

Micromagnetic Simulation of Magnetic Systems

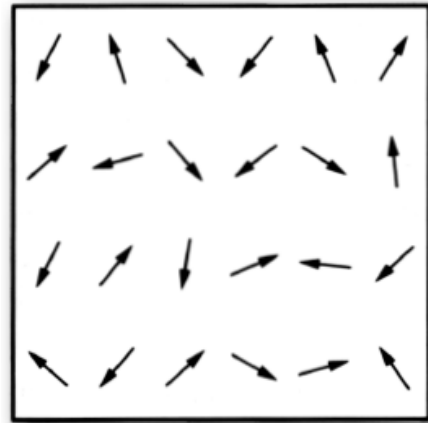
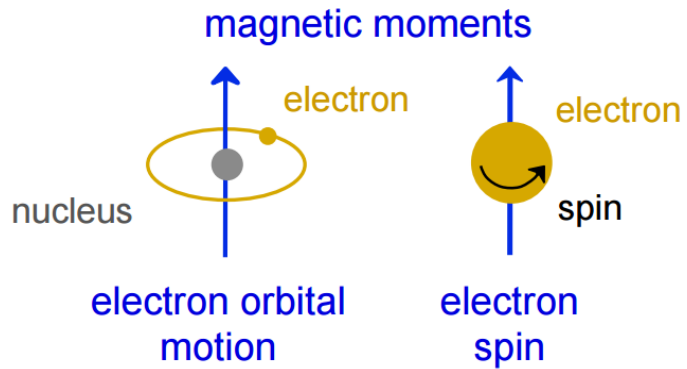
Speaker Dr. Weichao Yu (余伟超)

Advisor Prof. Jiang Xiao (肖江)

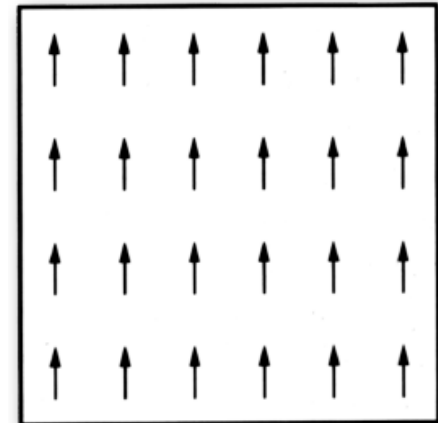
COMSOL
CONFERENCE
2018 SHANGHAI



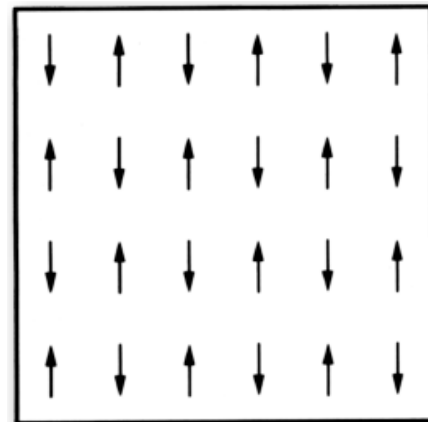
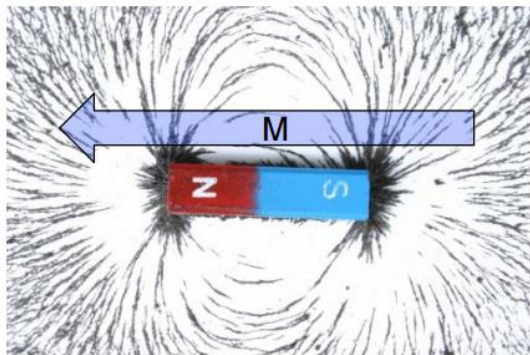
復旦大學
FUDAN UNIVERSITY



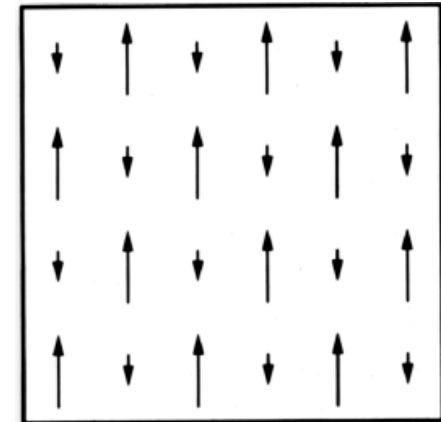
Paramagnet



Ferromagnet

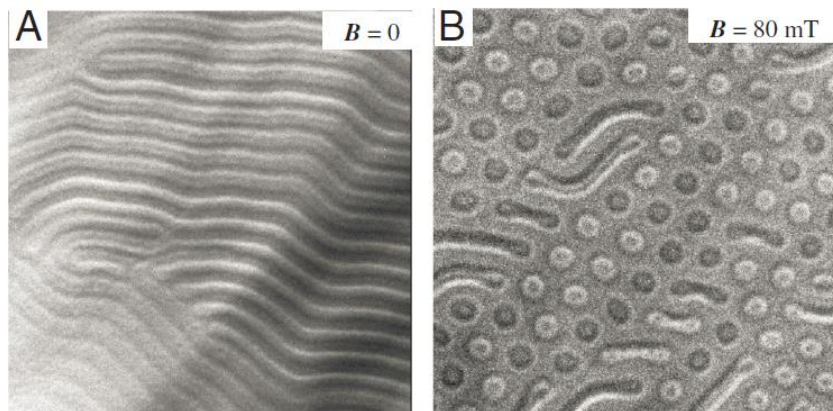
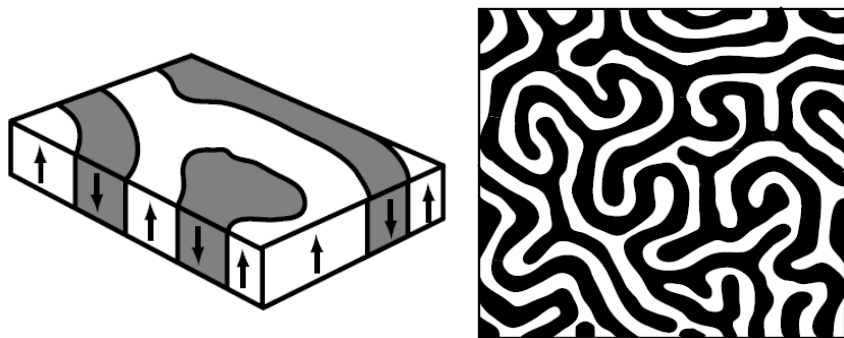


Antiferromagnet

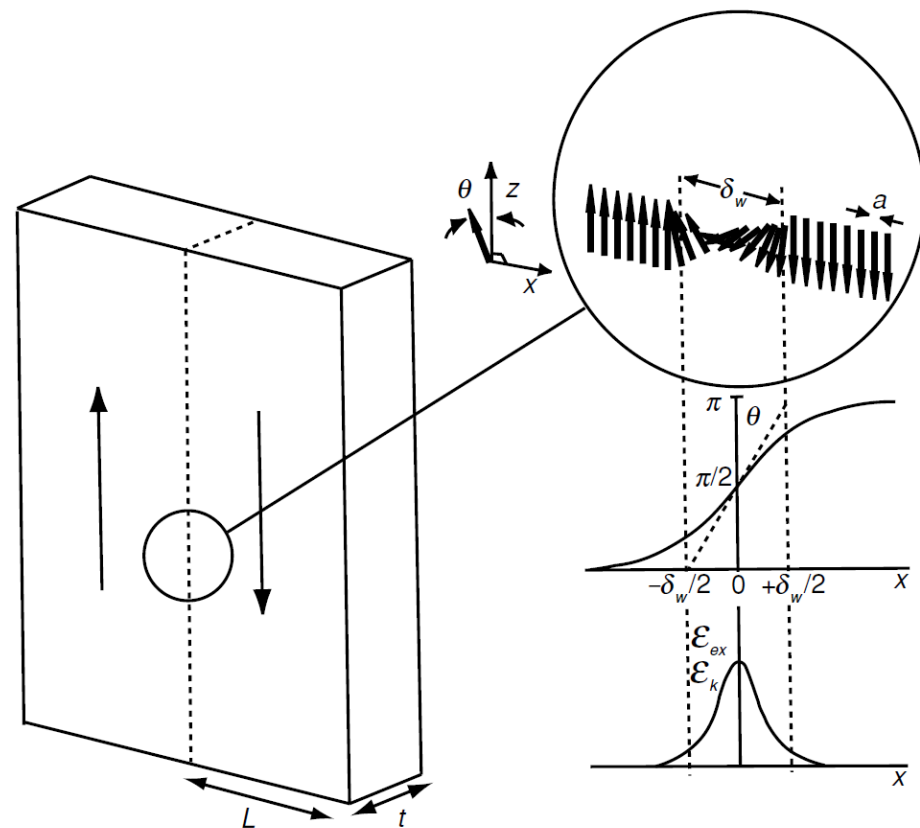


Ferrimagnet

magnetic domain and domain wall



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



$$\epsilon_{tot} = \int \{A(\nabla M/M_s)^2 - K_1 \sin^2 \theta - \dots - \frac{1}{2}\mu_0 \mathbf{M} \cdot \mathbf{H}_d - \mu_0 \mathbf{M} \cdot \mathbf{H}\} d^3 r.$$

Select Physics

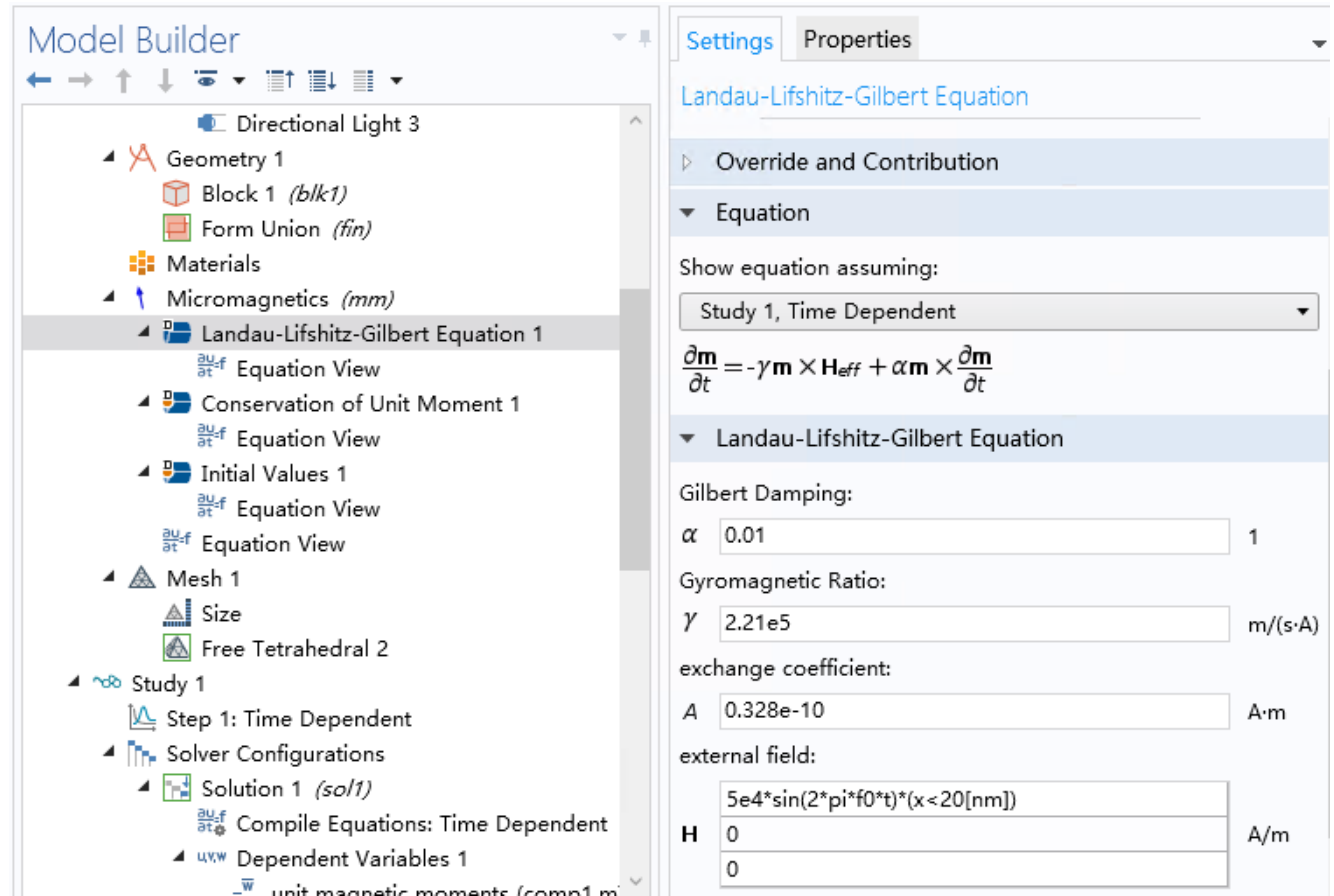
- ▷ Recently Used
- ▷ AC/DC
- ▷ Acoustics
- ▷ Chemical Species Transport
- ▷ Fluid Flow
- ▷ Heat Transfer
- ▷ Structural Mechanics
- ▷ Mathematics
- ◀ My physics interfaces
 - ↳ Micromagnetics (mm)

popular micromagnetics simulators:

OOMMF, MAGPAR, Nmag, MuMax3, MicroMagus etc.

Home-made

micromagnetic module



The screenshot shows the COMSOL Model Builder interface. The left pane displays the model tree with the following structure:

- Directional Light 3
 - Geometry 1
 - Block 1 (*blk1*)
 - Form Union (*fin*)
 - Materials
 - Micromagnetics (*mm*)
 - Landau-Lifshitz-Gilbert Equation 1
 - Equation View
 - Conservation of Unit Moment 1
 - Equation View
 - Initial Values 1
 - Equation View
 - Equation View
 - Mesh 1
 - Size
 - Free Tetrahedral 2
 - Study 1
 - Step 1: Time Dependent
 - Solver Configurations
 - Solution 1 (*sol1*)
 - Compile Equations: Time Dependent
 - Dependent Variables 1
 - unit magnetic moments (*comp1 m*)

The right pane shows the settings for the selected "Landau-Lifshitz-Gilbert Equation".

Settings | Properties

Landau-Lifshitz-Gilbert Equation

Override and Contribution

Equation

Show equation assuming:

Study 1, Time Dependent

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

Landau-Lifshitz-Gilbert Equation

Gilbert Damping:

α 0.01 1

Gyromagnetic Ratio:

γ 2.21e5 m/(s·A)

exchange coefficient:

A 0.328e-10 A·m

external field:

H 5e4*sin(2*pi*f0*t)*(x<20[nm]) A/m

0

0

LLG(Landau-Lifshitz-Gilbert) Equation

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

\mathbf{H}_{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)
	...	etc.

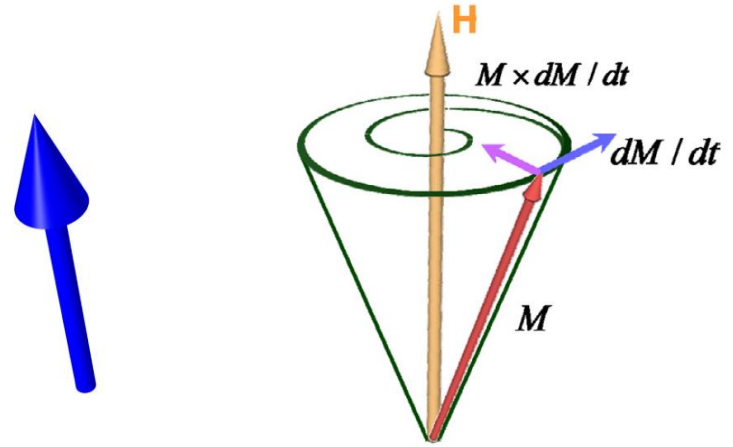
solved numerically by mathematics module

Parameters are chosen from YIG.

Macrospin Precession

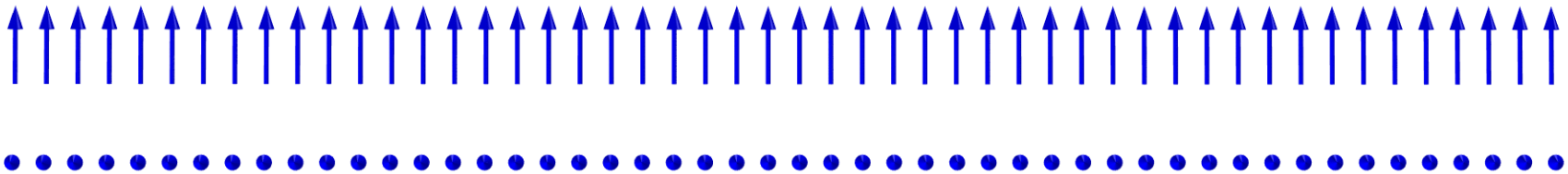
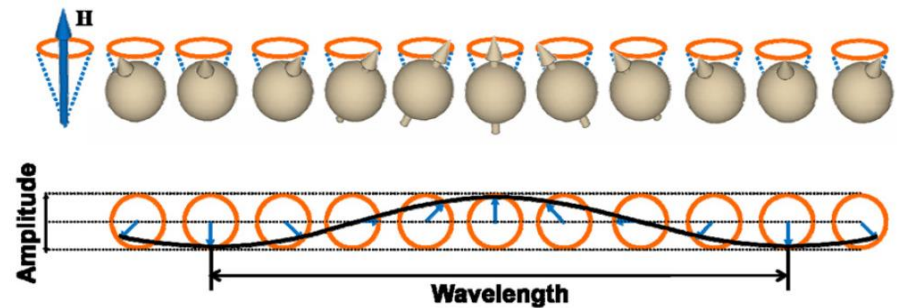
Landau-Lifshitz-Gilbert (LLG) equation

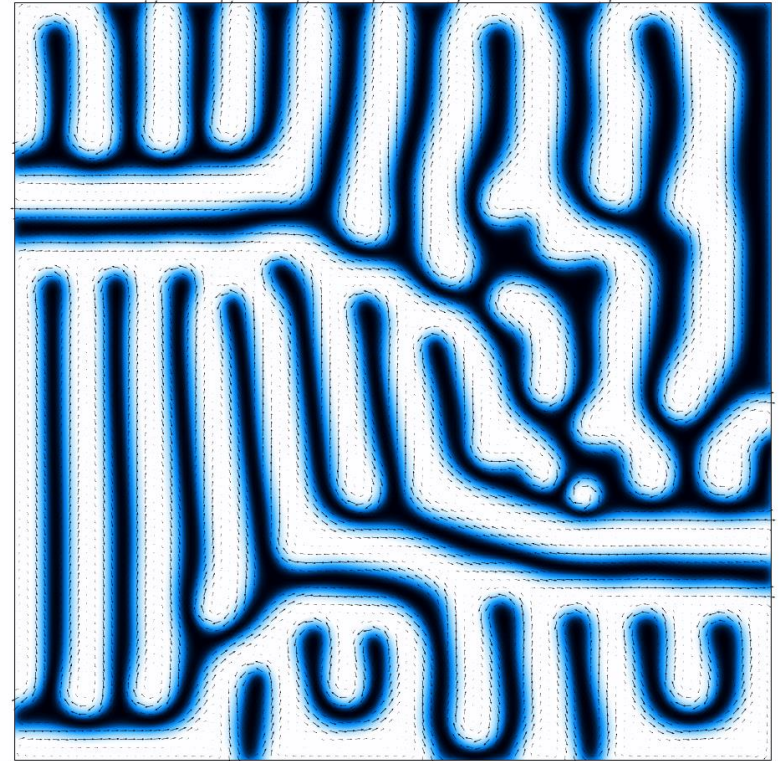
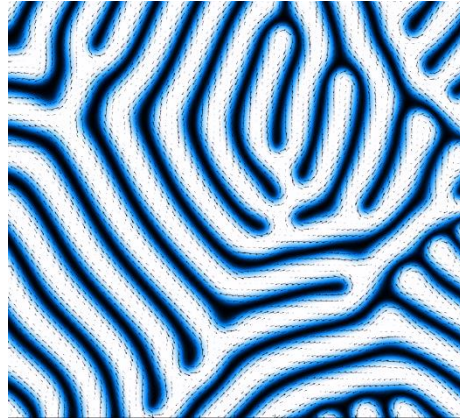
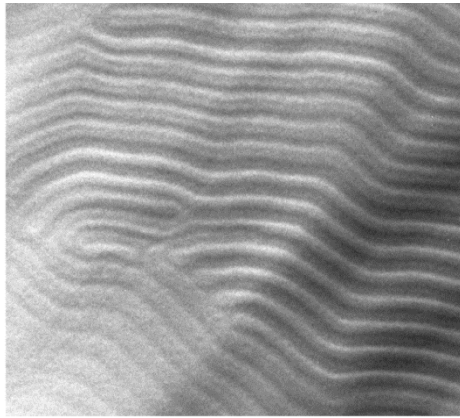
$$\frac{\partial \mathbf{m}}{\partial t} = -\gamma \mathbf{m} \times \mathbf{H}_{\text{eff}} + \alpha \mathbf{m} \times \frac{\partial \mathbf{m}}{\partial t}$$



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

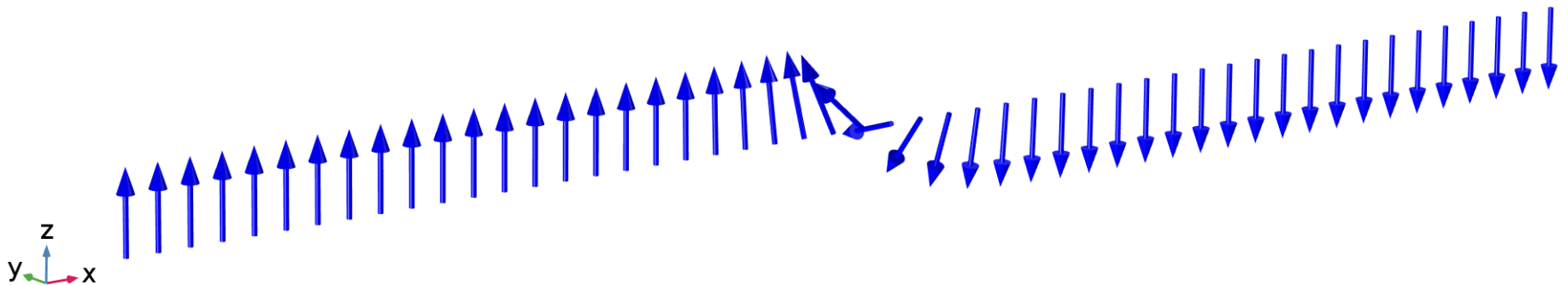
Spin Waves (Magnons)



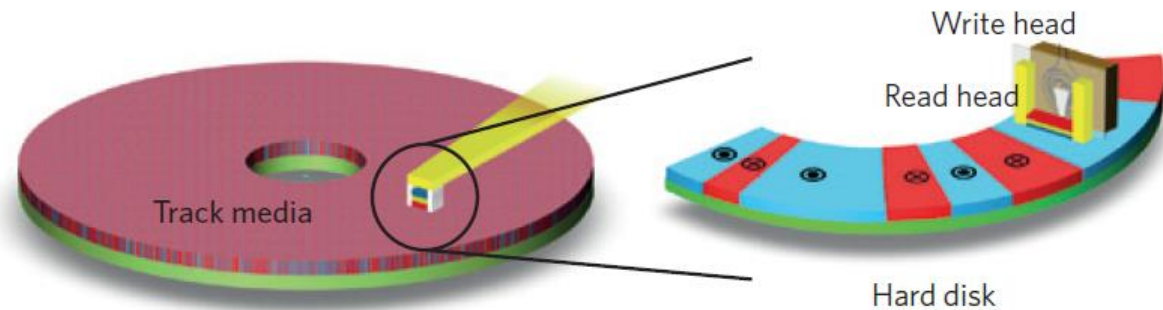


PNAS, 2012, 109(23): 8856-8860.

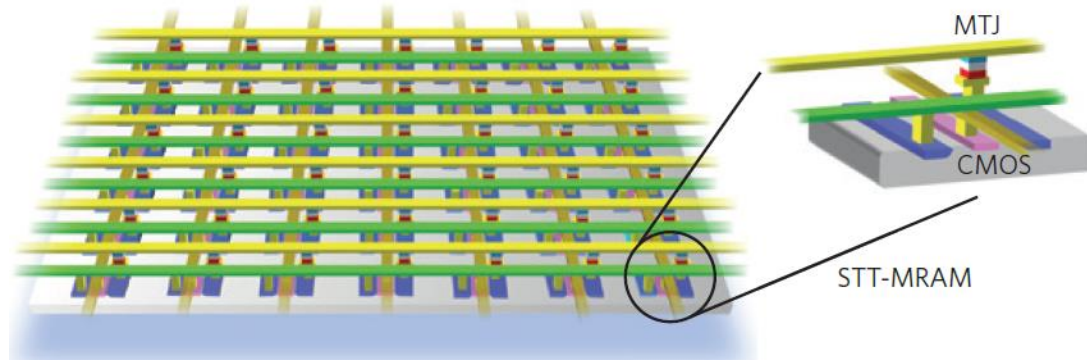
Current-driven Domain Wall Motion



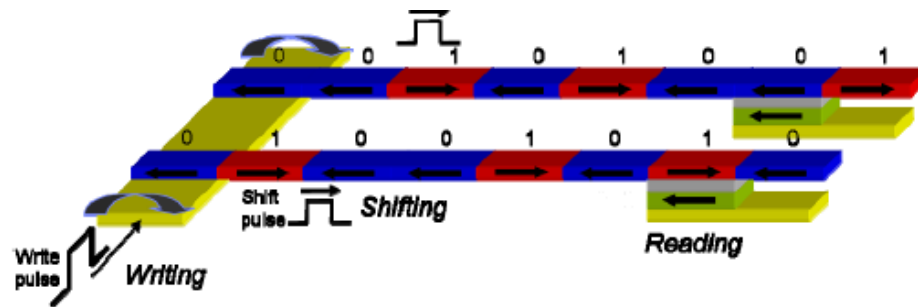
Hard Disk Driver



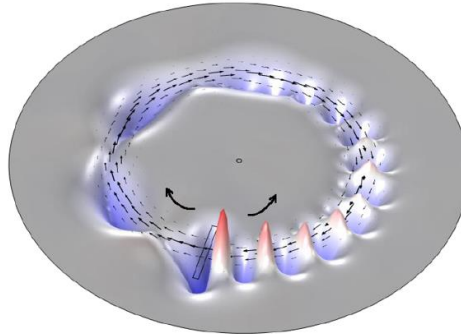
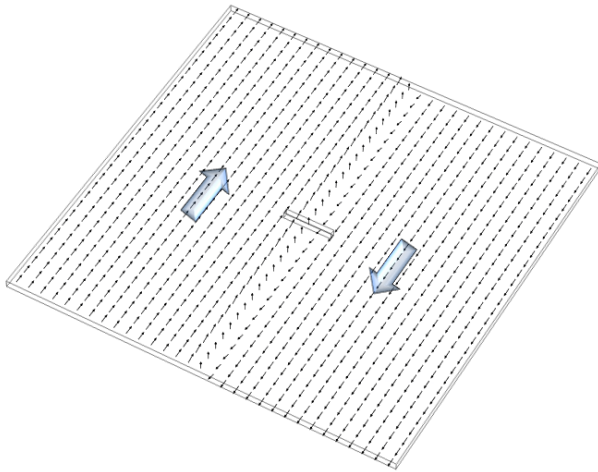
STT-MRAM (Spin-Transfer-Torque Magnetic Random Access Memory)



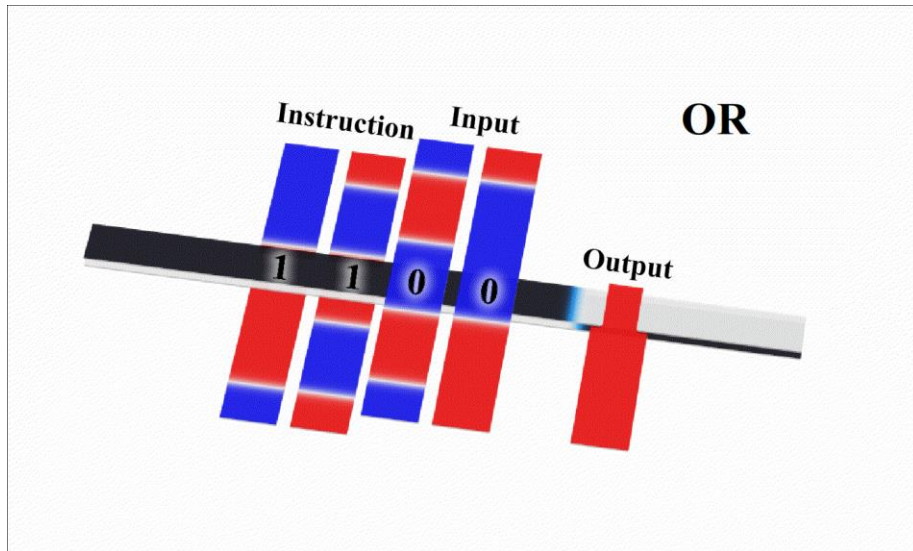
Domain Wall Racetrack Memory



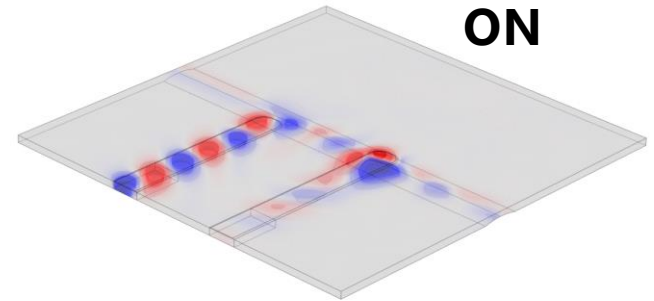
Bound state spin waves in domain wall/skyrmions



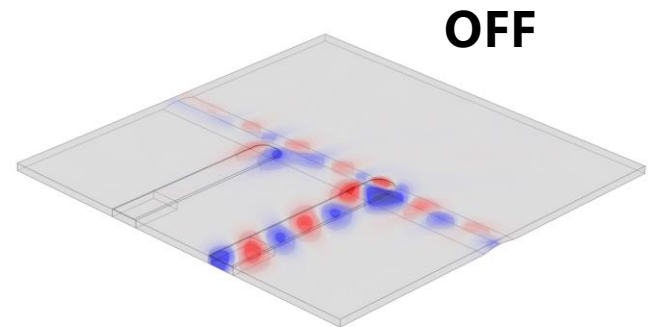
Universal logic gate



Spin-wave diode

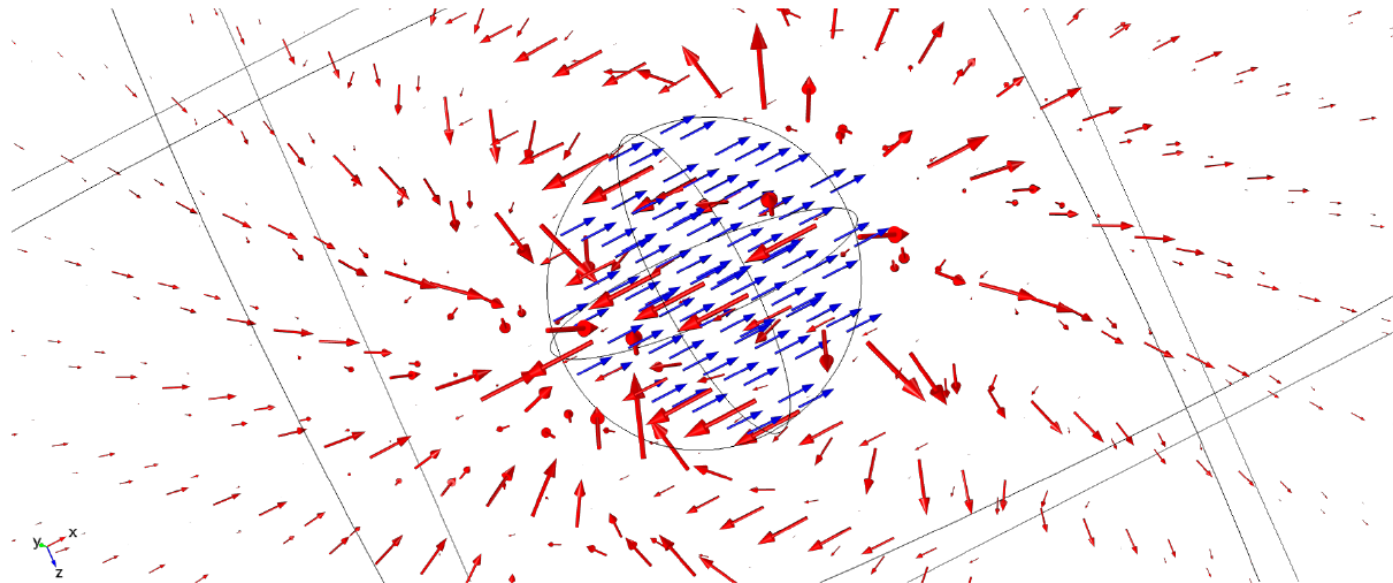
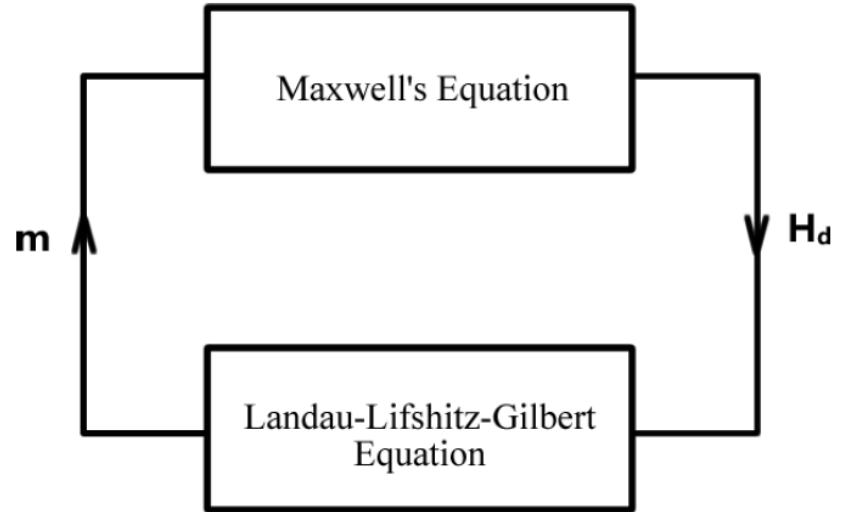
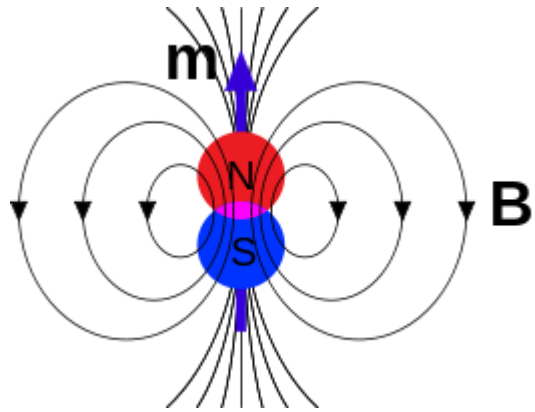


ON



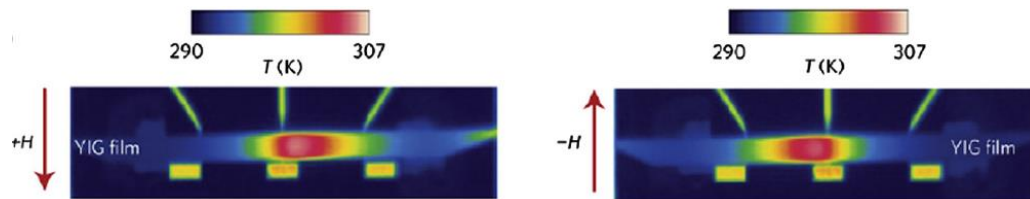
OFF

Magnetic dipole



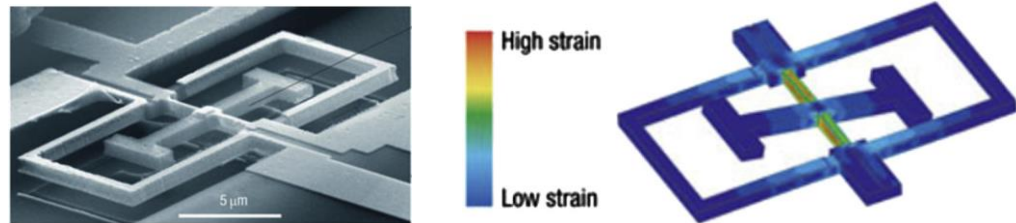
couple **Micromagnetics** with **other physics**

1. magnon-thermal



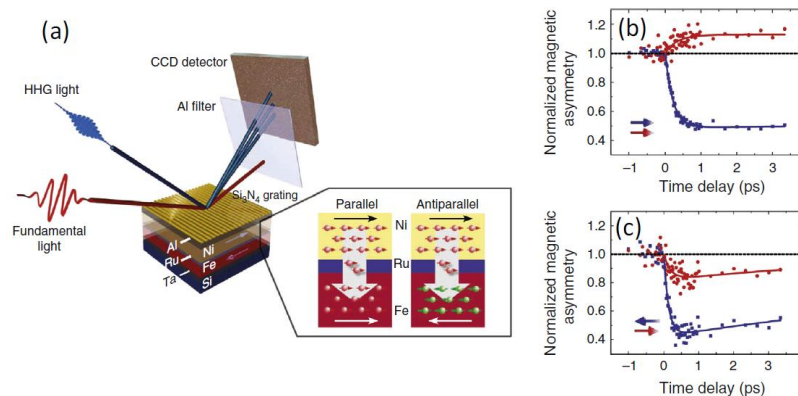
An T, Vasyuchka VI, et al. Nat Mater 2013;12(6):549–53.

2. magnon-elastic



Zolfagharkhani G et al. Nat Nanotechnol 2008;3:720.

3. magnon-optics



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

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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



Group Website

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