Interplay between structural roughness and magnetization reversal in thin Fe films

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Outline

Fe films, 300Å thick, were deposited by molecular beam epitaxy on amorphous SiO_2 substrates previously coated with an Ag buffer layer of varying thickness (0-50-100-150Å).
The surface roughness of the Ag buffer layer grows with increasing thickness.
Magnetization measurements revealed that both the magnetization reversal process and the coercivity are profoundly influenced by the surface roughness.

Motivation

Magnetic properties of thin films and nanostructures ↕ Surface/interface roughness

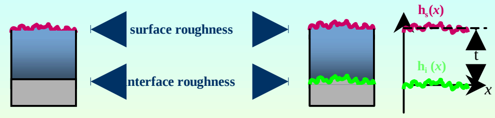
e.g. magnetic anisotropy, coercivity, reversal process, magnetoresistance, domain structure

Surface/interface roughness:
Preparation conditions
Crystalline structure
Composition
Thickness
Size

- many experimental difficulties, only indicative results
- difficulties to match theory with experimental results

Different systems

Single rough boundary — **Double rough boundary**



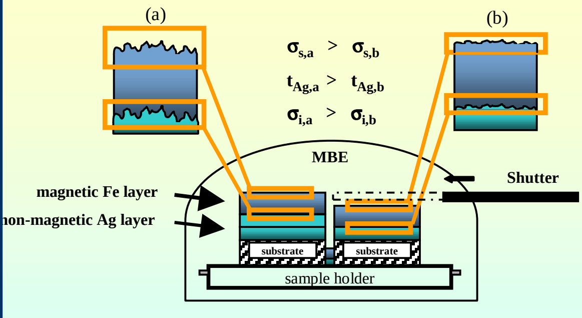
$\xi_s, \sigma_s > 0$
$\sigma_i = 0$, $\xi_i = \infty$

Important parameters:
- *Vertical* interface width or rms roughness σ
- *Lateral* correlation length ξ or average grain size

(i) Correlated boundaries
$h_s(x) = t + h_i(x)$
⇒ $\sigma_s \approx \sigma_i$ and $\xi_s \approx \xi_i$

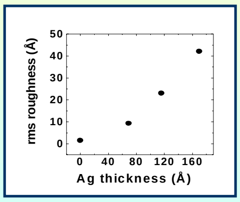
(ii) Uncorrelated boundaries
$h_s(x)$? $h_i(x)$

Roughness control of a double rough boundary system



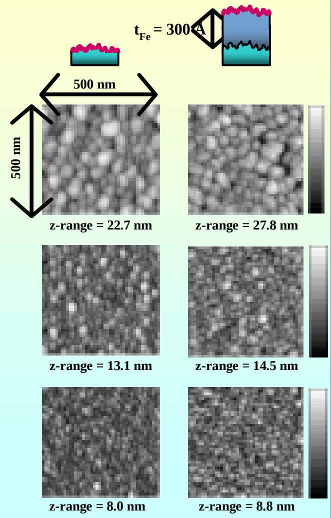
Surface and interface roughness dependent on thickness of buffer layer

Method: by using a shutter, we are able to deposit simultaneously on several substrates a non-magnetic Ag buffer layer with varying thickness. The surface roughness of these buffer layers increases dramatically with thickness t.



Structural characteristics (AFM)

Ag surface — Fe surface



σ = 42 Å, Grain size = 500 Å -700 Å; t_{Ag} = 150 Å

σ = 23 Å, Grain size =150 Å - 250 Å; t_{Ag} = 100 Å

σ = 9 Å, Grain size = 100 Å -150 Å; t_{Ag} = 50 Å

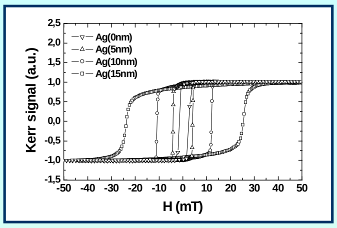
Morphology Fe surface similar to morphology Ag surface ⇒ In-phase double rough boundary system

Magnetic properties (MOKE)

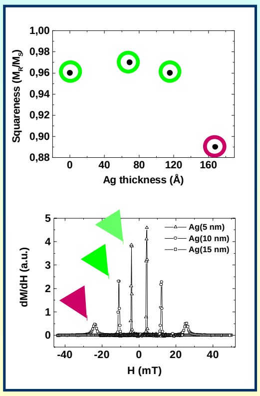
Polycrystalline 300Å thick Fe film

⇒ no in-plane anisotropy
⇒ Néel domain walls:
Core domain wall width $w = \pi(2A/\mu_0 M_S^2)^{1/2} \approx 100Å$
with exchange stiffness $A = 1.7\ 10^{-11}$ J/m
and magnetostatic energy density $\mu_0 M_S^2/2 = 19\ 10^5$ J/m³

Hysteresis loops of in-plane magnetization



Hysteresis loop characteristics



Squareness ≈ 1 ⇒ magnetization reversal dominated by domain wall nucleation and motion

Squareness < 1 ⇒ complex process, combination of both spin rotation and domain wall motion.

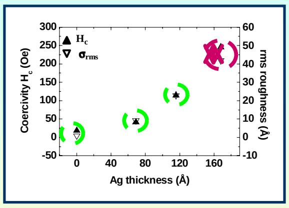
Squareness << 1 ⇒ magnetization reversal dominated by irreversible spin rotation

Sharp reversal Ag(50),Ag(100) ⇒ coercivity caused by delay of domain wall nucleation:
$H_{coercive} = H_{nucleation}$

Less sharp reversal ⇒ Structural inhomogeneities cause fluctuations Ag(150) in domain wall energy
⇒ if domain wall width w << correlation length of these fluctuations
⇒ domain wall pinning occurs
$H_{coercive} = H_{nucleation} + \Delta H_{pinning}$

Discussion

Coercivity versus surface characteristics



Coercivity determined by vertical interface width or rms roughness:
$H_c = H_n = f(\sigma_{rms}, \xi) = a\sigma_{rms}$

Since domain wall width w (100Å) << grain size (500-700Å)
⇒ lateral characteristics of surface start playing a role
⇒ enhanced coercivity:
$H_c > a\sigma_{rms}$

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