Micromagnetic Simulation of Magnetic Systems

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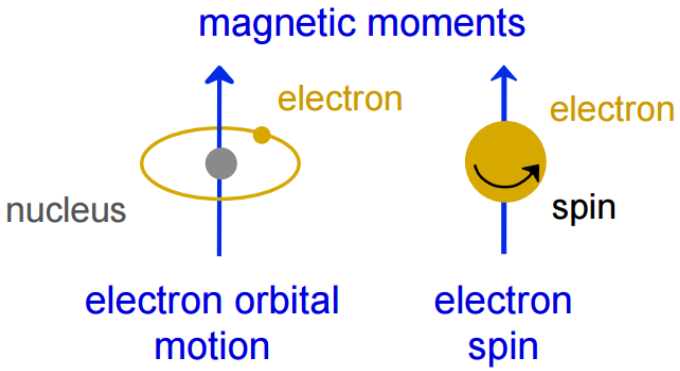
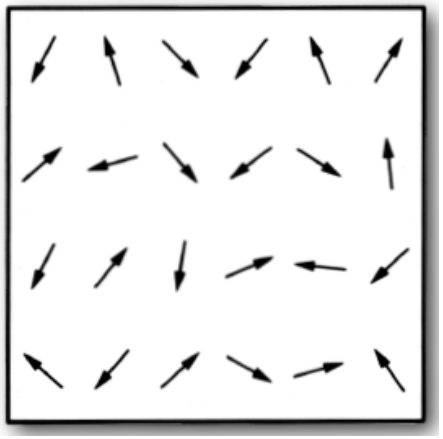
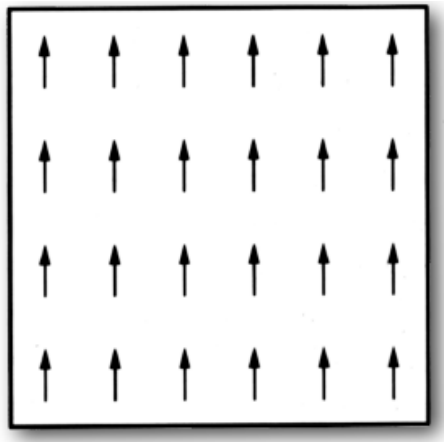
COMSOL CONFERENCE 2018 SHANGHAI

FUDAN UNIVERSITY 復旦大學

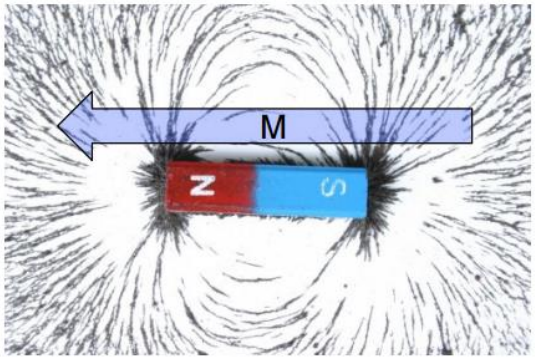


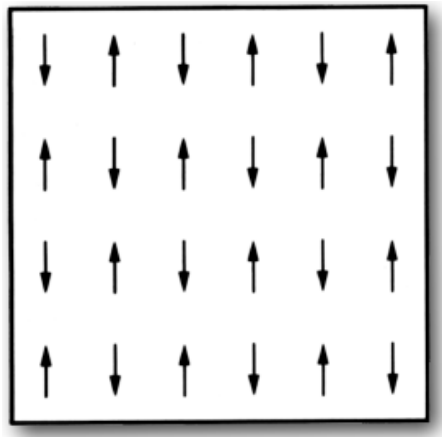


Paramagnet

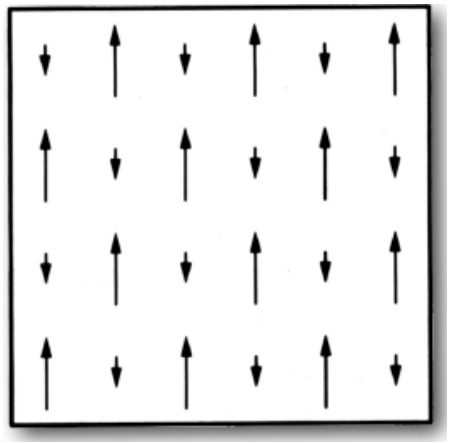


Ferromagnet



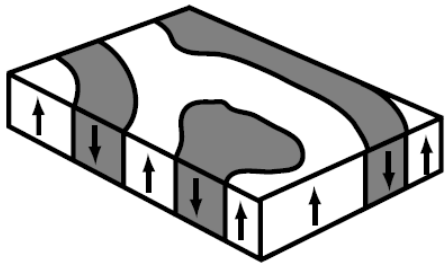


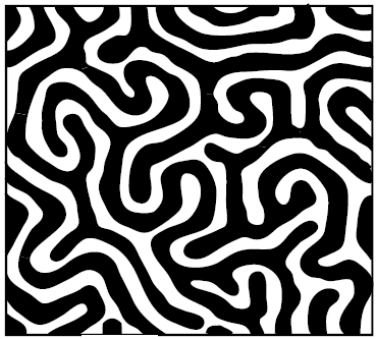
Antiferromagnet

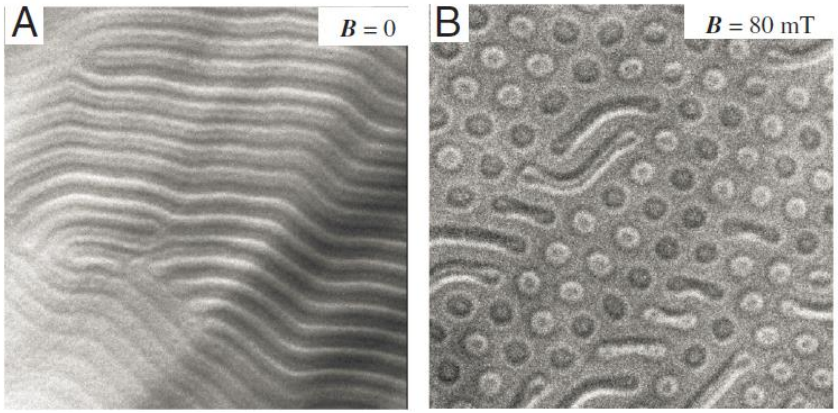


Ferrimagnet

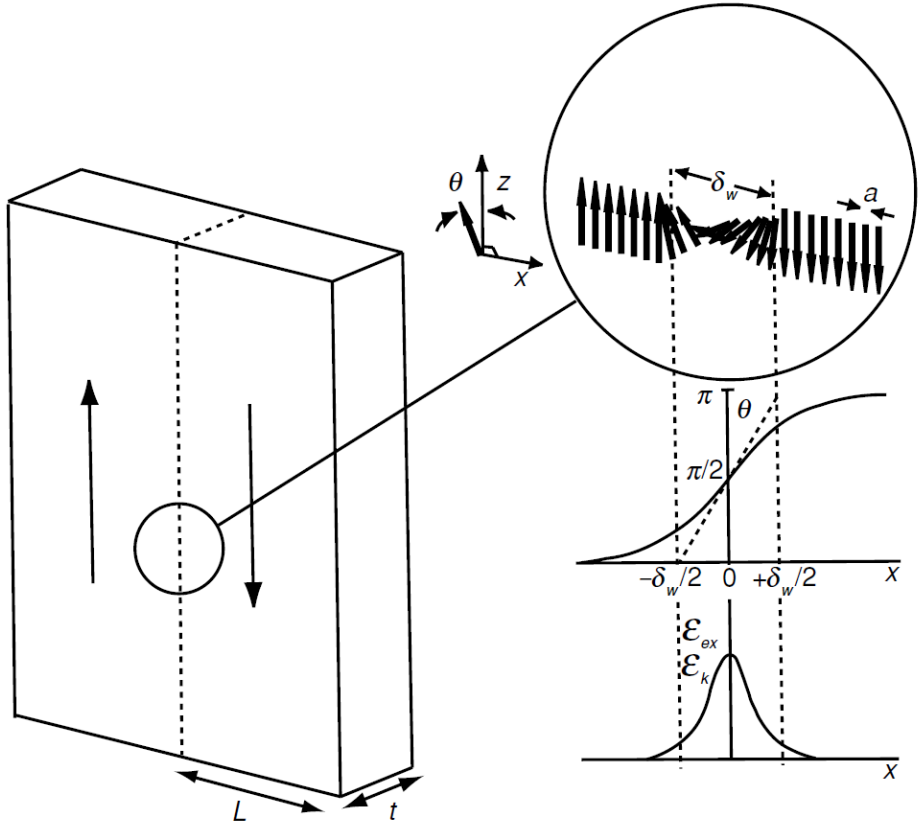
magnetic domain and domain wall



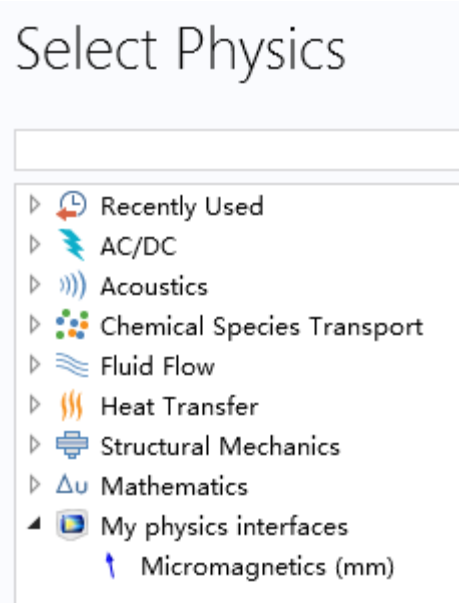




PNAS, 2012, 109(23): 8856-8860.



$$\varepsilon_{tot} = \int \{A(\nabla \boldsymbol{M}/M_s)^2 - K_1 \sin^2\theta - \cdots - \tfrac{1}{2}\mu_0 \boldsymbol{M}\cdot\boldsymbol{H}_d - \mu_0 \boldsymbol{M}\cdot\boldsymbol{H}\}\mathrm{d}^3 r.$$

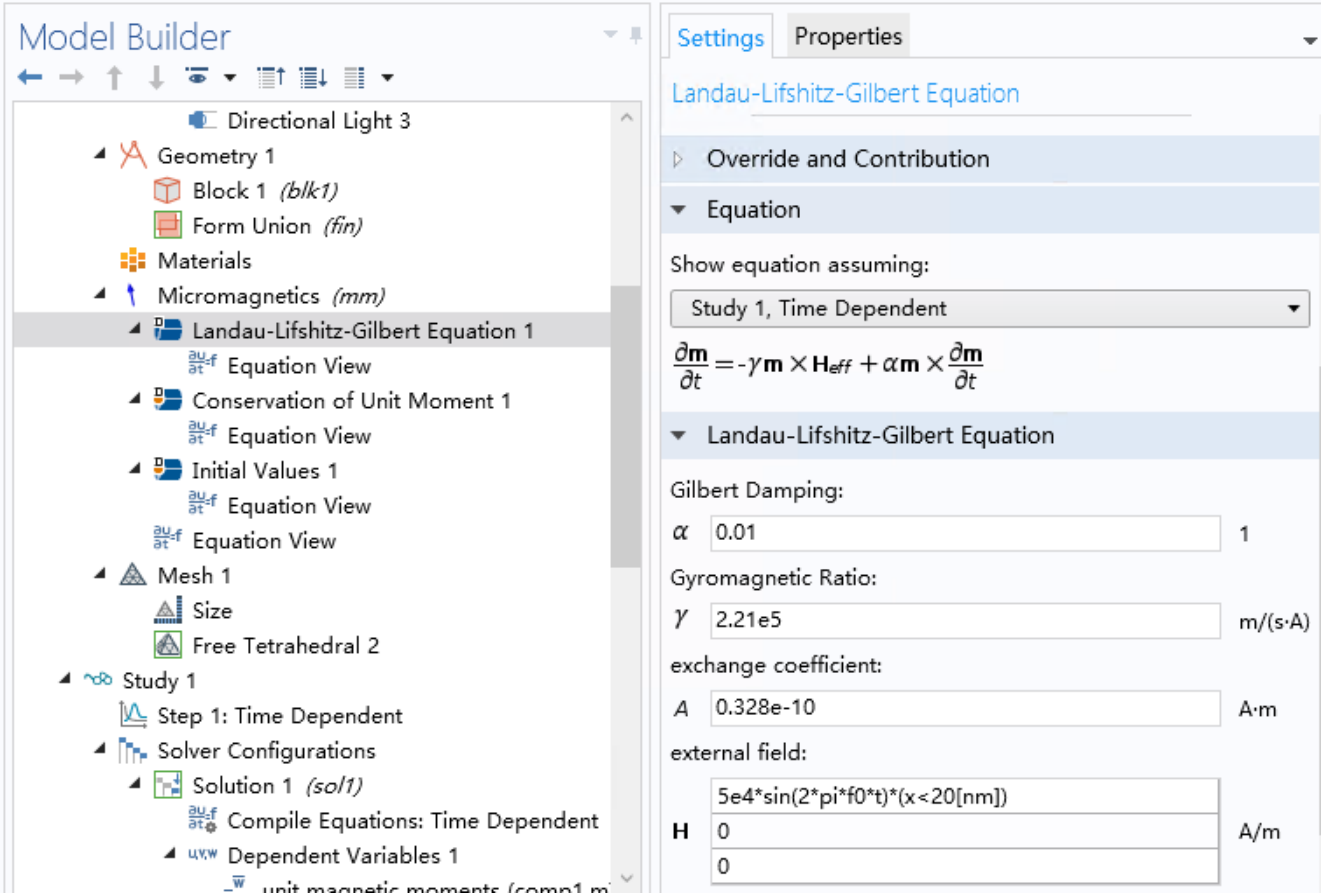


popular micromagnetics simulators:

OOMMF, MAGPAR, Nmag, MuMax3, MicroMagus etc.

Home-made

micromagnetic module



D. D. Stancil and A. Prabhakar, Spin waves (Springer, 2009).

LLG(Landau-Lifshitz-Gilbert) Equation

$$\frac{\partial \mathbf{m}(\mathbf{r},t)}{\partial t} = -\gamma \mathbf{m}(\mathbf{r},t) \times \mathbf{H}_{\mathbf{eff}} + \alpha \mathbf{m}(\mathbf{r},t) \times \frac{\partial \mathbf{m}(\mathbf{r},t)}{\partial t}$$

$\mathbf{H}_{\mathbf{eff}}$ effective field :

$A\nabla^2\mathbf{m}$	exchange interaction
$K\mathbf{m}\cdot\mathbf{e}$	easy(hard)-axis anisotropy
$\frac{1}{4\pi}\int\left(\frac{3\mathbf{r}(\mathbf{m}\cdot\mathbf{r})}{r^5}-\frac{\mathbf{m}}{r^3}\right)d\mathbf{r}$	dipole-dipole interaction
$-D\nabla\times\mathbf{m}$	Dzyaloshinskii-Moriya interaction (DMI)
$\bullet\bullet\bullet$	etc.

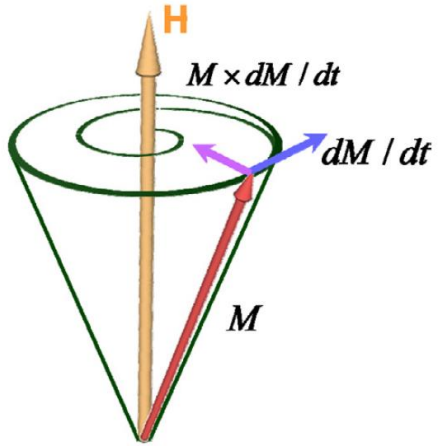
solved numerically by mathematics module

Parameters are chosen from YIG.

Macrospin Precession

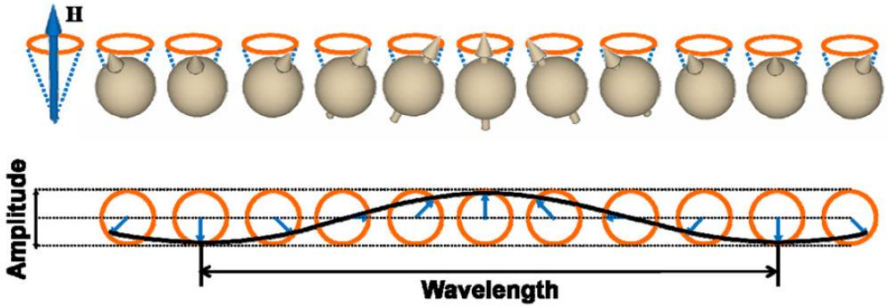
Landau-Lifshitz-Gilbert (LLG) equation

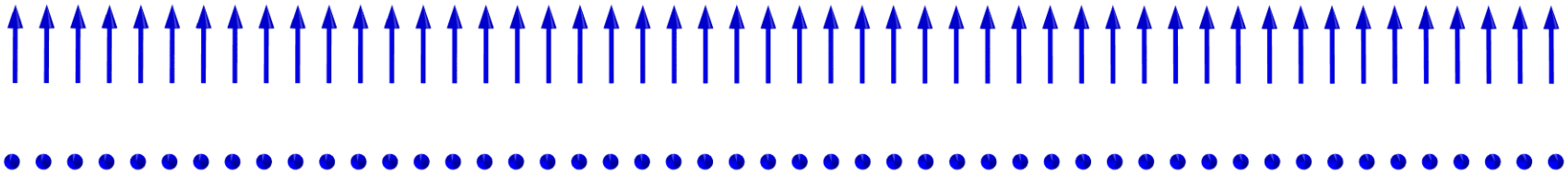
$$\frac{\partial \mathbf{m}}{\partial t} = -\gamma \mathbf{m} \times \mathbf{H_{eff}} + \alpha \mathbf{m} \times \frac{\partial \mathbf{m}}{\partial t}$$

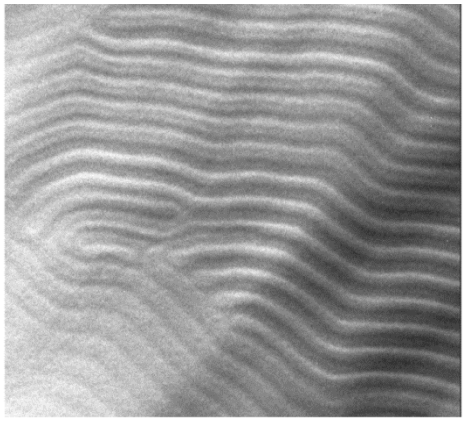


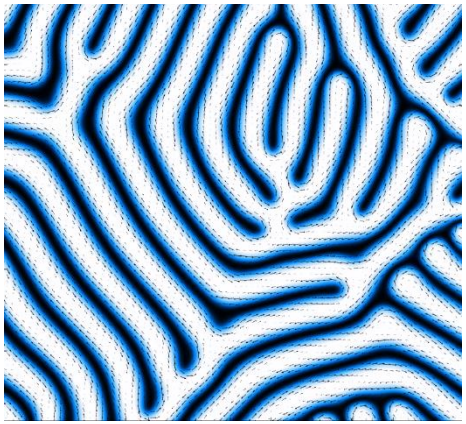
S. K. Kim, J. Phys. D: Appl. Phys. 43 (2010)

Spin Waves (Magnons)

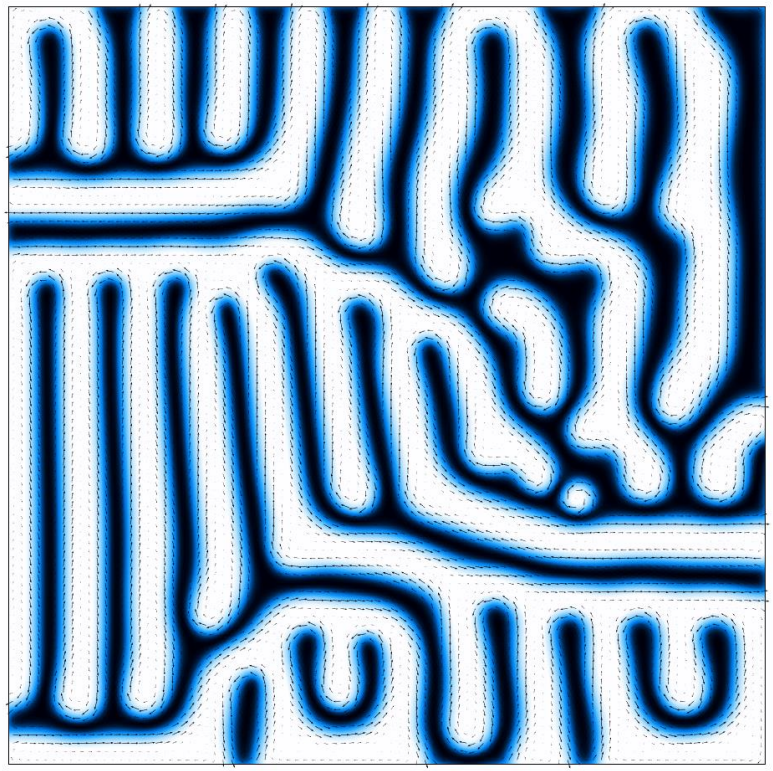




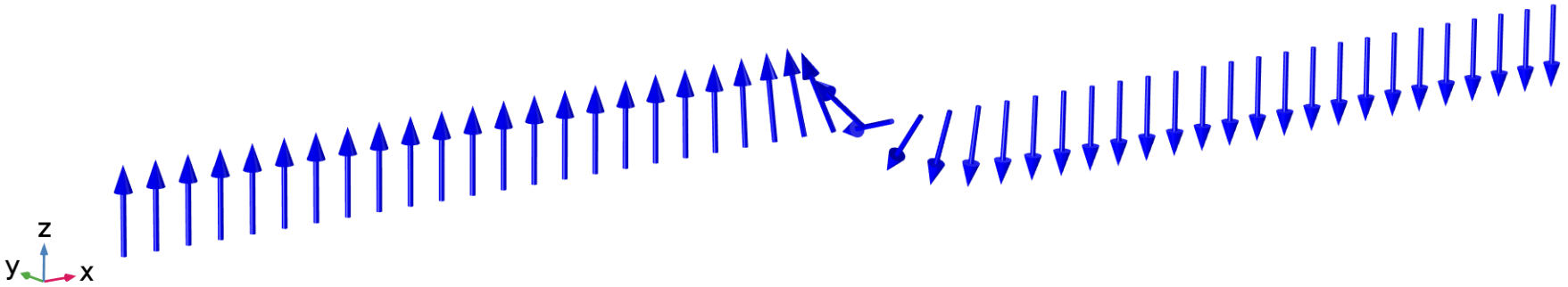




PNAS, 2012, 109(23): 8856-8860.

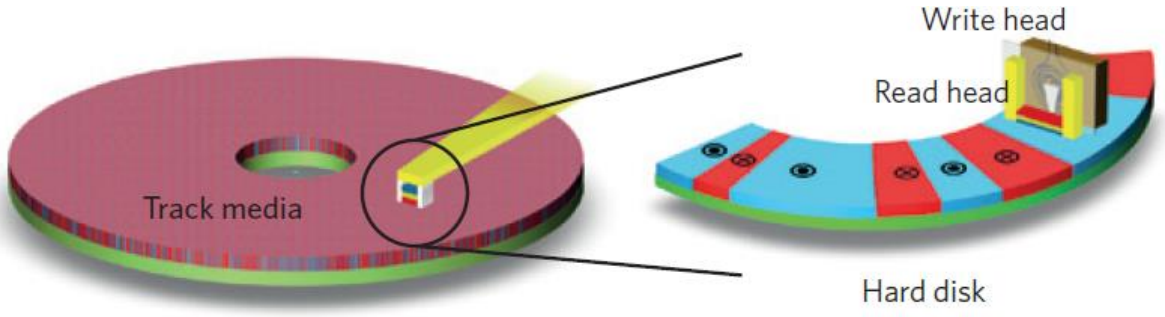


Current-driven Domain Wall Motion

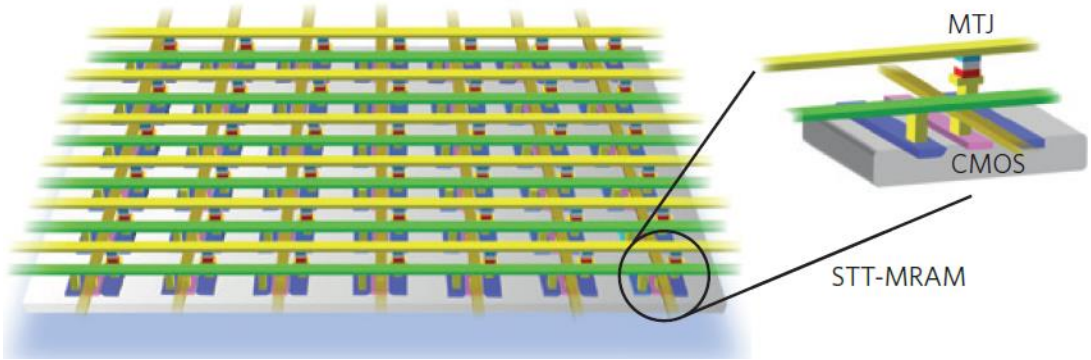


Parkin S, Yang S H. Nature Nanotechnology, 2015, 10(3):195-8.

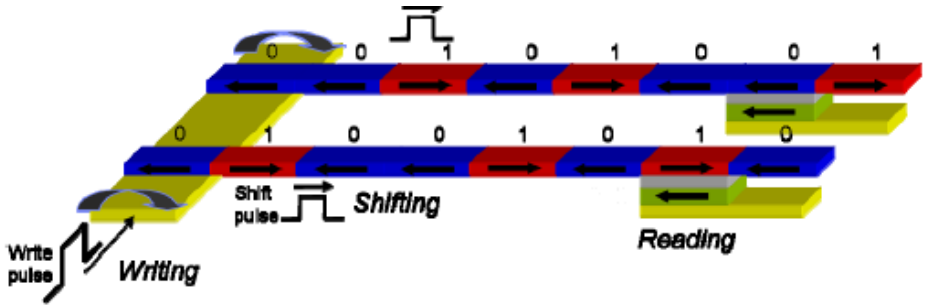
Hard Disk Driver



STT-MRAM (Spin-Transfer-Torque Magnetic Random Access Memory)

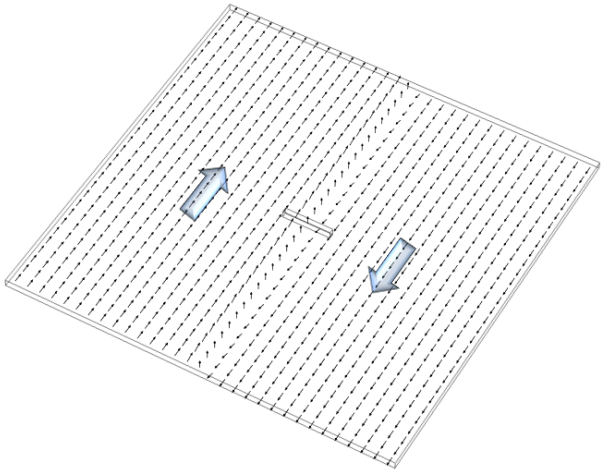


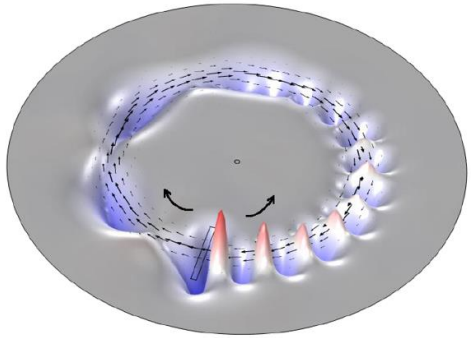
Domain Wall Racetrack Memory



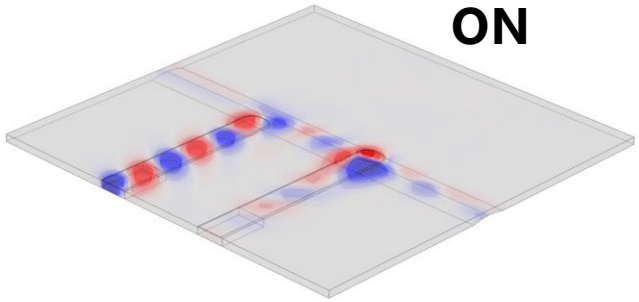
Jin Lan*, **Weichao Yu***, et al. Physical Review X, 5,041049 (2015)

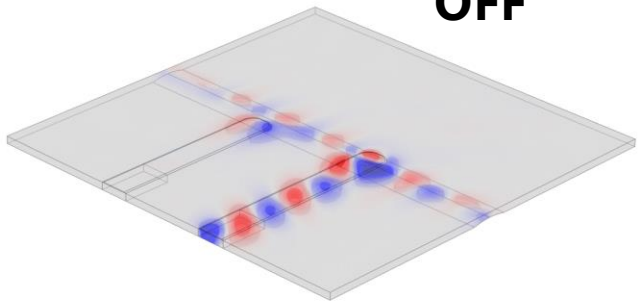
Bound state spin waves in domain wall/skyrmions



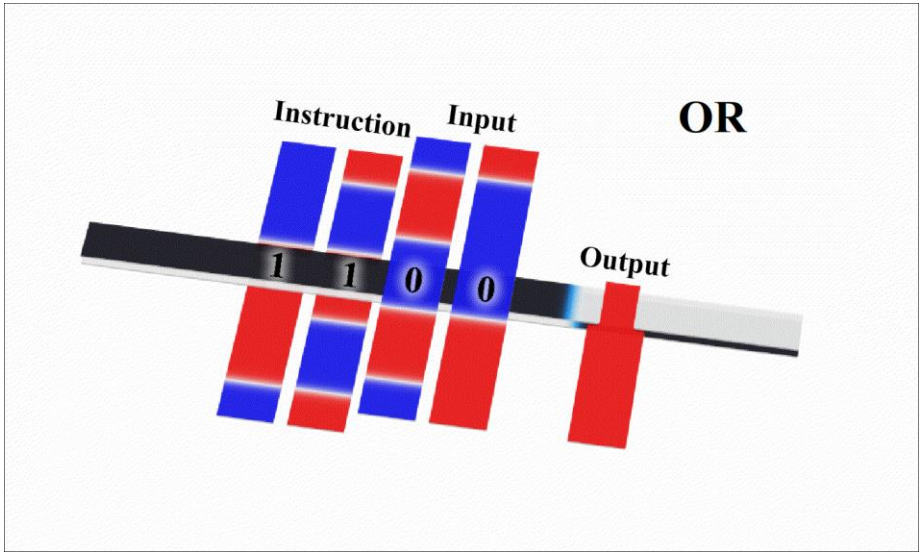


Spin-wave diode

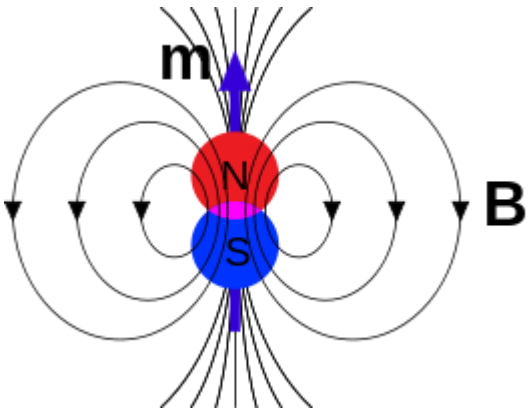


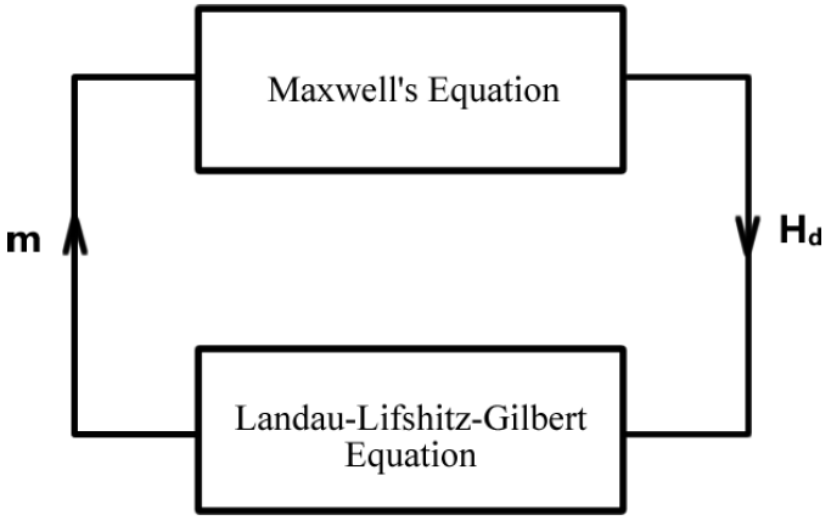


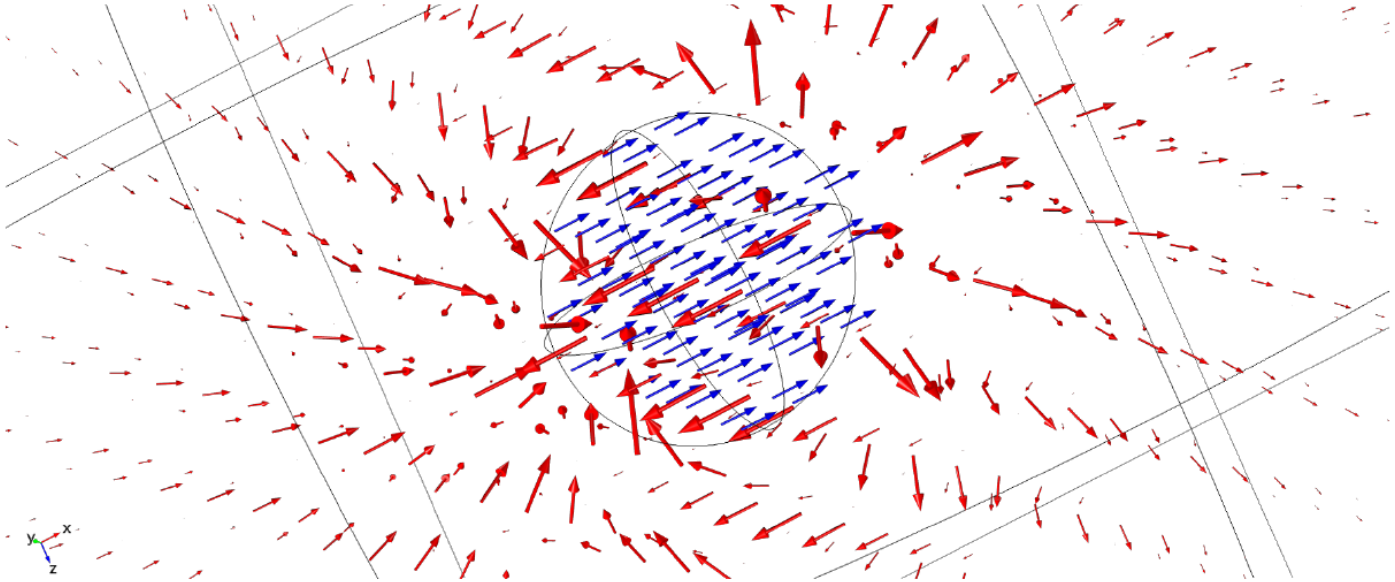
Universal logic gate



Magnetic dipole

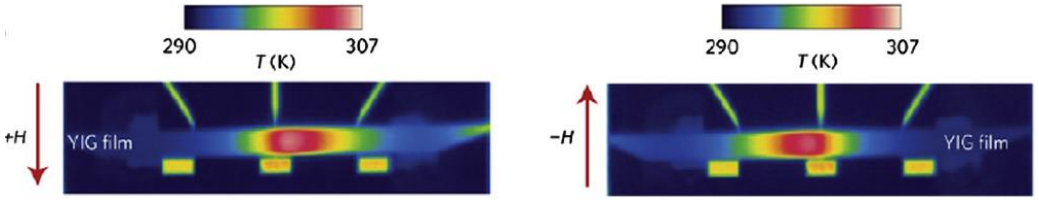






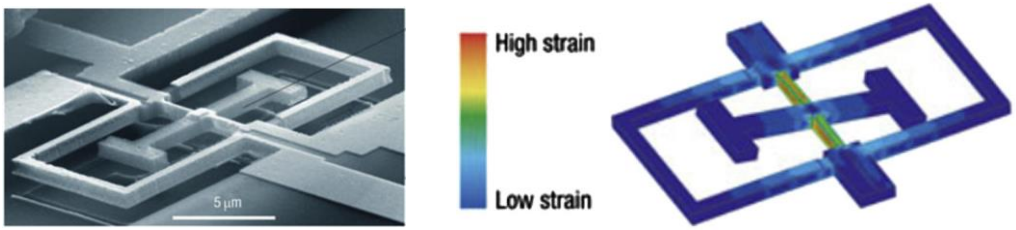
couple Micromagnetics with other physics

1. magnon-thermal



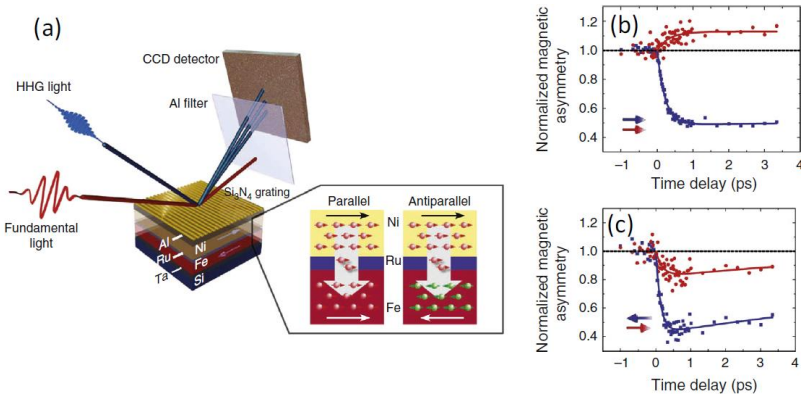
An T, Vasyuchka VI, et al.Nat Mater 2013;12(6):549–53.

2. magnon-elastic



Zolfagharkhani G et al. Nat Nanotechn2008;3:720.

3. magnon-optics



Rudolf D, et al. Nat Commun 2012;3:1037.

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SUMMARY

Numerical Tool

COMSOL micromagnetics module

Magneto-elastic coupling

Magneto-electric coupling

Spin Caloritronics

Spin Cavitronics

AMR vs STT

Physics

Bound state spin waves in domain wall / skyrmion

Scattering of spin waves by domain wall / skyrmion

Spin wave driven domain wall / skyrmion motion

Interaction between POLARIZED spin waves and CHIRAL textures in AFM

Application

Spin wave circuits

Spin wave diode

Spin wave fiber

Spin wave circulator

Spin wave polarizer and retarder

Non-volatile spin wave computing architecture

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Group Website