Effect of magnetoelastic anisotropy on domain wall dynamics in amorphous microwires

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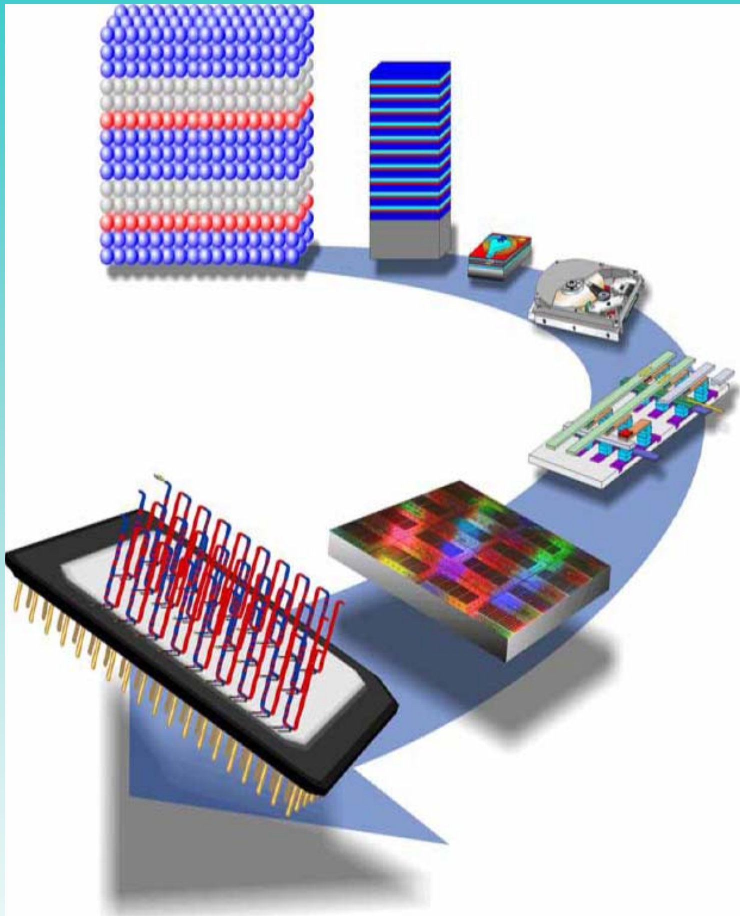
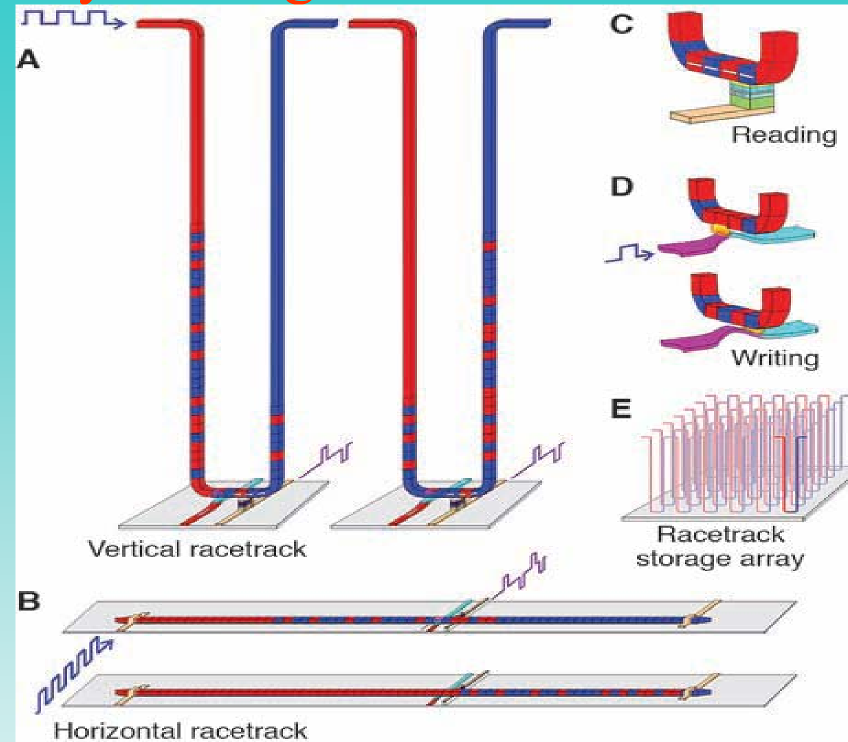
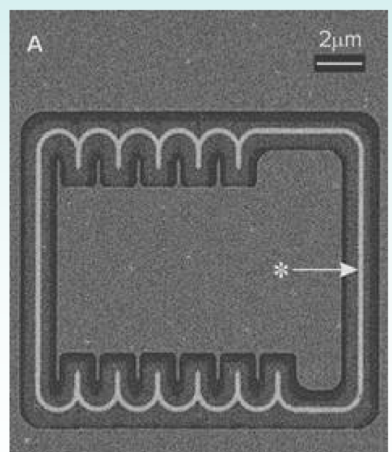
Outline

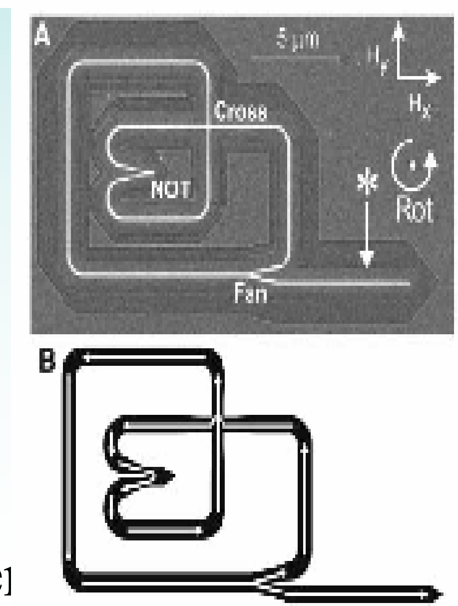
1. INTRODUCTION
1.1. STATE OF THE ART
2.EXPERIMENTAL TECHNIQUE :
-FABRICATION PROCESS
-MEASUREMENTS METHODS
3.EXPERIMENTAL RESULTS
4. **Domain Wall Propagation (DWP)**
4.1. Viscous region
4.2. Effect of magnetoelastic anisotropy
4.3. Non-linearity and defects
5. DISCUSSION
6. CONCLUSIONS

Motivation: Proposed magnetic memory and logic based on DWP







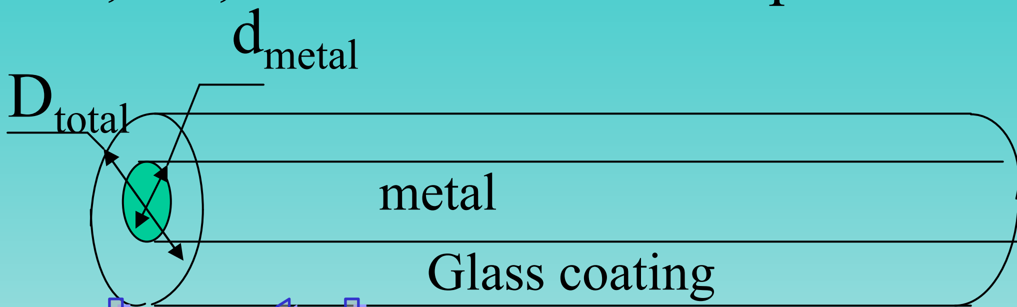


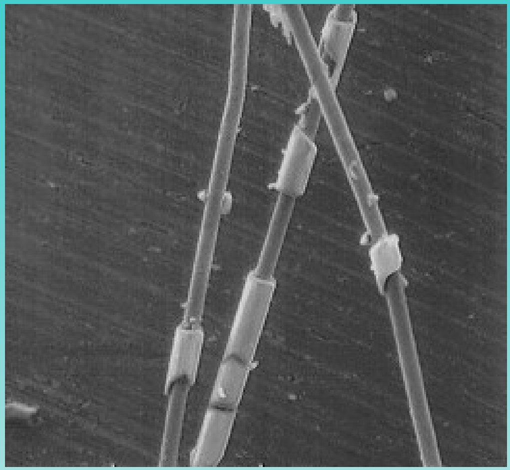
Possible MRAM and logic applications
Stuart S. P. Parkin, *et al. Science* **320**, 190 (2008);

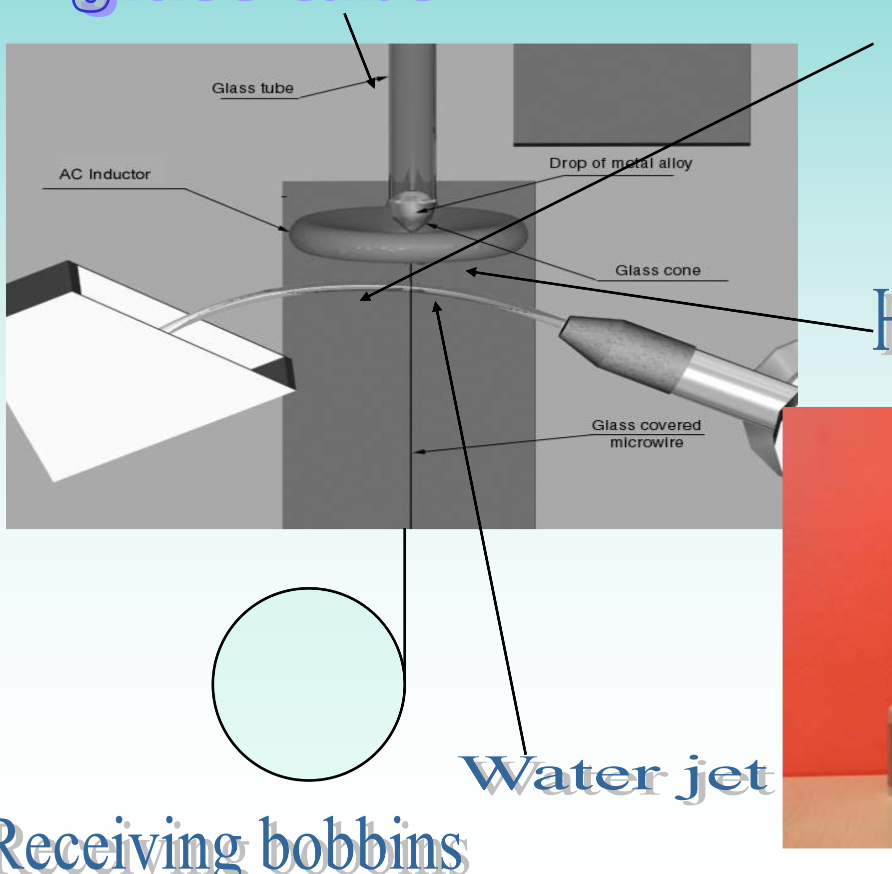
Controlled and fast DW moveme

Fabrication of Glass coated microwires

- Co, Ni , Fe and Cu rich compositions







Typical dimensions:
Total diameter 4-40 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

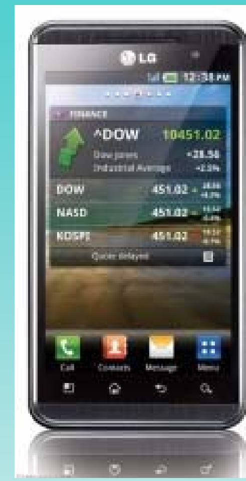
Application in Smart phone using MI sensor with microw

LG-optimus ONE

All models are manufacturing.

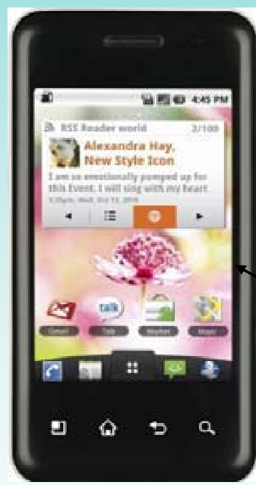
Amount $4x10^6$/month MI elements

LG-optimus 3D



LG-optimus 2X

LG-optimus Pad
(Tablet PC)



LG-LU3100

LG-VS660

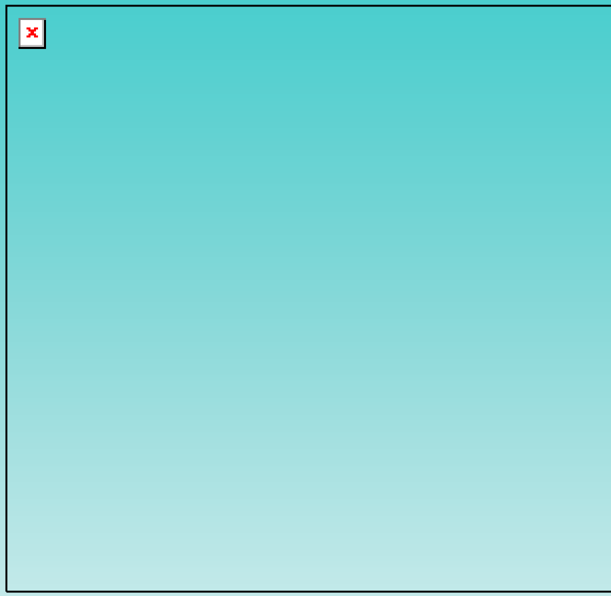
LG-optimus chat

LG-MS690

SHARP

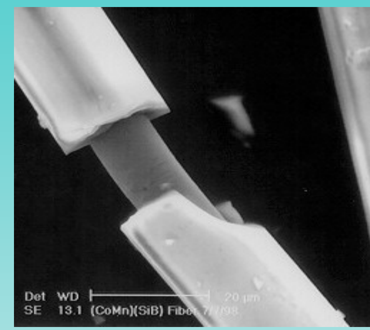
Garmin-ASUS

Internal stresses in composite microwires



σ (MPa)

t (μм)



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

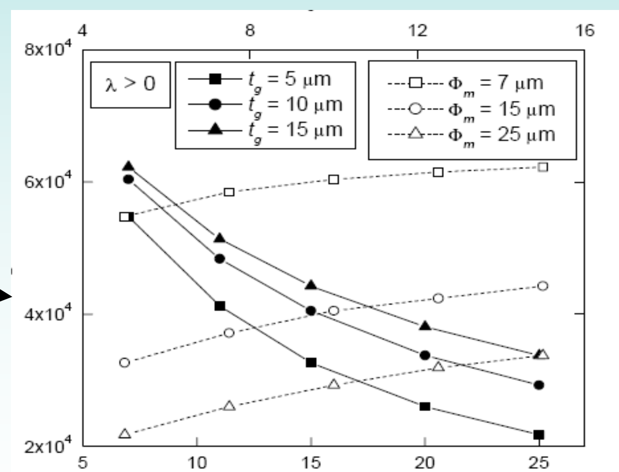
$\sigma_z = P(k+1)\Delta + 2/(k\Delta+1) \approx 3\sigma_r$ (2)

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

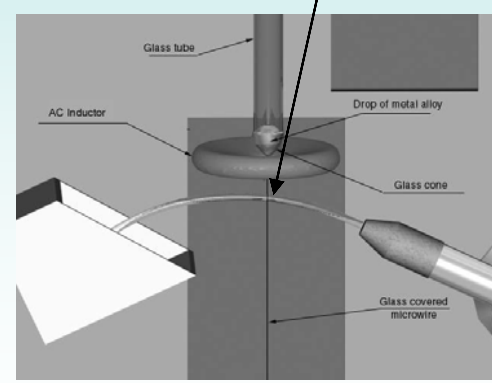
Stress appears at simultaneous solidification of metallic alloy inside the glass coating

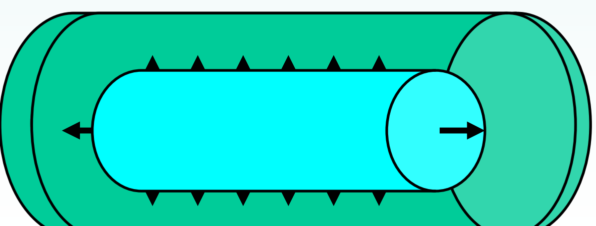
$\sigma = f(\rho)$, $\rho = d/D$

K (J/м^3)



Φ (μм)





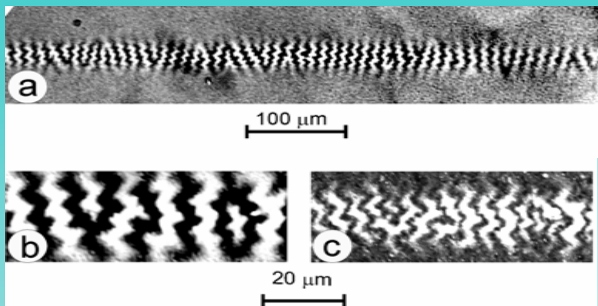
T↓

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

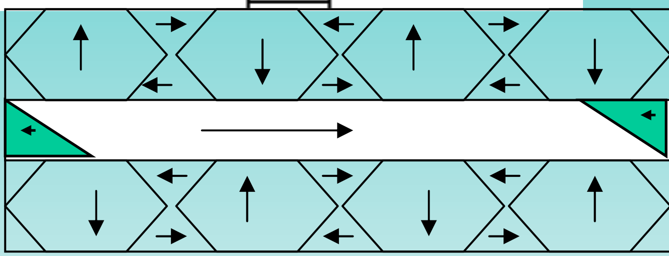
MAGNETIZATION PROCESSES IN Fe-RICH THIN MAGNETIC WIRES.

Yu. Kabanov, A. Zhukov, et al,

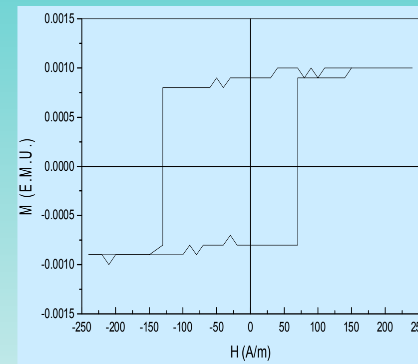
Appl. Phys. Lett. 87 (2005) p142507



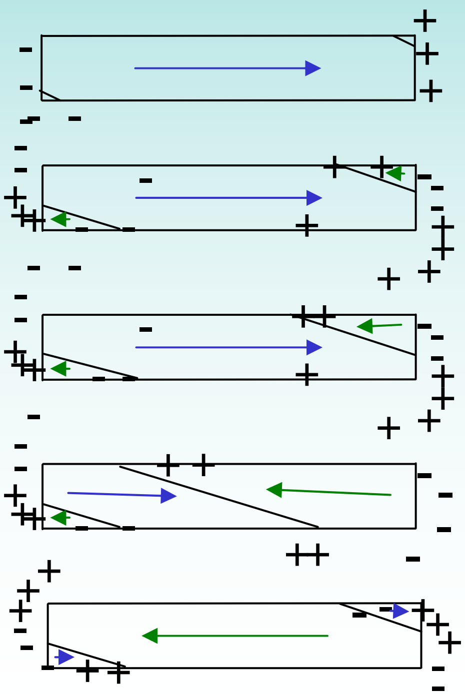
Bistable Loops



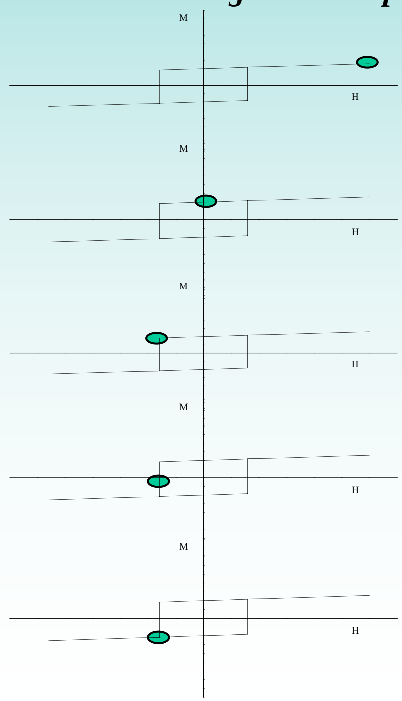
Thin Dimensions:
2 mm long
5 µm diameter



Pyrex coated FeSiBC amorphous microwire



Schematic presentation of the re-magnetization process



A. Zhukov et al, JMMM(1995)

Magnetic properties suitable for technologic applications:

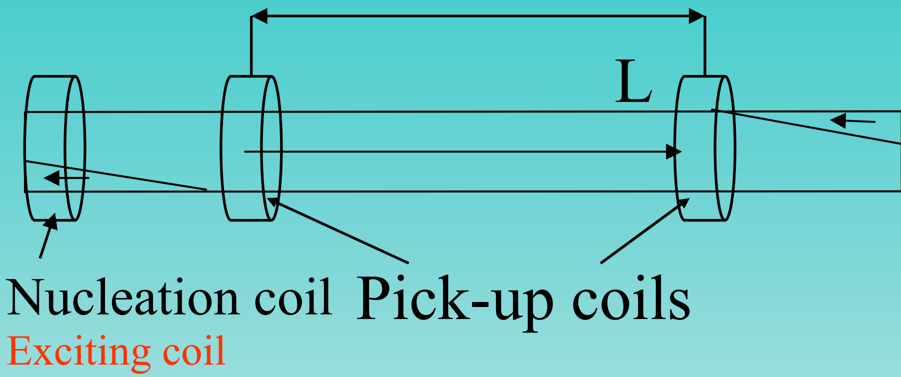
-Enhanced magnetic softness and GMI

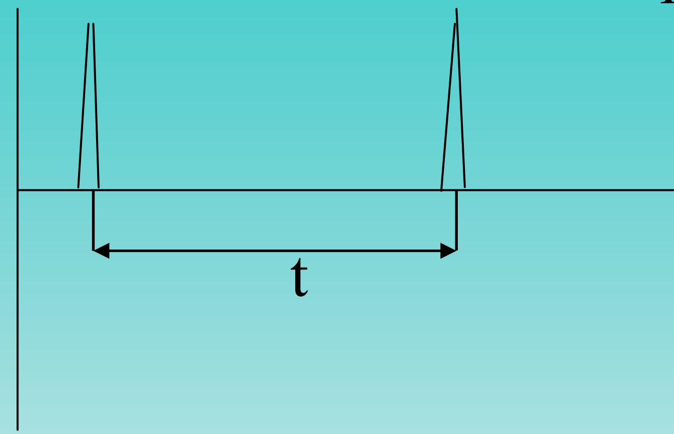
-Thin Dimensions

-Magnetic bistability ($\lambda > 0$) and DW propagation

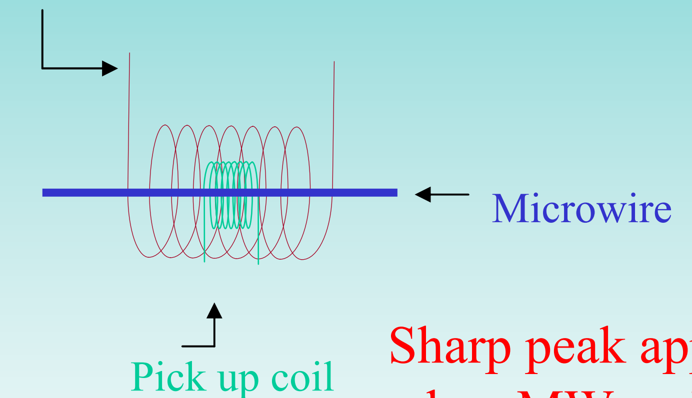
Measurements technique

1. Sixtus-Tonks like experiment

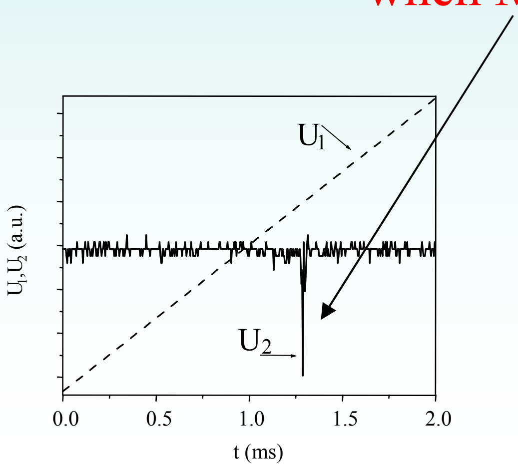


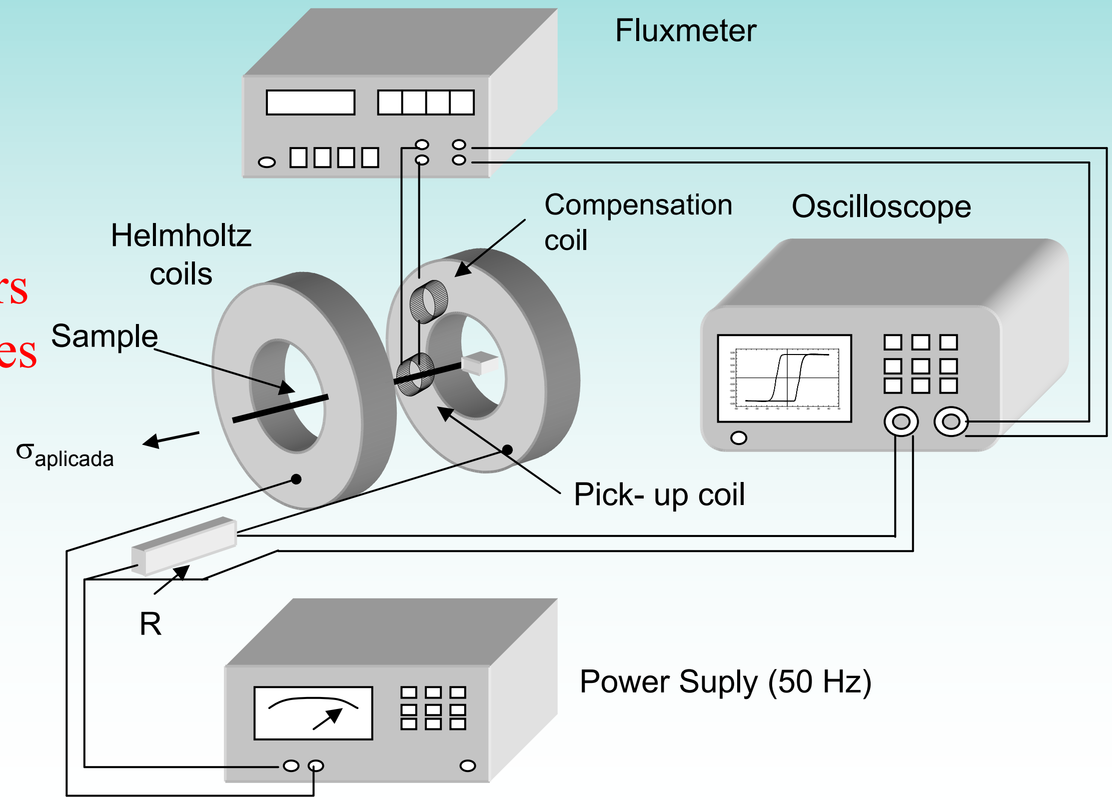


$V = L/t$

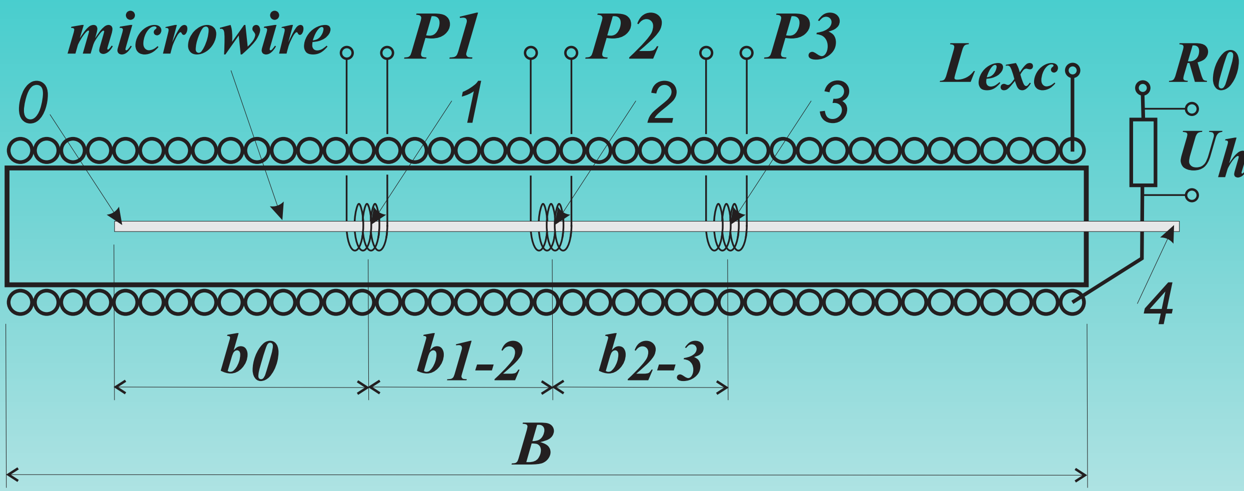


Sharp peak appears when MW switches





modified set-up for DW propagation studies



Differences:

1- single layered wounding of magnetizing solenoid with reduced number of turns for reduction of time of transient process to avoid the situation when the DW can start propagating while *H* is still growing

2- Use three pick-up coils set to detect possible multible DW nucleation

M. Ipatov,V. Zhukova, A. K. Zvezdin and A. Zhukov,
J. Appl. Phys. ,**106**, 103902, 2009

Effect of magnetoelastic energy

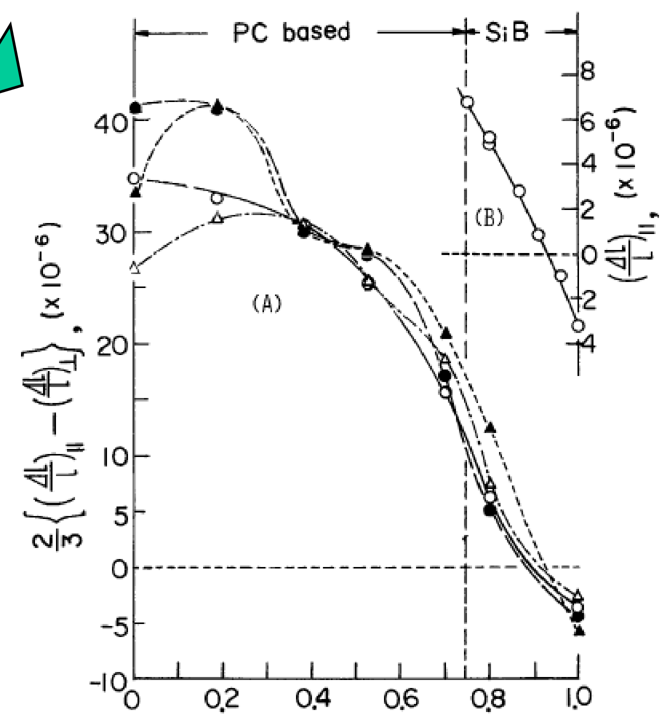
$K_{me} \approx 3/2\, \lambda_s \sigma_i$, :

λ_s -determines by the chemical composition

$\sigma = \sigma_i + \sigma_a$

σ_a‘- applied stresses

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



Sources:

1. H. Chiriac, T. A. Ovari, and Gh. Pop, 1995 *Phys. Rev. B*, **52** 10104.
2. J. Velázquez, M. Vazquez and A. Zhukov, J. Mater. Res. V.11 No10 (1996) 2499-2505

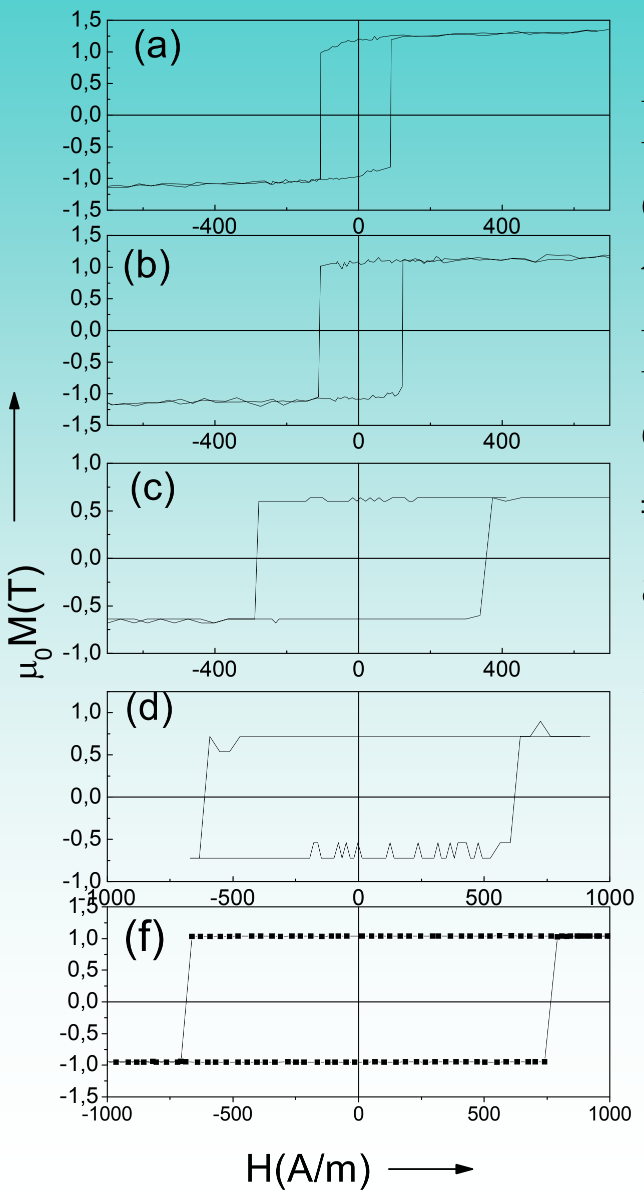
Source:

JAPAN. J. APPL. PHYS. VOL. 15 (1976), No. 4

Magnetostriction of Fe-Co Amorphous Alloys

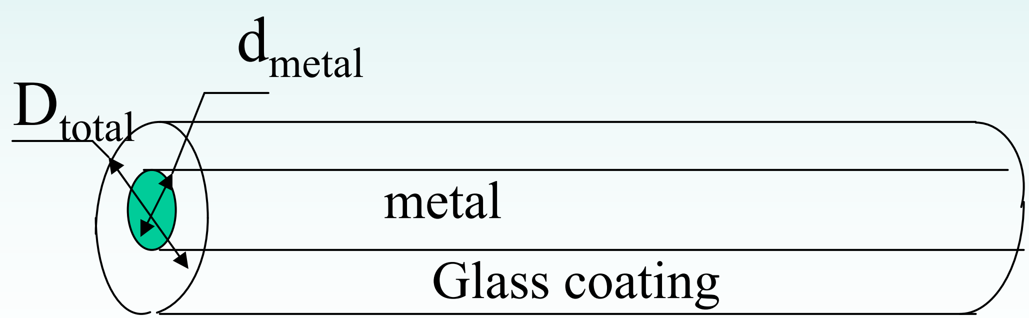
Hiroyasu FUJIMORI, Ken Ichi ARAI†, Hisanori SHIRAE, Hideo SAITO, Tsuyoshi MASUMOTO and Noboru TSUYA†

Effect of magnetelastic anisotropy



Hysteresis loops of Fe-rich microwires with different metallic nucleus diameter d and total diameters D:

$Fe_{70}B_{15}Si_{10}C_5$ microwires 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 of $Fe_{72.75}Co_{2.25}B_{15}Si_{10}$ microwire with ρ= 0.14, d≈ 1.4 μm D≈ 10 μm (f).



ρ=d/D

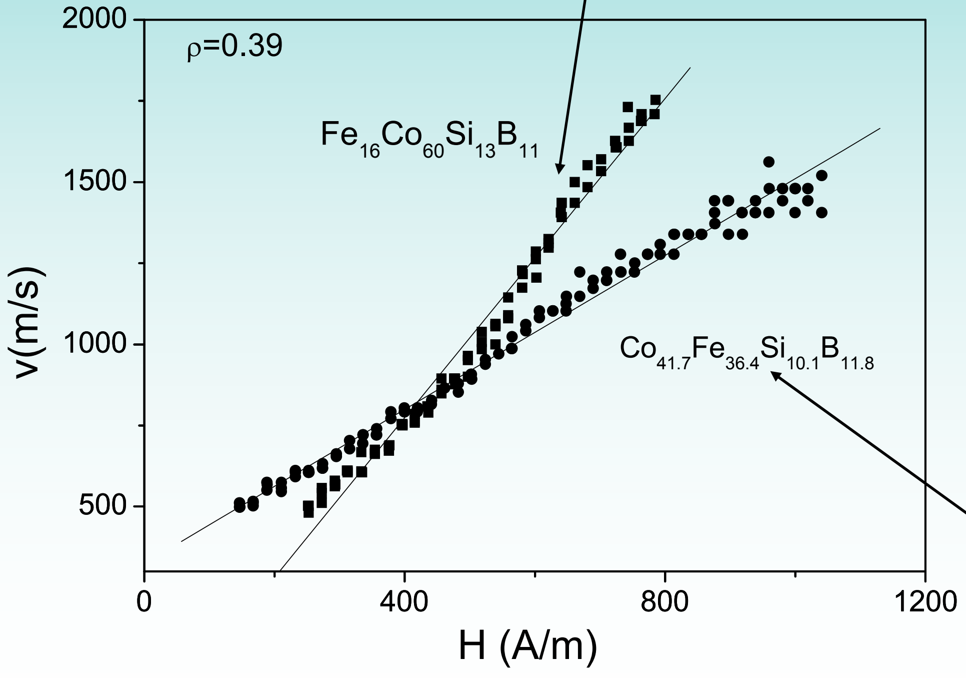
Effect of magnetolastic anisitropy on DW propagation

$v=S(H-H_0)$

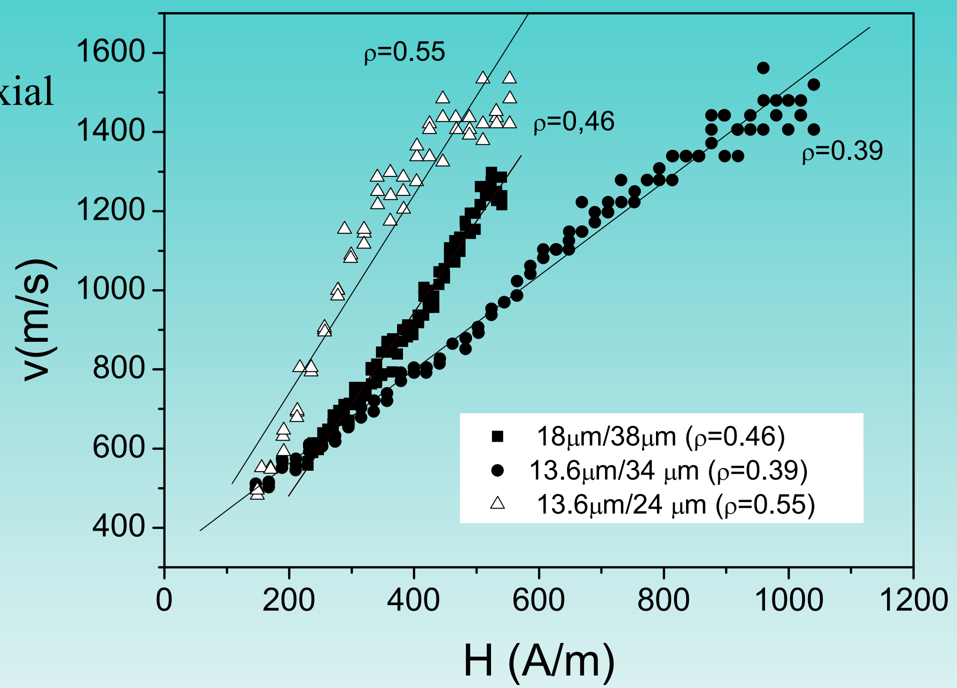
where S is the DW mobility, H is the axial magnetic field and H_0 is the critical propagation field.

v(H) dependences for $Fe_{16}Co_{60}Si_{13}B_{11}$ and $Co_{41.7}Fe_{36.4}Si_{10.1}B_{11.8}$ microwires with ρ=0,39:

effect of magnetostriction $\lambda_s \approx 20x10^{-6}$



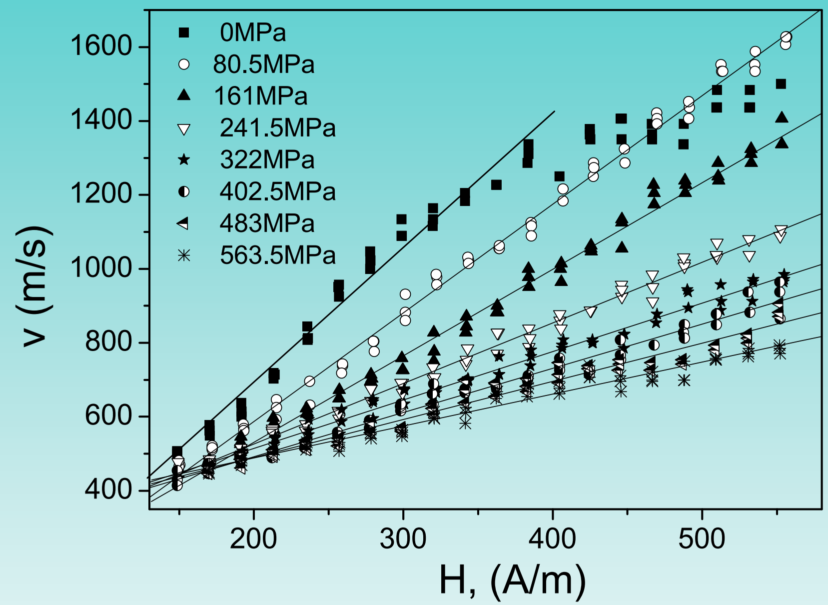
$\lambda_s \approx 40x10^{-6}$



v(H) dependences for $Co_{41.7}Fe_{36.4}Si_{10.1}B_{11.8}$ microwires with different ratios ρ:

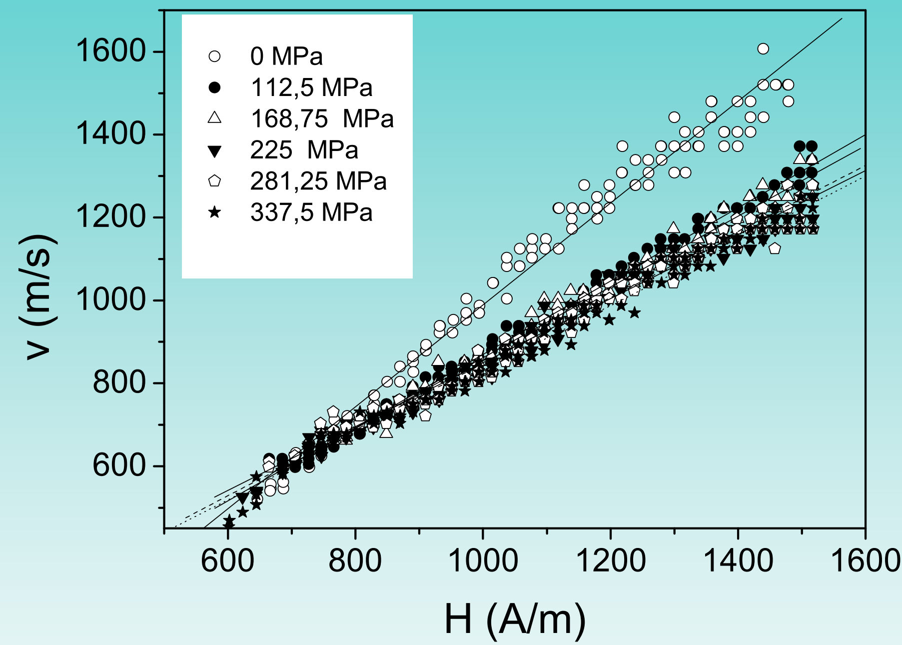
Effect of internal stresses

Effect of magnetolastic anisitropy on DW propagation



v(H) dependences for $Co_{41.7}Fe_{36.4}Si_{10.1}B_{11.8\ 3}$ microwires (d≈ 13,6μm, D≈ 24,6μm, ρ≈ 0,55) measured under application of applied stresses, σ_a.

$\lambda_s \approx 20x10^{-6}$



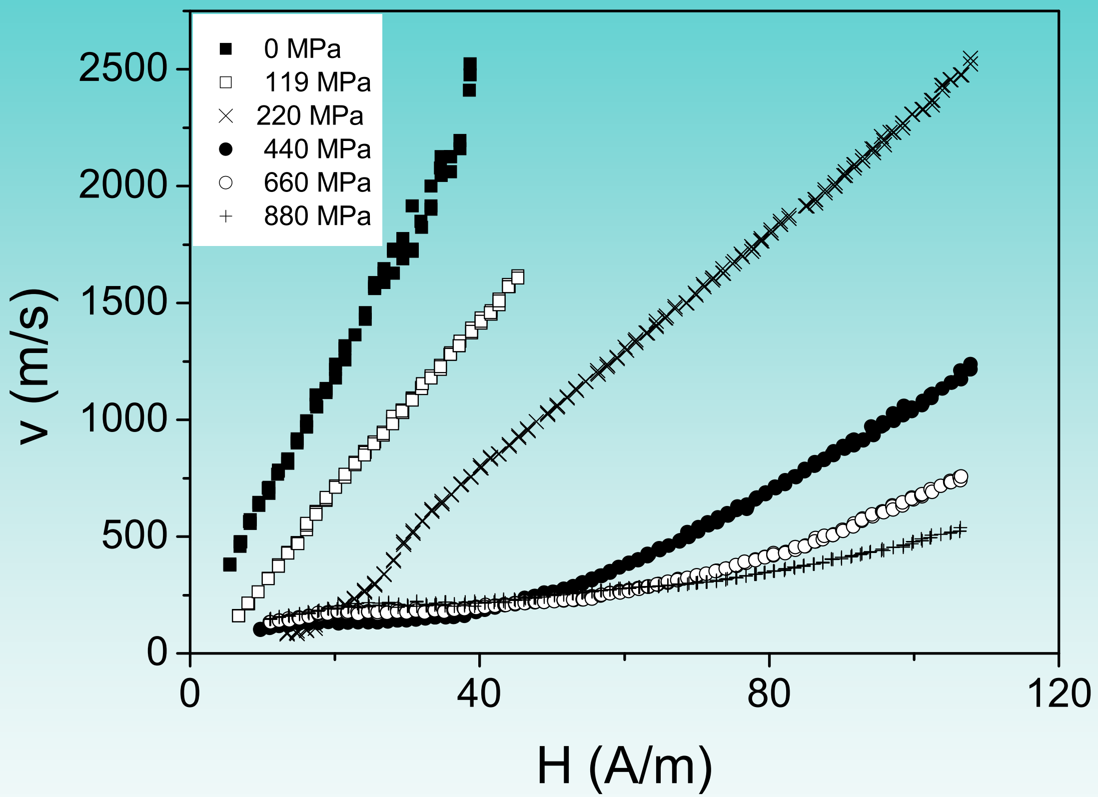
v(H) dependences for $Fe_{16}Co_{60}Si_{11}B_{13}$ microwires (d≈ 12μm, D≈ 29μm, ρ≈ 0,41) measured under application of applied stresses, σ_{app}.

$\lambda_s \approx 40x10^{-6}$

Effect of magnetolastic anisitropy on DW propagation

$\lambda_s \approx 10^{-7}$

$v=S(H-H_0)$, where S is the DW mobility, H is the axial magnetic field and H_0 is the critical propagation field.



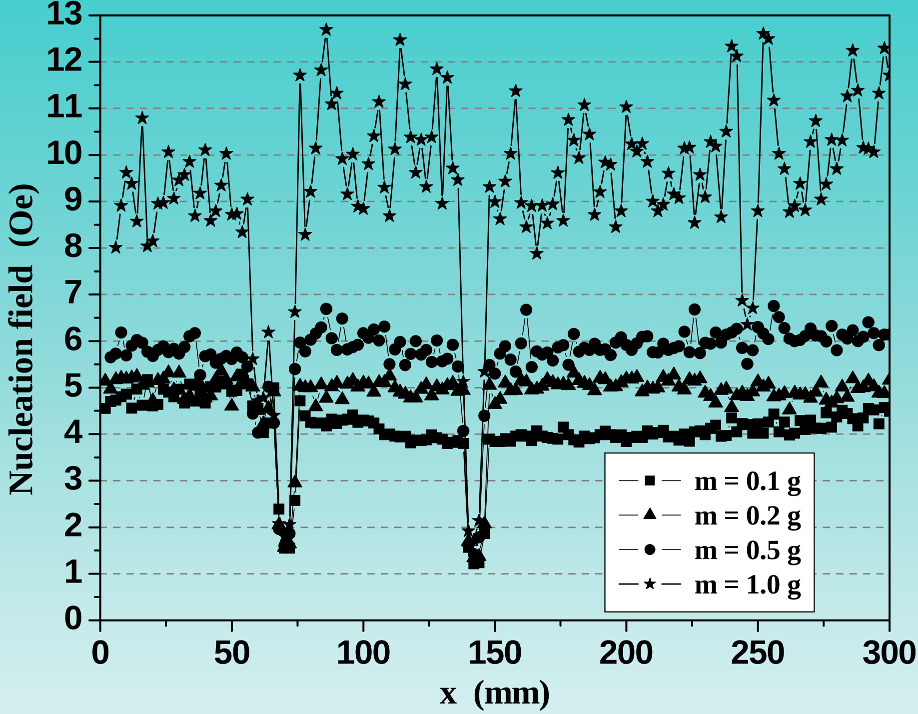
The domain wall mobility, S, is given by:
$S=2\mu_0 M_s/\beta$
This damping is related to the Gilbert damping parameter, α and is inversely proportional to the domain wall width δ_w,
$\beta_r \approx \alpha M_s/\gamma\delta_w \approx M_s(K_{me}/A)^{1/2}$

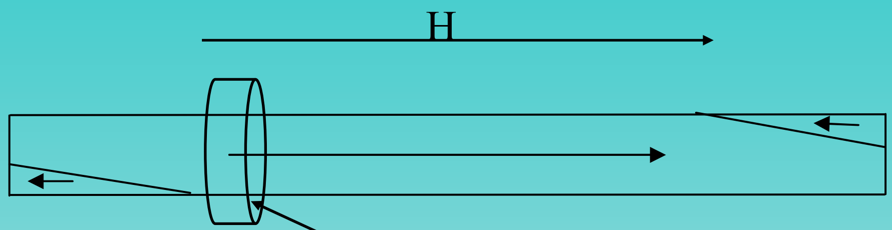
v(H) dependences for $Co_{56}Fe_8Ni_{10}Si_{11}B_{16}$ microwires measured under application of applied stresses, σ_{app}.

Magnetoelastic energy, K_{me}, is given by
$K_{me} \approx 3/2\ \lambda_s\sigma$,

V(H) is affected by K_{m}

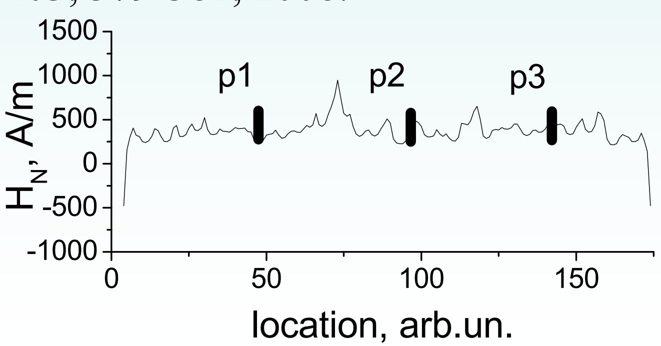
Defects in microwires



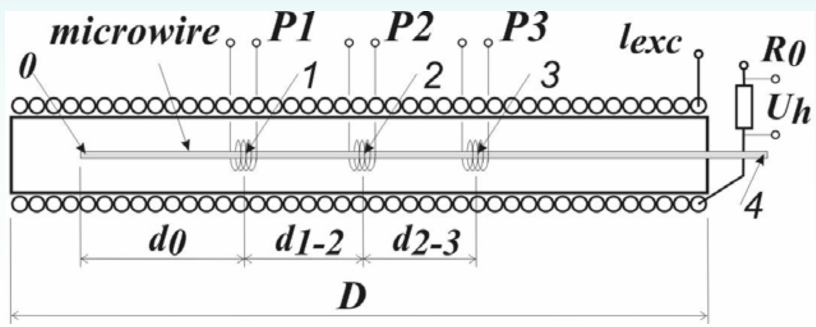


Moving nucleation and pick-up coil (far from ends)

M. Ipatov,N. Usov, A. Zhukov et al.. "Local nucleation fields of Fe-rich microwires and their dependence on applied stresses" Phys. B. 403, 379-381, 2008.



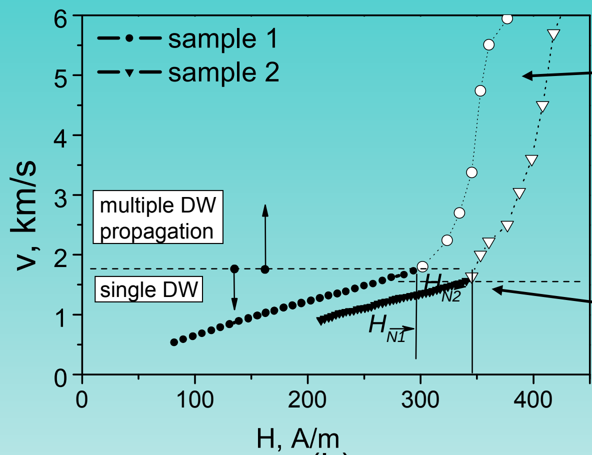
Modified method (3 pick-up coils)



On non-linearity of v(H) dependence

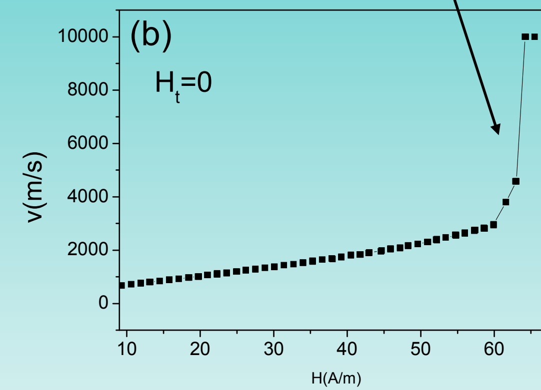
$v=S(H-H_0)$ where *S* is the DW mobility, *H* is the axial magnetic field and H_0 is the critical propagation field.

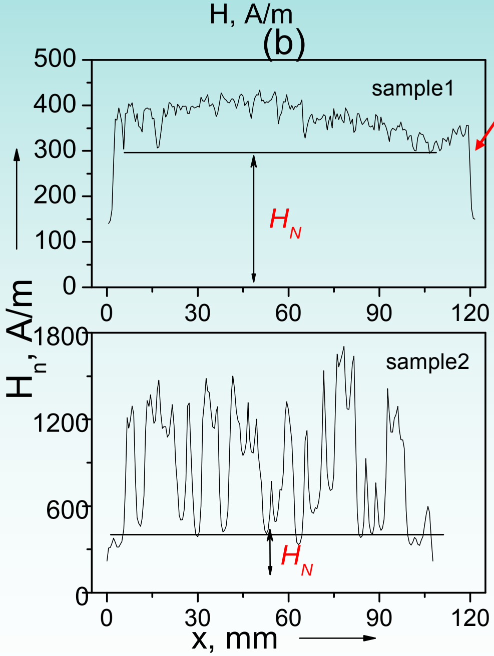
$H>H_N$



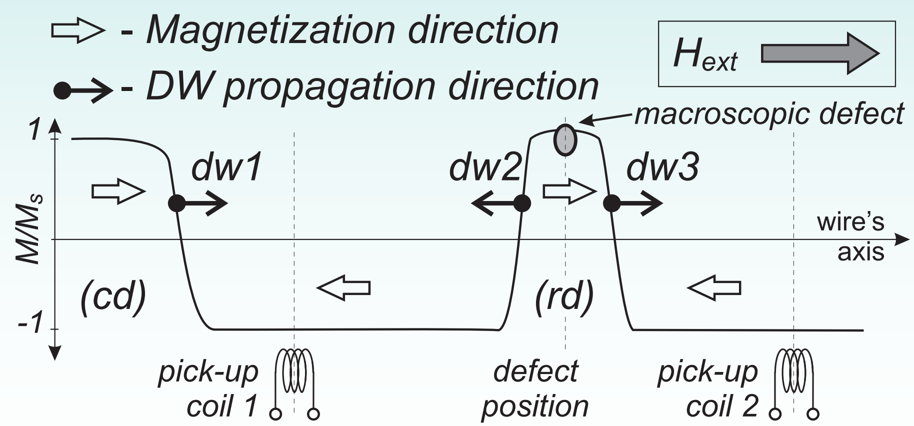
H_N is lower at the ends

$H<H_N$





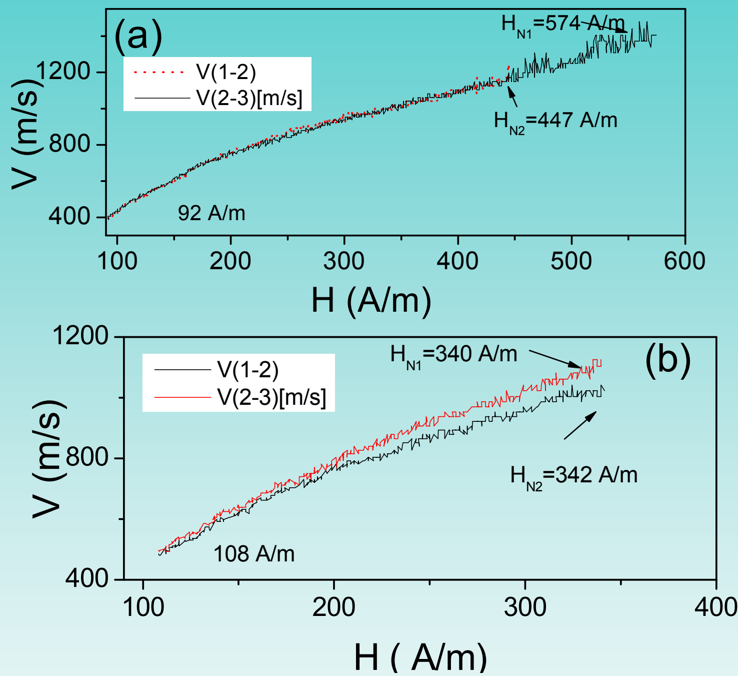
Dependences of domain wall velocity versus applied magnetic field measured in magnetically bistable amorphous microwires (a) and distribution of local nucleation fields measured in the same samples (b)



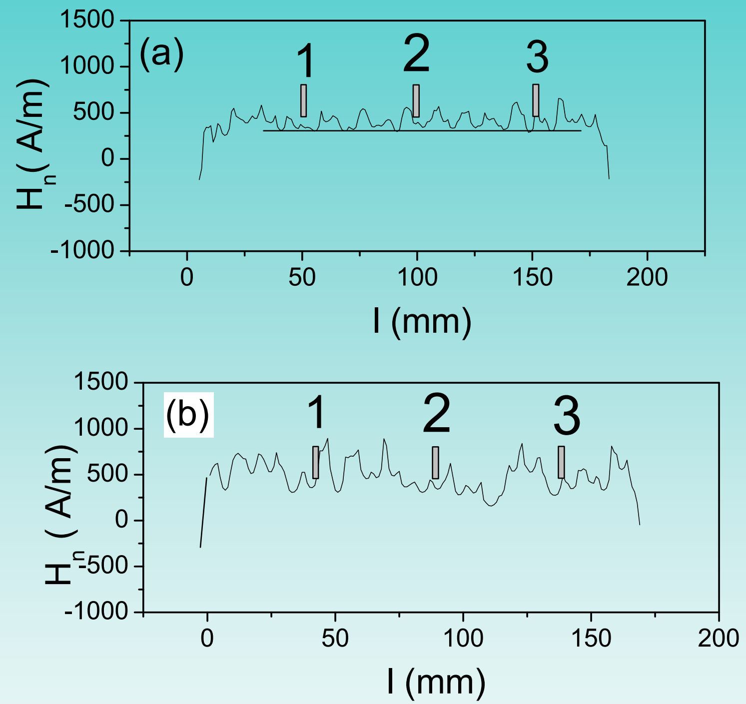
Role of defects for $H>H_N$

(J. Appl. Phys., **106** (2009) 103902 ,)

Role of Defects

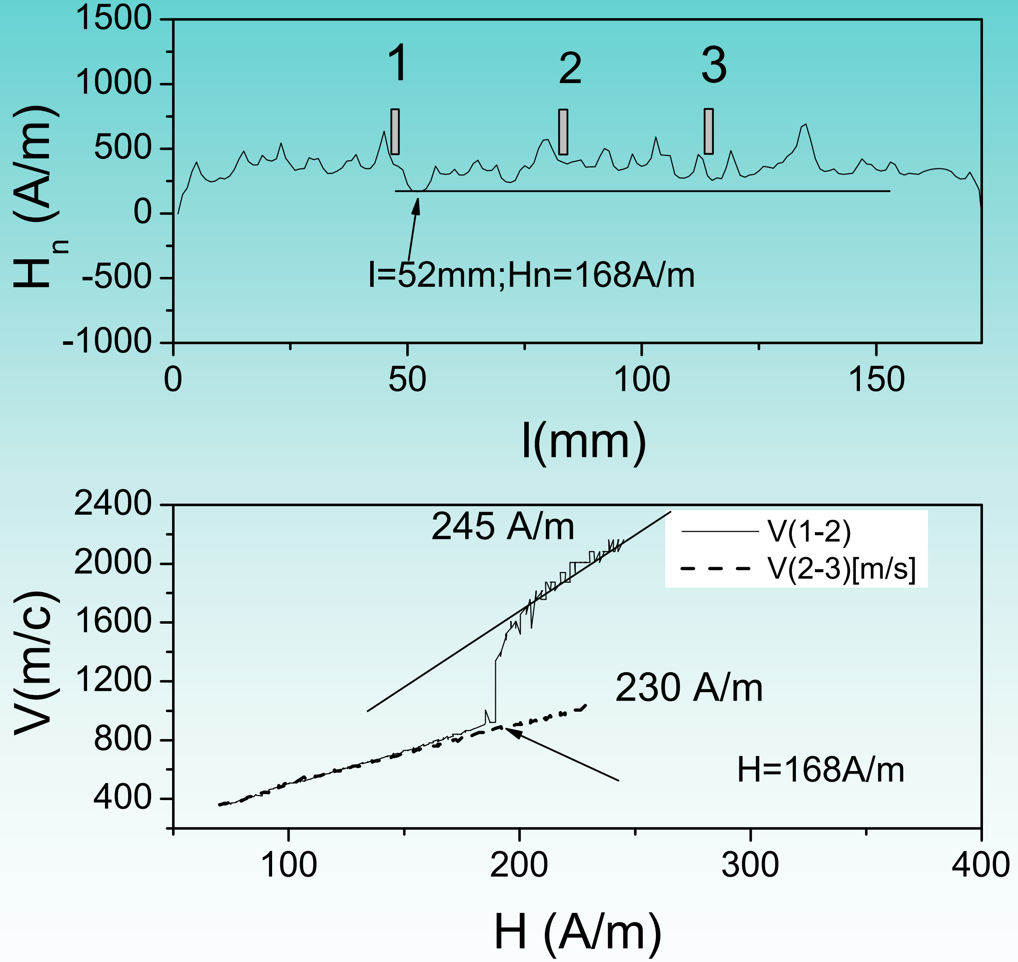


Typical v(H) dependences measured in different samples of magnetically bistable amorphous $Fe_{74}B_{13}Si_{11}C_2$ microwires exhibiting (a) **uniform** and (b) **accelerated** DW propagation.



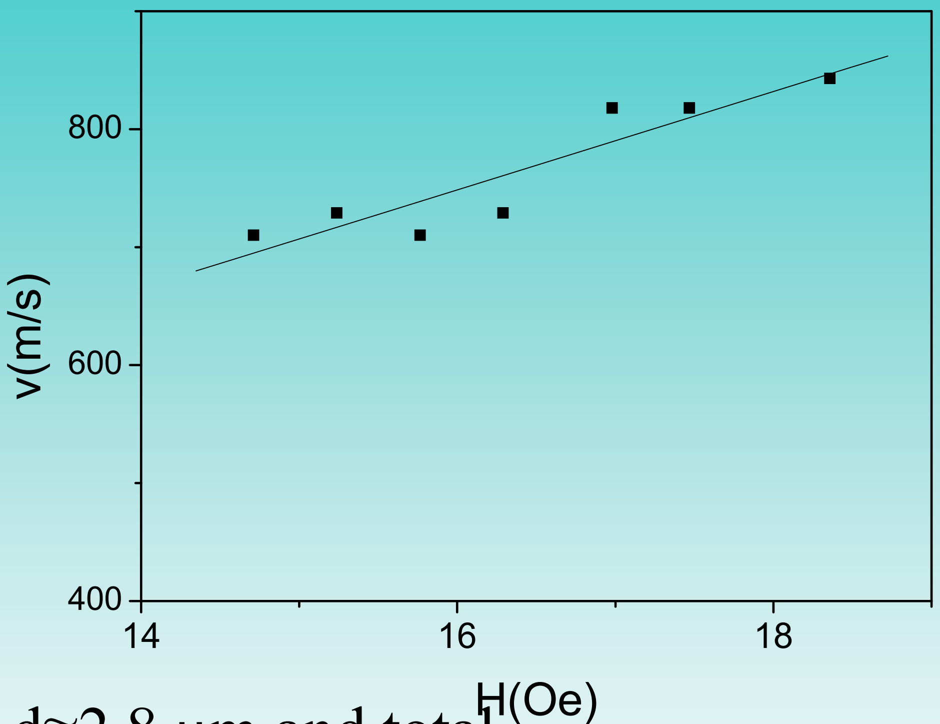
Typical distributions of the local nucleation fields measured in the same $Fe_{74}B_{13}Si_{11}C_2$ microwires for (a) uniform and (b) accelerated domain wall propagation. 1, 2 and 3 are the position of the pick-up coils.

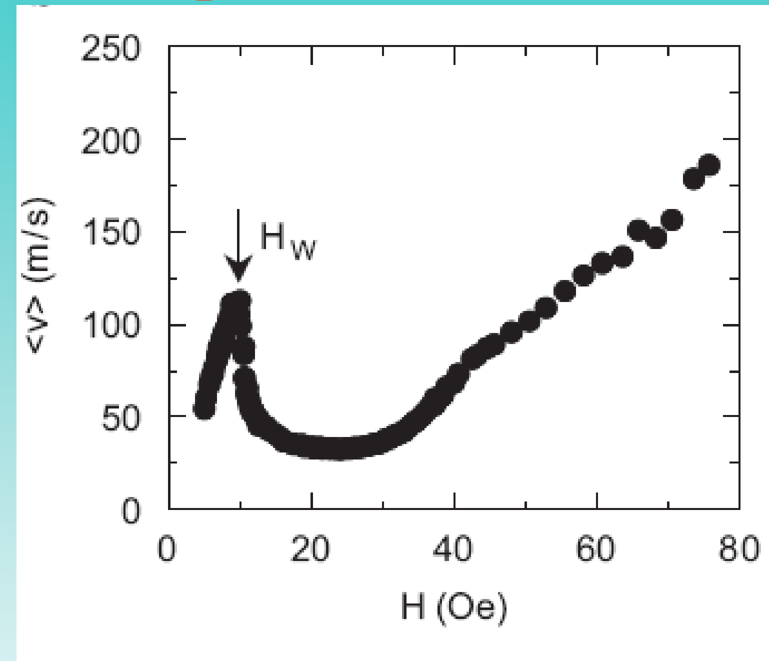
Role of Defects



Correlation of **local nucleation fields distribution** (a) and ***V(H)*** **dependences** in magnetically bistable amorphous $Fe_{74}B_{13}Si_{11}C_2$ microwire exhibiting accelerated domain wall propagation, 1, 2, 3 are the positions of the pick-up coils

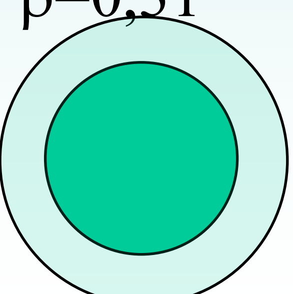
Comparison of domain wall velocity *v* in amorphous $Fe_{72.75}Co_{2.25}B_{15}Si_{10}$ micrometric wire and planar nanowire.

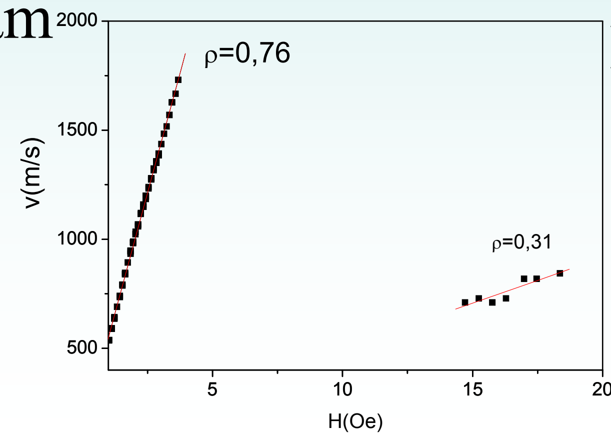




d≈2,8 μm and total diameter D≈ 9μm

ρ=0,31



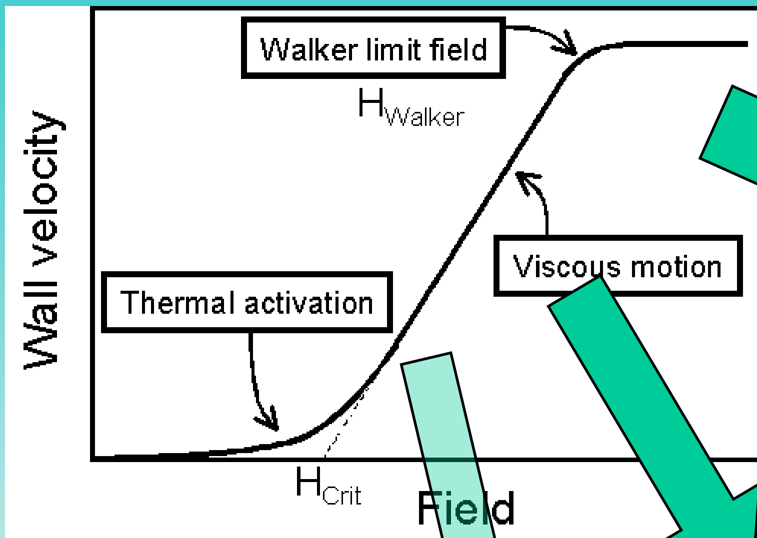


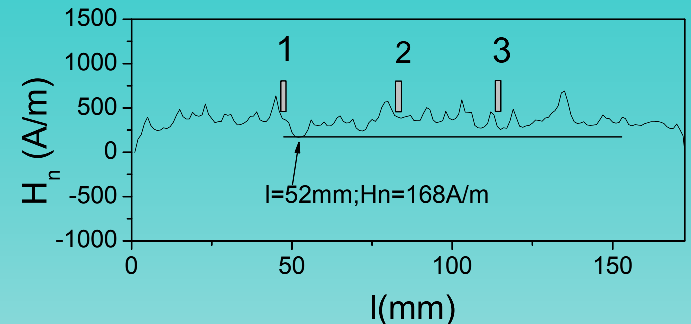
Measured v(H) for 490nm x 20nm Permalloy nanowire

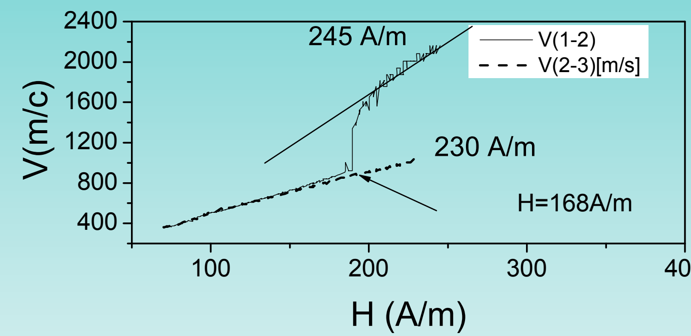
G.S.D. Beach et al. / J. Magn. Magn. Mater. 320 (2008) 1272–1281 (maximum v ≈110 m/s at 9 Oe)

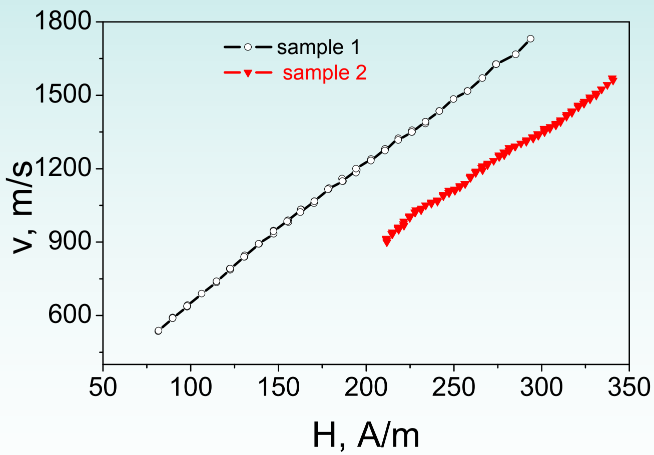
Elevated ME energy? (Small ρ-ratio)

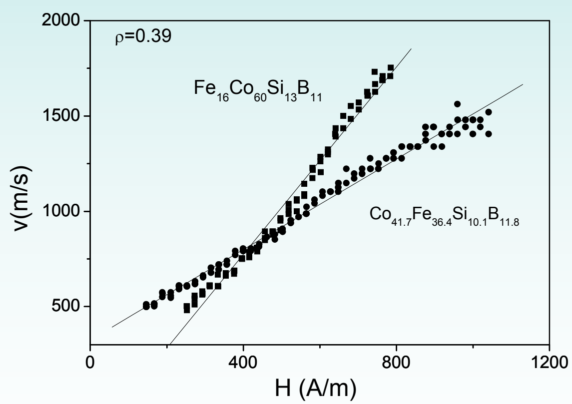
Resumen











Role of defects

ME energy
is important

Conclusions

- DW propagation in μwires is quite fast (few km/s).
- We observed correlation of DW dynamics with magnetoelastic energy.
- Quite fast DW propagation (*v* till 2500 m/s at H about 30 A/m) has been observed in low magnetostrictive $Co_{56}Fe_8Ni_{10}Si_{11}B_{16}$ microwires.
- Applied and internal stresses result in decreasing of DW velocity.We assume that in order to achieve higher DW propagation velocity at the same magnetic field and enhanced DW mobility special attention should be paid to decreasing of magnetoelastic energy.
- At elevated magnetic field the role of defect is quite impotant:a new domain can be spontaneously nucleated in front of the propagating head-to-head domain wall.

Magnetic bistability