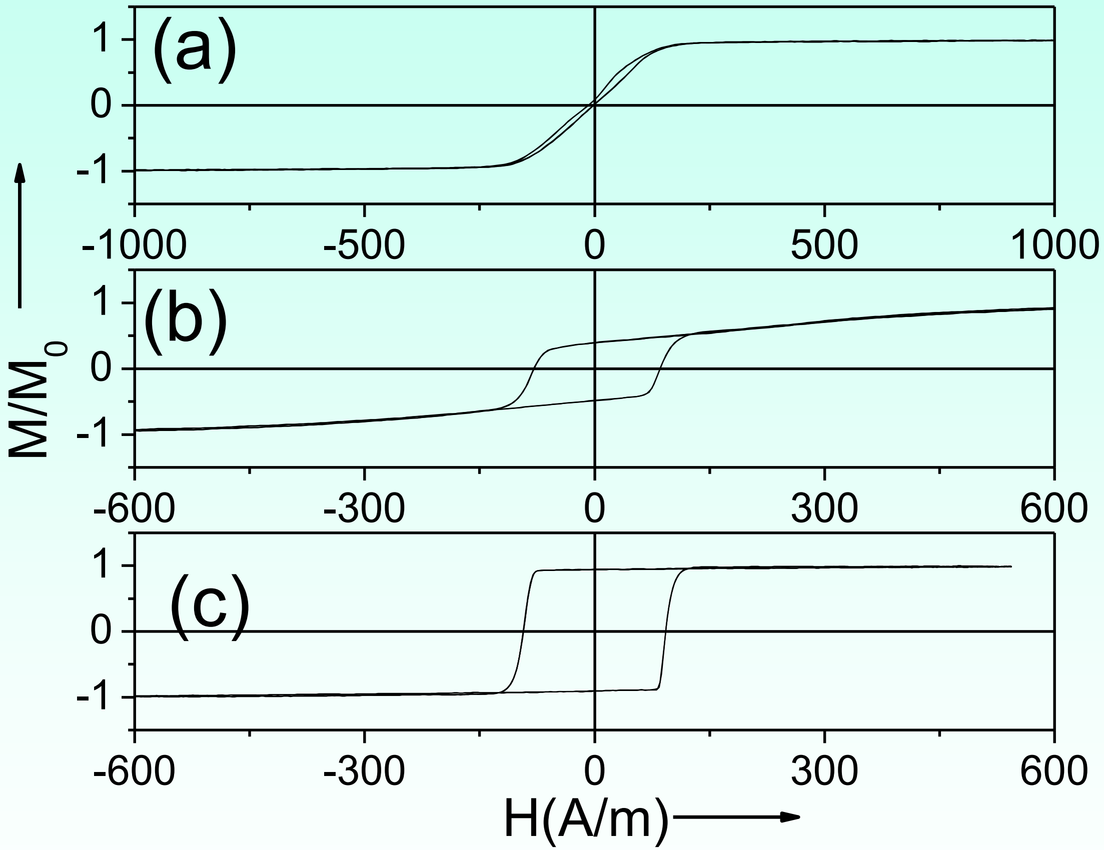






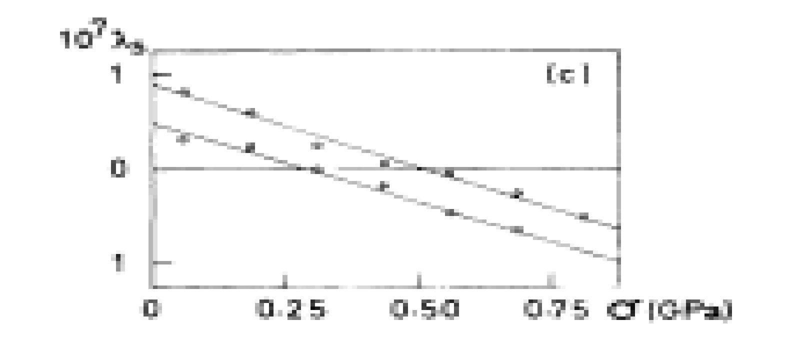
Effect of annealing on properties of Fe-Co based microwires

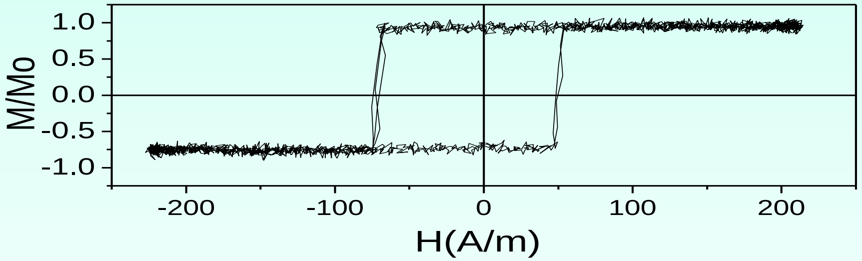
$\lambda s \approx -1 \times 10^{-7}$

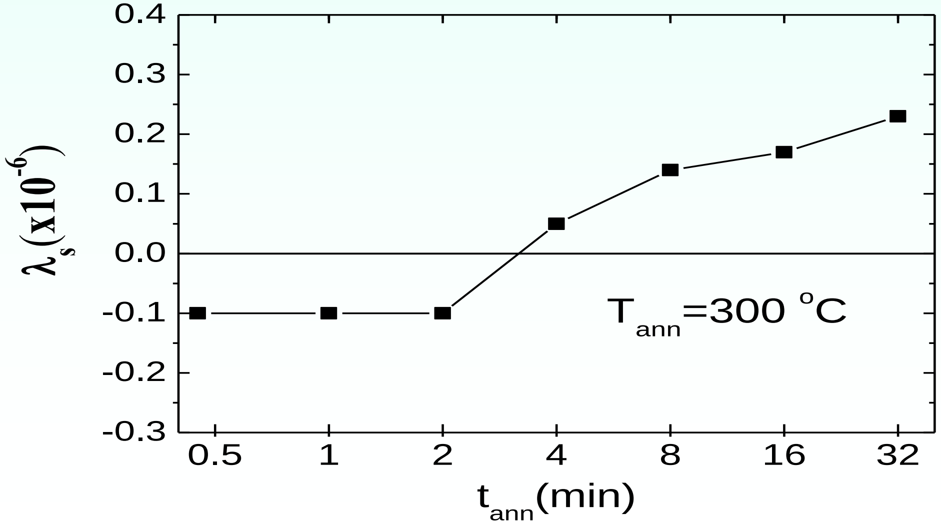


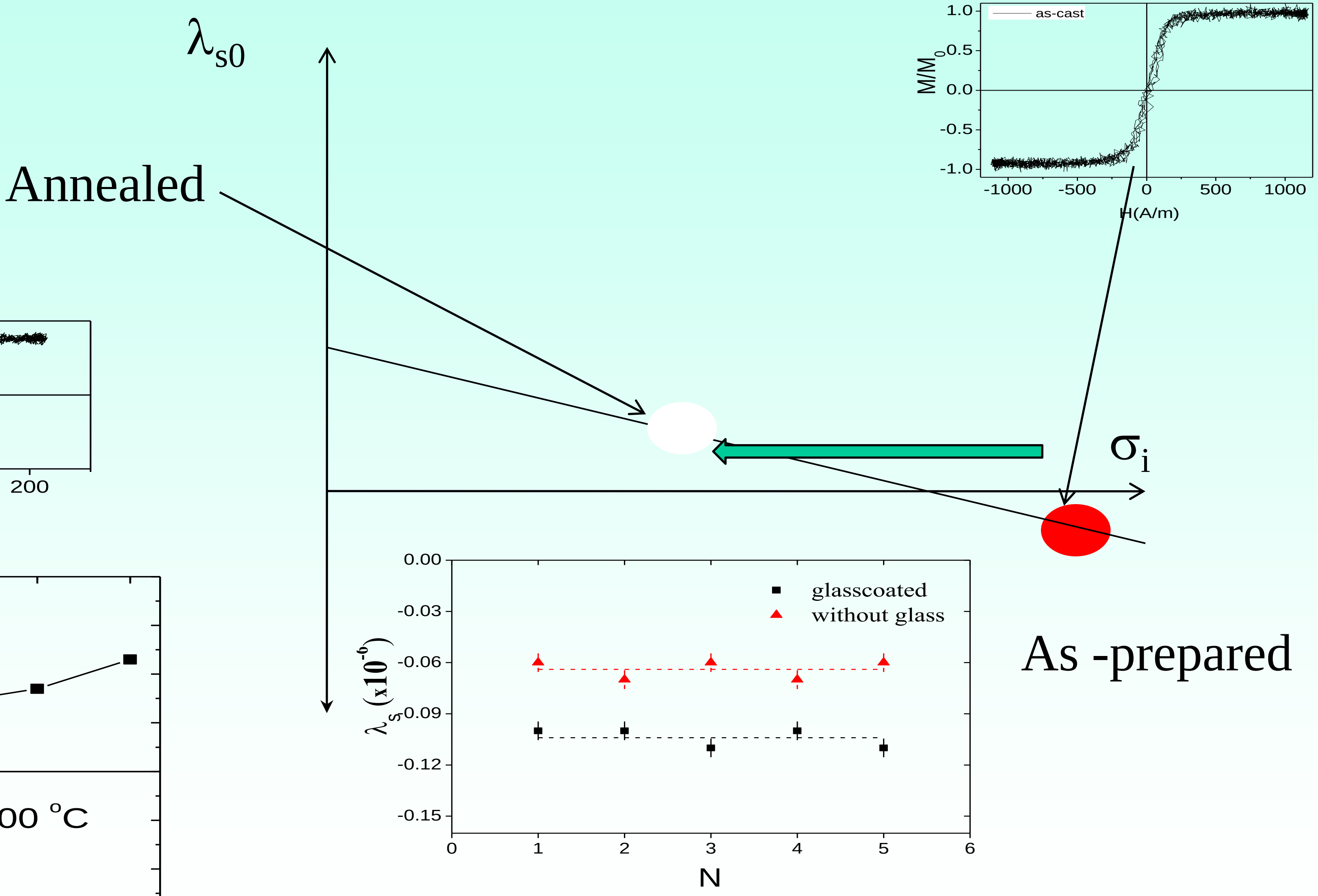
Hysteresis loop of as-prepared (a) and annealed at T_{ann} = 250 °C (b) and T_{ann} = 300 °C (c) $Fe_{3.6}Co_{69.2}Ni_1B_{12.5}Si_{11}Mo_{1.5}C_{1.2}$ microwires.

Origin of annealling induced changes in Co-rich microwires





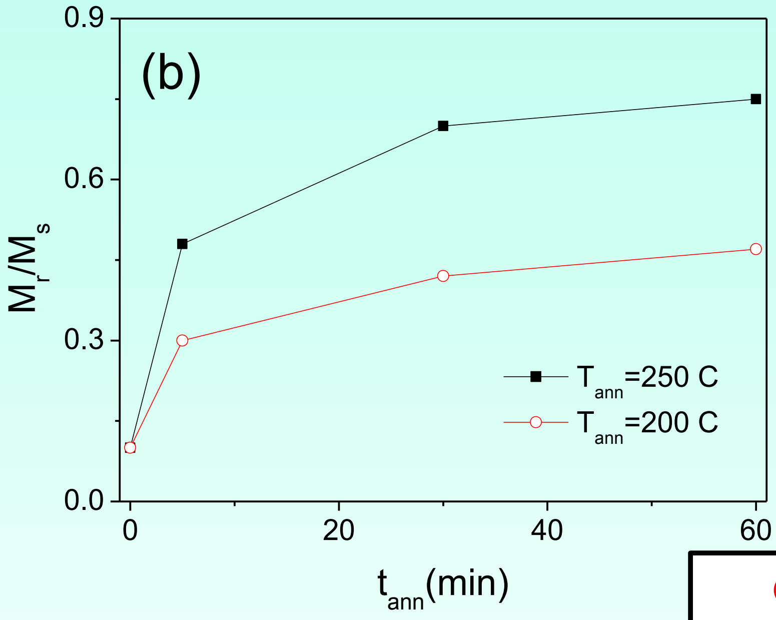




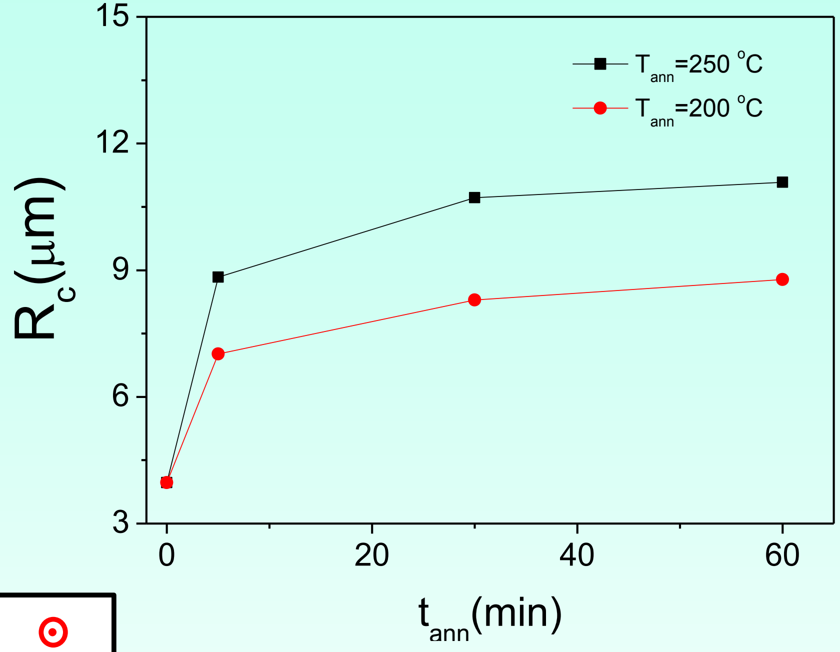
A. ZHUKOV, et.al J. ELECTRONIC MATERIALS (2015)
DOI: 10.1007/s11664-015-4011-2

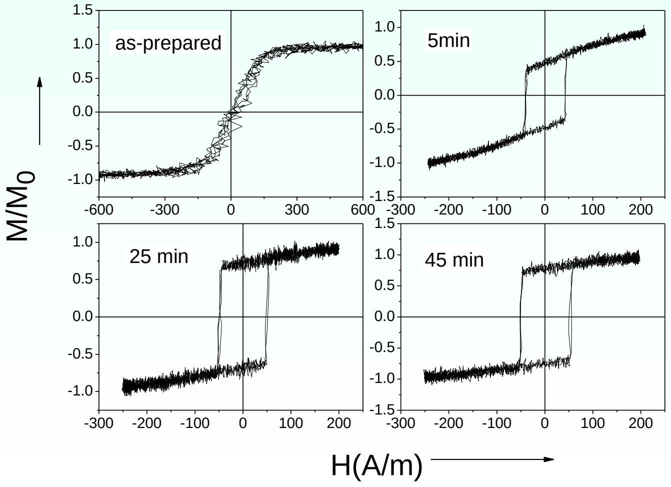
Origin of annealling induced changes in Co microwires

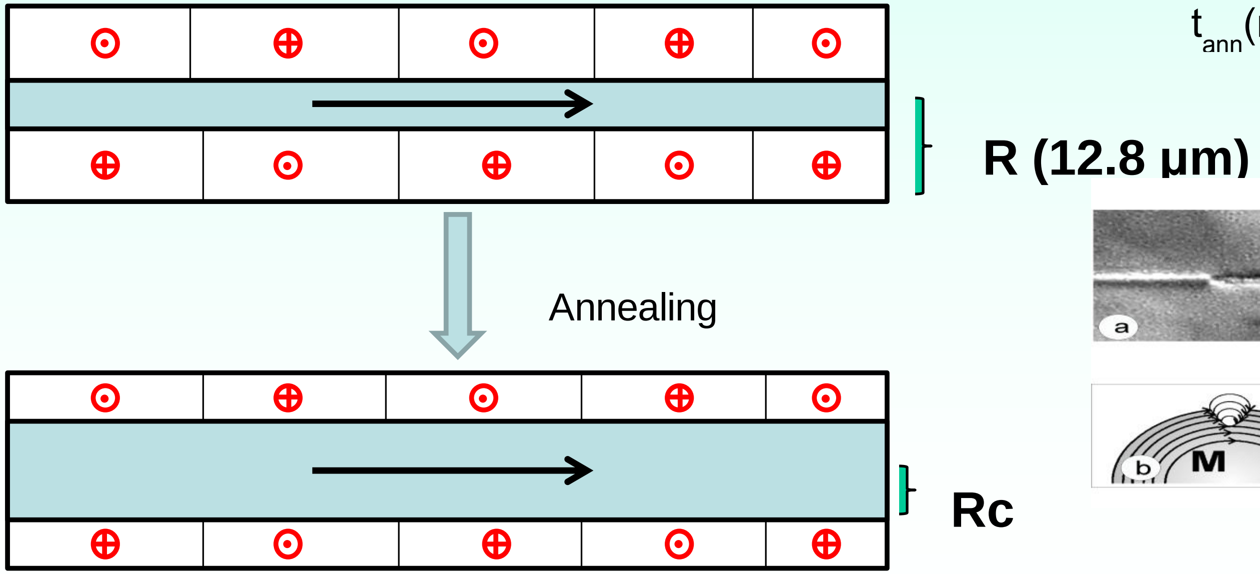
Stress relaxation?

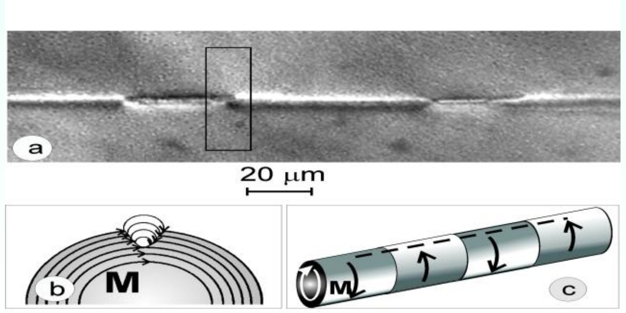


$$R_c = R(M_r/M_s)^{1/2},$$



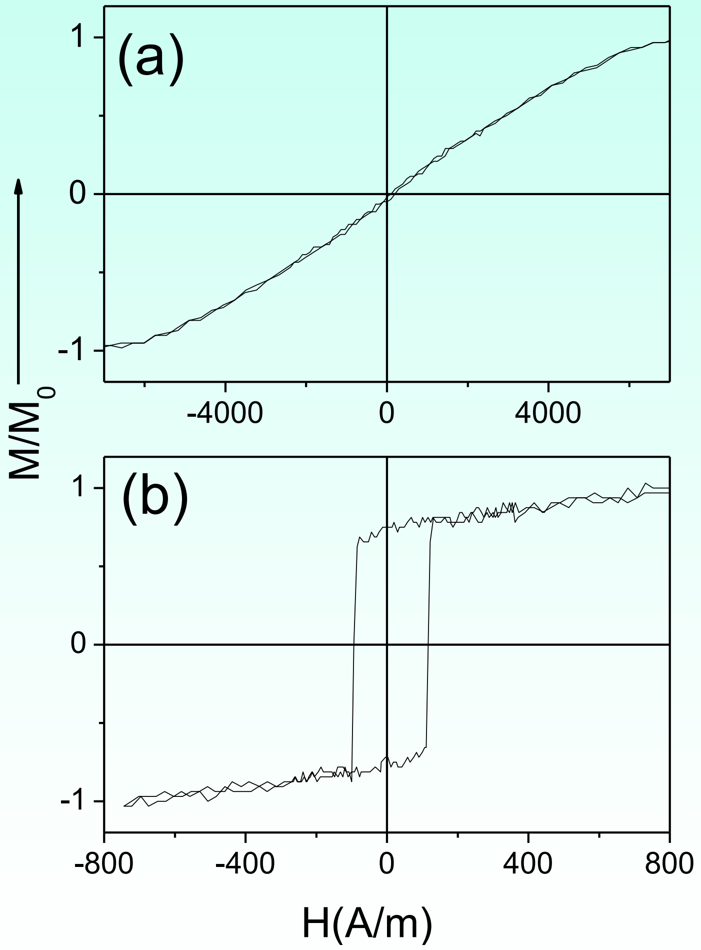






A. Zhukov, M. Ipatov, M.Churyukanova, A. Talaat, J.M. Blanco and V. Zhukova, Trends in optimization of giant magnetoimpedance effect in amorphous and nanocrystalline materials (Review paper), J. Alloys Compound. 727 (2017) 887-901

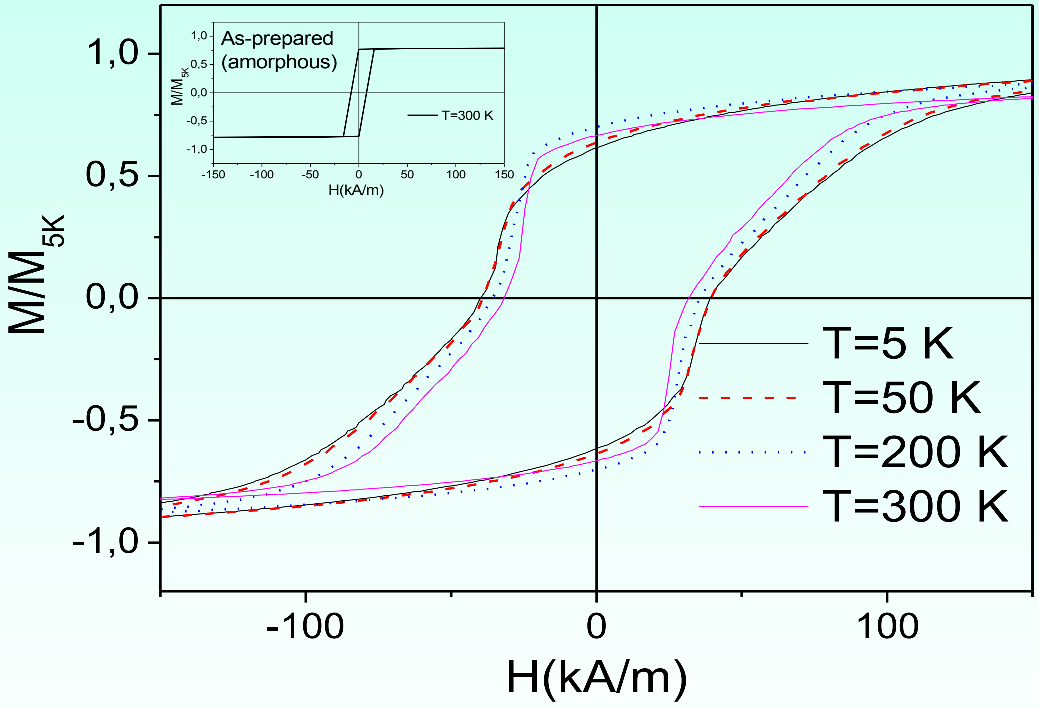
Effect of internal stresses on properties of as-prepared microwires



Hysteresis loops of as-prepared (a), and subjected to chemical etching for 50 min (b) $Co_{68.5}Si_{14.5}B_{14.5}Y_{2.5}$ microwires.

$\lambda s \approx -5 \times 10^{-6}$

Magnetic hardening in microwires



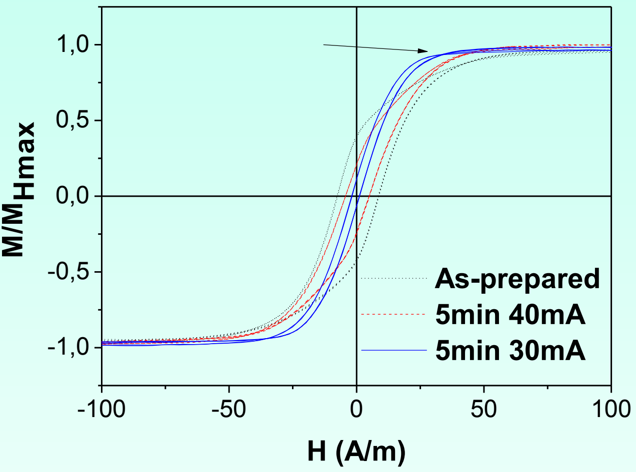
Hysteresis loops of annealed at 500 ° C for 1 h $Fe_{50}Pt_{40}Si_{10}$ microwires measured at different temperatures. Hysteresis loops of as-prepared are provided in the inset.

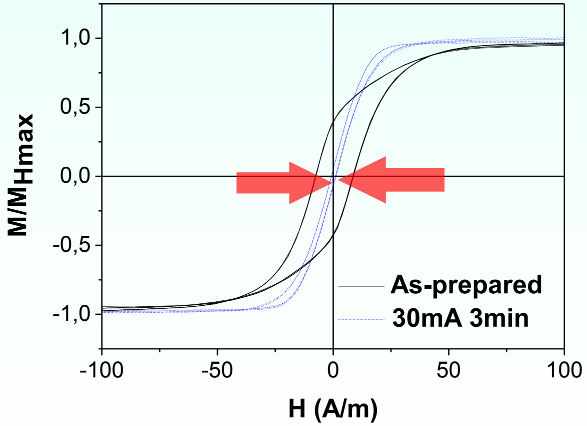
Magnetic softening in microwires

Tailoring by Joule heating

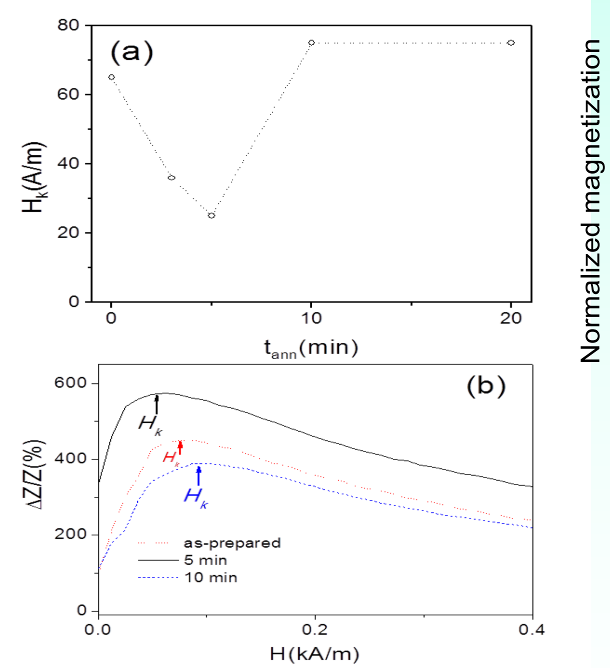
- Internal stresses relaxation
- Induced magnetic anisotropy

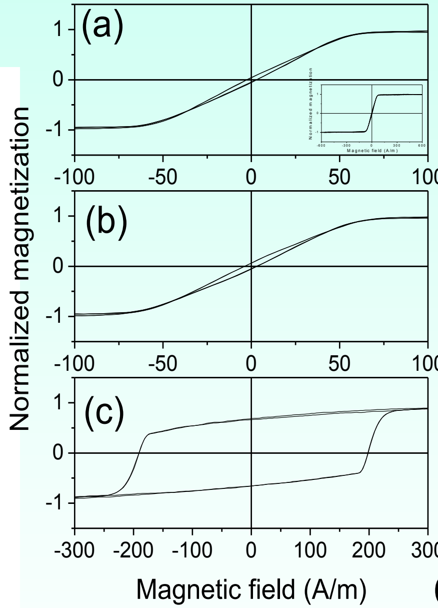
H_k=25A/m



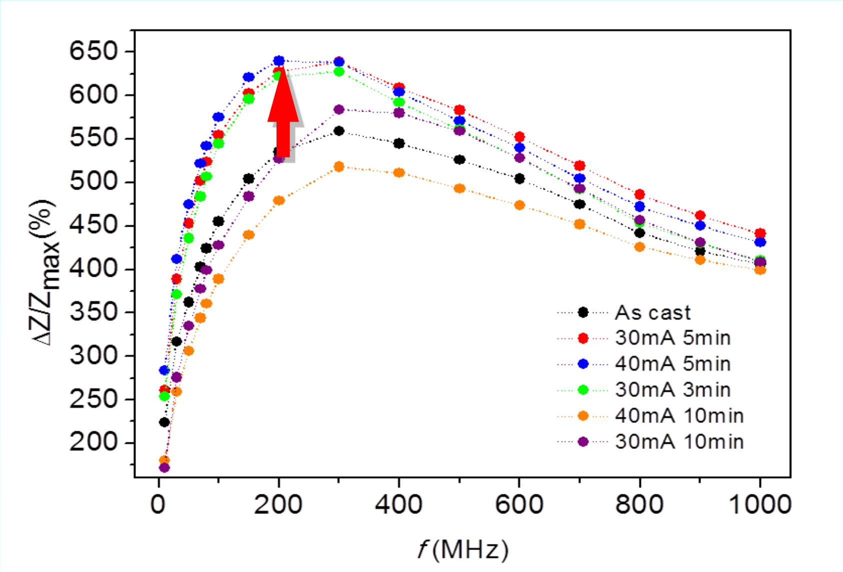


Hc=2 A/m

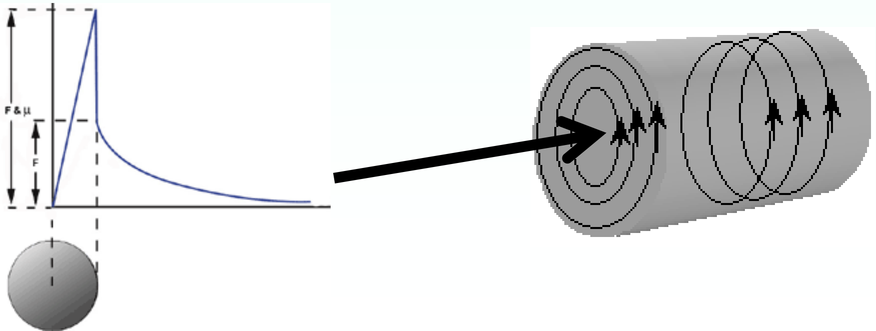




GMI ratio up to 650%



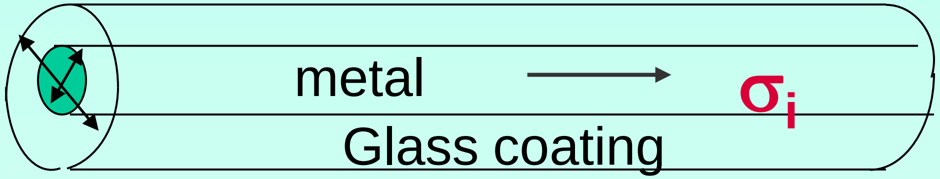
Circular magnetic field by current:



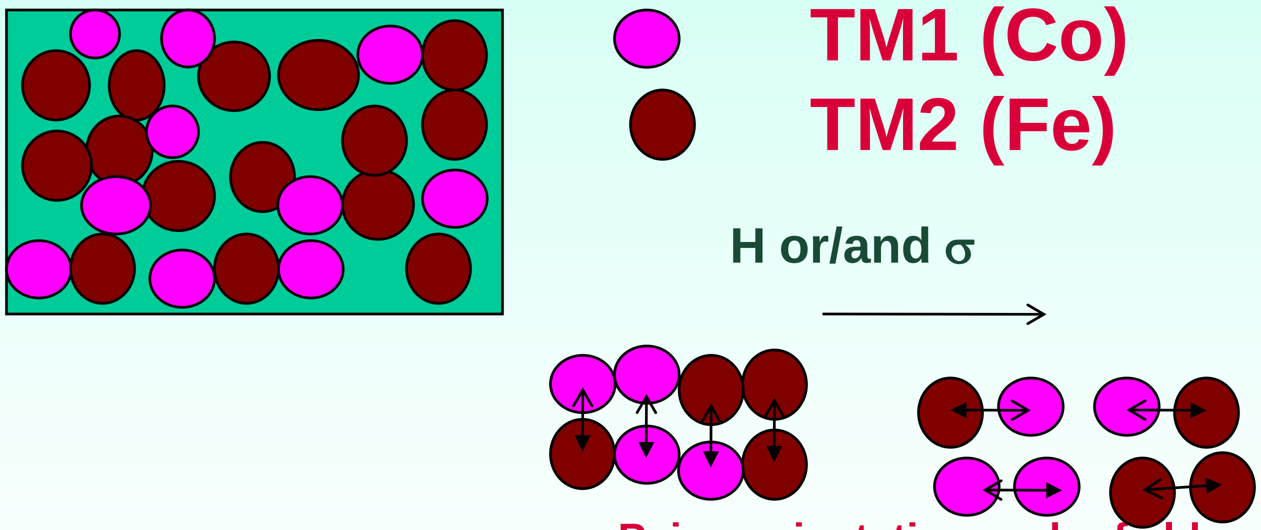
V. Zhukova, J.M. Blanco, M. Ipatov, M. Churyukanova, J. Oliver, S. Taskaev, A. Zhukov, Optimization of high frequency magnetoimpedance effect of Fe-rich microwires by stress-annealing, Intermetallics, 94 (2018) 92-98

Origin of induced anisotropy

Possilbe origin:
-Stress induced anisotropy (stress from glass coating)?



Origin: Pair ordering usually considered



Pair reorientation under field and/or stress annealing (after Neel)

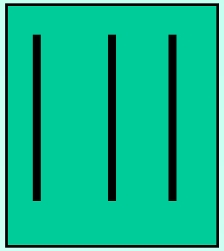
Possible origin 3:
The topological short range ordering (also known as structural anisotropy) can play an important role. This involves the angular distribution of the atomic bonds and small anisotropic structural rearrangements at temperature near the glass transition temperature

[1] F. E. Luborsky and J. L. Walter, “Magnetic Anneal Anisotropy in Amorphous Alloys”, *IEEE Trans.Magn.* Vol.13 (2), pp.953-956, 1977.
[2] J. Haimovich, T. Jagielinski, and T. Egami, “Magnetic and structural effects of anelastic deformation of an amorphous alloy”, *J. Appl. Phys*. Vol. 57, pp. 3581-3583, 1985.

18

APPLICATIONS:

Magnetic codification based on magnetic bistability



Publications

- A. Zhukov, J.González, J.M. Blanco, M.Vázquez and V. Larin, J. Mat. Res 15, (2000), 2107.

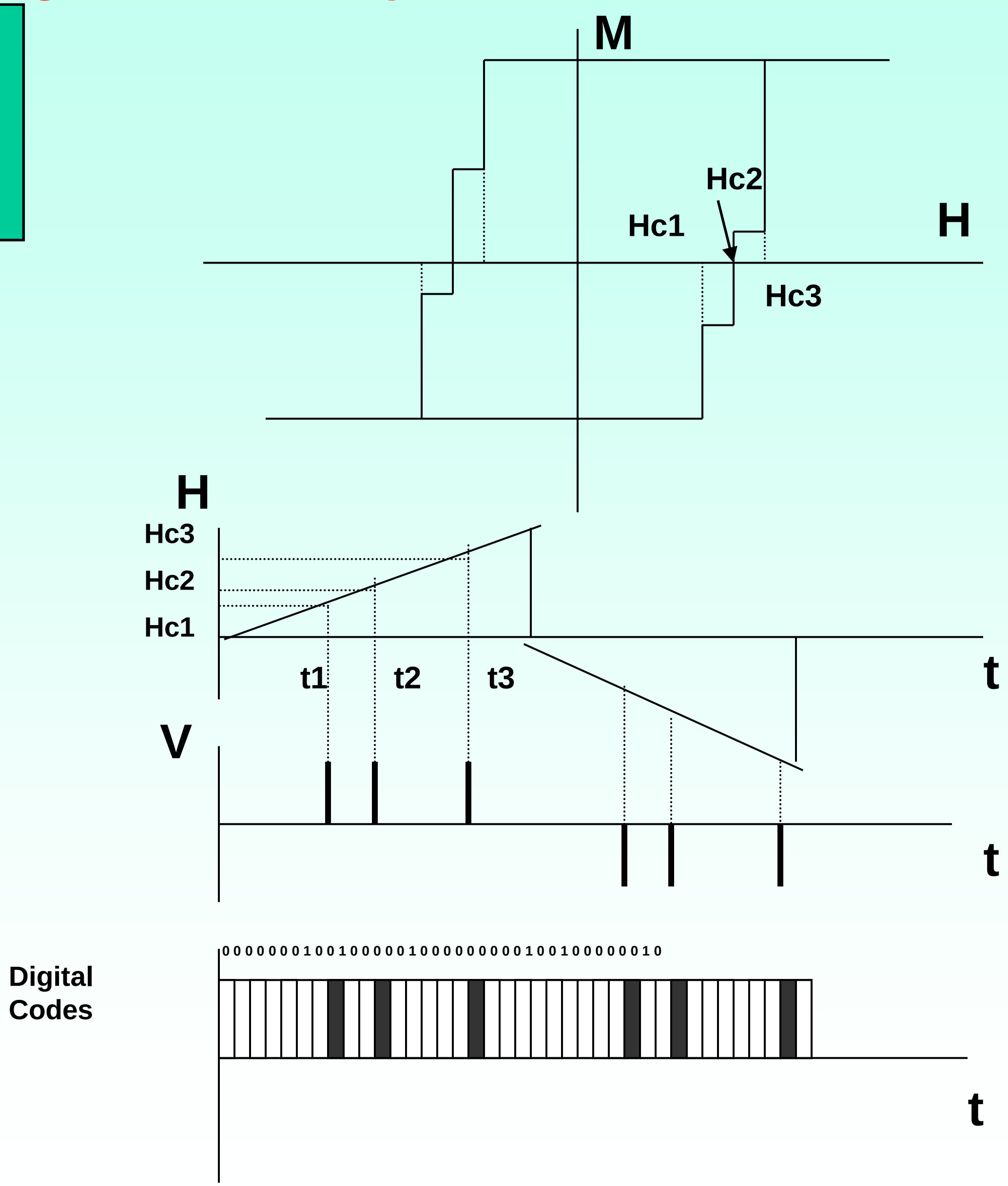
Patentes:

1. V. Larin, A. Torcunov, S. Baranov, M. Vázquez, A. Zhukov and A. Hernando, "Method of magnetic codification and marking of the objects", Patent (Spain) Nº P 9601993 (1996).

2. M. Vázquez, A. Zhukov, A. Hernando, V. Larin, A. Torcunov, L. Panina, J. Gonzalez and D. Mapps, *TITULO:*
"Microwire and process of their fabrcation. AWP/RPS/56672/000, No0108373.2 *(UE) 01.11.2001*
"Four wnds", Amotec" and "Tamag Iberica. S.L."

3. A. Zhukov, V. Zhukova, M. Vázquez, J. González, V. S. Larin y A.V. Torcunov " Amorphous micwories as an element of magnetic sensor based on magnetic bistabily, magneto-impedance and material for the radiation protection".
P200202248 *(Span) 02.10.2002 "Tamag Iberica. S.L."*

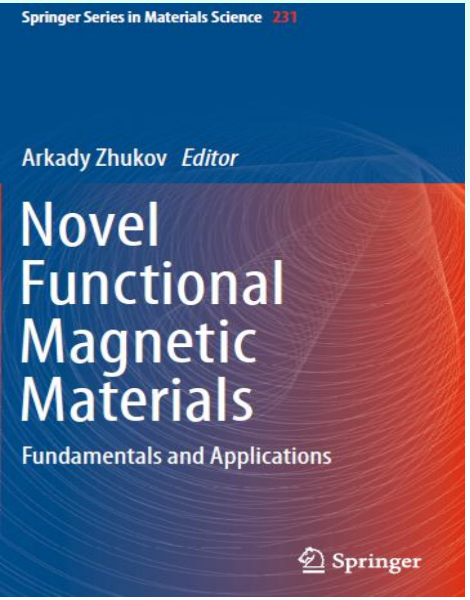
4 A. Zhukov, V. Zhukova, J. González, V. S. Larin y A.V. Torcunov *"*Ultra-thin glass-coated microwires with GMi effect at elevated frequencies."*PCT Es/2006/000434 (USA)*

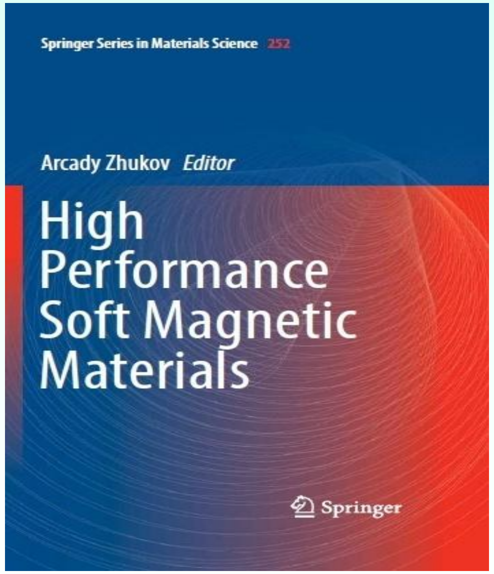


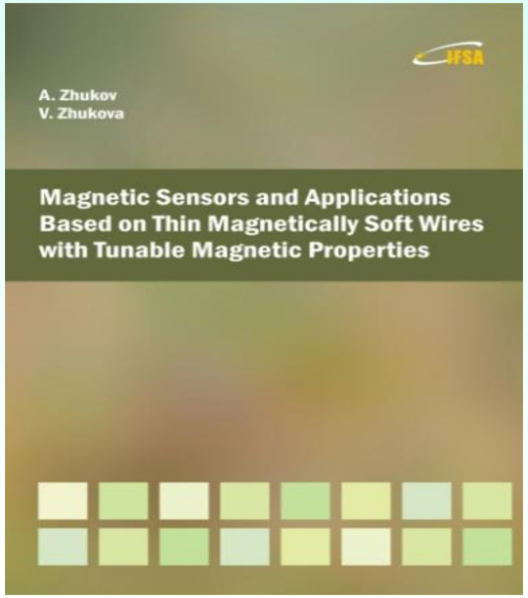
Conclusions

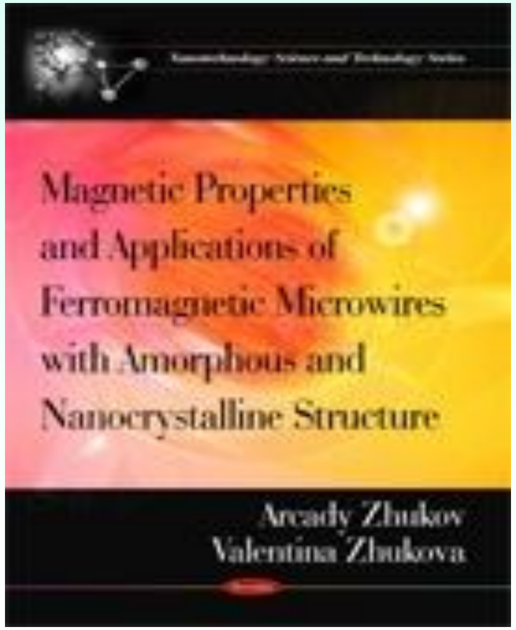
- **By appropriate selection of chemical composition and post-processing conditions we can considerably tune magnetic properties of microwires**

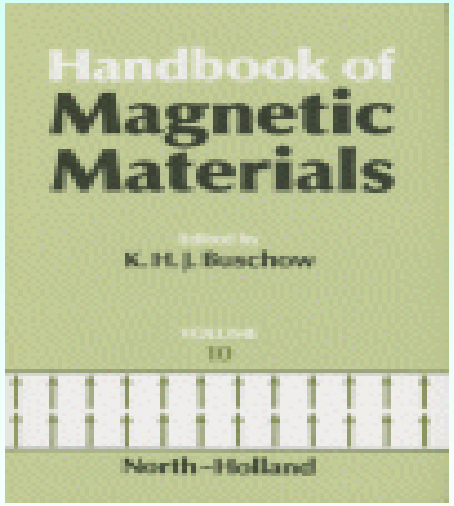
Thank you for the attention!











“Advances in Giant Magnetoimpedance Materials” by A. Zhukov, M. Ipatov and V. Zhukov (issue October 2015)

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