Curvilinear phenomena in magnetization dynamics

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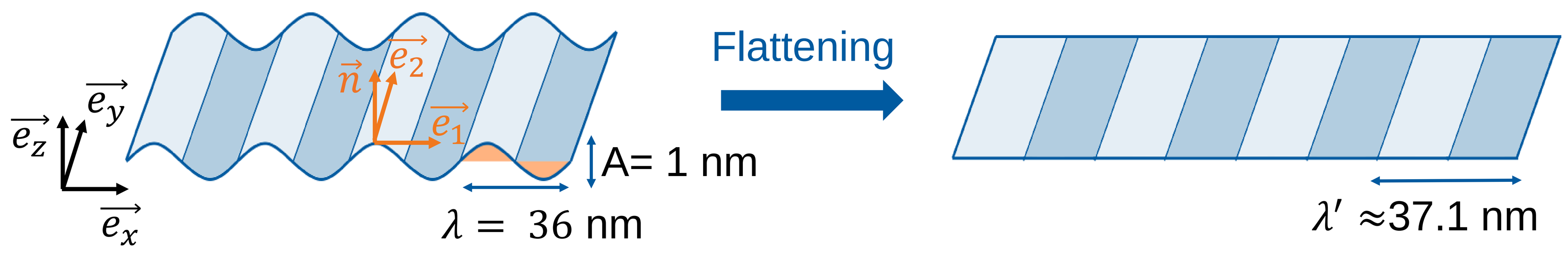
Motivation

Curvilinear magnetism has been attracting attention due to the vast range of phenomena that are appealing in stretchable and magnetoelectric devices, microrobots, sensors, flexible memories and nanoelectronics [1-5].

These phenomena encompass exchange- and Dzyaloshinskii-Moriya (DMI)-induced interactions that typically result in topological magnetization patterning in thin shells, symmetry breaking, and pinning of domain walls [1-9]. However, less attention has been paid to the role of the curvilinear effects in the magnetization dynamics [4]. For application development, spin-orbit torques provide an alternative way to manipulate magnetic domain walls and magnetization [10, 11] with reduced power consumption.

Here we present first results in stray field calculation in curvilinear geometries, and domain wall tilts in single 100 nm wide 2 nm thin periodically corrugated strips of CrOx/Co/Pt with average curvature of 0.06 nm^{-1}.



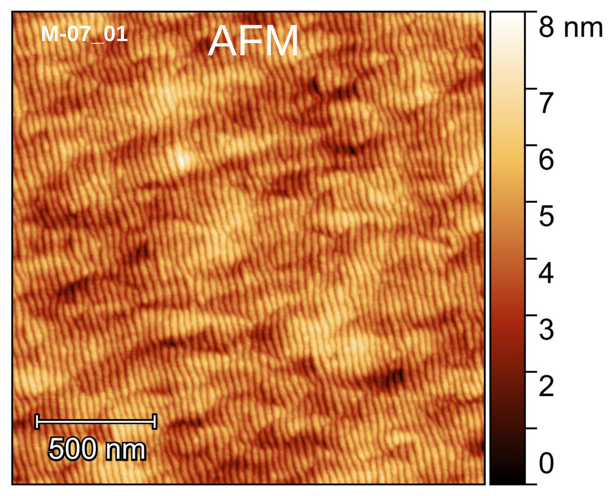
Curvilinear effects emerge as effective anisotropies and an additional exchange-induced DMI,

$$w_{ANIS}^{total} = (-K_{ex} - K_{rip})m_2^2 + (K_{DMI} - K_3)m_n^2 - K_{1,shape}m_x^2; \qquad w_{DMI}^{ex} = 2A_{ex}k_1\left(m_1\frac{\partial m_n}{\partial x_1} - m_n\frac{\partial m_1}{\partial x_1}\right);$$

where

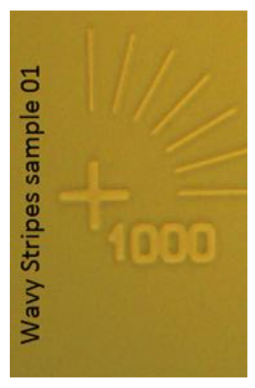
- k_1 is the curvature and A_{ex} the exchange stiffness.
- $K_{ex} = k_1^2 A_{ex}$, and $K_{DMI} = Dk_1$ are the exchange-induced and DMI-induced anisotropies, respectively.
- K_3, $K_{1,shape}$ and K_{rip} are the perpendicular anisotropy, the shape anisotropy and the intra-Ripple dipolar interaction.

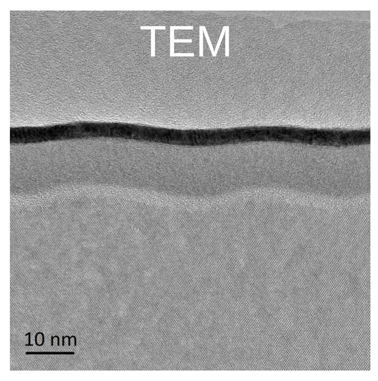
Fabrication



Si corrugated templates at HZR: LEI instrument

- Ion species: Ar+ . Ion energy: 250 eV
- Incidence angle: 45°, 48°, 50° *
- Nom. ion flux: 10^{15} cm^{-2}s^{-1} Nom.fluence: 10^{18} cm^{-2}

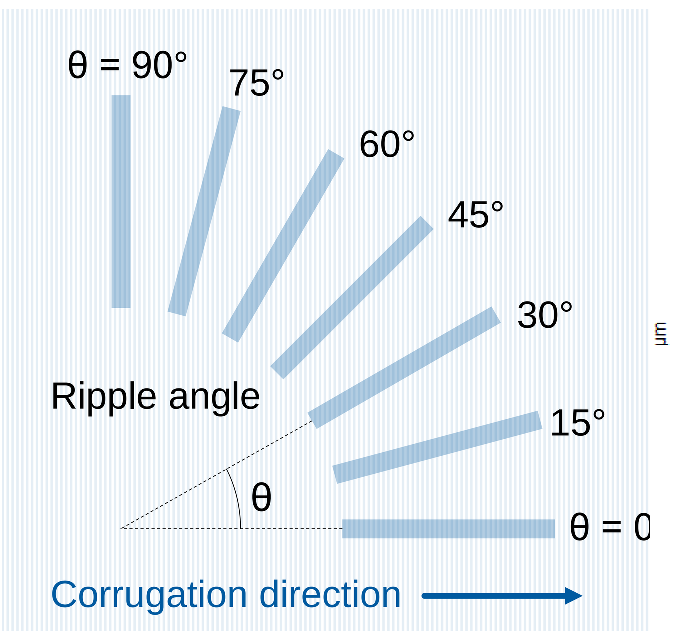


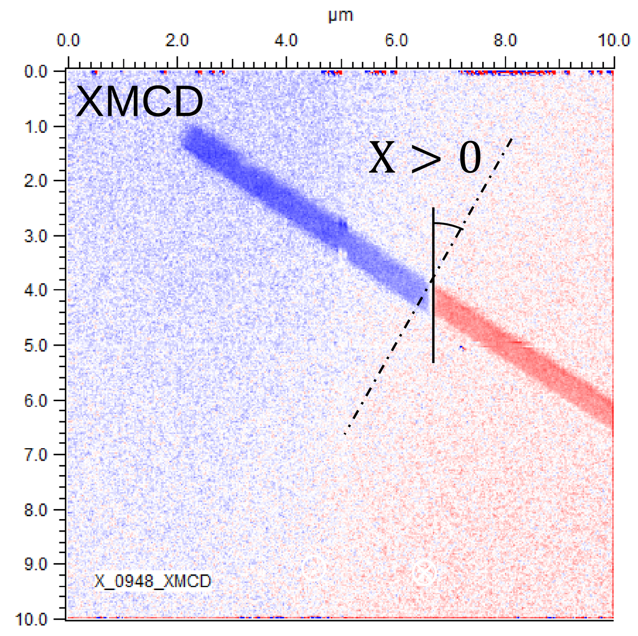


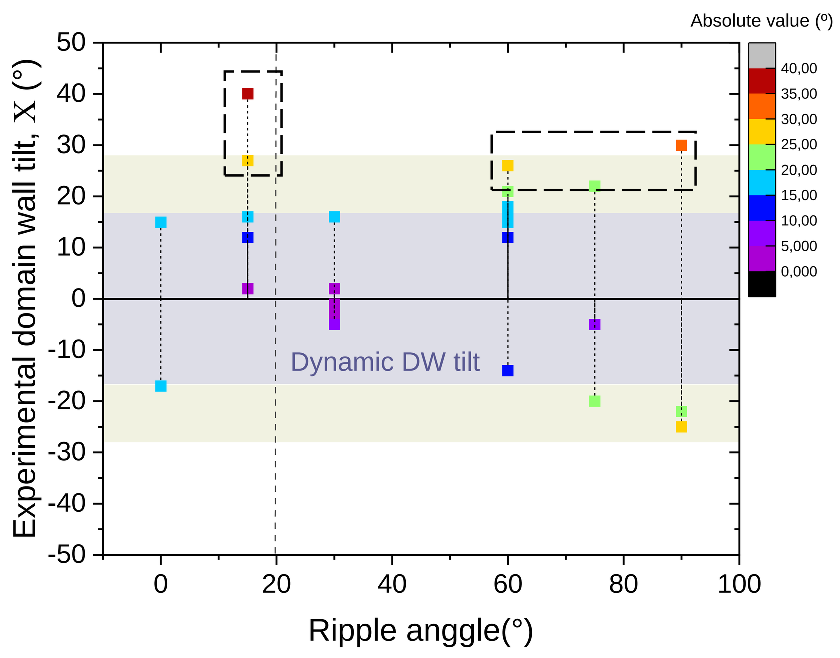
Sputter deposition with BESTEC at RT Ar 8·10^{-4} mbar

- Si/CrOx (5 nm)/Co (1 nm)/Pt (2 nm)
- P_{CrOx} = 100 W. P_{Co} = 75 W. P_{Pt} = 25 W

Domain wall tilt measurement from X-ray Magnetic Circular Dichroism imaging



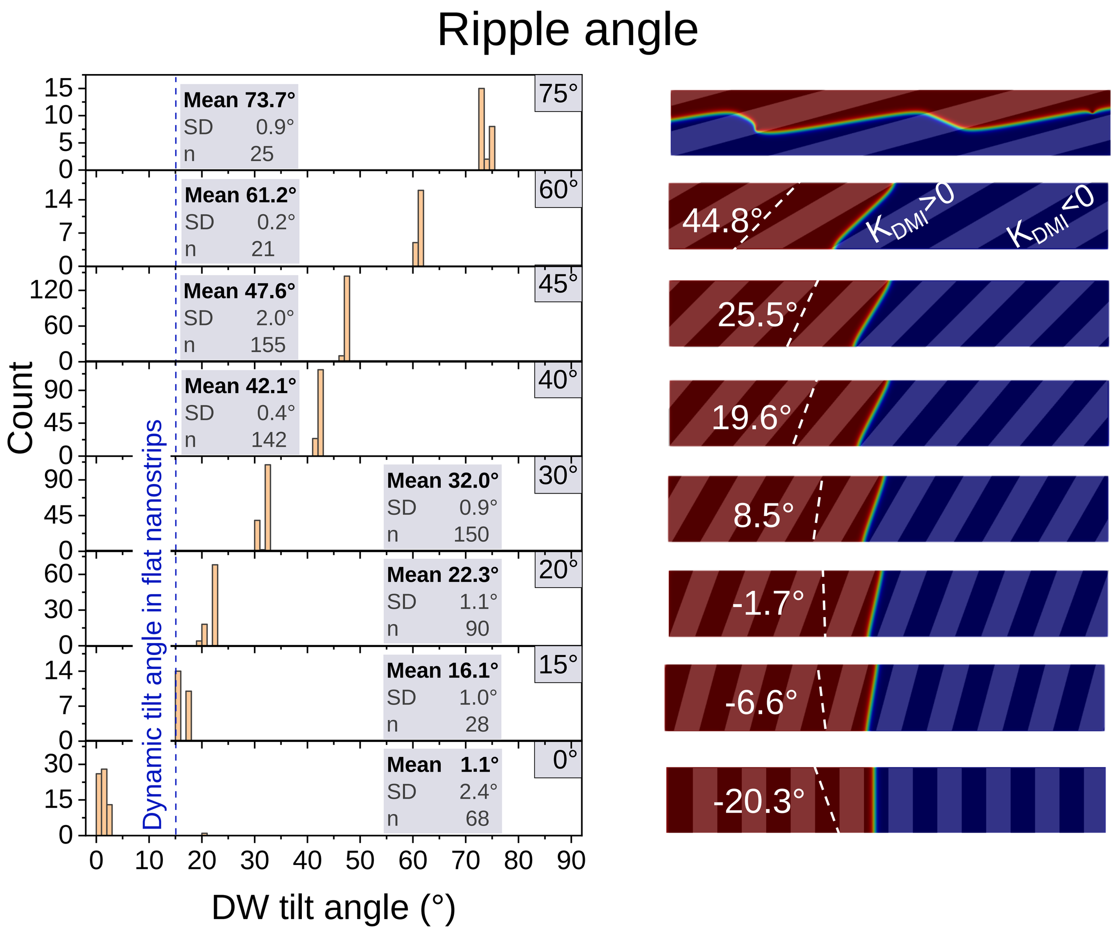




- The stabilization of a dynamic domain wall tilt of the Thiavielle model by means of granular defects explains only the experimental values in the grey region up to a maximum theoretical angle of 16º in Volkov et al. [11] .
- However, the large domain wall tilt values in the yellow region could be only possible in the presence of exchange- and DMI-induced curvilinear effects.
- To unravel the specific mechanism leading to larger tilt values we are carrying out three modelling approaches with mumax, SLaSI and MagnumFe.

Micromagnetic modelling with mumax

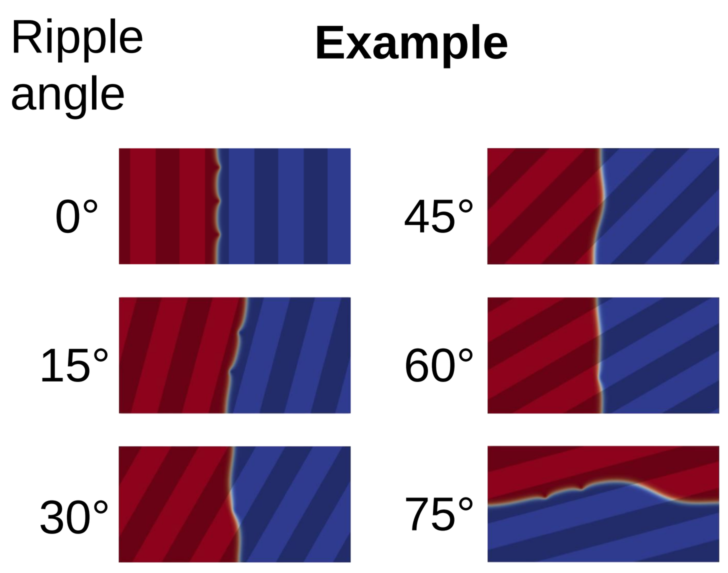
Ripple angle



We consider a flat stripe with effective curvilinear interactions, relax the system for > 100 different initial conditions, and make statistics.

- These results indicate that large domain wall tilts could be explained by means of exchange-induced and DMI-induced interactions.
- However, Intra-ripple dipolar energy is neglected.

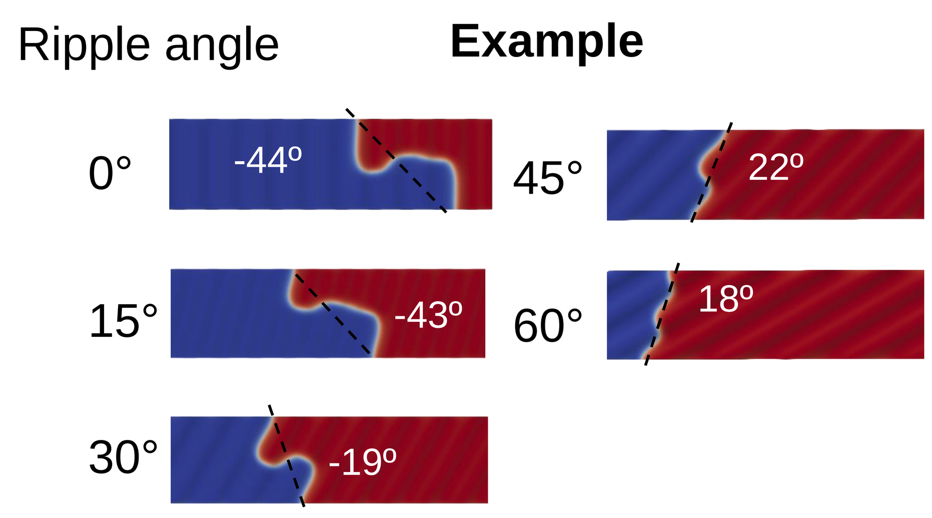
SLaSi



Following a similar approach, we are considering a flat stripe with effective curvilinear interactions and relax the system for different initial domain wall conditions in our home-made Spin Lattice System (SLaSi).

- SLaSi enables customizable interfacial DMI and anisotropies, including spatial gradients.
- SLaSi provides scale-free modelling in units of exchange length

MagnumFe



Statistics with MagnumFe are leading to a complex landscape of domain wall tilts, that requires statistics for understanding the curvilinear mechanism behind.

References

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