Micromagnetic analysis of the magnetization dynamics in Permalloy nanorings driven by the Oersted field

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DS-02

56TH ANNUAL CONFERENCE ON MAGNETISM AND MAGNETIC MATERIALS
30 October–3 November 2011. Scottsdale, Arizona

1. Introduction - Motivation

- Understanding and controlling the **Domain Wall (DW) dynamics** driven by the **Oersted field** due to a current injected through a vertical wire across the center of a thin ferromagnetic ring.
- To provide a **theoretical explanation for recent experiments** (Yang et al. APL, 98, 242505 (2011))
- To explore the possibility of promoting the **direct Vortex Circulation Reversal** from Clockwise (CW) to Counterclockwise (CCW).
- Technological relevance for developing further **MRAM devices based on arrays of ferromagnetic rings**, with:
  - Well defined states: CW vortex and CCW vortex.
  - Low magnetostatic coupling between adjacent rings.
  - Easy and well controlled, and fast transitions.

2. Experimental background

Yang et al. APL, 98, 242505 (2011)

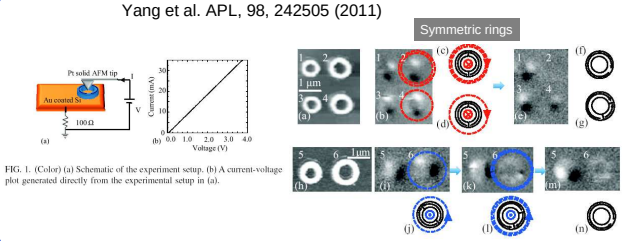
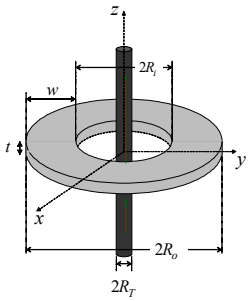


FIG. 1. (Color) (a) Schematic of the experiment setup. (b) A current-voltage plot generated directly from the experimental setup in (a).

3a. Numerical Details

Geometry:



Ring dimensions

$w = 60\text{nm}$
$t = 3\text{nm}$
$R_o = 15\text{nm}$

Infinite conductive wire

$R_T = 20\text{nm}$

Injected current

$$\boldsymbol{j}_{app} = j_a \boldsymbol{u}_z = \frac{I}{\pi R_T^2}\boldsymbol{u}_z$$

Cell size: $\Delta x = \Delta y = 1\text{nm} \quad \Delta z = 3\text{nm}$

Material parameters: Typical Permalloy

$$\begin{cases} M_s = 8.6\times10^5\ \text{A/m} \\ A = 1.3\times10^{-11}\ \text{J/m} \\ K_1 = 0 \\ \alpha = 0.02 \end{cases}$$

Landau-Lifshitz-Gilbert:

$$\frac{d\boldsymbol{M}}{dt} = \overbrace{-\gamma_0 \boldsymbol{M}\times\boldsymbol{H}_{eff}}^{\text{precession}} + \overbrace{\frac{\alpha}{M_s}\boldsymbol{M}\times\frac{d\boldsymbol{M}}{dt}}^{\text{dissipation}}$$

Effective field: $\boldsymbol{H}_{eff} = \boldsymbol{H}_{exch} + \boldsymbol{H}_{dmg} + \boldsymbol{H}_{Oe}$

Oersted field: Infinite wire approach (Ampere's Law)

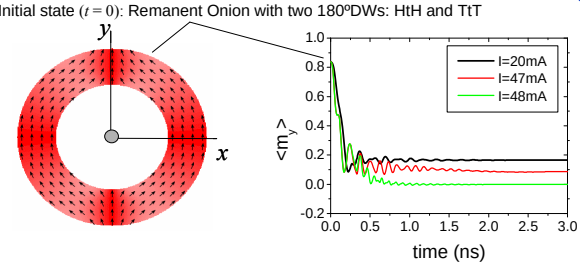
$$\boldsymbol{H}_{Oe}(\rho > R_T) = \frac{\mu_0 I}{2\pi\rho}\boldsymbol{u}_\phi$$

6. Conclusions and future work

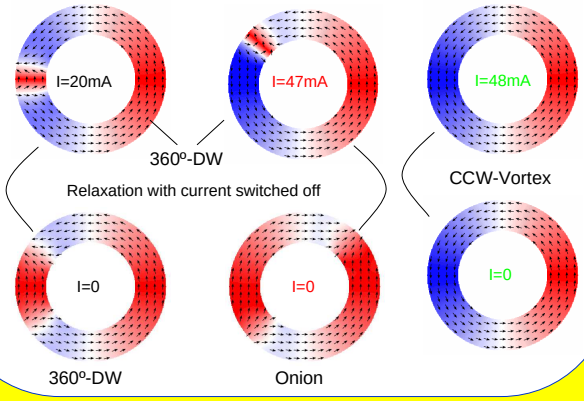
- **Micromagnetic analysis of the magnetization dynamics** driven by the **Oersted field** due to a current injected through a vertical wire across the center of a thin ferromagnetic ring.
- **From Onion to Vortex**: Good agreement with recent **experiments** by Yang et al. APL, 98, 242505 (2011): Symmetric ring with the wire in the center.
- **Direct switching of vortex circulation from CW to CCW** and vice can be efficiently achieved in a symmetric ring by displacing the conductive wire.
- Promising properties for **MRAM devices based on arrays of rings**: well defined states, and easy and very fast (<100ps) transitions avoiding unwanted Joule heating effects.
- **Optimization of the ring size is required to reduce the critical current <40mA.**

4a. Dynamics from the onion state

Initial state ($t = 0$): Remanent Onion with two 180ºDWs: HtH and TtT

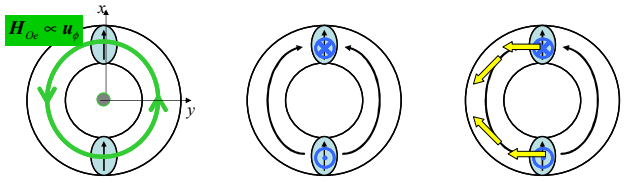


Final equilibrium state under positive injected currents



4b. Understanding the DW dynamics from the onion state driven by $\boldsymbol{H}_{Oe}$

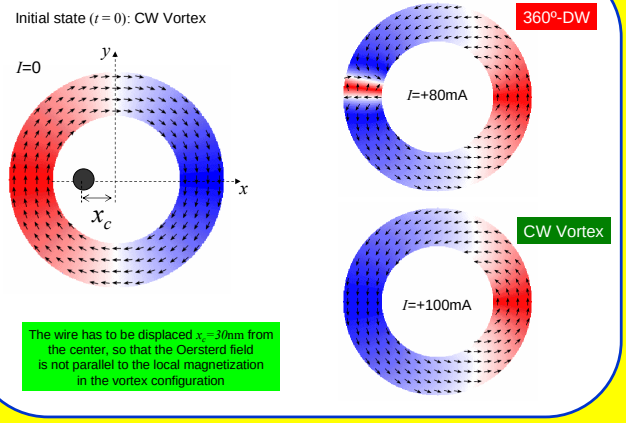
	precession	dissipation
	$\boldsymbol{\tau}_p = \gamma_0 \boldsymbol{H}_{Oe}\times\boldsymbol{M}$	$\boldsymbol{\tau}_d = \frac{\alpha}{M_s}\boldsymbol{M}\times\frac{d\boldsymbol{M}}{dt}$
$\boldsymbol{m}_{DW,Top} \sim +\boldsymbol{u}_\rho$	$\boldsymbol{\tau}_{p,T} \sim -\boldsymbol{u}_z$	$\boldsymbol{\tau}_{d,T} \sim +\boldsymbol{u}_\phi$



$\boldsymbol{m}_{DW,Bottom} \sim -\boldsymbol{u}_\rho \quad \boldsymbol{\tau}_{p,B} \sim +\boldsymbol{u}_z \quad \boldsymbol{\tau}_{d,B} \sim -\boldsymbol{u}_\phi$

5a. Direct switching from CW to CCW

Initial state ($t = 0$): CW Vortex



The wire has to be displaced x_c=30nm from the center, so that the Oersterd field is not parallel to the local magnetization in the vortex configuration

Tuesday, 1 Nov, 2011
SAGUARO BALLROOM, 1:00 - 5:00

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