Manipulation of magnetic domain walls

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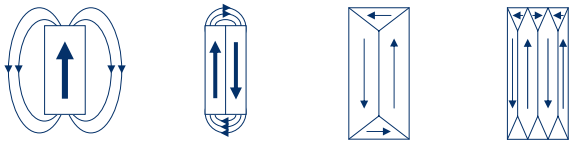
OUTLINE

- Introduction
- Simulations
- Sample design
- Line patterns
- Embedded lines
- Conclusions & outlook

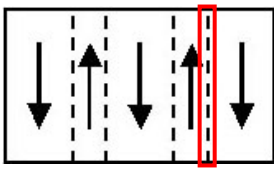
MAGNETIC DOMAIN WALLS

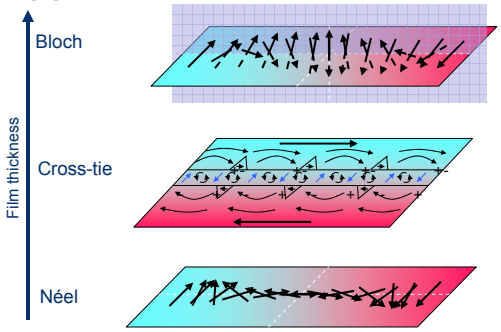
• Competition between ***exchange energy*** and ***stray field***



• Different types of magnetic domain walls

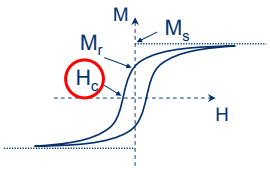
180° Domain Walls





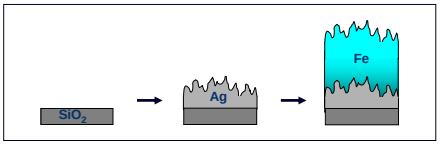
ROUGHNESS

Magnetic properties of thin films ⟷ preparation conditions
crystalline structure
composition
substrate
thickness
surface roughness

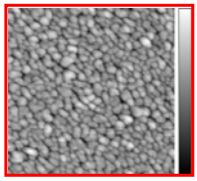


• Roughness induced by Ag buffer layer

• Well-defined surface morphology: magnetic layer (Fe) copies morphology



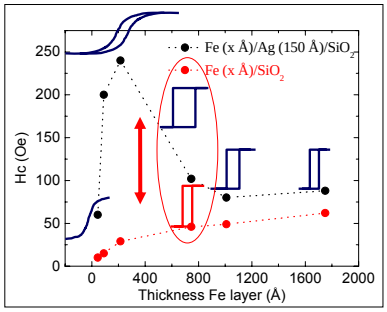
Ag (15 nm), 1x1 µm²



Z-range: 247 Å

ROUGHNESS

- Coercivity of thin ferromagnetic film increases with increasing roughness
- Coercivity vs. Thickness



We can *produce* thin Fe films with a *modulated surface roughness* and we can *tune* the *coercivity* of these films.

J. Swerts, S. Vandezande, K. Temst, and C. Van Haesendonck, Solid State Communications 131, 359 (2004)

OOMMF SIMULATIONS

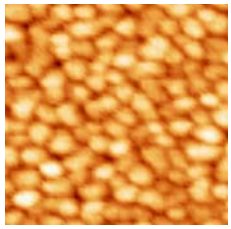
- Micromagnetic simulations: Introduction

0. Divide the magnetic body into cells with an initial magnetic moment $\vec{M}_{i,init}$
1. Calculate the total energy E_{total}
2. The moment in each cell feels an effective magnetic field $\vec{H}_{eff} = -\frac{1}{\mu_0}\frac{\partial E_{total}}{\partial \vec{M}}$
3. The Landau-Lifshitz-Gilbert (LLG) equation: precession of magnetic moment around effective field:

$$\frac{d\vec{M}}{dt} = -\gamma \vec{M} \times \vec{H}_{eff} + \frac{\gamma\alpha}{M_s}\vec{M} \times (\vec{M} \times \vec{H}_{eff})$$

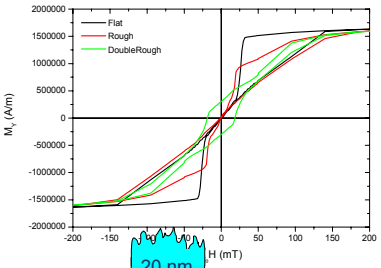
4. A new magnetic moment is found for each cell $\vec{M}_i$

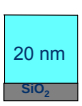
- Object-oriented micromagnetic framework (OOMMF)
  - 3D calculation: Version 1.2.0.3
  - Mesh: $(7.78125\ nm)^2$ x 1 nm (64 x 64 pixels^2, 500 x 500 nm^2)
  - Roughness from real data:
    - t_{Ag} = 22 nm
    - σ_{Ag} = 2.36 nm
    - average height = 9.76 nm

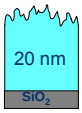


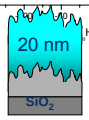
OOMMF SIMULATIONS

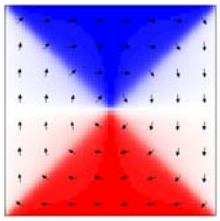
- Micromagnetic simulations: Results
  - remanent state (zero field) after saturation
  - hysteresis loop widens with increased roughness
  - roughness is an important parameter!

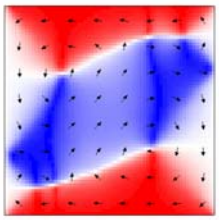


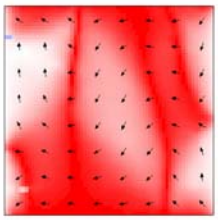








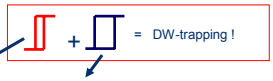


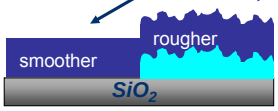


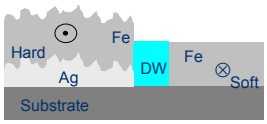
H_{APP}

DOMAIN WALL TRAP

- Concept

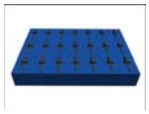






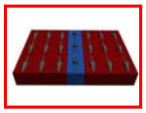
Fe layer

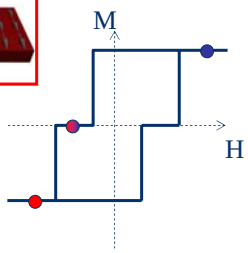
Ag buffer layer



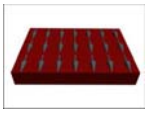
*J. Swerts, K. Temst, M.J. Van Bael, C. Van Haesendonck, and Y. Bruynseraede, APL, **82**, 1239 (2003)*

Different switching behavior for rougher (harder) and smoother (softer) parts of the film





Magnetic domains with opposite magnetization, separated by 180° DW's

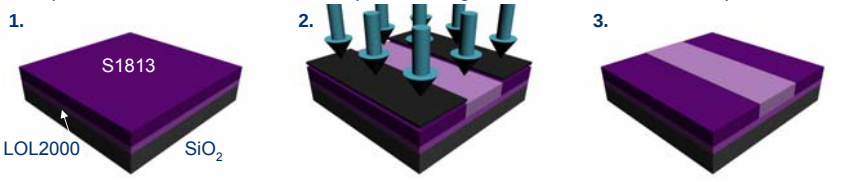


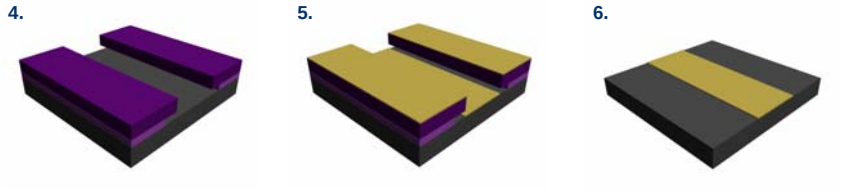
LITHOGRAPHY

0 Making the patterns: optical lithography

Improved procedure: dual layer resist processing + (dry etching) + MBE growth

Spin-coated & baked | *UV exposure through mask* | *After UV exposure*





After development | *Deposition* | *After lift-off*

LITHOGRAPHY

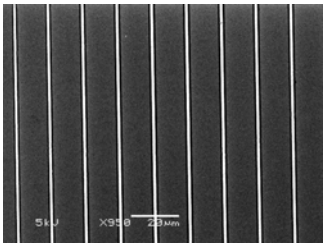
Main advantage: *dual layer* (~ E-beam lithography) → UNDERCUT STRUCTURE

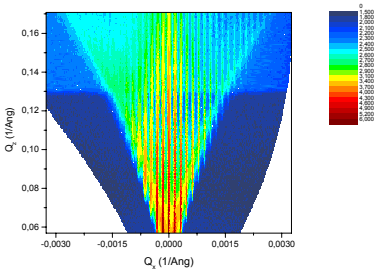
- No high peaks due to resist leftovers at the edge of the lines!
- Improved lift-off after deposition!

• ***XRD mapping:***

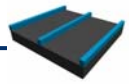
Line pattern very reproducible over large area

(Sample with 2 µm lines in period of 4 µm)



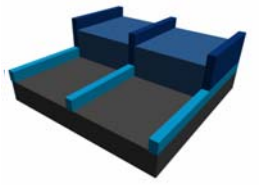


LINE PATTERNS



1 Rough Ag lines on top of the SiO_2 substrate

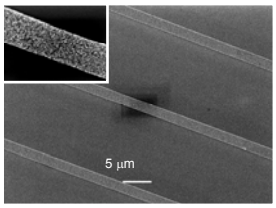
SiO_2 substrate
Spin coated with S1813
& LOL2000

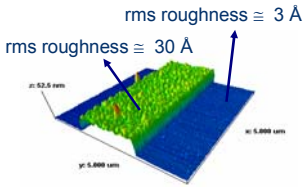


Deposition of 18 nm high Ag lines
& Lift-off

2 µm wide, 15 µm period

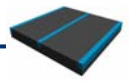
Deposition of Fe (30 -60 nm thick)





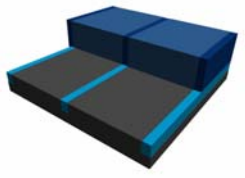
5 x 5 µm²

INTRODUCTION



2 Rough Ag lines embedded in the SiO_2 substrate

SiO_2 substrate
Spin coated with S1813
& LOL2000

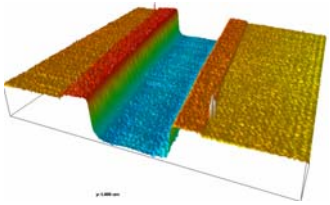


Dry etching (18 nm) by
Ar^+ bombardment

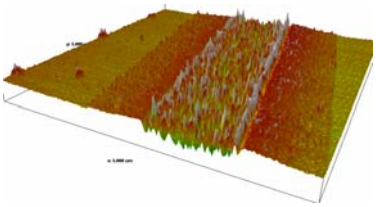
2 µm wide, 15 µm period

Deposition of 18 nm high Ag lines
& Lift-off

Deposition of Fe (20 nm thick)

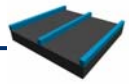


5 x 5 µm²

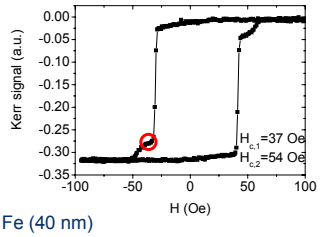


5 x 5 µm²

STATIC MFM



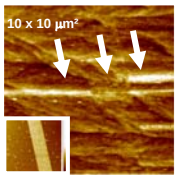
- No external magnetic field during scans
- Brought in anti-parallel state with Moke



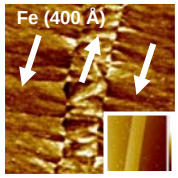
Fe (40 nm)

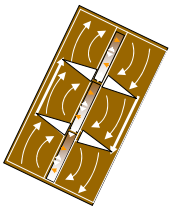
Ripple structure

saturation



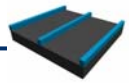
plateau

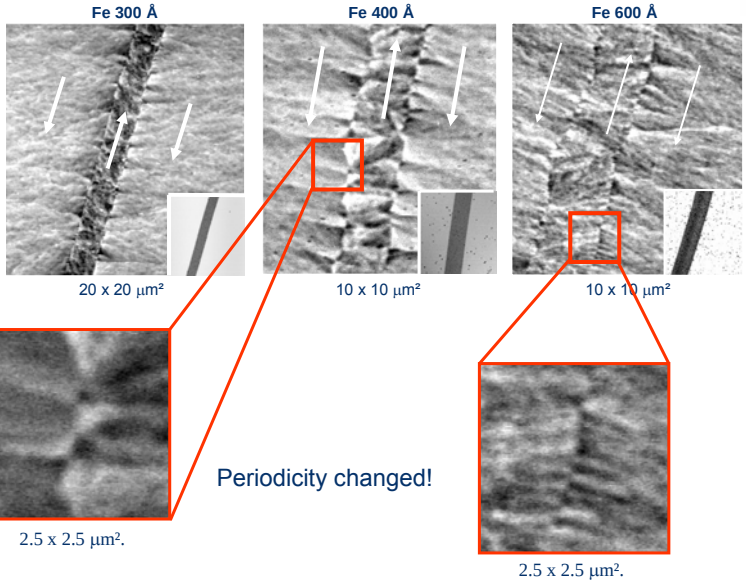




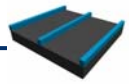
Cross-tie domain walls

STATIC MFM vs. THICKNESS



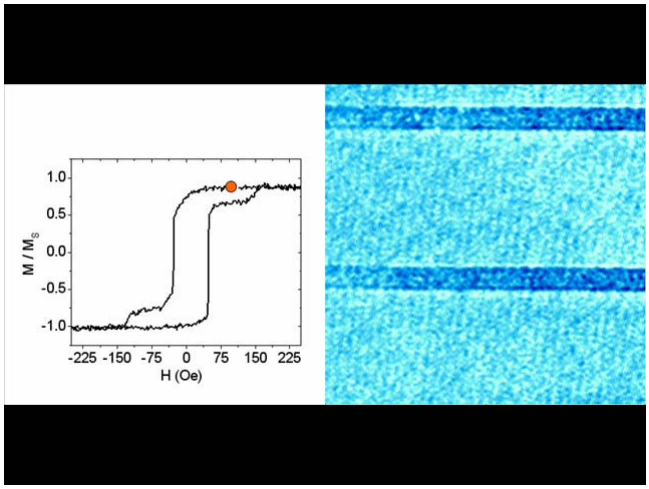


IN–FIELD MFM

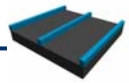


- External magnetic field applied during scans (parallel to lines)
- Fe (30 nm)

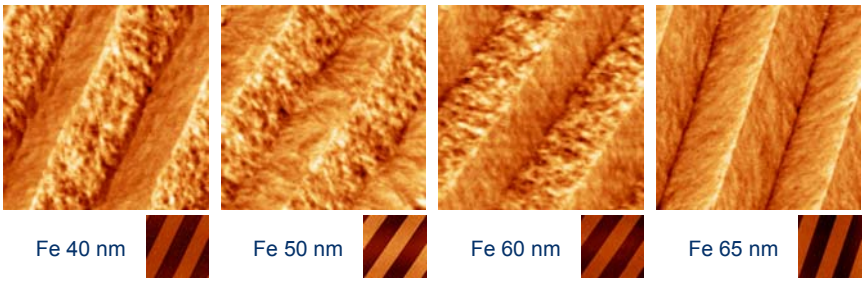
H



IN–FIELD MFM

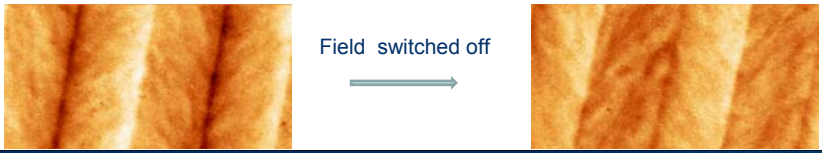


- External magnetic field applied during scans (parallel to lines)
- Images in AP state, all images 20 x 20 μm², 5 μm in 10 μm

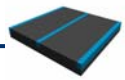


Fe 40 nm | Fe 50 nm | Fe 60 nm | Fe 65 nm

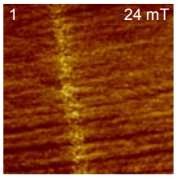
- AP state: no cross-tie domain walls
- AP state: not stable!

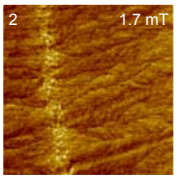


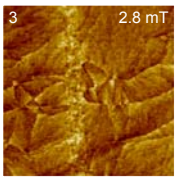
MOKE & IN–FIELD MFM (EMBEDDED)



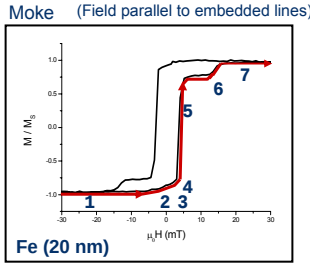
Saturation



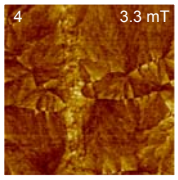


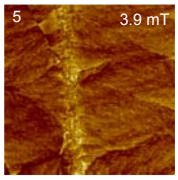


Moke (Field parallel to embedded lines)



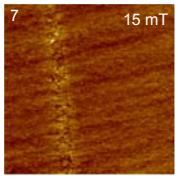
Fe (20 nm)

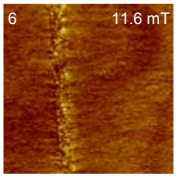




Near the first switching field, almost anti-parallel

Saturation





At the plateau

(All images 20 x 20 μm²)

CONCLUSIONS & OUTLOOK

- Micropatterning leads to trapping of domain walls @ specific locations
- Moke loops and MFM indicate that anti-parallel (AP) state can be achieved
- Works for different thicknesses of the Fe layer
- Nucleation of domains, wall movement and 180 degree domain walls (DWs)
- AP state is not stable, no cross-tie DWs in in-field MFM measurements
- Embedded lines behave like their non-embedded counterparts, no clear AP state
- Transport measurements do not reveal AP state, correlation to be further investigated
- Outlook: Ion implantation to change bulk of the Fe

THE END

THANK YOU FOR YOUR ATTENTION!