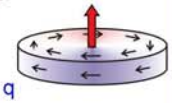
Synchrotron X-Ray PEEM Study of Vortex Dynamics in Ferromagnetic Nanodots

Konstantin Guslienko [a], Jack Han [b], Dave Keavney [b], Ralu Divan [b], and Sam D. Bader [a]
[a] Materials Science Division, [b] Advanced Photon Source
Argonne National Laboratory

Motivation

Fundamental questions: How fast we can re-magnetize nanomagnets?
What are the properties of spin excitations in small magnetic elements?
Develop theory/models of complex dynamics in nano-magnetic systems (0.1–10 ns range)
Consider dynamics of topologically non-trivial magnetization distributions

Magnetic Vortex Properties:
Chirality (CCW, CW)
Polarization p = ±1
Vorticity (topological charge) q



Pioneering studies at ALS and SLS disagree on the nature of the vortex dynamics. Our theoretical analysis and experiments resolved it!

Accomplishments

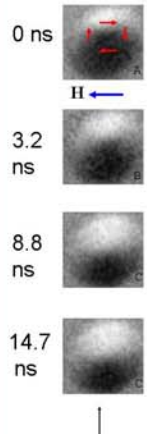
New effects in dynamics of nanomagnets were predicted and confirmed experimentally

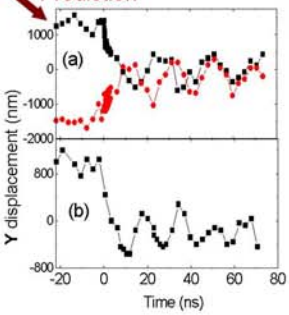
Vortex core mode in a circular dot
(ns-dynamics on nanoscale)

Vortex translation mode
-Polarization dictates direction of motion
-Magnetostatics dictates frequency

Guslienko *et al.*, *J.* Appl. Phys. **91**, 8037 (2002)

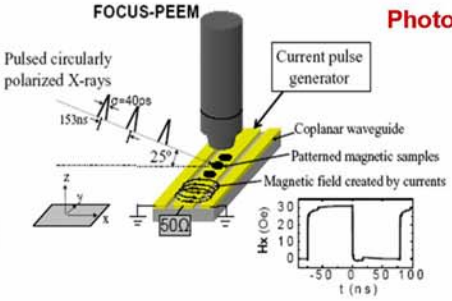
Prediction





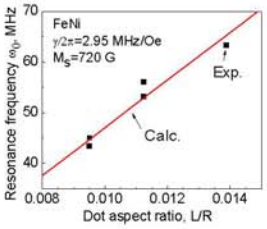
Time dependence of the *Y*-displacement of the vortex core: (a) 6.3-μm diameter dot - black, 5.3-μm dot - red; (b) 4.3 μm dot. Field pulse length is 75 ns

XMCD images of the dot (30-nm thick, 6.3 μm diameter) as a function of time



Photoemission Electron Microscopy (PEEM)

Time resolved (0.1 ns) PEEM at APS. The lower right displays the waveform of the magnetic field generated by the current pulses



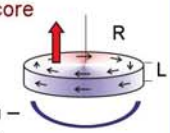
Field driven excitation of magnetic vortex core

Theory

X = (*X*, *Y*) vortex core position

Shifted vortex core

Dynamic energy - potential well W(**X**)



Equation of magnetic vortex motion – vortex mass (M) and gyrovector (G)

$$\hat{M}\ddot{\mathbf{X}} - \mathbf{G}\times\dot{\mathbf{X}} + \frac{\partial W(\mathbf{X})}{\partial \mathbf{X}} = 0$$

$$\mathbf{G} = -G\hat{\mathbf{z}} \qquad G = 2\pi qpLMs/\gamma$$

$$W_m(\mathbf{X}) = \frac{1}{2}\int d^3\mathbf{r}\, d^3\mathbf{r}'\, \frac{\sigma(\mathbf{r},\mathbf{X})\sigma(\mathbf{r}',\mathbf{X})}{|\mathbf{r}-\mathbf{r}'|}$$

Vortex eigenfrequency

$$\omega = \omega_M \frac{5}{9\pi}\frac{L}{R} \qquad \omega_M = \gamma 4\pi M_s$$

- **The SLS group used too short time intervals between field pulses to observe the vortex dynamics**
- **Initial core shift is perpendicular to the pulse field direction**
- **Vortex translation mode does exist and its frequency is determined by the aspect ratio L/R**

Oscillations in the XMCD/PEEM image of the vortex core position are in agreement with Guslienko's model

Outlook

- **Explore multivortex dynamics via arrays of square and elliptic magnetic nanostructures**
- **Explore spin-polarized current-driven vortex excitations and GMR field sensors via tri-layers dots: Ferromagnet / Spacer / Ferromagnet**
- **Explore a new approach to magnetic information storage based on the vortex state dynamics/reversal in small fields - vortex core reversal by *a.c.* in-plane magnetic field of resonance frequency**

K. Yu. Guslienko et al., Phys. Rev. Lett. 96, Feb. 17 (2006)

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