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 antiferromagnets (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)

Micromagnetic Simulation

Memory cell size 200*200*2 nm
pulse peak width : 2 ns
rise/fall time : 0.5 ns
\( \alpha = 0.02 \)
\( H_{\text{flop}} = 45 \, \text{Oe}, H_{\text{x,sat}} = 277 \, \text{Oe} \)

The parameters are normalized by the anisotropy field, \( H_k \).

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

 Numeric Analysis of Toggle Switching Using LLG Equation

LLG Equation

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

\( \gamma \): gyromagnetic ratio, \( \alpha \): damping factor

Success/Fail Diagram of Toggle-Switch

Parameter

\[
\begin{array}{|c|c|c|}
\hline
M_s & 850 \, \text{emu/cm}^3 & H_{\text{flop}} \, 30.5 \, \text{Oe} \\
H_k & 10 \, \text{Oe} & H_{\text{x,sat}} \, 117 \, \text{Oe} \\
H_J & 88 \, \text{Oe} & V \, 5 \times 10^{-16} \, \text{cm}^3 \\
N_x = N_y = 0, N_z = 1 \\
\hline
\end{array}
\]

The parameters are normalized by the anisotropy field, \( H_k \).

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Switching Critical Curves
(Analytic/Numeric Method)

Summary

• The critical switching fields \( H_{\text{flop}} \) and \( H_{\text{x,sat}} \) 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.
• \( H_{\text{flop}} \) and \( H_{\text{x,sat}} \) increase substantially due to magnetization inhomogeneity caused by demagnetizing field.

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