Dynamic Simulation of Toggle Mode MRAM

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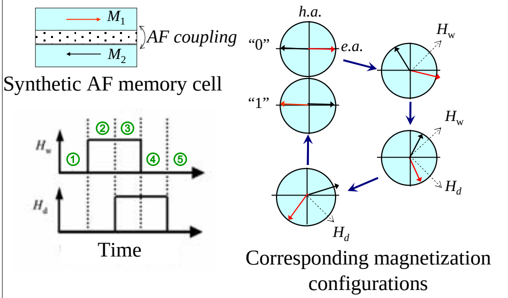
Motivation/Introduction

- MRAM is considered to be one of the important candidates for future non-volatile memories.
- Too small operating field margin limits the broad application of conventional MRAM.
- Toggle mode MRAM (T-MRAM) employing synthetic antifrromagnets (SAF) provides a new write-scheme promising a large operating field margin.
- We have established a parameter optimization method for the toggle-MRAM based on a static single domain model using analytic/numeric method.
- We study the effects of dynamic switching and magnetization inhomogeneity based on the Landau-Lifshitz-Gilbert (LLG) equation and micromagnetic simulation.

Toggle-Switching (Schematics)



Synthetic AF memory cell

Corresponding magnetization configurations

Numeric Analysis of Toggle Switching Using LLG Equation

LLG Equation

$$\frac{d\boldsymbol{M}}{dt} = -\gamma\left[\boldsymbol{M}\times\left(\boldsymbol{H}-\frac{\alpha}{\gamma M}\frac{d\boldsymbol{M}}{dt}\right)\right]$$

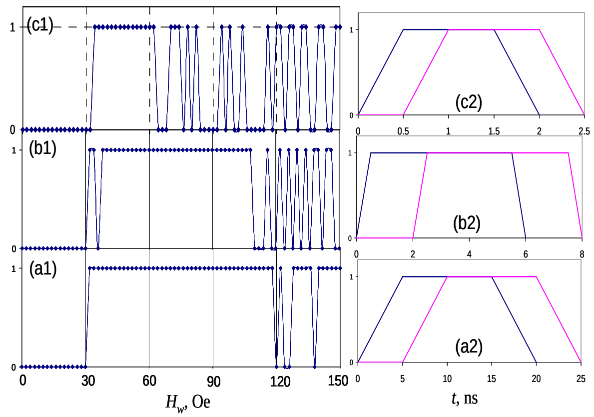
γ: gyromagnetic ratio, α: damping factor

Parameters

M_s	850 emu/cm^3	$H_{w,flop}$	30.5 Oe
H_k	10 Oe	$H_{w,sat}$	117 Oe
H_J	88 Oe	V	5x10^{-16} cm^3

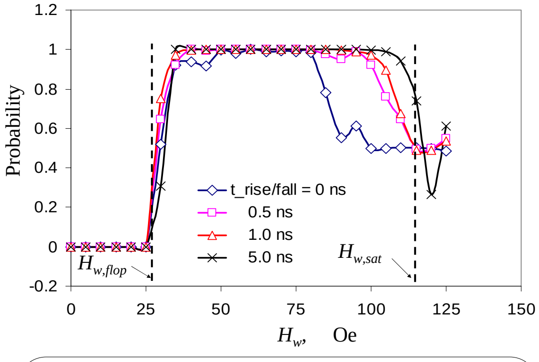
$N_x = N_y = 0,\ N_z = 1$

Success/Fail Diagram of Toggle-Switch



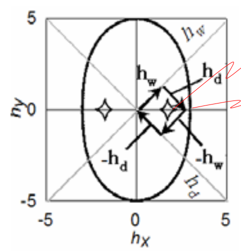
Dynamic simulation is consistent with static analysis results for longer pulse width and rise/fall.

Toggle-Switch Probability



- 10,000 total repeats at each field
- Langevin's random field at room temperature
- Pulse peak width of 10ns and rise/fall time from 0 ~ 5ns
- Longer rise/fall time provides larger operating field margin

Switching Critical Curves
(Analytic/Numeric Method)

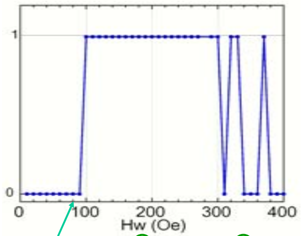


$$h_{flop} = \sqrt{2h_J + 1}$$

$$h_{x,s} = 2h_J - 1$$

The parameters are normalized by the anisotropy field, H_k.

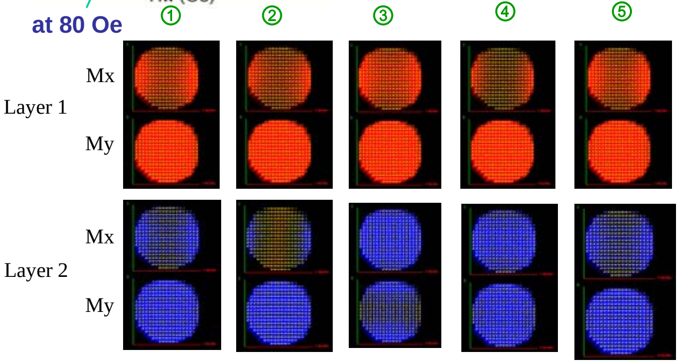
Micromagnetic Simulation



Memory cell size 200*200*2 nm

pulse peak width : 2 ns
rise/fall time : 0.5 ns
$\alpha = 0.02$

H_{flop}=45 Oe, $H_{x,sat}$=277 Oe



Summary

- The critical switching fields H_{flop} and H_{sat} are consistent with the previous statistic analysis with longer pulse width and pulse rise/fall time.
- Dynamic switching probability at room temperature was calculated at 10ns pulse width. It was found the longer rise/fall time providing larger operating field margin.
- H_{flop} and $H_{x,sat}$ increase substantially due to magnetization inhomogeneity caused by demagnetizing field.

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