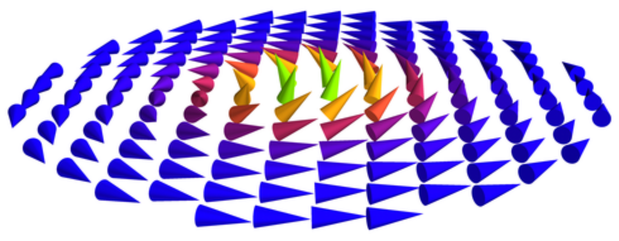

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Domain wall motion in perpendicular nanowires with surface roughness

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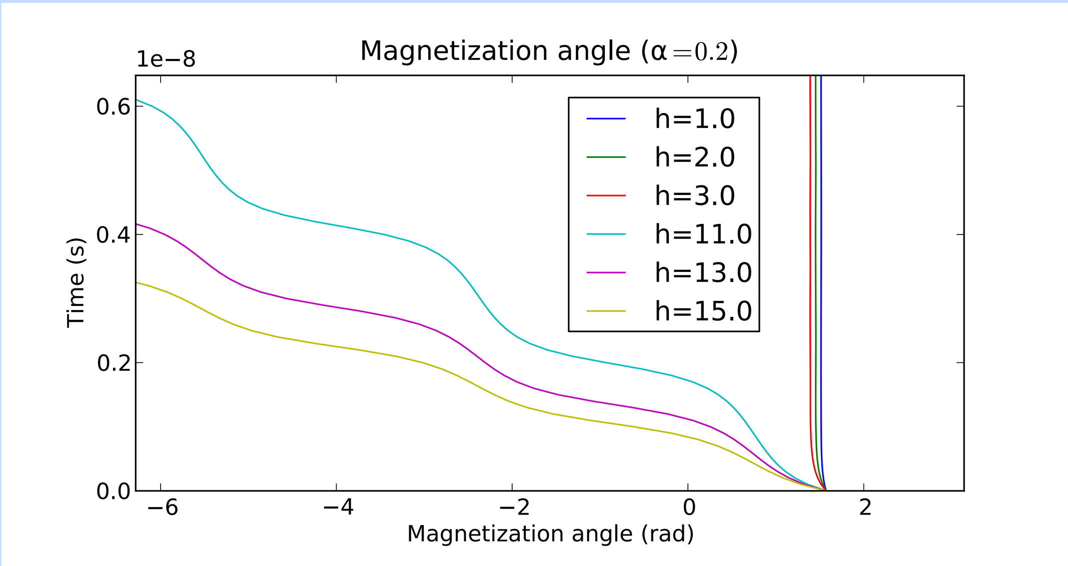
Overview

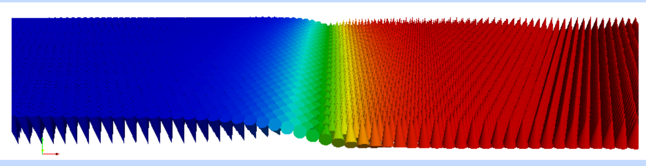
- Most micromagnetic simulations use idealised, smooth meshes.
- In real-world systems, the production process introduces distortions on various scales (e.g., electron beam lithography, sputter deposition).
- Distortions have a significant impact on magnetization dynamics. [1,2,3]
- We present a systematic exploration of effects introduced by roughness.
- We use finite element (FE)-based calculations with proper mesh distortion, in contrast to finite difference methods with varied material constants. [1,3]



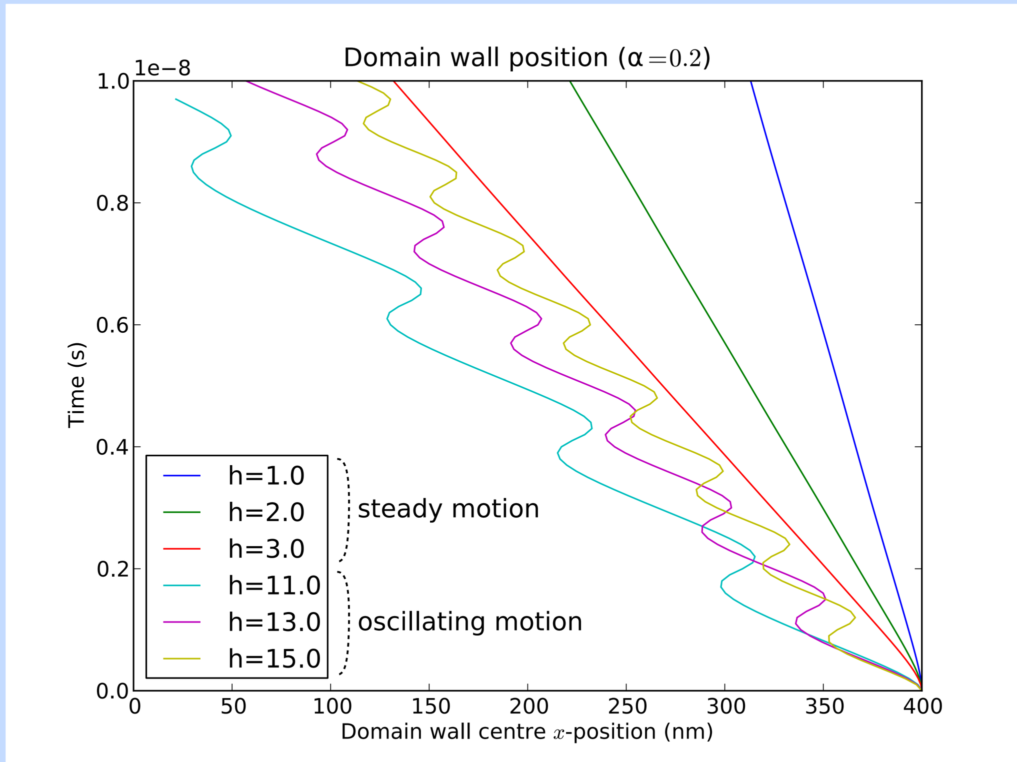
Simulations with a smooth nanowire

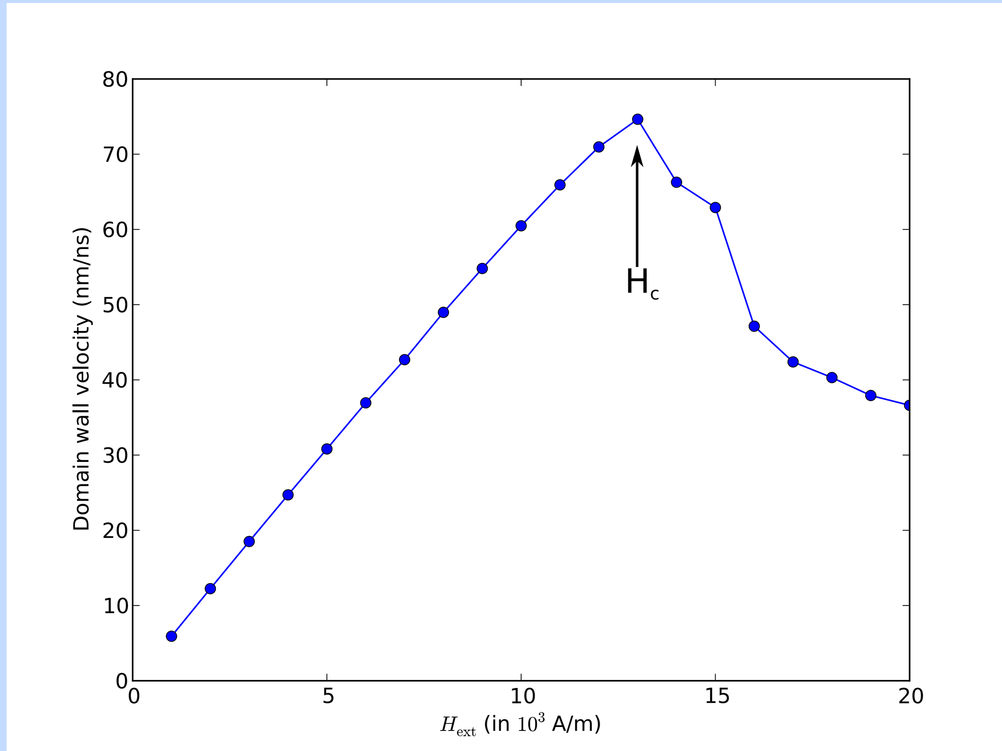
The simulated system is a thin (multilayered) Co/Ni nanowire (800 nm x 20 nm x 5 nm) with strong perpendicular anisotropy ($K_1 = 3.8 \times 10^5$ J/m^3). All computations were done using the FE-based simulation package nmag [4].

Phase 1: Relax system into stable configuration (perp. domain wall in center).
Phase 2: Apply external field in vertical direction, record DW motion for 10 ns.



→ Phase transition of DW motion from steady to oscillating at a critical field H_c ("Walker breakdown" [5]).



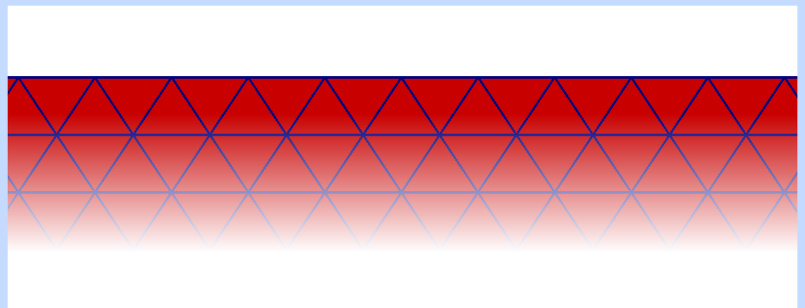


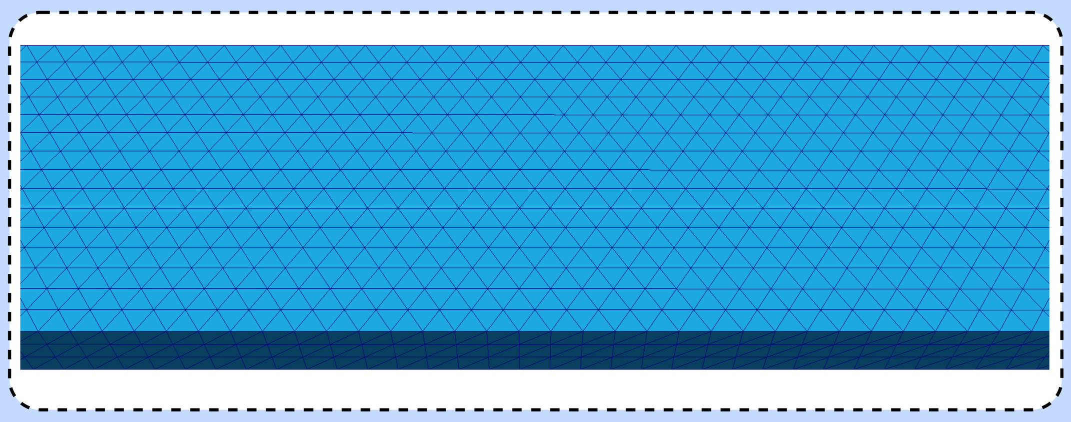
Modelling roughness

Smooth mesh

Rough mesh

1





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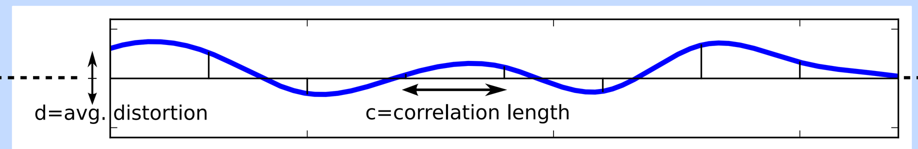


1) Start with smooth mesh.

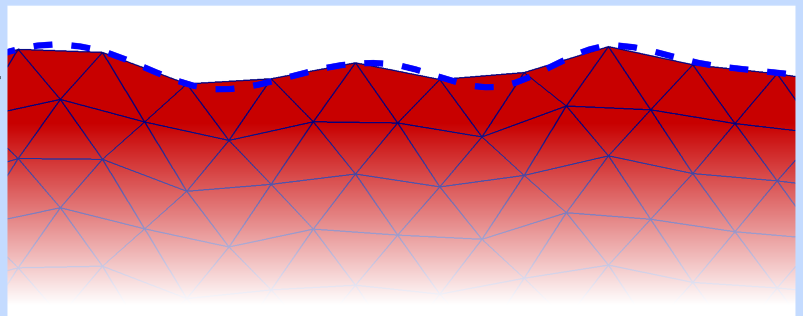
2) On either side of the wire, choose random distortions at equidistant nodes. Interpolate with spline functions.

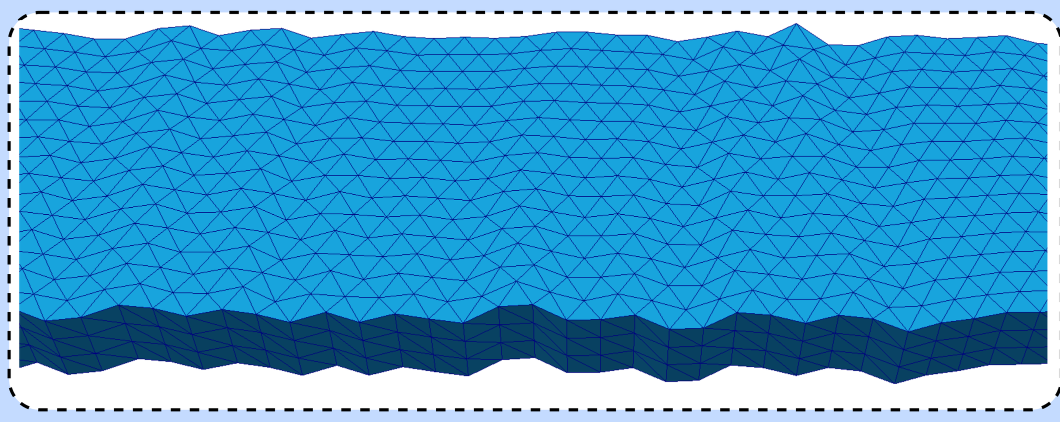
The distortions follow a normal distribution with mean zero and standard deviation d ("average distortion").

3) Stretch mesh to fit between the curves.

Two-dimensional surface roughness and other kinds are also possible with this approach but not investigated in this study.

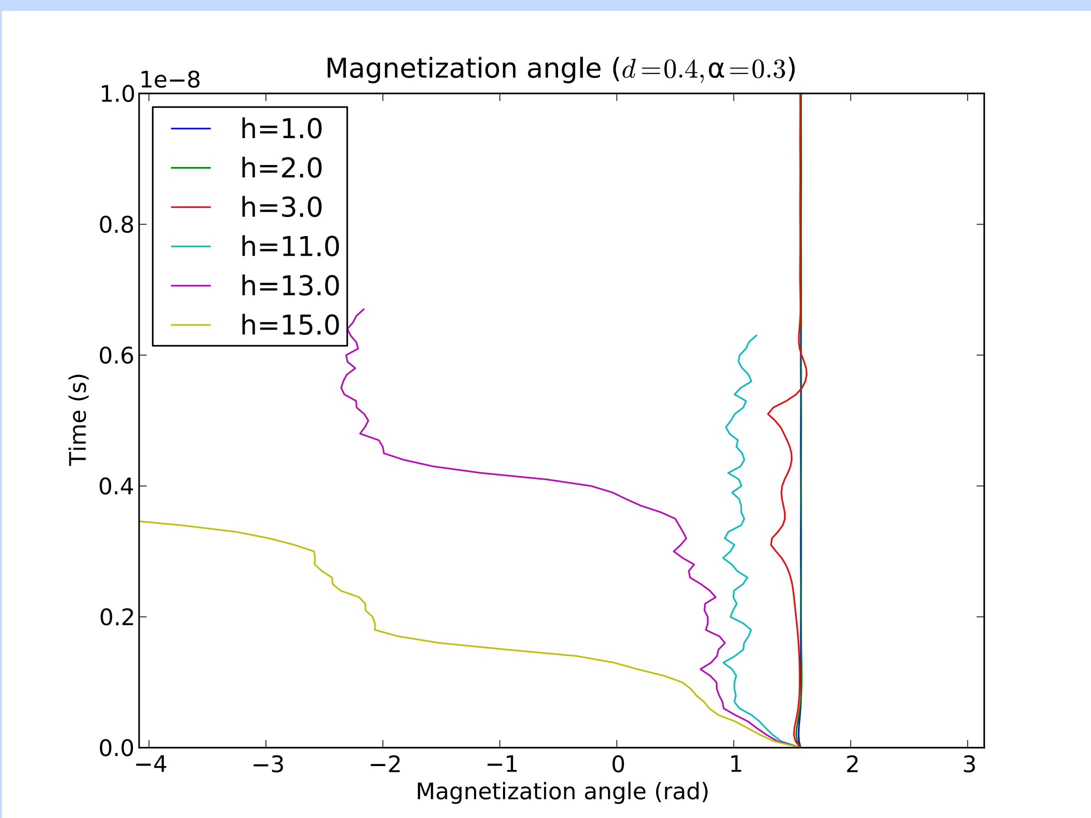
3



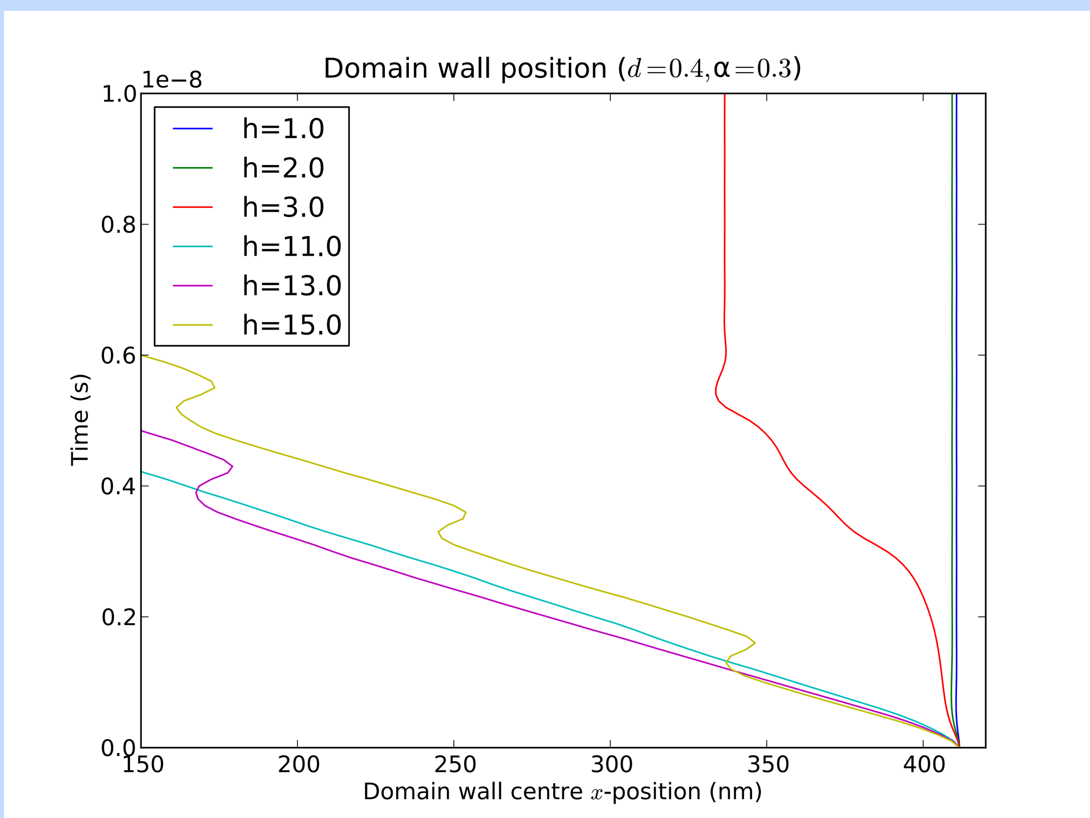


Simulations with a rough nanowire

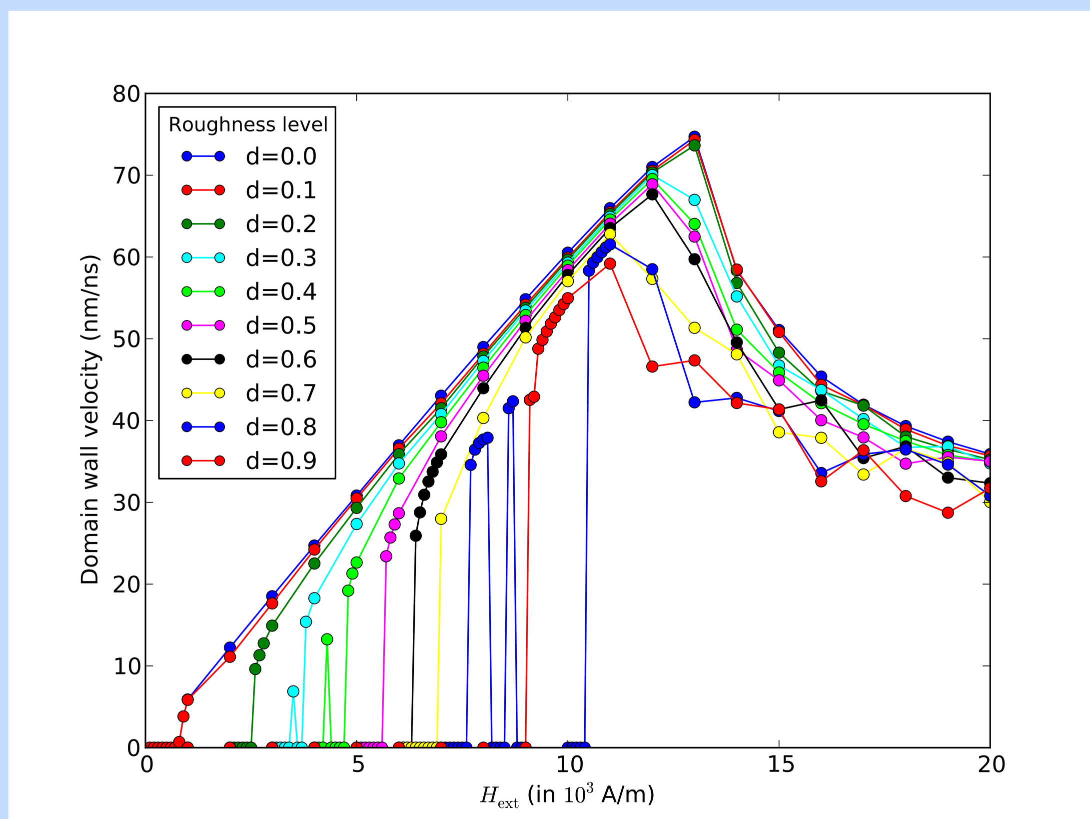
(All simulations were performed with correlation length c = 2.0 nm.)



The magnetization angle inside the domain wall shows considerable jittering due to the interaction of the domain wall with the demagnetizing field caused by the edge roughness.



For weak fields the domain wall is pinned at the origin. Pinning can also occur when the domain wall is already in motion (as happens for $H_{ext} = 3 \times 10^3$ A/m).



Dependence of the domain wall velocity on the external field for various levels of roughness d. Note that pinning occurs for d>0 (and the depinning field increases with roughness). For weak fields the domain wall is slowed down considerably with increasing roughness, whereas for large fields this effect is reduced. Note that the Walker breakdown occurs *earlier* in rough wires (in contrast with results from [1]).

Notation: d = average distortion; α = Gilbert damping factor; h = strength (in 10^3 A/m) of external field applied in z-direction.

Summary

- Significant influence of roughness on domain wall dynamics.
- Domain wall gets pinned at the origin; can also get pinned during motion (even for stronger fields where pinning does not occur for weaker fields).
- Slowdown of the domain wall with increasing roughness (effect is more prominent for weak fields)
- Walker breakdown already occurs for weaker fields in rough wires.

References

[1] Nakatani, Thiaville, Miltat, "Faster magnetic walls in rough wires", Nat. Mater. 2 (8), 521-523, 2003.
[2] Hankemeier, Frömter, Mikuszeit et al., "Magnetic Ground State of Single and Coupled Permalloy Rectangles", Phys. Rev. Lett. 103, 2009.
[3] Min, McMichael, Donahue et al., "Effects of Disorder and Internal Dynamics on Vortex Wall Propagation", Physical Review Letters 104 (21), 217201, 2010.
[4] http://nmag.soton.ac.uk/
[5] Schryer, Walker, "The motion of 180° domain walls in uniform dc magnetic fields", J. Appl. Phys. 45 (12), 5406-5421, 1974.
[6] Tanigawa, Koyama, Yamada et al., "Domain Wall Motion Induced by Electric Current in a Perpendicularly Magnetized Co/Ni Nano-Wire", Appl. Phys. Express 2, 053002, 2009.