Microwave Assisted Magnetic Recording

Jimmy Zhu, Xiaochun Zhu, and Yuhui Tang
Outline

- Microwave assisted magnetic recording
- Generation of localized microwave field: spin torque
- Analysis of AC field generation
- Recording simulation
- Summary
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Recording Field Availability

Fe\textsubscript{65}Co\textsubscript{35} \quad M_s = 2.5 \ T

Fig. 4-22 Dependence of the saturation magnetizism of alloys on the number $n$ of $(3d + 4s)$ electrons per atom (Slater-Pauling curve). After Chikazumi [G-23]
Sub-coercivity Recording

\[ H_{ac} = 0.1H_k \]

\[ \vec{H}_{AC} = H_{ac} \cos(\omega t) \]

\[ H_r = 0.5H_k \]
Switching Dynamics

Normalized Magnetization $M/M_s$

Time $t$ (ns)

$H_r = 0.17H_k$

$H_{ac} = 0.1H_k$

$\omega = 0.69\gamma H_k$

$\theta = 30^\circ$

$\vec{M}$

$\vec{H}_{AC}$

$\vec{H}_r$
Damping: 

\[ \frac{d\vec{M}}{dt} = -\gamma\vec{M} \times \vec{H} + \frac{\alpha}{M} \vec{M} \times \frac{d\vec{M}}{dt} \]

\( \alpha = 0.02 \)  \( \alpha = 0.10 \)  \( \alpha = 0.20 \)
Effect of Reversal Field Angle

Normalized Switching Field $H/H_k$

Normalized Frequency $\omega (\gamma H_k)$

$H_{ac} = 0.1H_k$

$\theta = 2^\circ$

$\theta = 10^\circ$

$\theta = 30^\circ$

$H_{AC} = H_{ac} \cos(\omega t)$
Reversal Field Angular Dependence

Stoner-Wohlfarth Model

With AC Field (Broadband)

Normalized Switching Field $H/H_k$

$H_{ac} = 0.1H_k$

Reversal Field Angle $\theta$ (degree)
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Basic Oscillator Structure

X. Zhu & J. Zhu, Intermag 2006, Paper EF-09

- Electrode
- Easy axis
- Oscillating stack
- Metallic interlayer
- Layer with perpendicular anisotropy
- Field Generation Layer (FGL)
- Perpendicularly magnetized reference layer
- Electrode
About Oscillation Frequency

Field Generating Layer

\[ \alpha H_{\text{eff}} \sin \theta \]

\[ \vec{H} = \vec{H}_{\text{exchange}} - 4\pi M_S \cos \theta \]

\[ \frac{\hbar \varepsilon J}{eM\delta} \sin \theta \]

\[
\frac{d\hat{m}}{dt} = \frac{\gamma}{1 + \alpha^2} \left\{ -\hat{m} \times \left( \vec{H} - \frac{c\alpha}{\gamma} \hat{m}_0 \right) - \alpha \hat{m} \times \hat{m} \times \left( \vec{H} + \frac{c}{\gamma \alpha} \hat{m}_0 \right) \right\}
\]

If \[ \frac{c}{\gamma \alpha} \hat{m}_0 = -\vec{H} \]

\[ \frac{d\hat{m}}{dt} = \gamma \hat{m} \times \vec{H} \]

\[ f_0 = \frac{\gamma H}{2\pi} \]
Spin Torque Driven Oscillation

Magnetic easy axis
Ku = 5 x 10^6 erg/c.c.

Field generating layer/
spin torque driven layer

Oscillator size:
35 nm x 35 nm

Single Domain

In-Plane Magnetization M_x/M_s

\( J_\downarrow = P_0 J \)

Time (ns)

20.0 20.2 20.4 20.6 20.8 21.0

In-Plane Magnetization M_x/M_s

-1.0 -0.5 0.0 0.5 1.0
Frequency Tuning by Current

Ku = 5 \times 10^6 \text{ erg/cc}

Frequency Tuning Window

\begin{align*}
\text{Excited AC Frequency (GHz)} & \\
\text{Injected Current Density (A/cm}^2) & \\
\text{Tilting Angle (\theta)} & \\
\end{align*}

\[ J \]

\[ \theta_1 \]

\[ \theta_2 \]

X. Zhu & J. Zhu, Intermag 2006, Paper EF-09
Novel Write Head Design

- Writing pole
- Trailing shield
- Thin film medium
- Soft underlayer
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Generating AC Field

Field Generating Layer (FGL)
Fe$_{65}$Co$_{35}$  $4\pi M_s=2.5$T  $\delta =10$ nm

Calculated Magnetization Precession

$K_U=1.5\times10^8$ erg/cm$^3$
Precession in FGL

\[ I = 0.55\ mA \]
\[ I = 0.85\ mA \]
\[ I = 1.1\ mA \]
\[ I = 1.4\ mA \]
\[ I = 1.7\ mA \]
\[ I = 1.95\ mA \]
Power Spectral Density

Oscillating Layer
\[
\delta = 10 \text{nm}
\]
\[
4\pi M_s = 2.5 \text{T}
\]
Area = 35x35nm²

I = 1.95 mA
The effective interlayer exchange coupling on FGL is:

\[ \sigma = 2\sqrt{AK} \]

\[ H_{\text{effective}} \approx H_{\text{exchange}} = \frac{\sigma}{M_S \cdot t_{\text{FGL}}} \]
Field and Injected Current

AC Field Amplitude $H$ (x10^3 Oe)

Current Density $J$ (x10^8 A/cm^2)

- $\delta = 15 \text{ nm}$
- $4\pi M_s = 2.5T$

$\gamma_{wall} = 2\sqrt{AK}$

$K = 3 \times 10^8 \text{ erg/cm}^3$
$K = 2 \times 10^8 \text{ erg/cm}^3$
$K = 1 \times 10^8 \text{ erg/cm}^3$

$H_{\text{effective}} \approx \frac{\sqrt{AK}}{M_s \cdot t_{FGL}}$
When the current is too large, the magnetization precession becomes spatially non-uniform.

Oscillating Layer
δ=10nm
$4\pi M_s=2.5$ T
Area=35x35nm$^2$

$I = 4.5$ mA
Frequency and Current

- Frequency $f$ (GHz)
- Injected Current $I$ (mA)

Graph showing the relationship between frequency and injected current with different magnetic anisotropy constants $K$.

- $K=1 \times 10^8$ erg/cm$^3$
- $K=2 \times 10^8$ erg/cm$^3$
- $K=3 \times 10^8$ erg/cm$^3$

Constants:
- $\delta = 15\text{nm}$
- $4\pi M_s = 2.5\text{T}$
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Physical write head track width: 120 nm

Trailing Shield present
Write head field:  

Rise time 0.2 ns, Duration 1 ns, Magnitude 12 kOe

Conventional:

\[ M_s = 300 \text{ emu/cc} \]
\[ H_k = 8 \text{ kOe} \]
\[ H_{AC} = 0.0 \]

MAMR:

\[ M_s = 300 \text{ emu/cc} \]
\[ H_k = 30 \text{ kOe} \]
\[ H_{AC} = 3 \text{ kOe} \]
\[ f = 32 \text{ GHz} \]

No dispersion
\[ M_s = 300 \text{ emu/cc} , \quad H_k = 30 \text{ kOe} \quad H_{AC} = 3 \text{ kOe} \quad H_{head} = 12 \text{ kOe} \]

- \( f = 24 \text{ GHz} \)
- \( f = 32 \text{ GHz} \)
- \( f = 60 \text{ GHz} \)
Comparison at 1 MFCI

Conventional Recording
\[ H_{\text{head}} = 12 \text{ kOe} \]
\[ H_k = 10 \text{ kOe} \]

MAMR:
\[ H_{\text{head}} = 12 \text{ kOe} \]
\[ H_k = 30 \text{ kOe} \]
\[ f = 32 \text{ GHz} \quad H_{ac} = 3000 \text{ Oe} \]
MAMR @ 1.6 MFCI

**Head:**

\[ H_{\text{head}} = 12 \, kOe \quad H_{\text{ac}} = 3 \, kOe \quad f = 32 \, GHz \]

**Medium:**

\[ H_k = 30 \, kOe \quad D_{\text{grain}} = 5 \, nm \quad \delta = 10 \, nm \quad C^* = 0.05 \]

- **0° easy axis and 0% \( H_k \) dispersion**
- **3° easy axis and 3% \( H_k \) dispersion**
Exchange Coupling

**Head:** \( H_{\text{head}} = 12 \text{ kOe} \) \quad \( H_{\text{ac}} = 3 \text{ kOe} \) \quad \( f = 32 \text{ GHz} \)

**Medium:** \( H_k = 30 \text{ kOe} \) \quad \( D_{\text{grain}} = 5 \text{ nm} \) \quad \( \delta = 10 \text{ nm} \)

MAMR @ 1.6 MFCI

\[ C^* = 0.05 \]
\[ C^* = 0.0 \]
All "1"s pattern

Random bits

No nonlinear transition shift is observed.
Summary

- An in-plane ac field at the FMR frequencies results in significant reduction of perpendicular switching field.

- The scheme enables recording at a write field that is significantly below the medium coercivity.

- Spin momentum transfer can be used to generate localized ac field.

- Micromagnetic simulation of recording shows very promising results.