Magnetic properties and Giant Magnetoimpedance effect in multilayered Co-rich microwires

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Outline

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3.2. GMI effect
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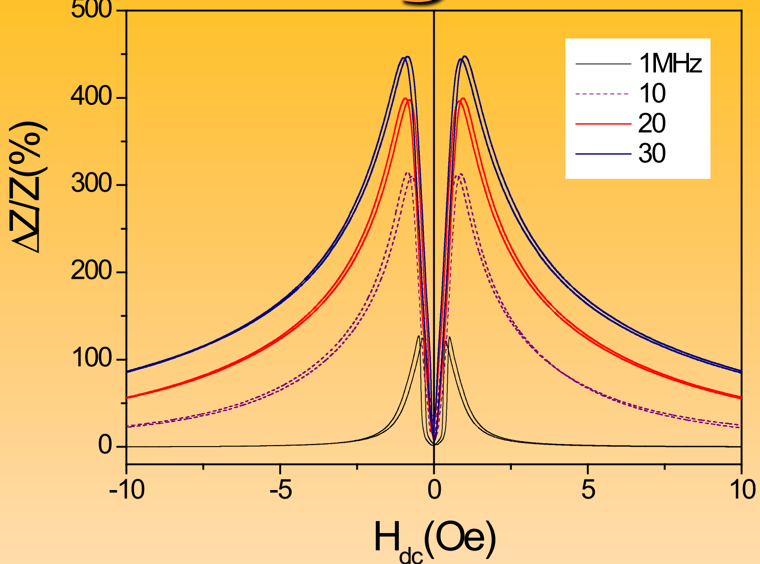
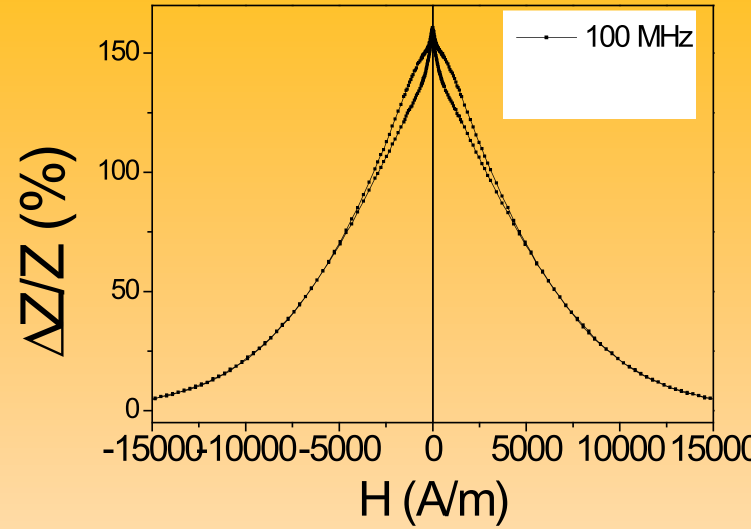
Giant Magneto-impedance effect





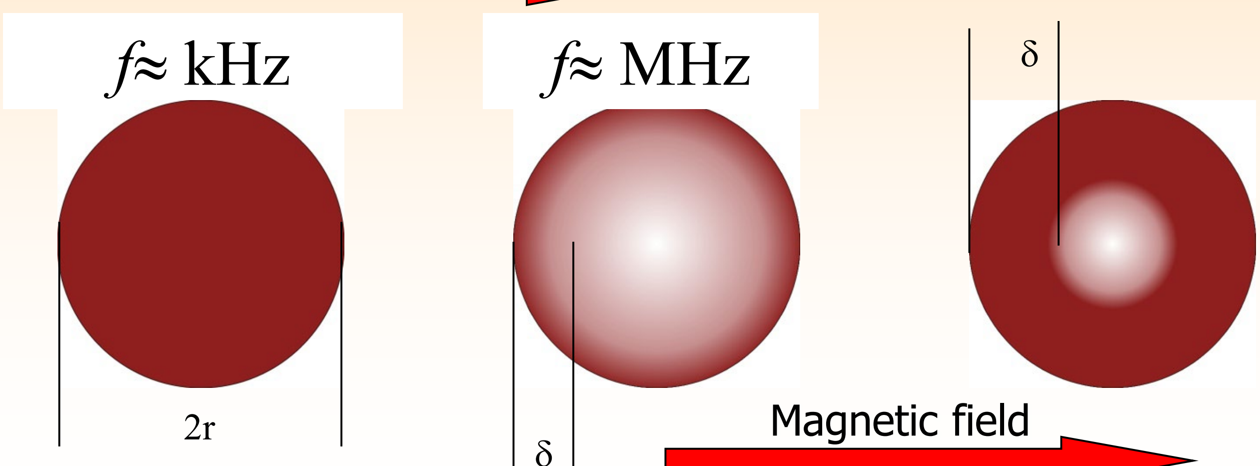
Magnetic filed depedence and value are affected by magnetic anisotropy

Skin Effect of the Magnetic Conductor

AC current frequency

$$\mu_\phi \Downarrow \;\rightarrow\; \delta \Uparrow$$

$$\delta = \sqrt{\frac{\rho}{\pi \mu_\phi f}}$$



$\mu_\phi(H,f)$

$$\delta < r$$

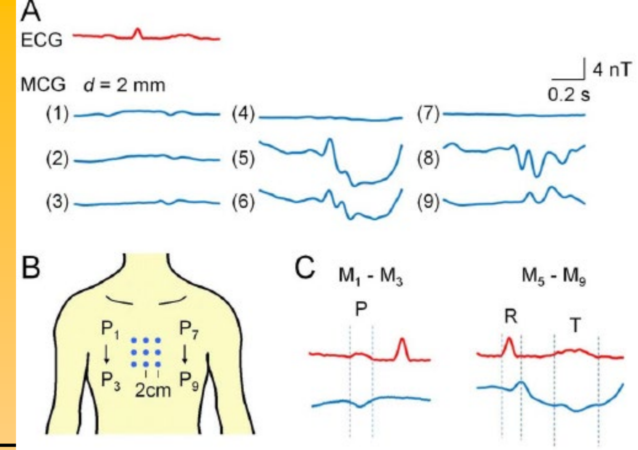
(at high enough f)

Z(H)

Magnetically soft low dimensional magnetic materials are needed

Magnetic Sensors Applications

up to 10%/A/m
pico-Tesla sensitivity !



Bio magnetic field

Nature magnetic field

Geo-magnetisms

Industrial magnetic field

Storage and magnet

SC-magnet

Space magnetic field

Tesla (T): pT, nT, μT, mT, T, kT

10^{-10}, 10^{-8}, 10^{-6}, 10^{-4}, 10^{-2}, 1, 10^{2}, 10^{4}, 10^{6}

Gauss (G): nG, μG, mG, G, kG, MG

Hall sensor (0 ~ 1 MHz)

MR, GMR sensor (0 ~ 10 MHz)

Fluxgate sensor (0 ~ 10 kHz)

Amorphous wire MI sensor (0 ~ 10 MHz)

Intrinsic noise level at room temperature.

SQUID

Proton magnetometer (0 ~ 0.01Hz)

4

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Pulse-Driven Magnetoimpedance Sensor Detection of Cardiac Magnetic Activity

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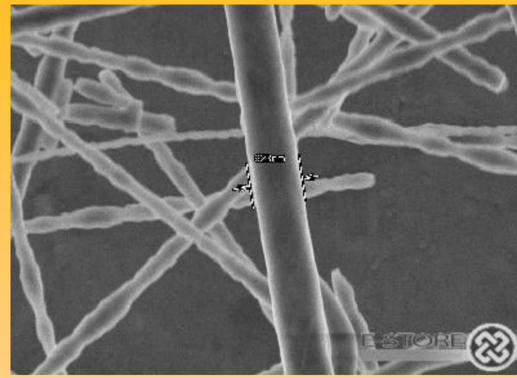
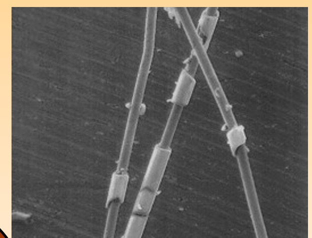
Source: Prof. K. Mohri

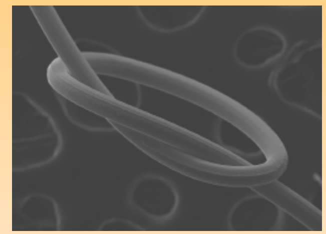
Magnetic wires:

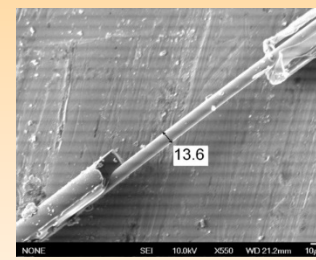


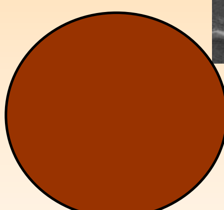
-Iron whiskers
-Wiegan magnetic wires (CoVFe,1970-th)

Amorphous: milli
(since 80-th) micro
nano
wires





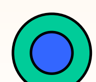




In-rotating water wires
(can be drawn to 20-30 μm) – rough surface

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

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

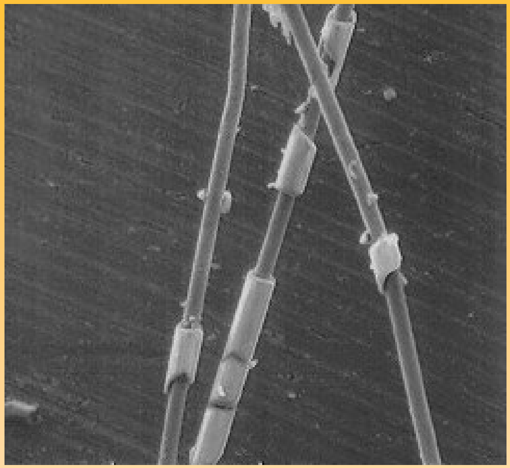


Glass coated microwires

- Co, Ni and Fe rich compositions

$$\rho = \frac{d_{metal}}{D_{total}}$$

•geometric ratio $0.1 < \rho < 0.98$



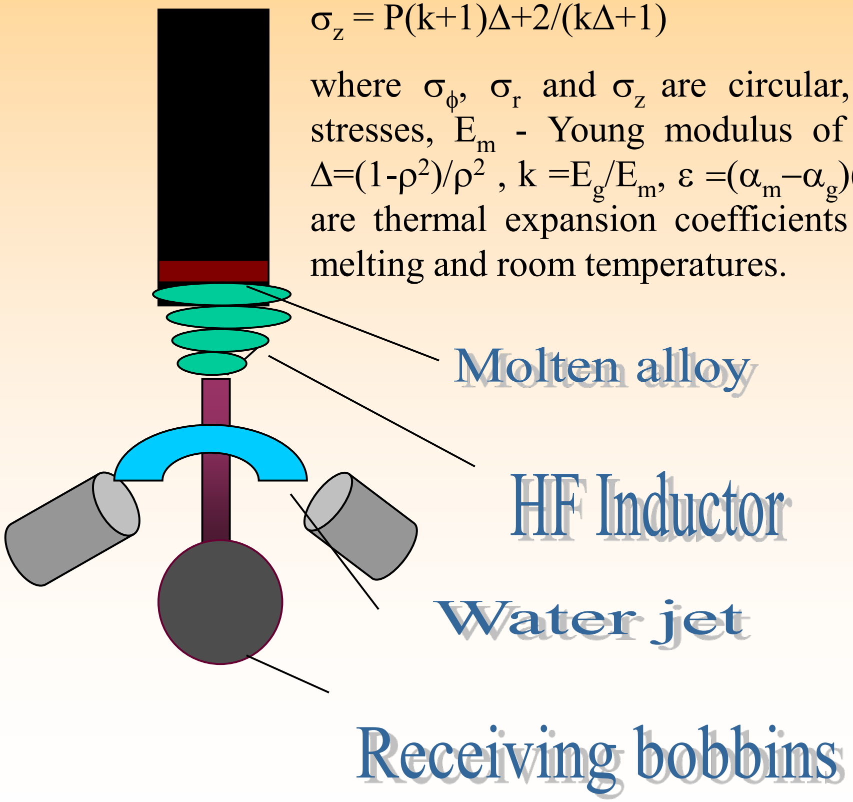
Strength of internal stresses depends mainly on difference of thermal expansion coefficients :

$\sigma_\phi = \sigma_r = P = \varepsilon E k \Delta / (k/3+1)\Delta + 4/3$ (1)

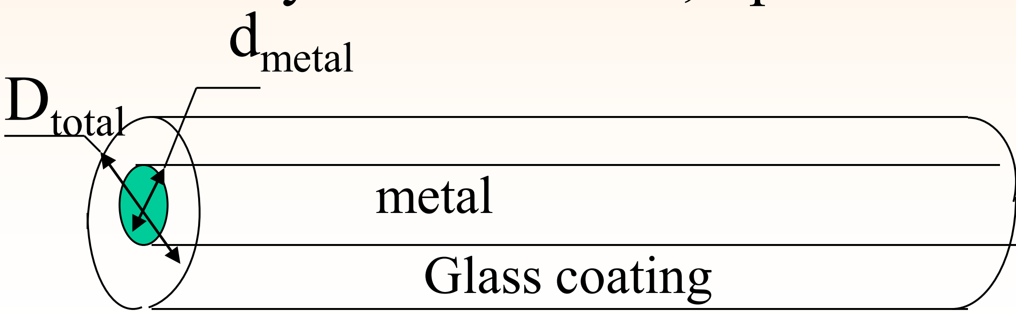
$\sigma_z = P(k+1)\Delta + 2/(k\Delta+1)$ (2)

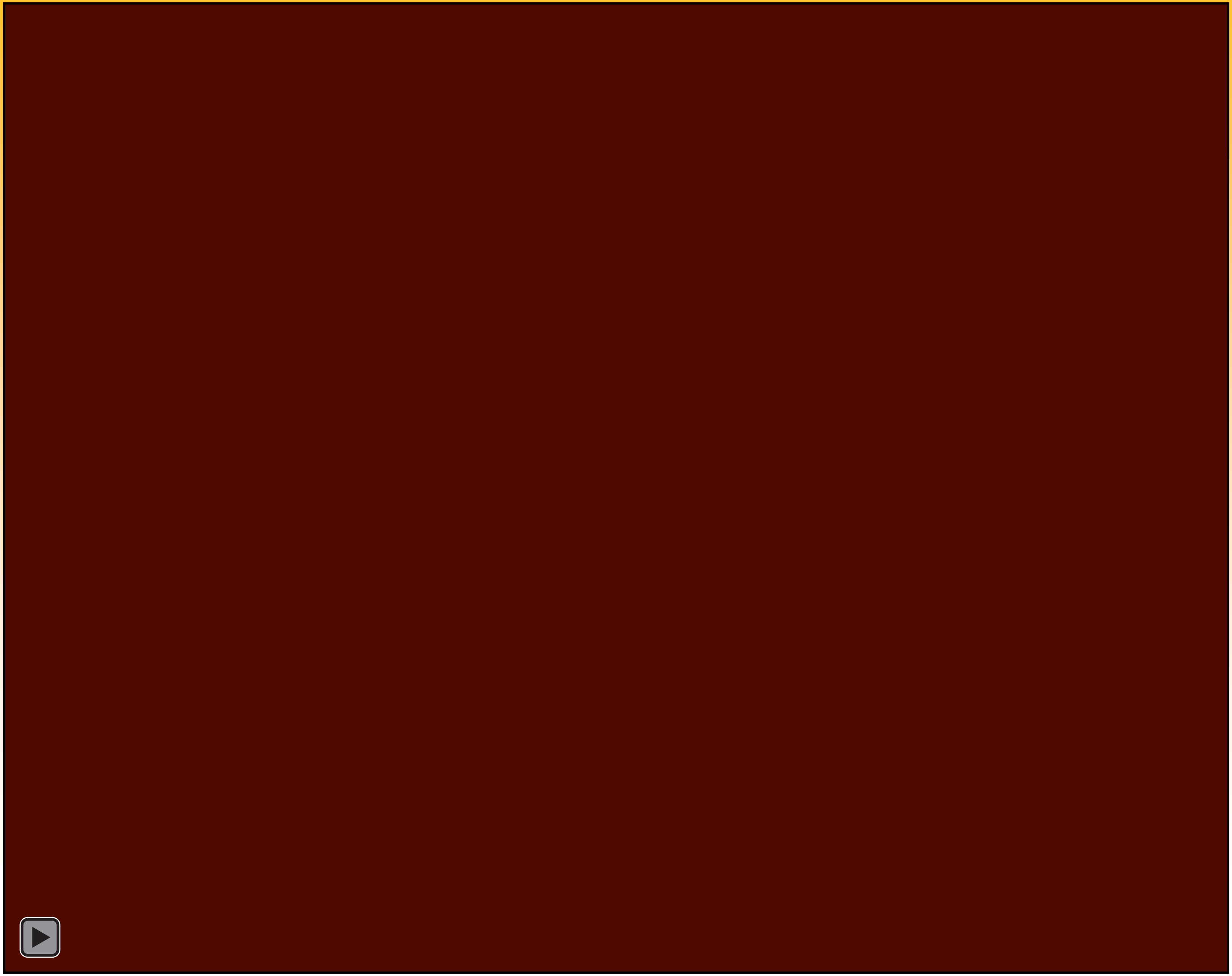
where σ_ϕ, σ_r and σ_z are circular, radial and axial stresses, E_m - Young modulus of metallic nucleus, $\Delta = (1-\rho^2)/\rho^2$, $k = E_g/E_m$, $\varepsilon = (\alpha_m - \alpha_g)(T_m - T_{room})$, α_1, α_2 are thermal expansion coefficients and T_m,T_{room} are melting and room temperatures.

Typical dimensions:
Total diameter 1-120 μm
Metallic nucleus diameter 0.2-100 μm
Glass coating thickness 1-10 μm
Length - few km (up to 10 in 1 bobbin



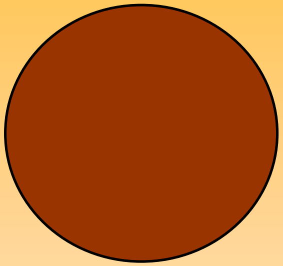
Fabrication – Univ. Basque Country and TAMAG, Spain





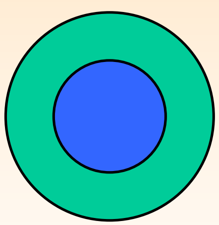
Comparison of microwires with other amorphous soft magnetic materials

Ribbons, Cross section above 5 x 10^3 μm^2, fast and cheap fabrication, extremely soft magnetic properties, too big for microsensors applications



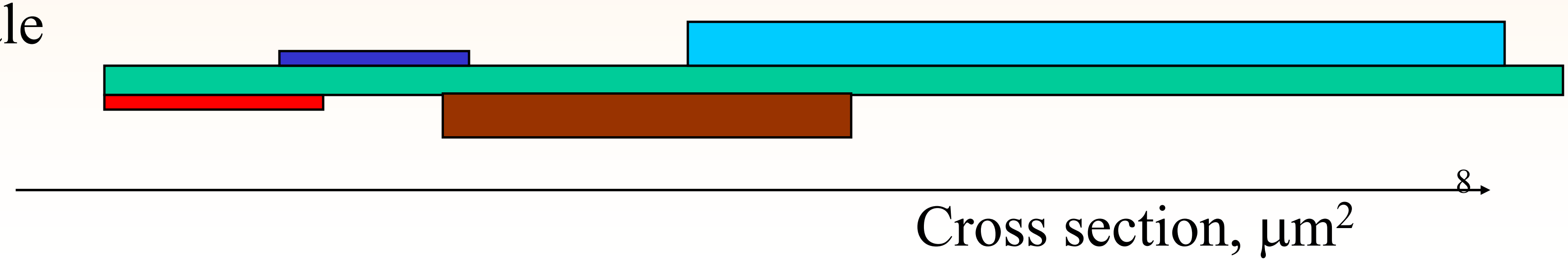
Wires, cross section above 10^3 μm^2, fast and cheap fabrication, good magnetic properties, effect of sample Length - too big for microsensors applications

Thin films, cross section 0.1– 10^2 μm^2, slow fabrication, Higher cost, worse magnetic softness, good compatibility in integrated circuits, effect of substrate



Microwires, typical cross section between 10- 2 x 10^3 μm^2, fast and cheap fabrication, extremely soft magnetic properties, good for micro- sensor applications

Scale

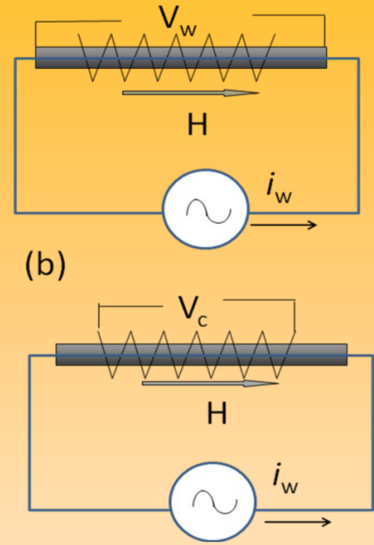


Measurements of GMI

Low-f impedance can be measured by the four-point method.

ΔZ/Z, is defined as:

ΔZ/Z = [(Z (H) - Z (H_{max})] / Z (H_{max})



$V_w = \xi_{zz} i_w$

$V_c = \xi_{\phi z} i_w$

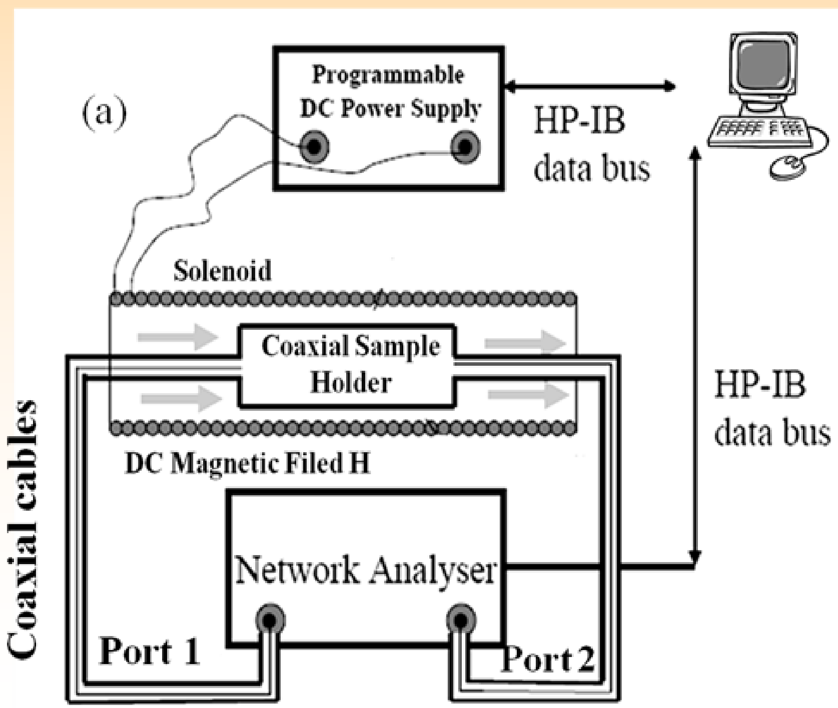
$$Z_{zz} \propto Z = \frac{1+S_{11}}{1-S_{11}} Z_0$$

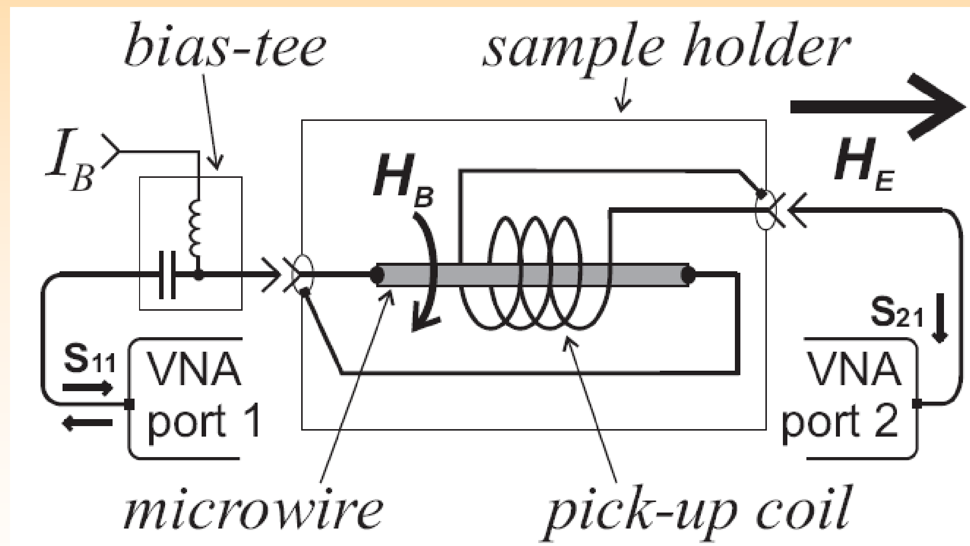
$$i_Z \rightarrow h_\varphi \rightarrow [\hat{\mu}]$$

$$[1]: m_\varphi, m_r$$

$$[2]: m_Z \rightarrow V_C$$

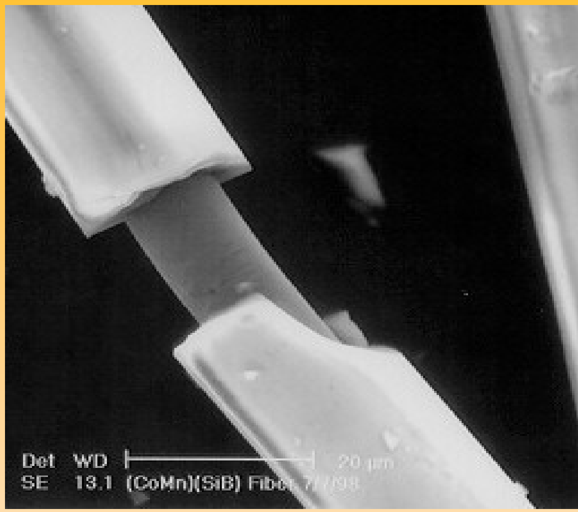
$$Z_{\varphi z} \propto V_c = S_{21}$$





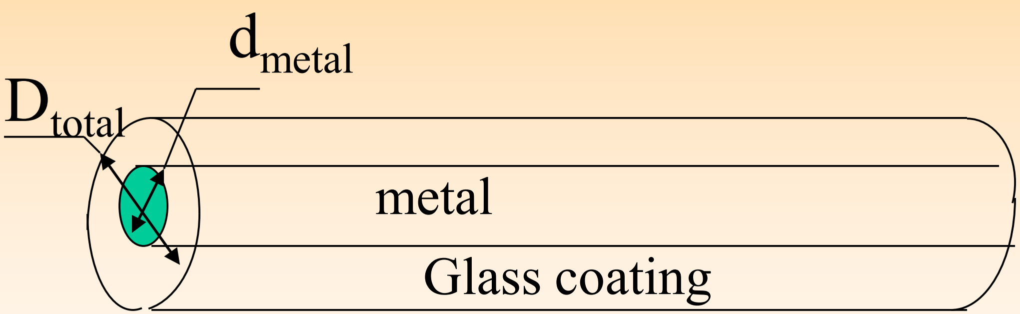
The impedance was evaluated using Network Analyzer HP8753 at frequency between 10MHz -3GHz .

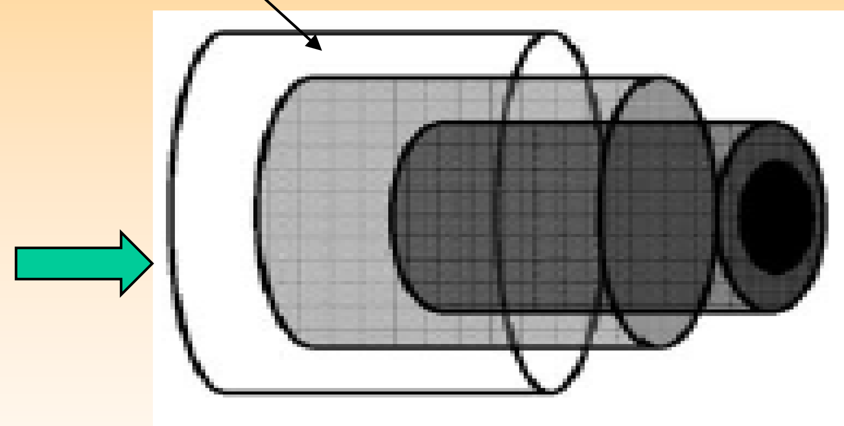
“Classical” glass-coated microwire



Glass-coated microwire coated by metallic coating

Metallic (magnetc or non-magnetic) layer: thin films (thickness 600 nm) of cobalt (Co), permalloy (PY) or copper (Cu) were deposited by rf magnetron sputtering onto the glass coating over the microwires.





Previous knowledge:

K.R. Pirota, M. Hernandez-Velez, D. Navas, A. Zhukov and M. Vázquez, “Multilayer microwires: Tailoring magnetic behaviour by sputtering and electroplating”, Adv. Funct. Mater. 14 No 3 (2004) pp.266-268

M. Vazquez, K. Pirota, J. Torrejon, G. Badini, A. Torcunov, Magnetoelastic interactions in multilayer microwires, JMMM 304 (2006) 197–202

J. Torrejón, M. Vázquez, and L. V. Panina, Asymmetric magnetoimpedance in self-biased layered CoFe/CoNi microwires, JAP, 105, 033911 (2009)

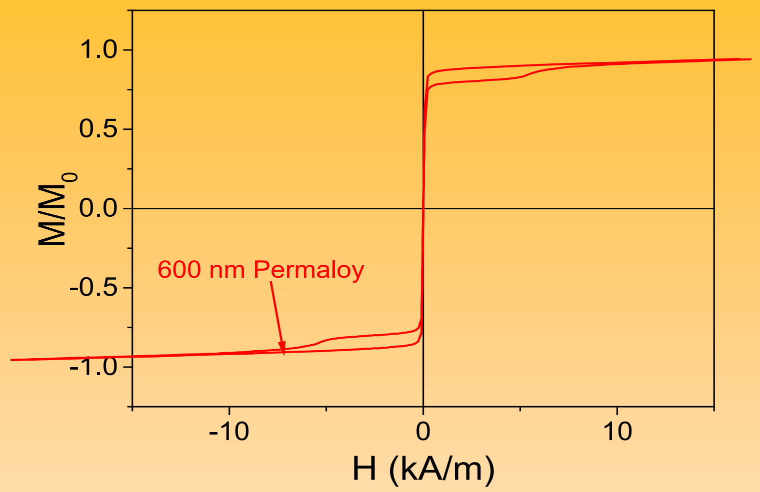
External layer preparation details

The geometry of the sample holder and the deposition system allowed the continuous rotation of the sample holder (at 14 r.p.m.), which permitted a homogenous deposition on all the surface of the microwire (excepting the fixed extremes).
The thicknesses of the thin films were 600 nm. The rate of deposition of each material was determined from x ray reflectometry measurements from thin films deposited over glass substrates in the same sample holder and in the same conditions (magnetron power, distance, rotation speed).

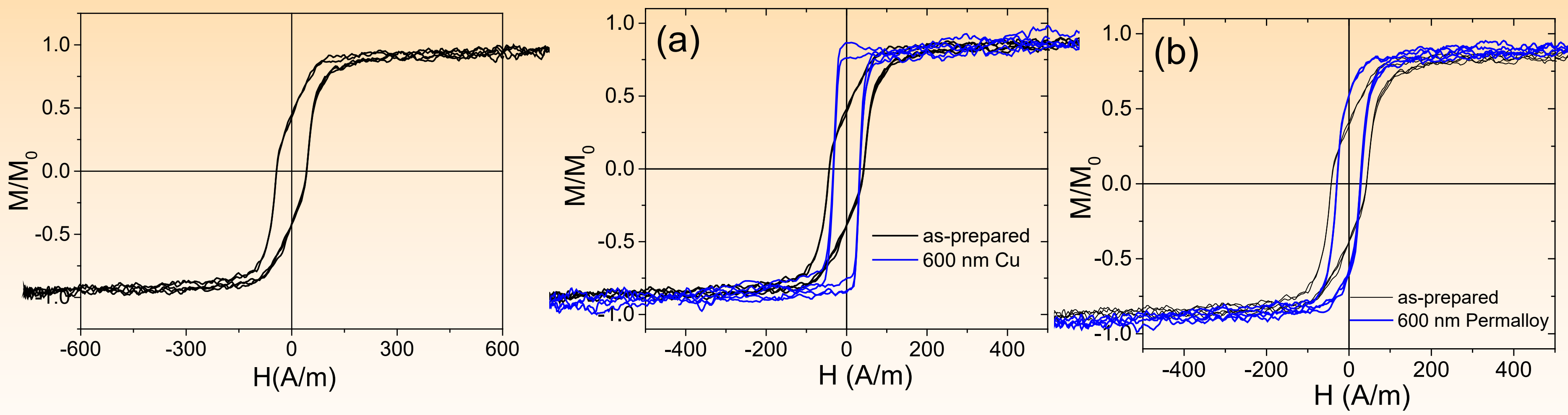
Hence, the thickness of the films over the microwires was controlled by adjusting the deposition time according to the deposition rate.

Magnetic properties

$Fe_{3,8}Co_{67}Ni_{1,4}B_{11,5}Si_{14,5}Mo_{1,7}$; d/D=8,5/11,9µm



Magnetically harder crystalline layer contribution is visible at relatevely hugh magnetic fields

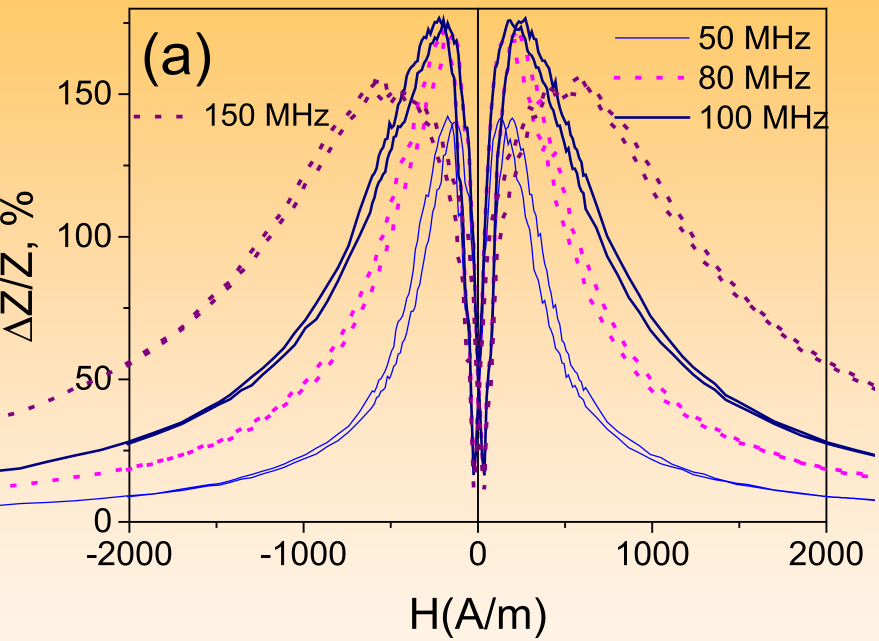


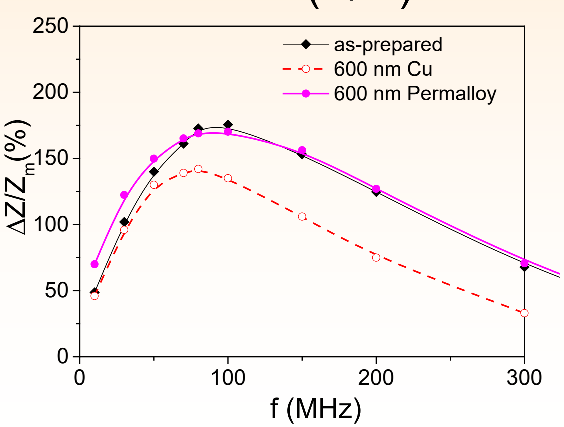
Slight change in low-field región, while visible contribution at high H-values: softer magnetic character of amorphous nucleus

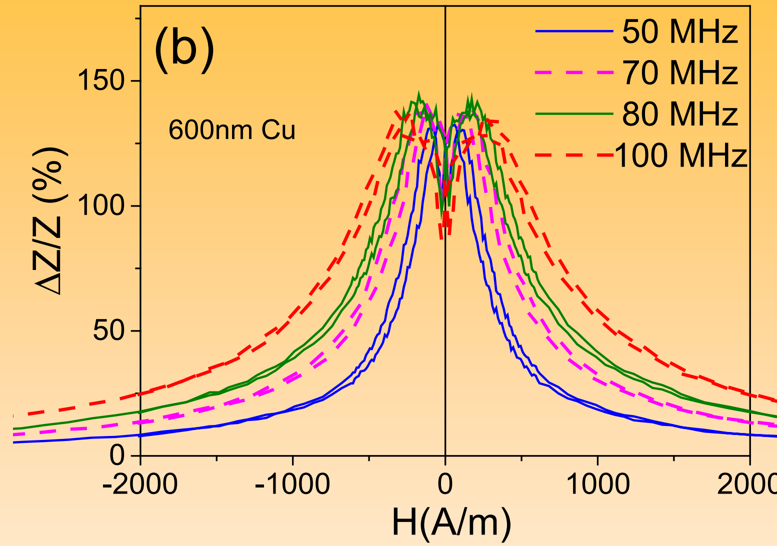
MI effect

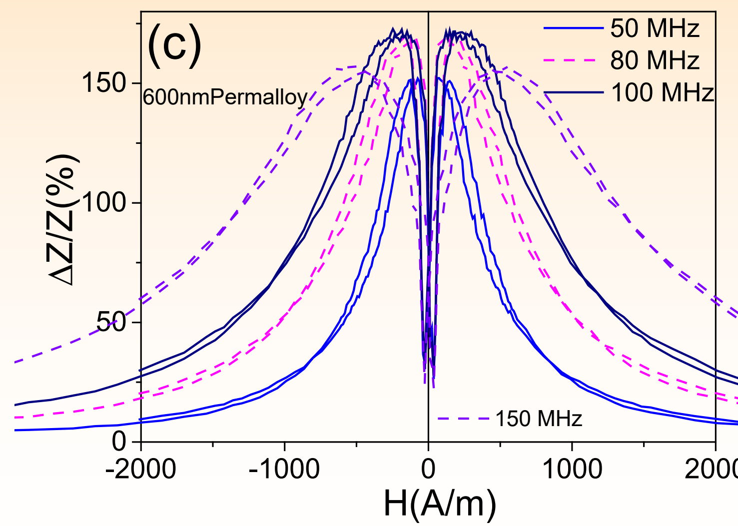
Glass+ coated (deposited) $Fe_{3,8}Co_{67}Ni_{1,4}B_{11,5}Si_{14,5}Mo_{1,7}$ *microwire*

As-prepared glass-coated $Fe_{3,8}Co_{67}Ni_{1,4}B_{11,5}Si_{14,5}Mo_{1,7}$ microwre







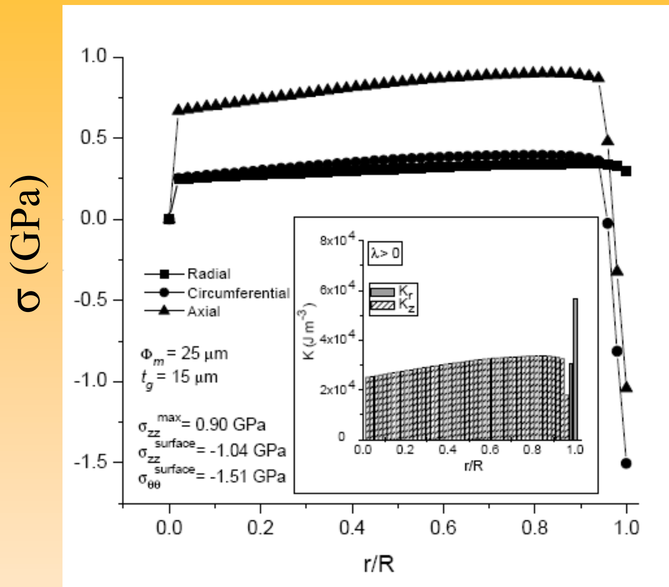


Discussion

Combination of 2 effects:

- Modification of the internal stresses distribution (for both magnetic and non-magnetic outer layers)
- Magnetostatic interaction of inner amorphous soft magnetic nucleus and outer magnetic shell (only for magnetic coating)

Discussion Internal stresses in composite microwires



t (μм)

$\sigma_\phi=\sigma_r=P=\varepsilon E k\Delta/(k/3+1)\Delta+4/3$ (1);

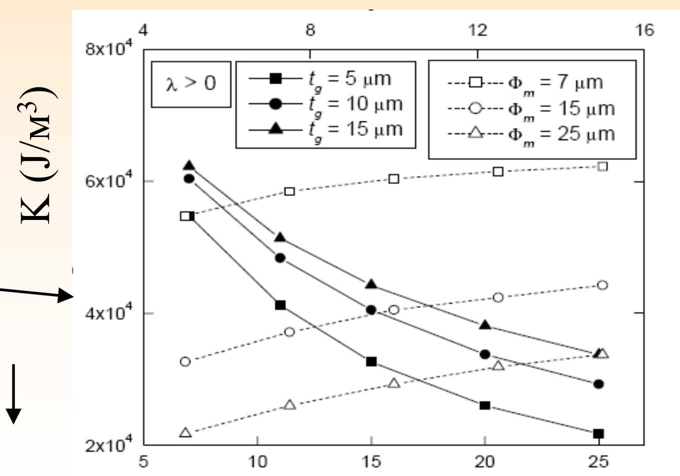
$\sigma_z = P(k+1)\Delta+2/(k\Delta+1)\approx 3\sigma_r$ (2)

where σ_ϕ, σ_r and σ_z - stresses, E_m, E_g – Young modulus $\Delta=(1-\rho^2)/\rho^2$, $k = E_g/E_m$, $\varepsilon = (\alpha_m-\alpha_g)(T_m-T_{room})$, α_1, α_2 – thermal expansion coefficients and T_m,T_{room} – melting temperatures

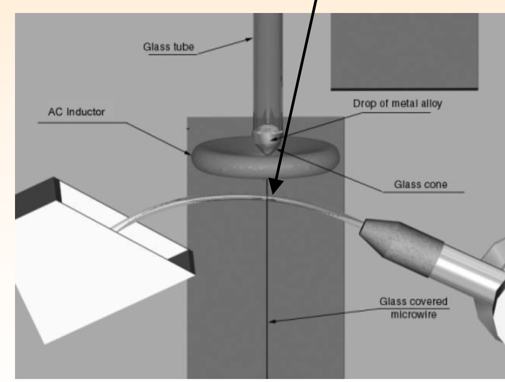
Stress appears at simultaneous solidification of metallic alloy inside the glass coating

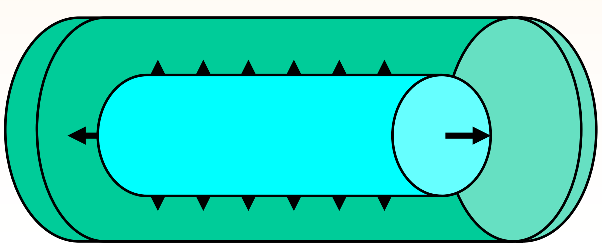
$\sigma_z \approx 50$- 100MPa (estimation)

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



Φ (μм)





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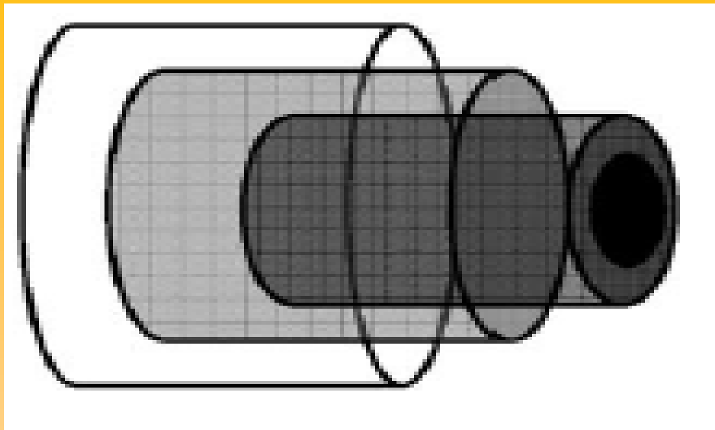
H. Chiriac, T.-A. Ovari, A. Zhukov, J. Magn. Magn. Mater. 254–255 (2003) 469–471

Discussion



The presence of such metallic layers on top of the glass-coating gives rise to additional compressive stresses. The compressive nature of the stresses induced by the deposited metallic layers is confirmed by the modification of the hysteresis loops: after the deposition of metallic layers, a low-field hysteresis loops become more rectangular.

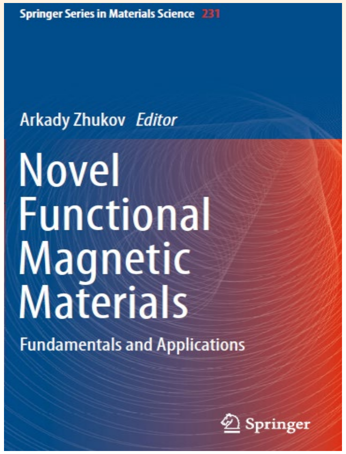
But for PY layer both HLs and GMI effect are different:
Magnetostatic interaction of inner amorphous soft magnetic nucleus and outer magnetic shell (for magnetic coating)

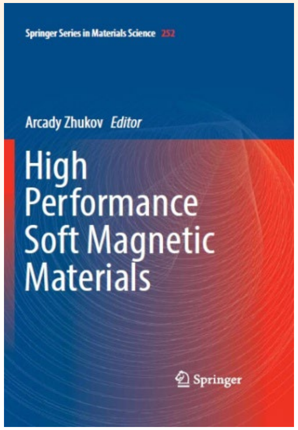
Conclusions

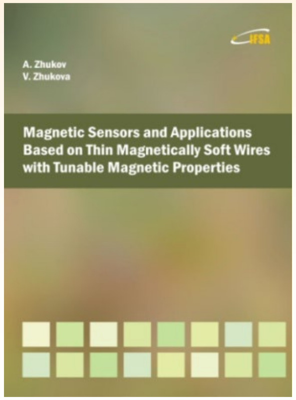
- We report on fabrication and characterization of multi-layered Co-rich glass coated microwires coated with Co –layer with metallic nucleus diameter of about 8.5 μm using modified Taylor-Ulitovsky method.
- We observed contribution of Py- and Cu-layers in hysteresis loops and modification of MI effect for magnetic and non-magnetic coatings.
- Both magnetoelastic and magnetostatic interaction must be considered

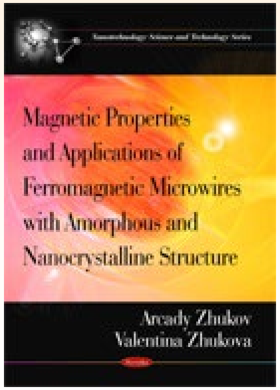
Feature work: GMI characterization of microwires coated with other coating (Co)

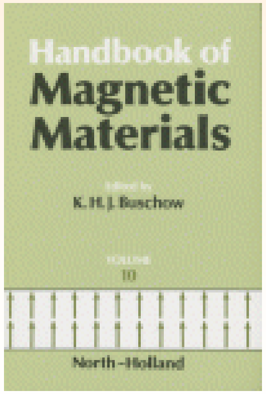
Thank you for the attention!





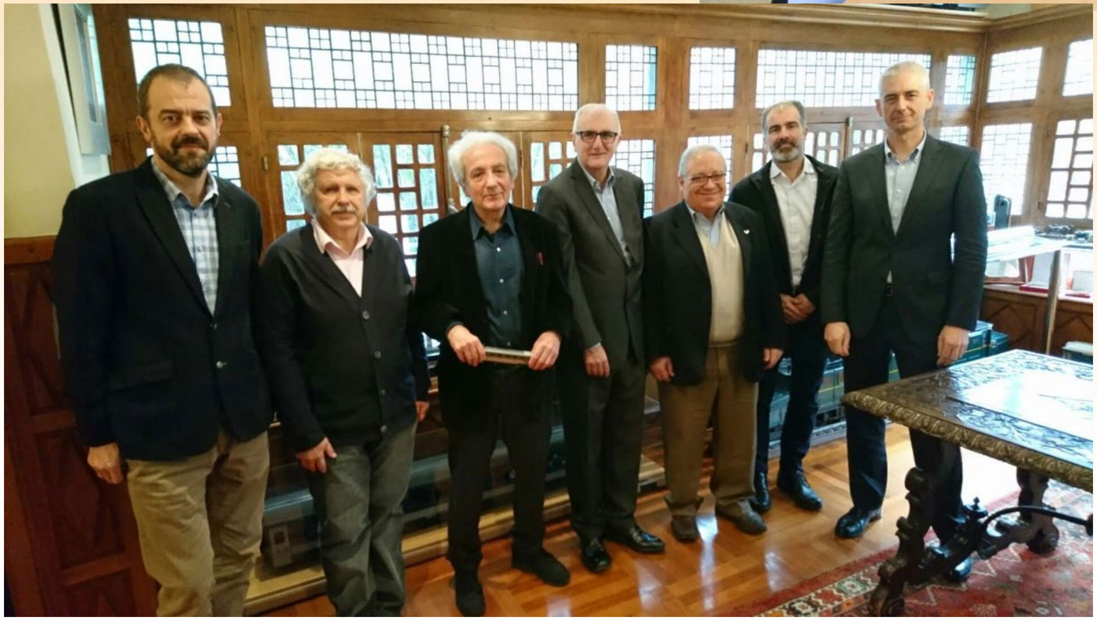






"Advances in Giant Magnetoimpedance Materials" by A. Zhukov, M. Ipatov and V. Zhukov (issue October 2015)

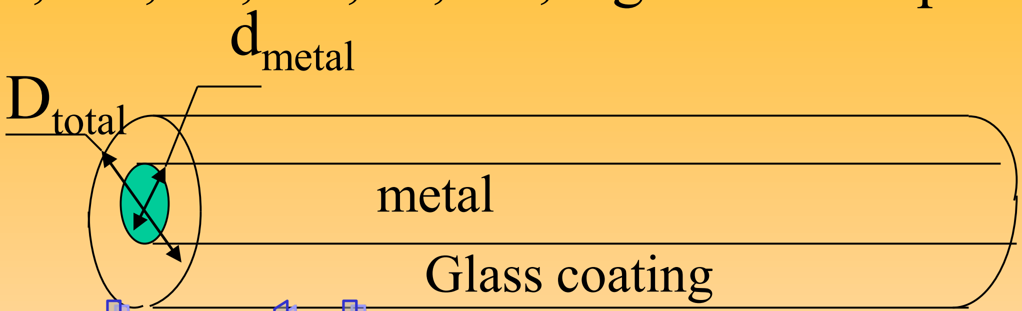

ikerbasque
Development of magnetic microwires for microsensors of interest to railway sector
Desarrollo de microhilos magnéticos para microsensores de interés para el sector ferroviario

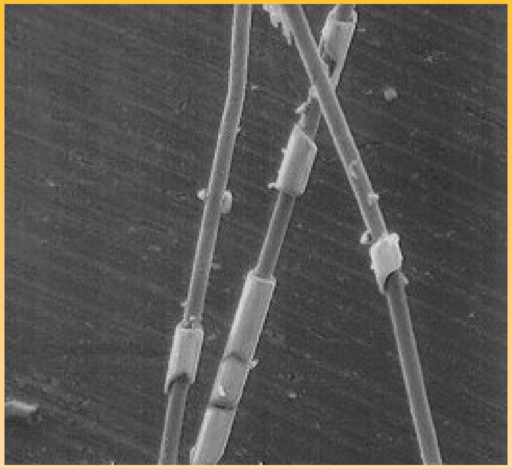


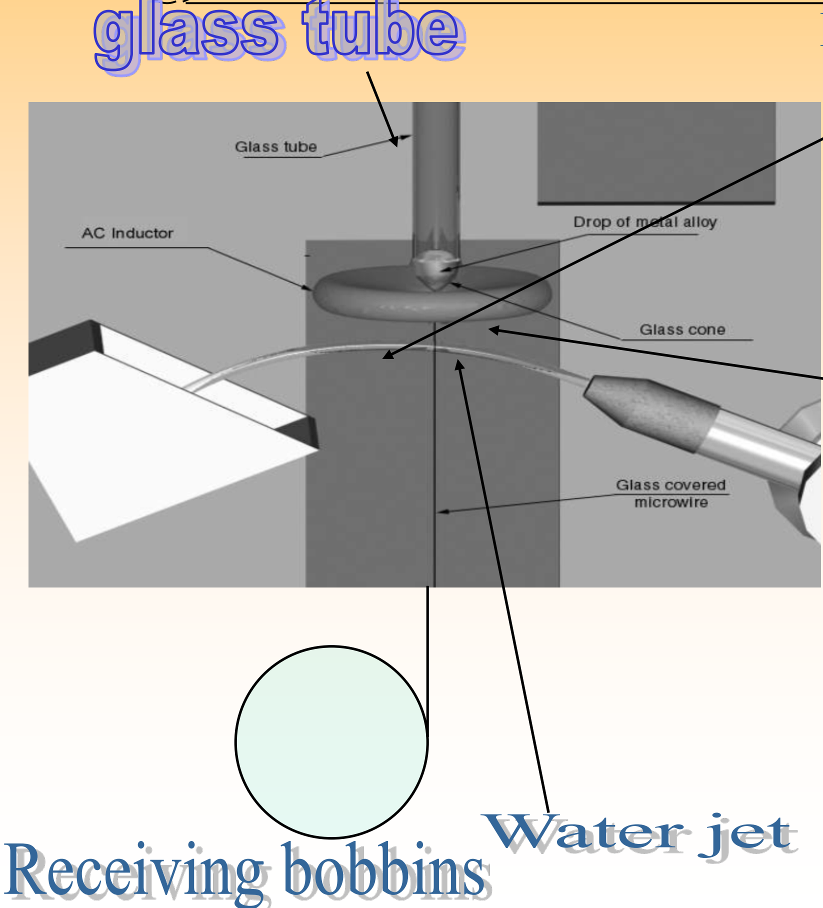
THANK YOU!

Glass coated microwires

Co, Ni , Fe, Cu, Pt, Au, Ag rich compositions







Typical dimensions:
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)

Fabrication – UPV/EHU, and TAMAG, Spain