Magnetic and Magnetotransport Properties of Fe-Ag Multilayers

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- Sample preparation & measuring techniques
  - discontinuous layers below 1 nm Fe
- Discontinuous multilayers as compared to granular composites
  - perpendicular anisotropy
  - concentration dependence of the magnetoresistance

Sample preparation

vacuum evaporation with two electron guns in a base pressure of 10^{-7} Pa
evaporation rate ≈ 0.2 nm/s

Si single crystal wafer or Al foil substrate
without cooling (~ 100 Celsius substrate temperature)

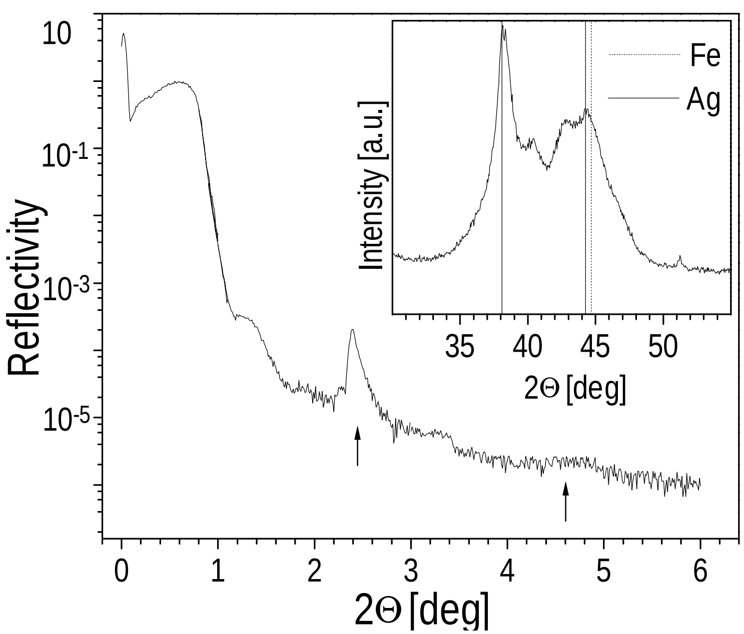
The layer thickness is controlled by a quartz oscillator
Bulk density is used to calculate the nominal thickness

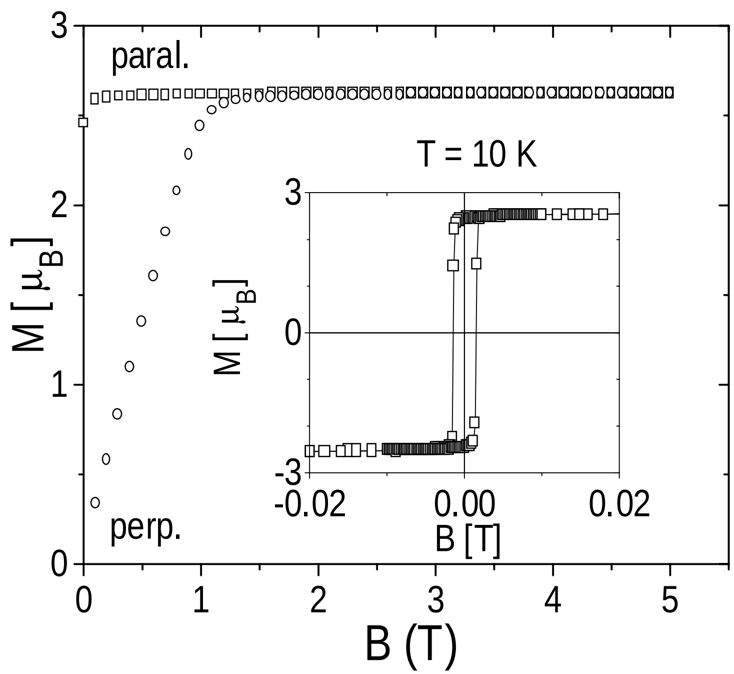
Samples in the 0.1-10 nm layer thickness range

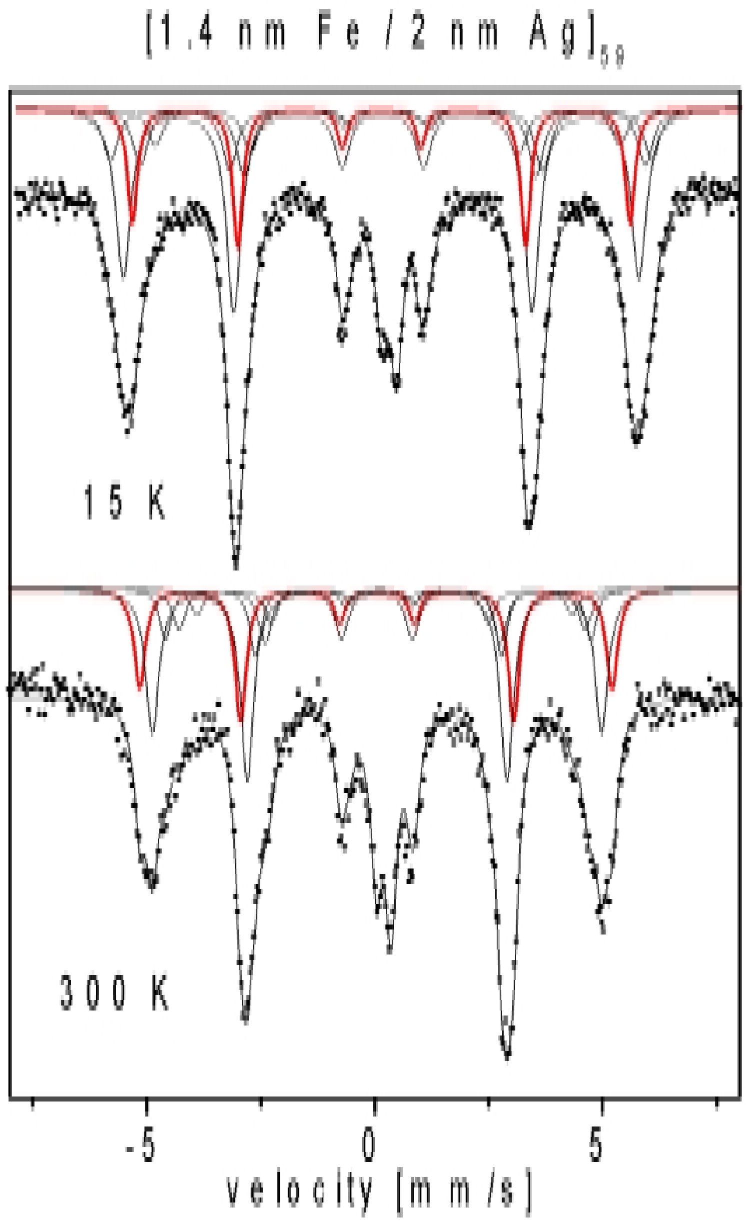
X-ray reflectivity and diffraction
SQUID magnetometry (5 Tesla)
Mössbauer spectroscopy
Magnetoresistance (12 Tesla)

$d_{Fe} > 1nm$
continuous ferromagnetic layers
in-plane magnetization
non-equilibrium alloying by interface mixing
(increased magnetic moments, lower Curie temperature, broadening of the Mössbauer linewidth)

$[Ag(2\ nm)/\ Fe(1.4\ nm)]_{60}$ multilayer







in-plane magnetic moments
(I_{2-5}= 4 $\sin^2\Theta/(1+\cos^2\Theta)$)

hyperfine field distribution

Sharp interface and atomic terraces
or rough interface and atomic mixing ?

P. J. Schurer et al. Phys Rev. B 51, 2506 (1995)

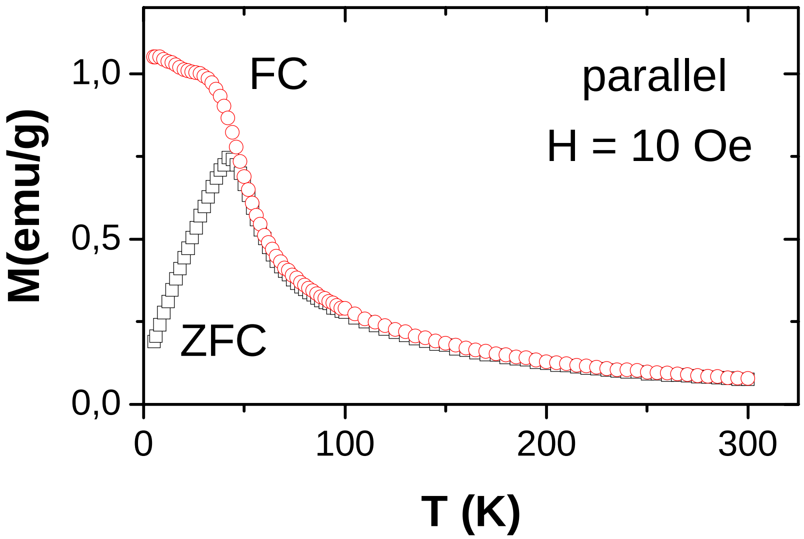
Systematic comparision of
polycrystalline and epitaxial layers

Below 1nm Fe layer thickness

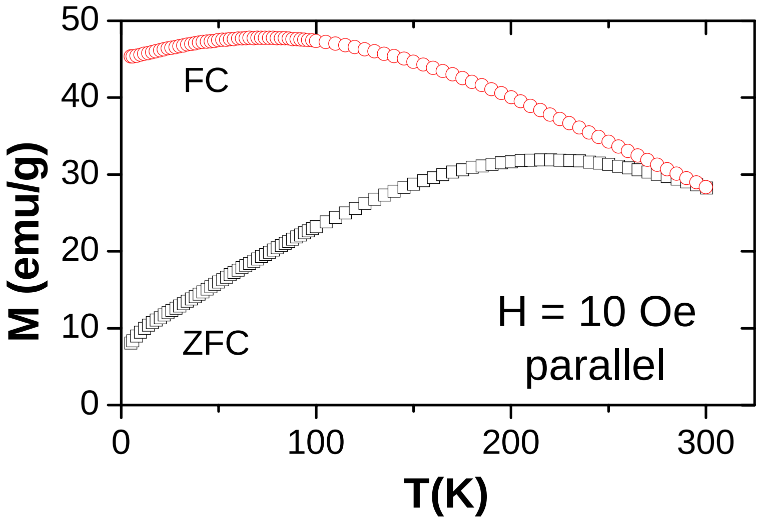
-No reflectivity peak is observed

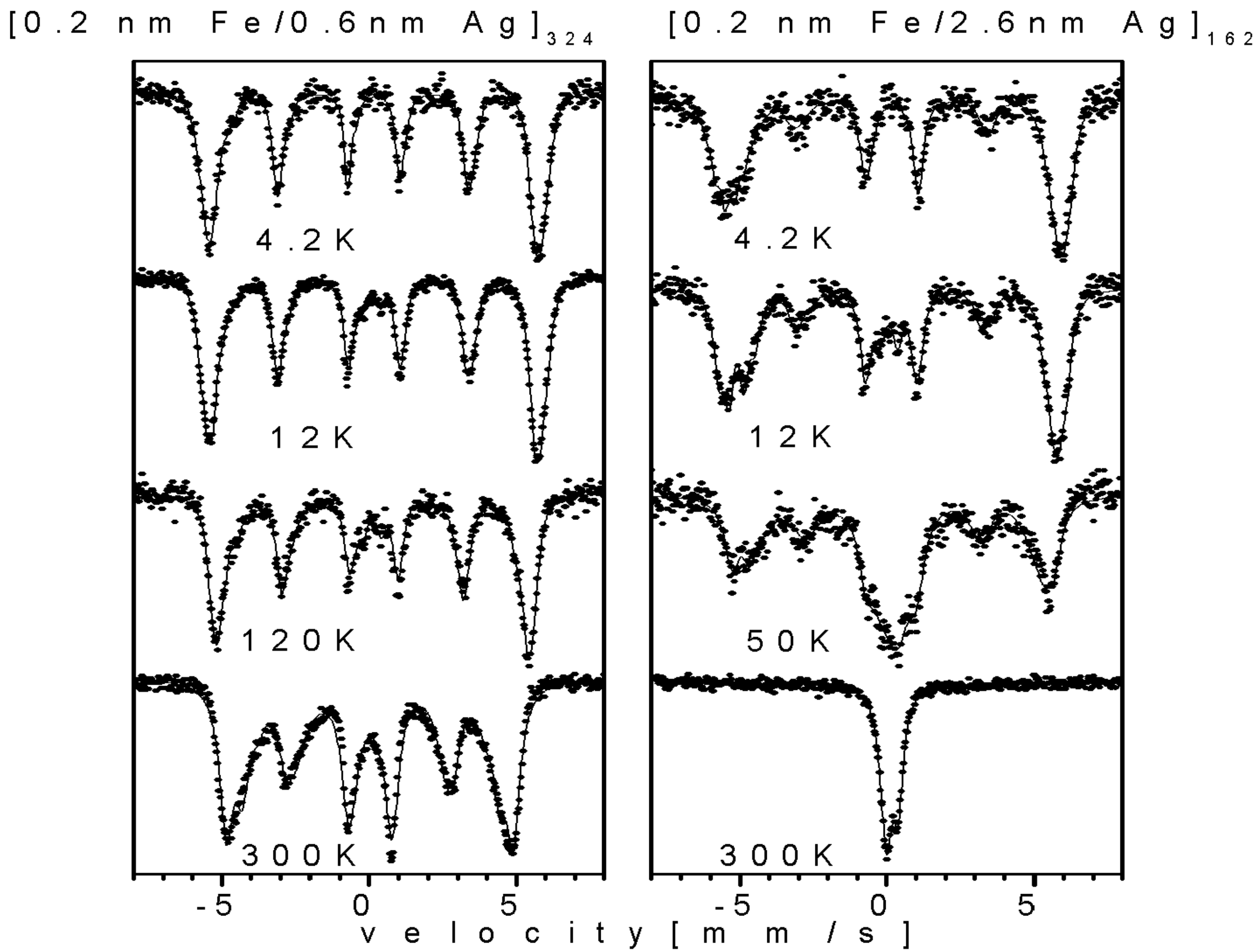
-Superparamagnetic relaxation

[2.6 nm Ag / 0.2 nm Fe]$_{75}$



[0.6 nm Ag / 0.2 nm Fe]$_{324}$

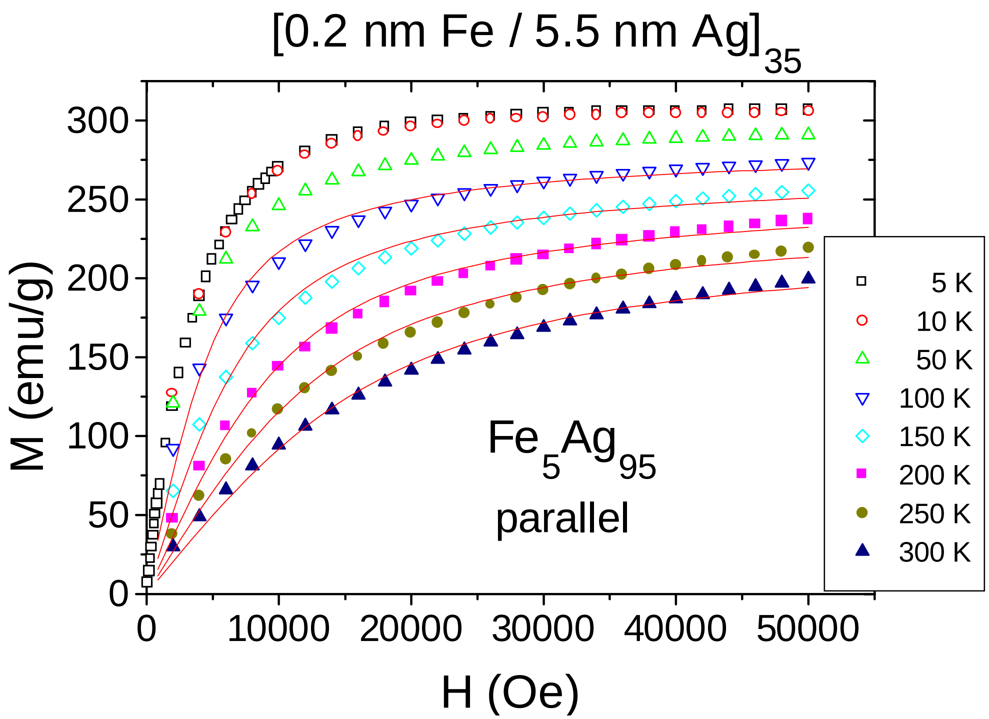


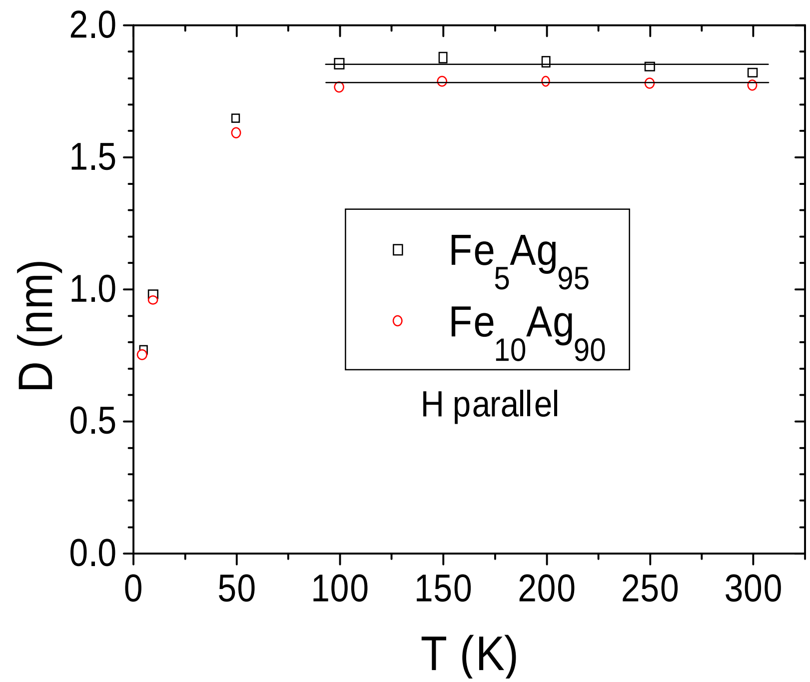


No substrate component!

The samples can be removed from the Si substrate.

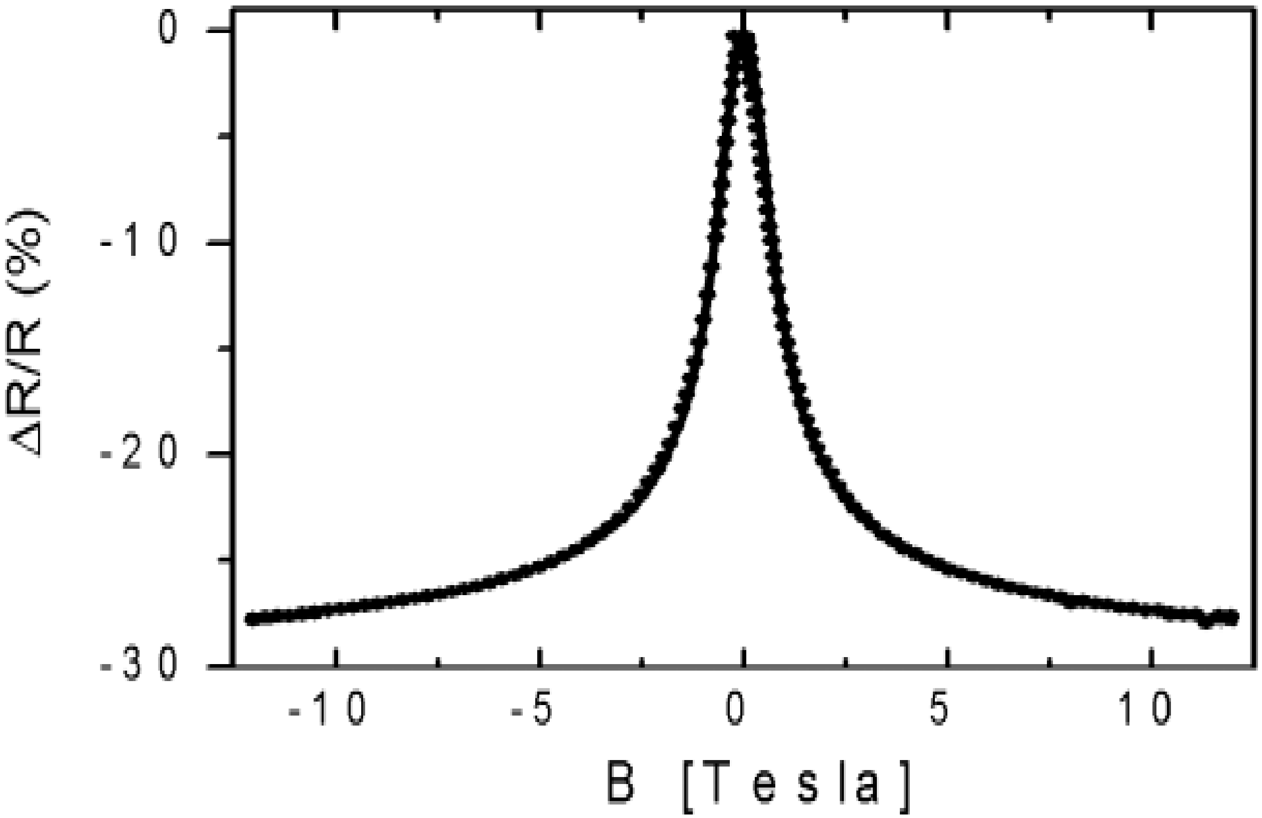
Grain size from magnetisation measurements





The magnetoresistance is similar to that of granular composits prepared by co-deposition of the elements

[2.6 nm Ag / 0.2 nm Fe]$_{75}$



$$\frac{\Delta R}{R} = -A_1[L(mH/kT)]^2 - A_2 H^2$$

m=19 μ_B , A_1=5.3 10^{-1} , A_2=5*10^{-5}

Why to deal with bad multilayers?

- poor man cooks with water

- **granular interface structure**

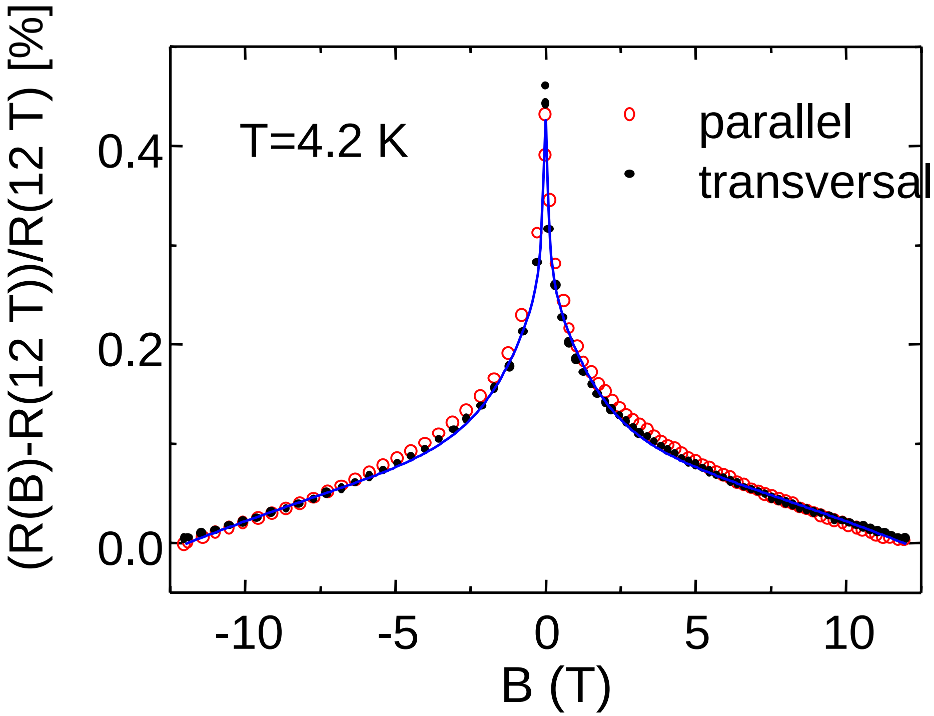
- **distinct features as compared to co-deposition**

  appearance of perpendicular anisotropy

  the grain size can be varied on the nanometer scale

Granular interface

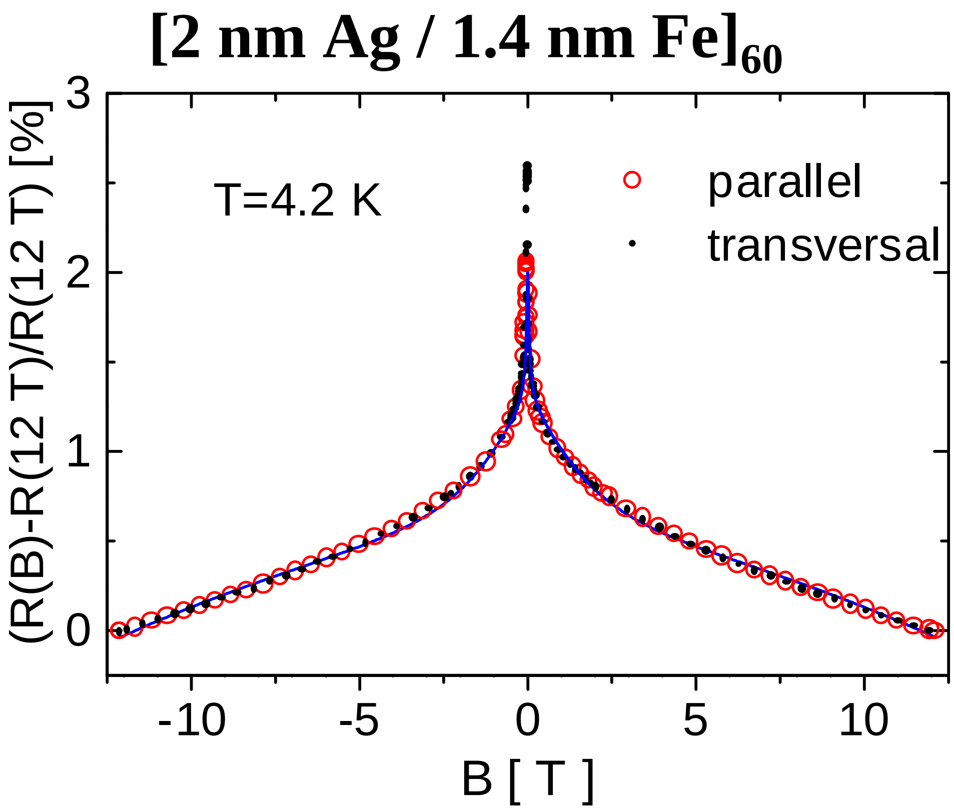
8 nm Ag / 25 nm Fe / 8 nm Ag trilayer



$$\Delta R/R = -(A_1 L(m_1 H/kT) + A_2 L(m_2 H/kT))^2 - A_3 H^2 + A_4$$

$m_1 = 6.4\ \mu_B$, $m_2 = 382\ \mu_B$,
$A_1 = 0.042$, $A_2 = 0.086$, $A_3 = 3 * 10^{-5}\ T^{-2}$ and $A_4 = 2 * 10^{-2}$.

Multilayer magnetoresistance is dominated by the granular interface



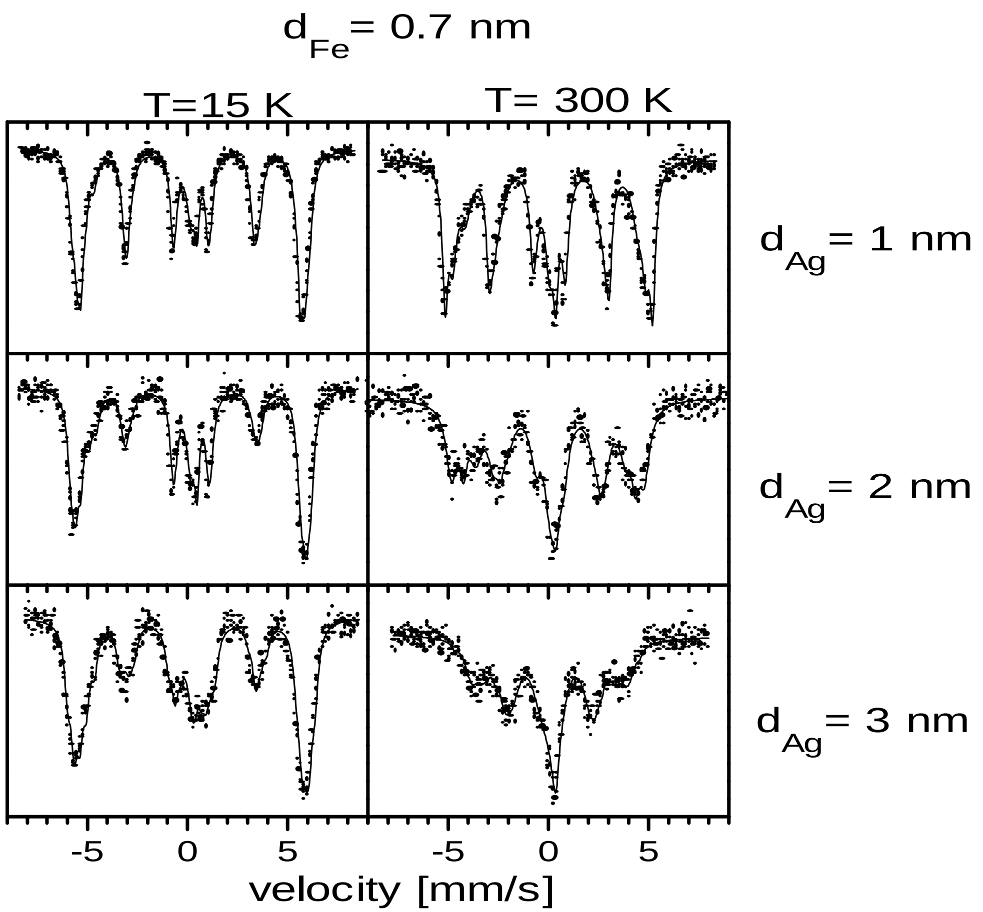
m_1=6.6 μ_B, m_2=188 μ_B,

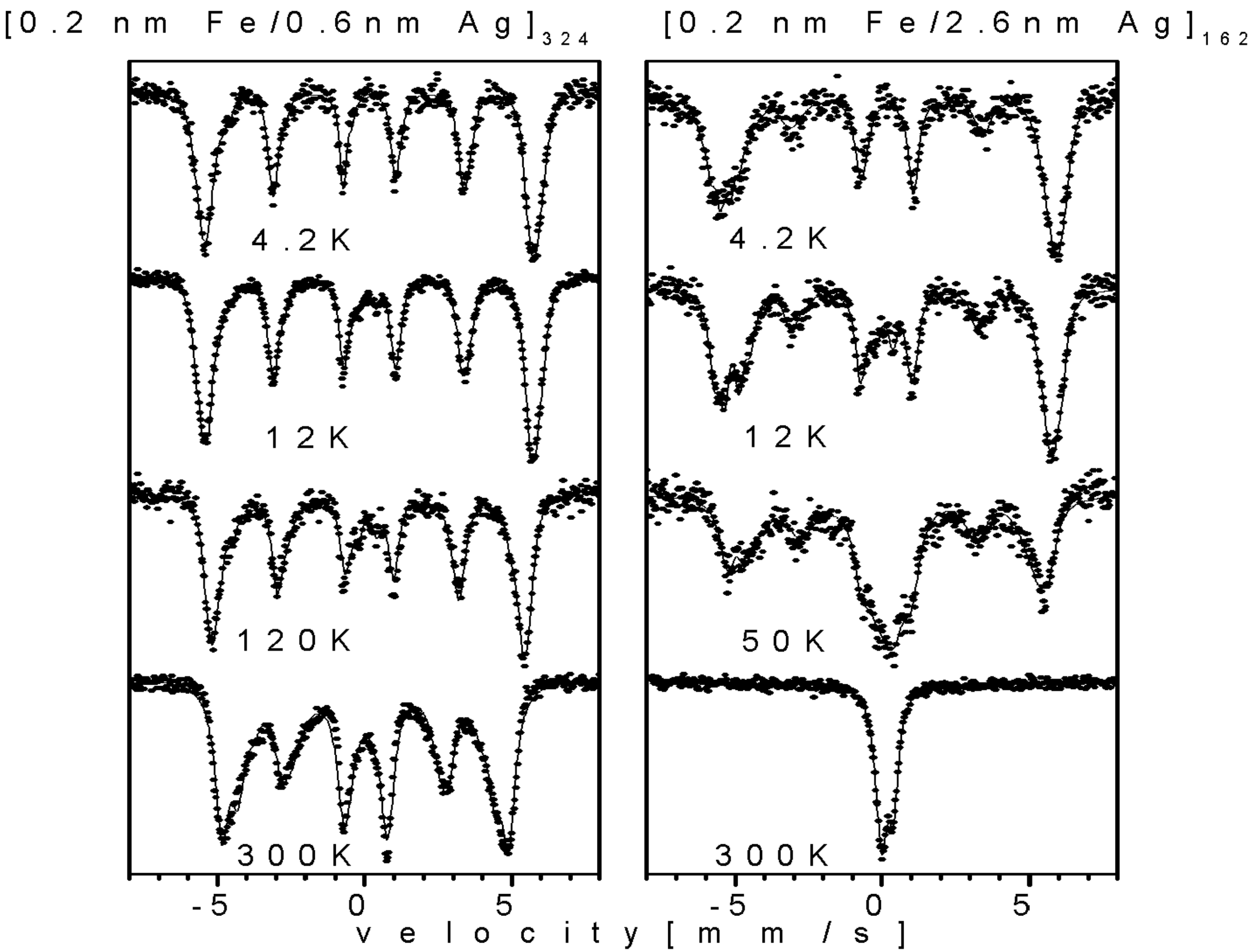
A_1=0.019, A_2=0.043, A_3=4.3*10 $^{-6}$ T $^{-2}$ and A_4=4*10 $^{-3}$

perpendicular anisotropy when $d_{Fe} < 1nm$

relative line intensities of the Mössbauer spectra

$$I_{2\text{-}5} = 4 \sin^2\Theta/(1+\cos^2\Theta)$$





[0.2 nm Fe/0.6nm Ag]324
[0.2 nm Fe/2.6nm Ag]162
4.2K
12K
120K
300K
4.2K
12K
50K
300K
-5
0
5
-5
0
5
velocity [mm/s]

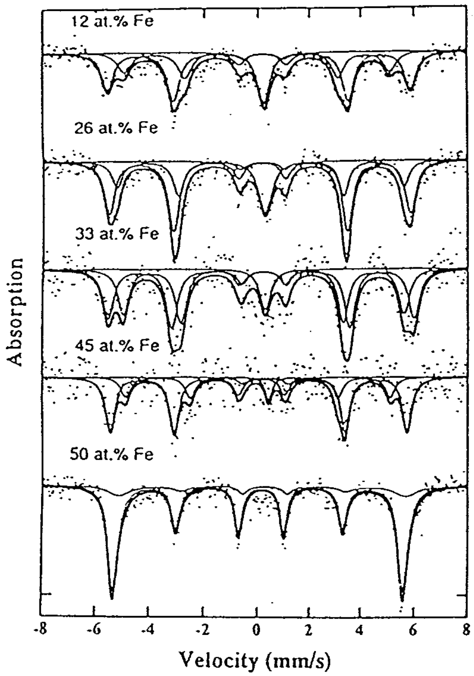


Fig. 7. Mössbauer spectra at 4.2 K for the CB-deposited Fe-Ag

K. Sumiyama et al.
J. Mat.Sci. Eng., 1995

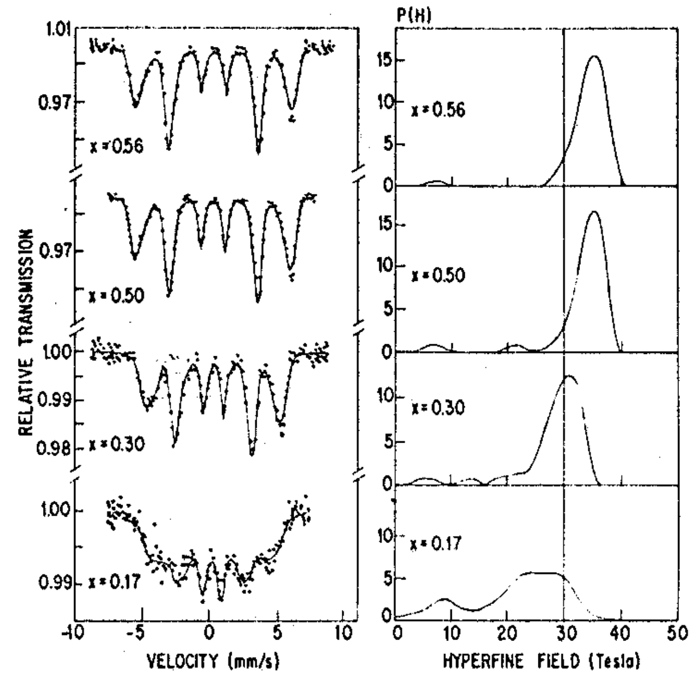


Fig. 2. Mössbauer Spectra and corresponding average hyperfine field distributions for various Ag–Fe films at 5.5 K.

C. Larica et al.
J.M.M.M., 1992

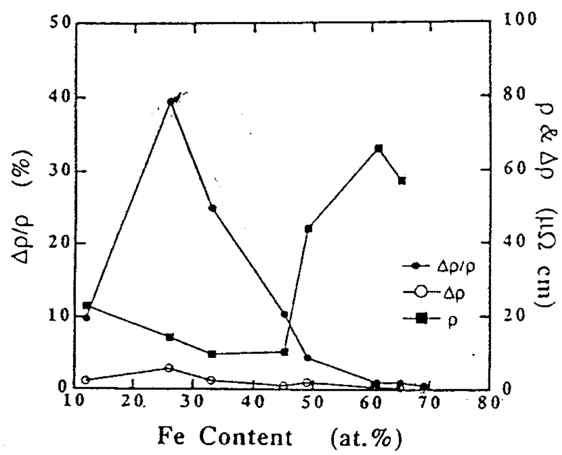
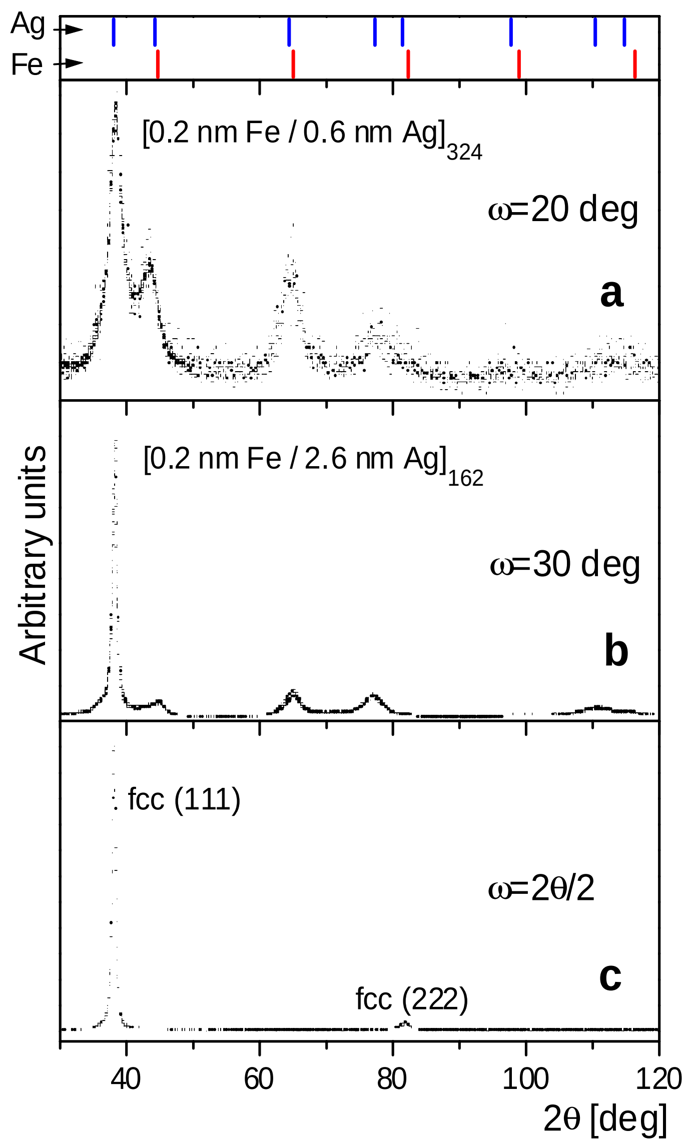


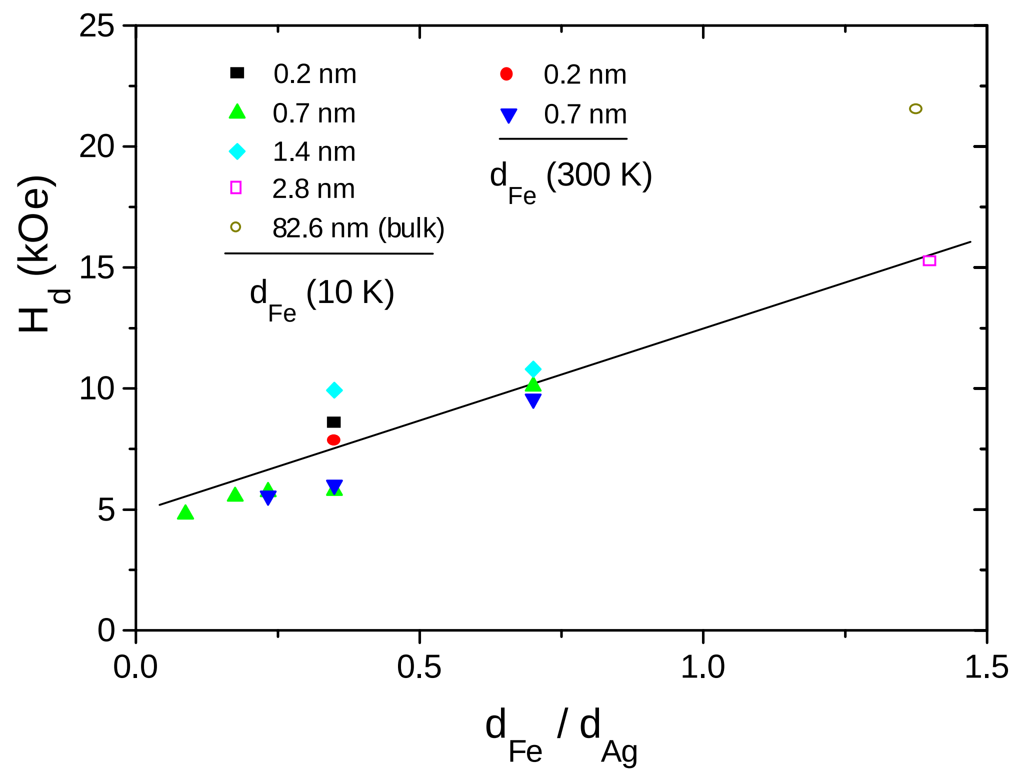
Fig. 8. Concentration dependence of electrical reistivity, $\rho(0)$, $\Delta\rho = \rho(H) - \rho(0)$, and magnetoresistance, $\Delta\rho/\rho$, at 4.2 K of the CB-deposited Fe-Ag films.

K. Sumiyama et al.
J. Mat.Sci. Eng., 1995

stress induced anisotropy?

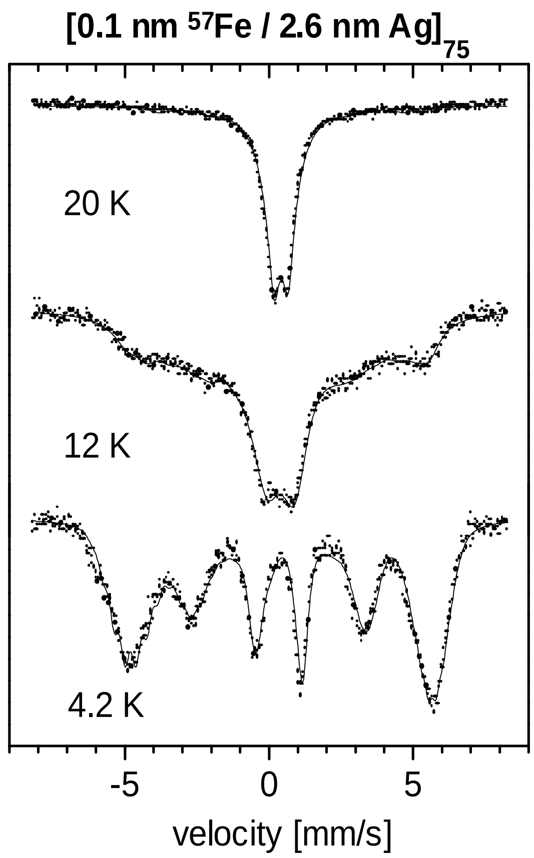
non-spherical particles?





The grain size can be varied on the nanometer scale

$\mathbf{T_B \approx V}$ for non-interacting particles (J. L. Dormann et al.)



$D \approx 1$ nm

K. Temst et al., Leuven

Concentration dependence of the magnetoresistance

universal behaviour
maximum GMR around 25% magnetic atom concentration
3D percolation limit

Conditions for optimum GMR in granular metals ,
D. Kechrakos and K. N. Trohidou, J. Appl. Phys., 89 , 7293 (2001)

J. Appl. Phys., Vol. 89, No. 11, 1 June 2001

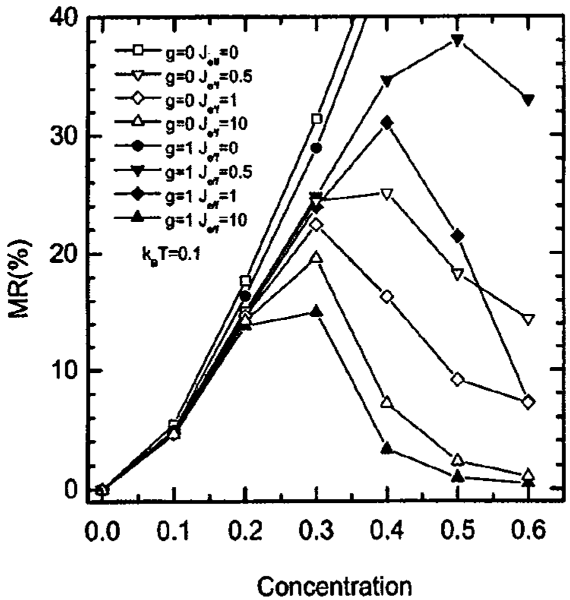
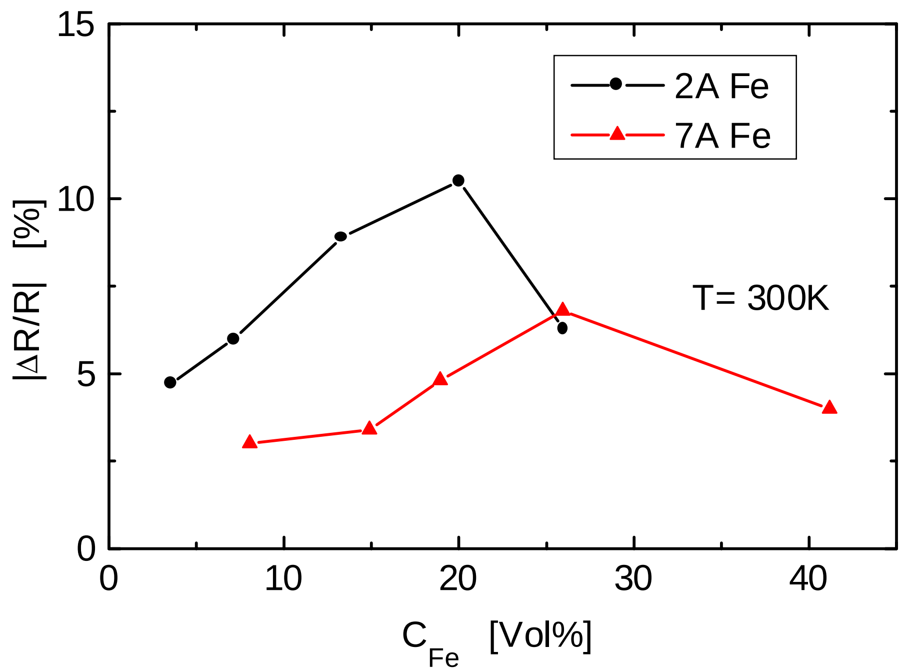


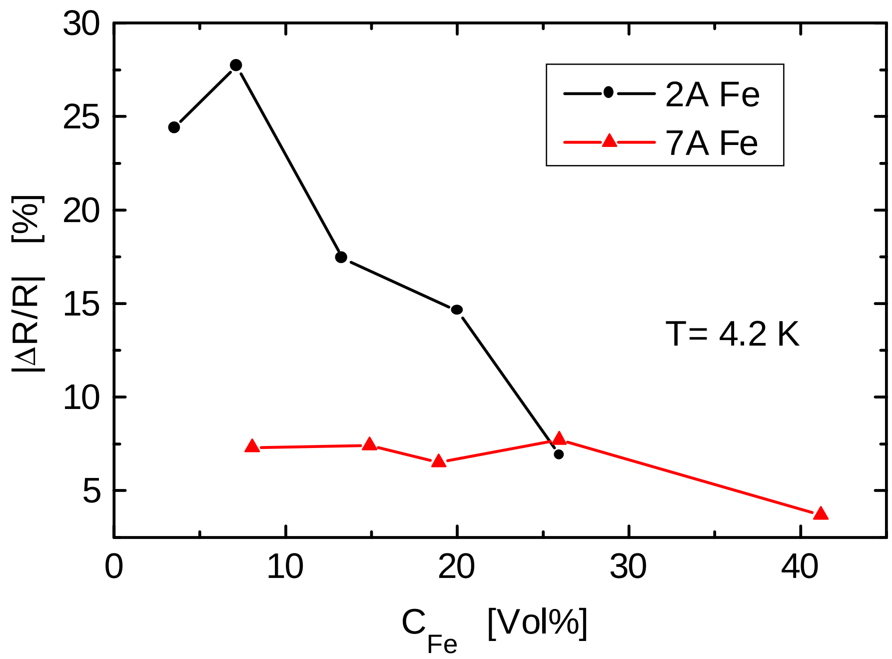
FIG. 2. Magnetoresistance as a function of magnetic particle concentration.

Interplay between dipolar interactions and interparticle exchange

-the grain size is determined by grain growth process during deposition
-percolation among different size grains and not individual atoms

The larger the space filling factor the lower the percolation threshold

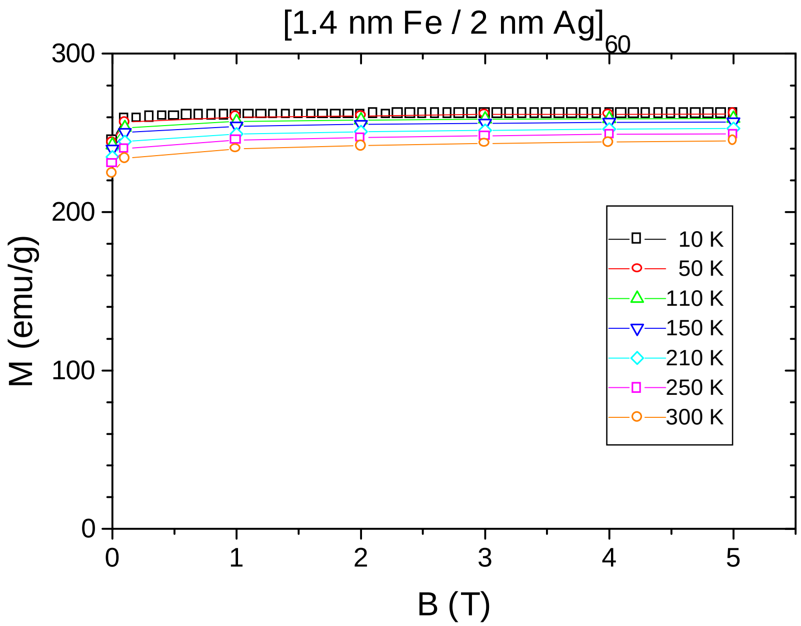


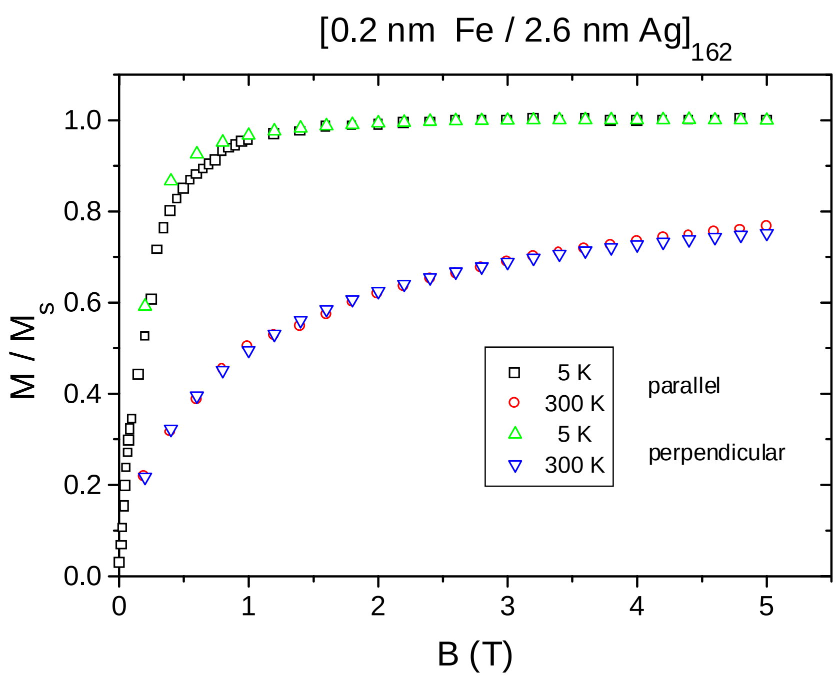


The position of the maximum depends on the size of the magnetic grains and the temperature.

Conclusions

- **Atomic mixing at the interface of Fe/Ag multilayers produces a granular interface structure.**
  GMR behaviour of a 8 nm Ag / 25 nm Fe/ 8 nm Ag trilayer
- **Granular composits prepared by sequential deposition show distinct features**
  Out of plane magnetic moments
  non-universal composition dependence of the magnetoresistance


[1.4 nm Fe / 2 nm Ag]60
M (emu/g)
B (T)
10 K
50 K
110 K
150 K
210 K
250 K
300 K


[0.2 nm Fe / 2.6 nm Ag]162
M / Ms
B (T)
5 K
300 K
5 K
300 K
parallel
perpendicular