Neel and Bloch domain walls

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Coordinate system:

Thin along z, infinite along y.

Material – permalloy
Small anisotropy could be present
$M_s = 795 \text{ erg/cm}$

$h$ – thickness
$w$ – width
Analytical expressions

If \( \frac{M}{M_s} = (v, u, 0), \ u \gg v : \)

\[
u(x) \approx \Lambda \int_{0}^{\infty} \frac{\cos(kx)}{k + 1/\omega} dk = \Lambda \left( \cos \left( \frac{x}{\omega} \right) \text{ci} \left( \frac{x}{\omega} \right) + \sin \left( \frac{x}{\omega} \right) \text{si} \left( \frac{x}{\omega} \right) \right) \quad \omega = \sqrt{\frac{J}{K}}
\]

In the center:

\[
u \sim \text{sech} \left( \sqrt{\frac{h}{w}} \frac{x}{l_{ex}} \right) \quad l_{ex} = \sqrt{\frac{A}{2\pi M_s^2}}
\]
Tails

- $w=750\,\text{nm}, \, h=12\,\text{nm}$
- $w=750\,\text{nm}, \, h=30\,\text{nm}$
- $w=200\,\text{nm}, \, h=12\,\text{nm}$

$M_y/M_s$

$y, \, \text{nm}$
Anisotropy-dominated sample

\[ u(x) \]

- logarithmic fit
- micromagnetic result
- analytical fit

\[ x \text{ (nm)} \]
Dipole-Dipole dominated sample

- micromagnetic result
- logarithmic fit
  $a = -0.273 \pm 0.0014$
  $b = 1623.8 \pm 13.03 \text{ nm}$

- micromagnetic result
- sech fit
Normal Modes
Phase transitions

• Lyapunov stability analysis and normal modes from solving linearized Landau-Lifshitz equation

• RKMAG (www.rkmag.com) micromagnetics package

• Neel and Bloch regimes
Surface modes, frequency rapidly drops

Mode repulsion (bulk and surface modes have the same symmetry)

Mode crossover (bulk and surface modes have different symmetry)

w=200nm

$\omega$, GHz

$h$, nm

Neel, Bloch

breather
Critical thickness

Data

\[ h_c = h_{c0} + b \cdot I \cdot \log\left(\frac{(w-w_0)}{I}\right) \] Fit

\[ h_c = h_{c0} + b \cdot (l^{1-c}) \cdot (w^c) \] Fit

\[ h_{c0} = 0.68 \quad b = 4.93258 \quad c = 0.08814 \]
Neel wall, w=200nm, h=10nm

Bloch wall, w=200nm, h=39nm

Bloch wall, assymetric, w=200nm, h=43nm
Breather mode

\[ \omega, \text{ GHz} \]

\[ h, \text{ nm} \]
w=200nm, breather mode
Neel to Bloch transition

- Happens for large enough thickness
- Second order transition, mediated by a single mode ("breather" mode), whose frequency goes through zero.
- Total energy and at least its first derivatives are continuous while both exchange and dipole-dipole energies have a discontinuous first derivative.
- Frequencies of the modes are continuous.
- The frequency of the "breather" mode goes to zero as square root – Landau-Ginzburg theory
- The instability is extremely small and can be easily missed by conjugate gradient and other methods that do not calculate the modes, as a result wrong conclusions can be reached.
1 nm  3.74 Ghz  8.36 Ghz
1.41 Ghz-breather  5.89 Ghz  11.05 Ghz

layer 0

layer 5

graph showing variations in frequency and amplitude with distance.
385nm 8.81 GHz 12.48 GHz
0.11 GHz-breather 9.07 GHz 13.07 GHz
uniform r.f. field out of plane

- Neel wall, unstable
- Bloch wall

b = 50 nm
w = 200 nm

surface breather