# Microwave Assisted Magnetic Recording


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The Data Storage Systems Center

# 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

$Fe_{65}Co_{35}$ $M_s = 2.5\ T$

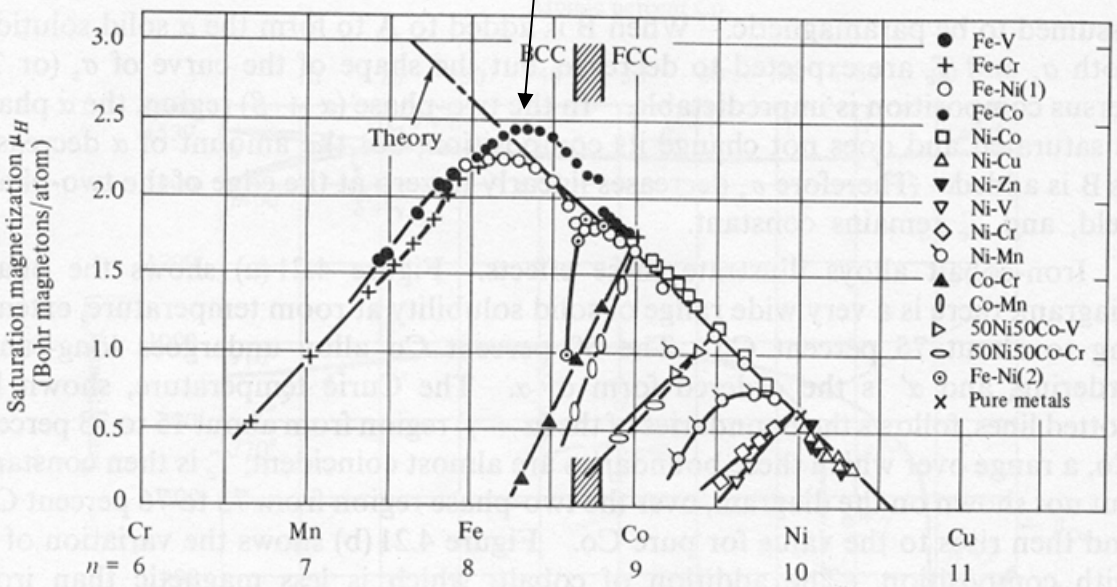
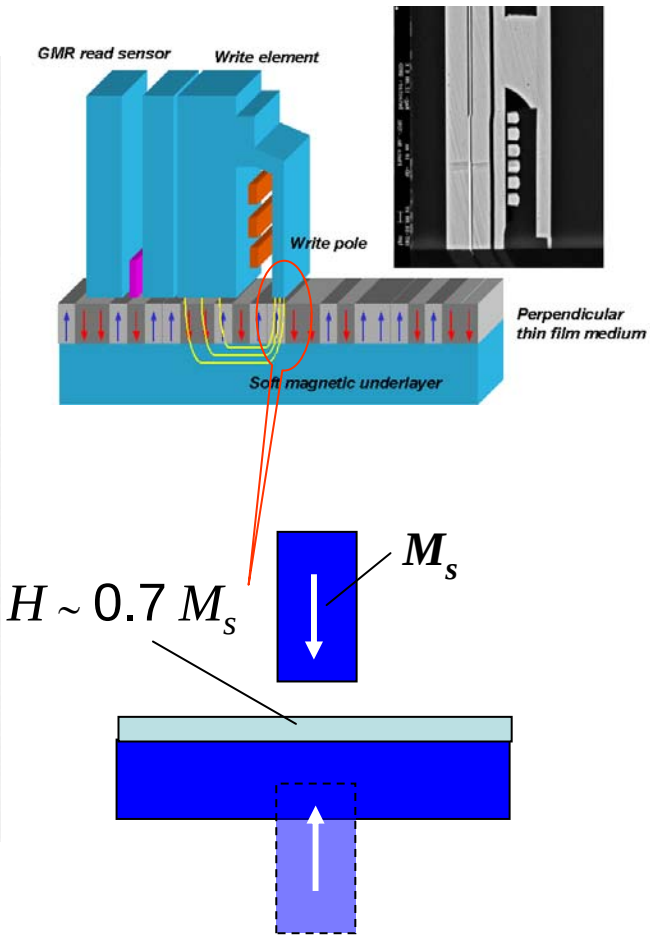
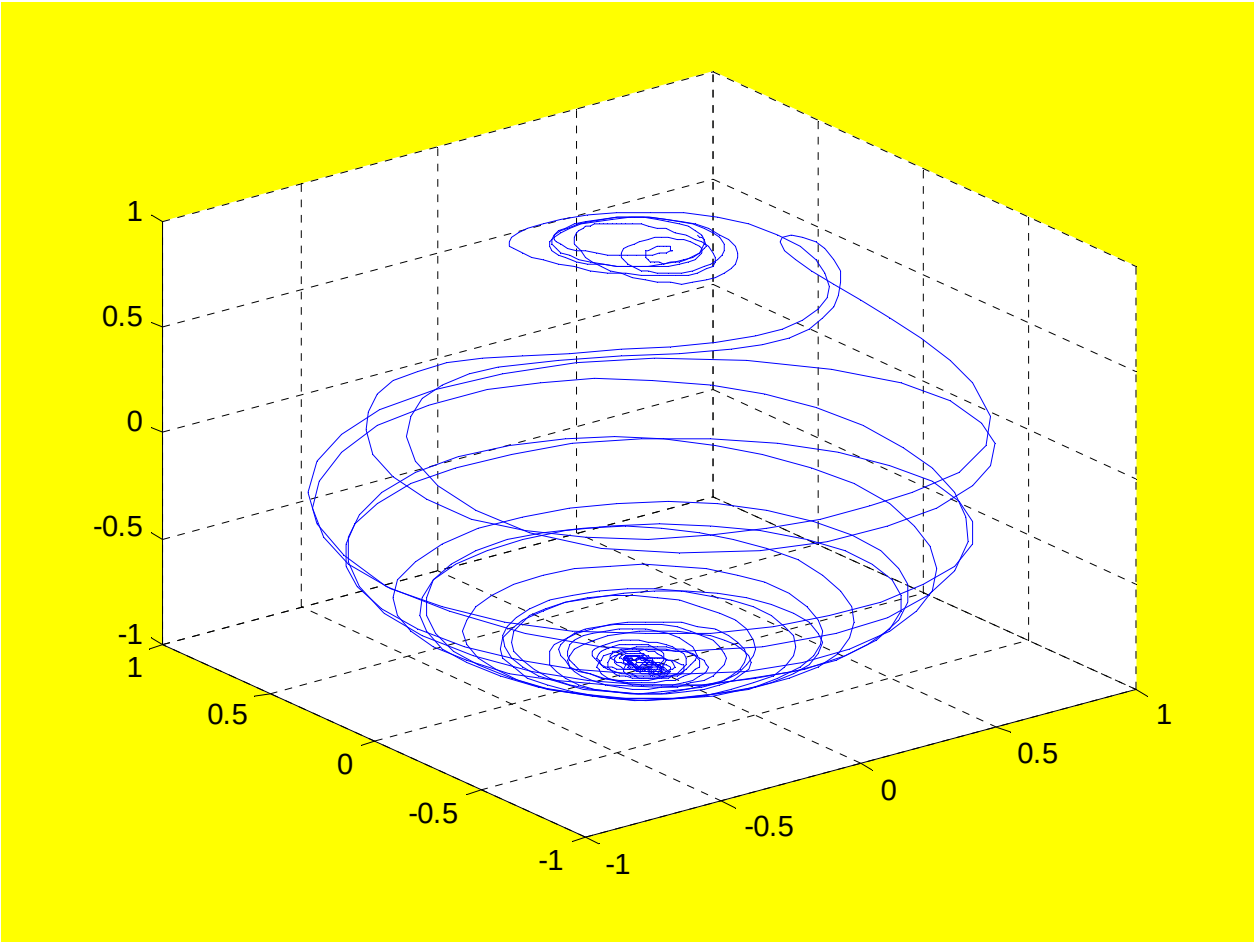


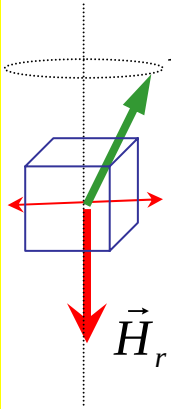

**Fig. 4-22** Dependence of the saturation magnetizatism of alloys on the number $n$ of $(3d + 4s)$ electrons per atom (Slater-Pauling curve). After Chikazumi [G-23].



# Sub-coercivity Recording

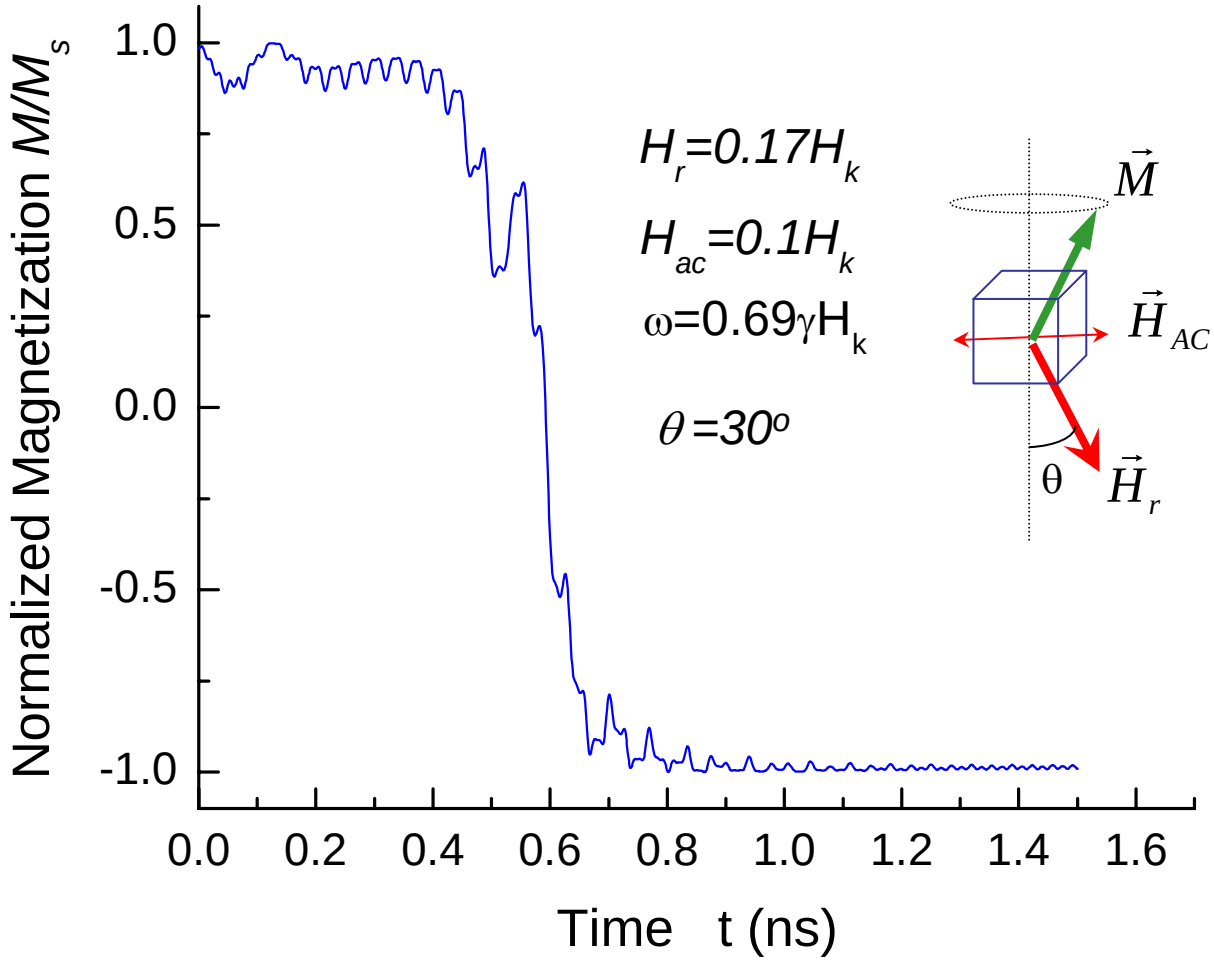



$$H_{ac} = 0.1 H_k$$




$$H_r = 0.5 H_k$$

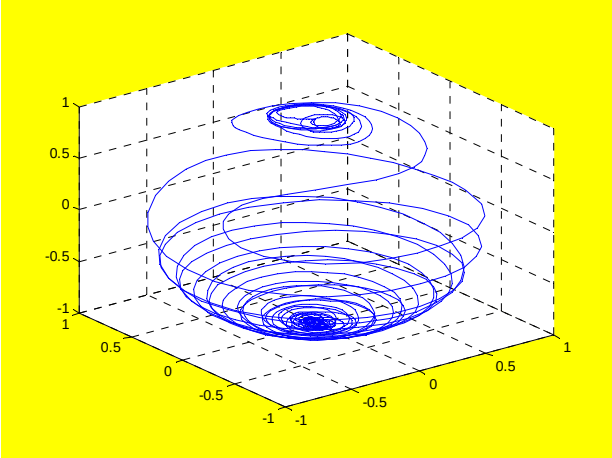
# Switching Dynamics

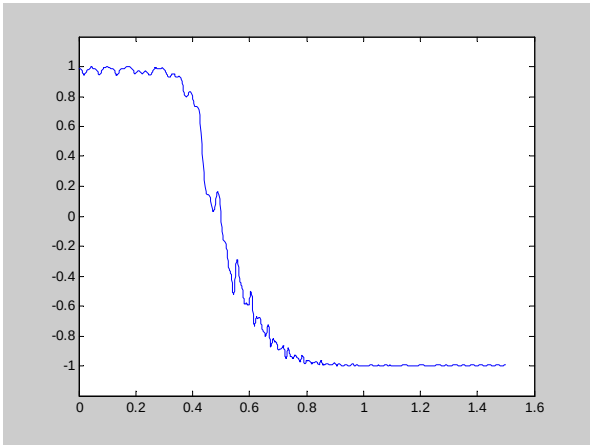


# Damping:

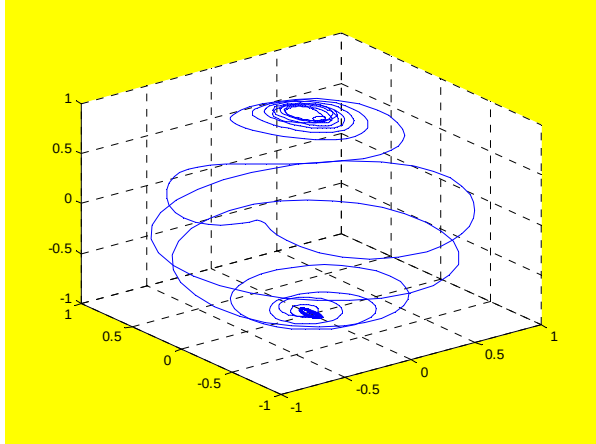
$$\frac{d\vec{M}}{dt} = -\gamma \vec{M} \times \vec{H} + \frac{\alpha}{M} \vec{M} \times \frac{d\vec{M}}{dt}$$

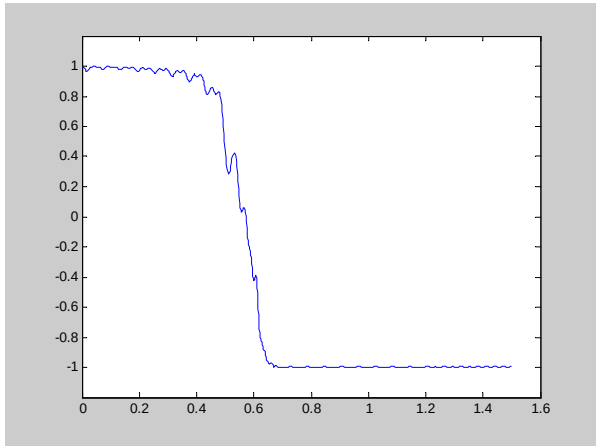
$\alpha = 0.02$



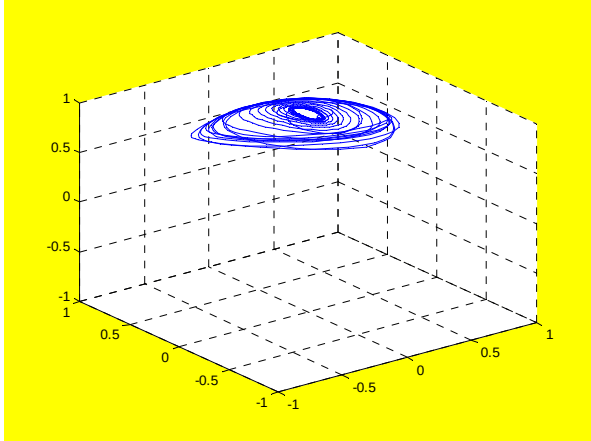



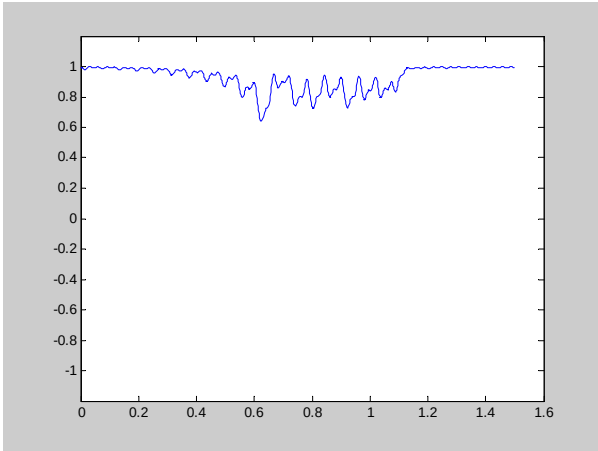

$\alpha = 0.10$



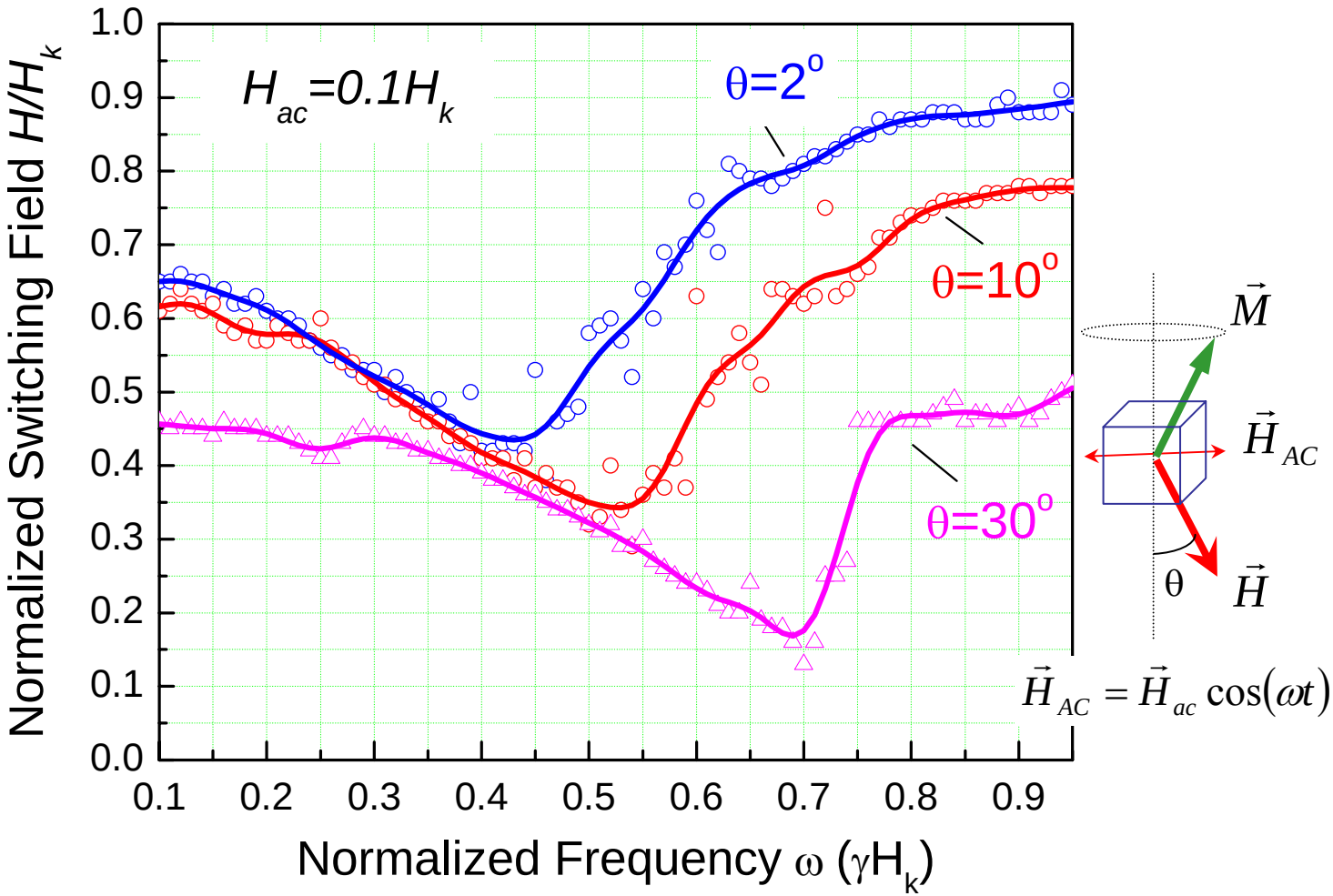




$\alpha = 0.20$

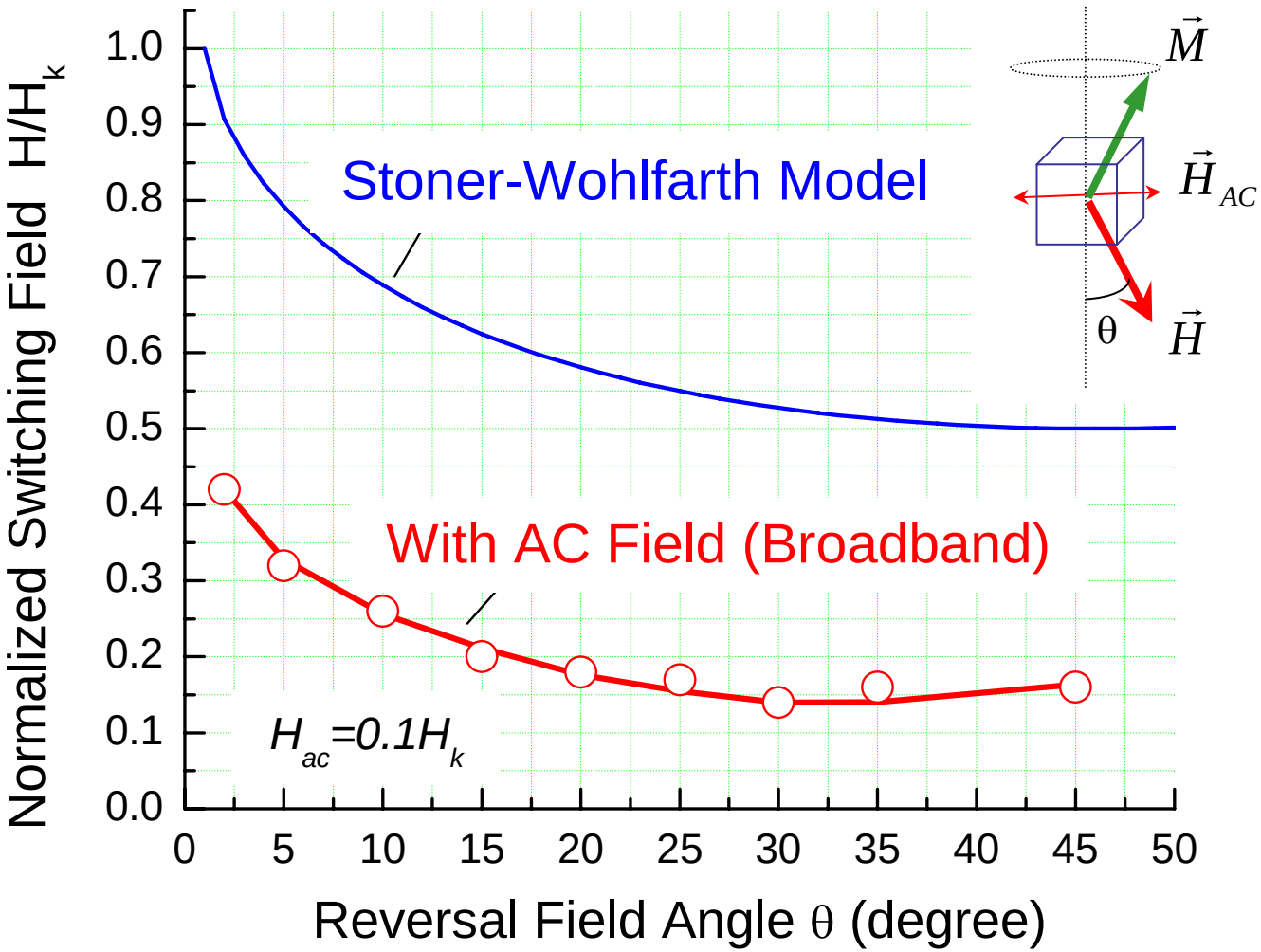


# Effect of Reversal Field Angle



# Reversal Field Angular Dependence



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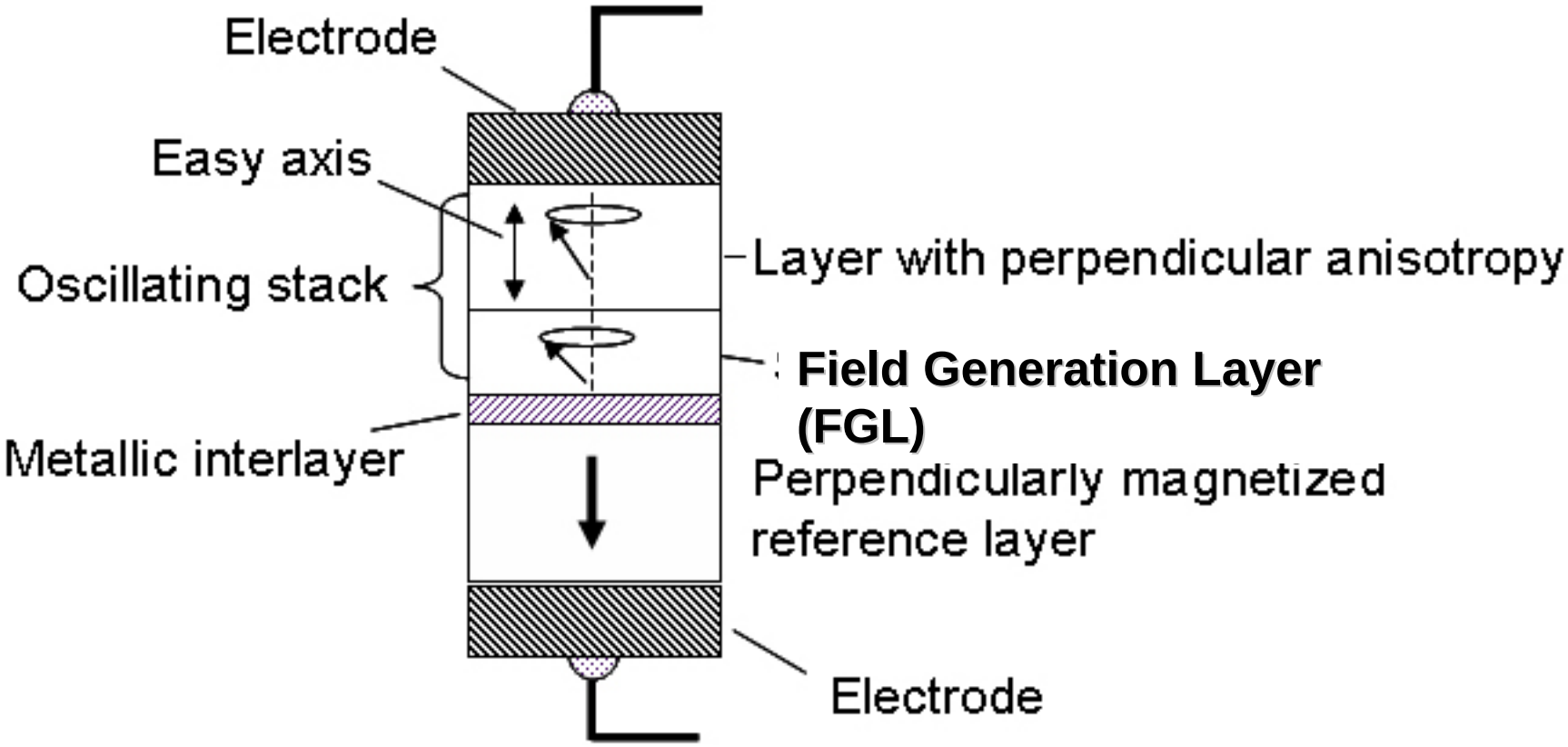
- *Microwave assisted magnetic recording*
- ***Generating localized microwave field: spin torque***
- *Analysis of AC field generation*
- *Recording simulation*
- *Summary*

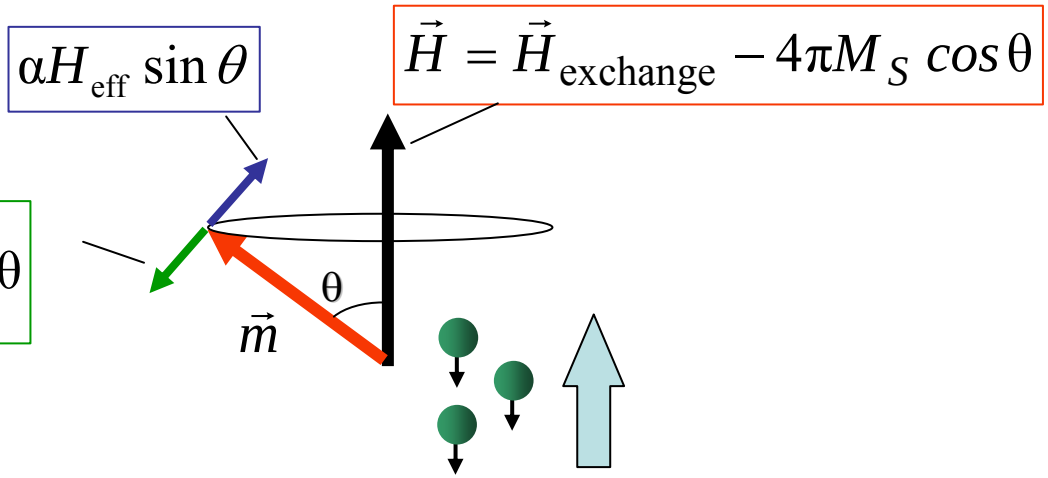
# Basic Oscillator Structure

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



# About Oscillation Frequency

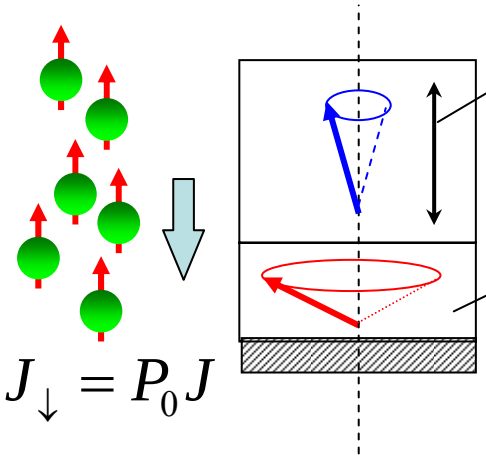
**Field Generating Layer**




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

*If* $\frac{c}{\gamma\alpha}\hat{m}_0 = -\vec{H}$ ⇒ $\frac{d\hat{m}}{dt} = \gamma\hat{m}\times\vec{H}$ $\qquad f_0 = \frac{\gamma H}{2\pi}$

# Spin Torque Driven Oscillation



$$J_{\downarrow} = P_0 J$$

*Magnetic easy axis*

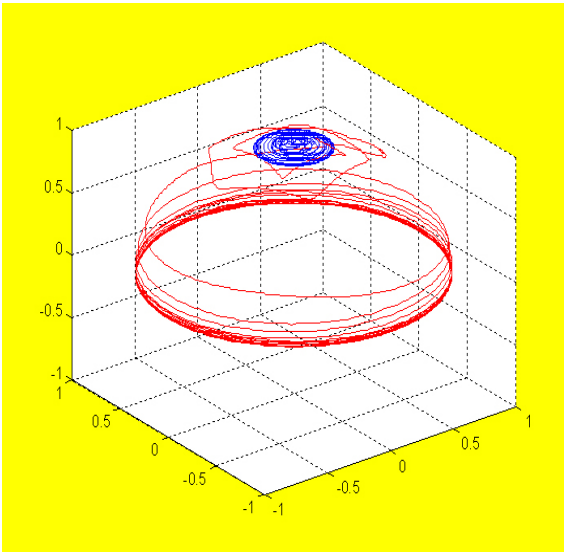
Ku = 5 x $10^6$ erg/c.c.

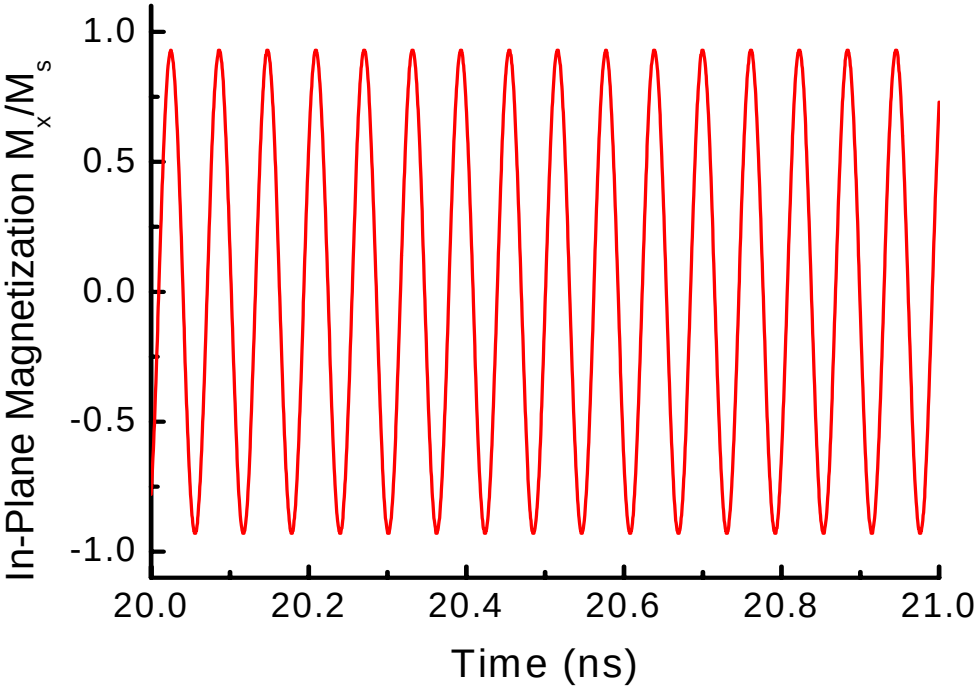
*Field generating layer/ spin torque driven layer*

*Oscillator size:*

*35 nm x 35 nm*

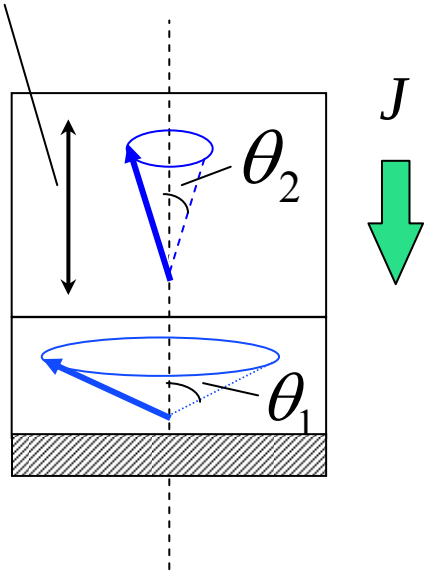
Single Domain



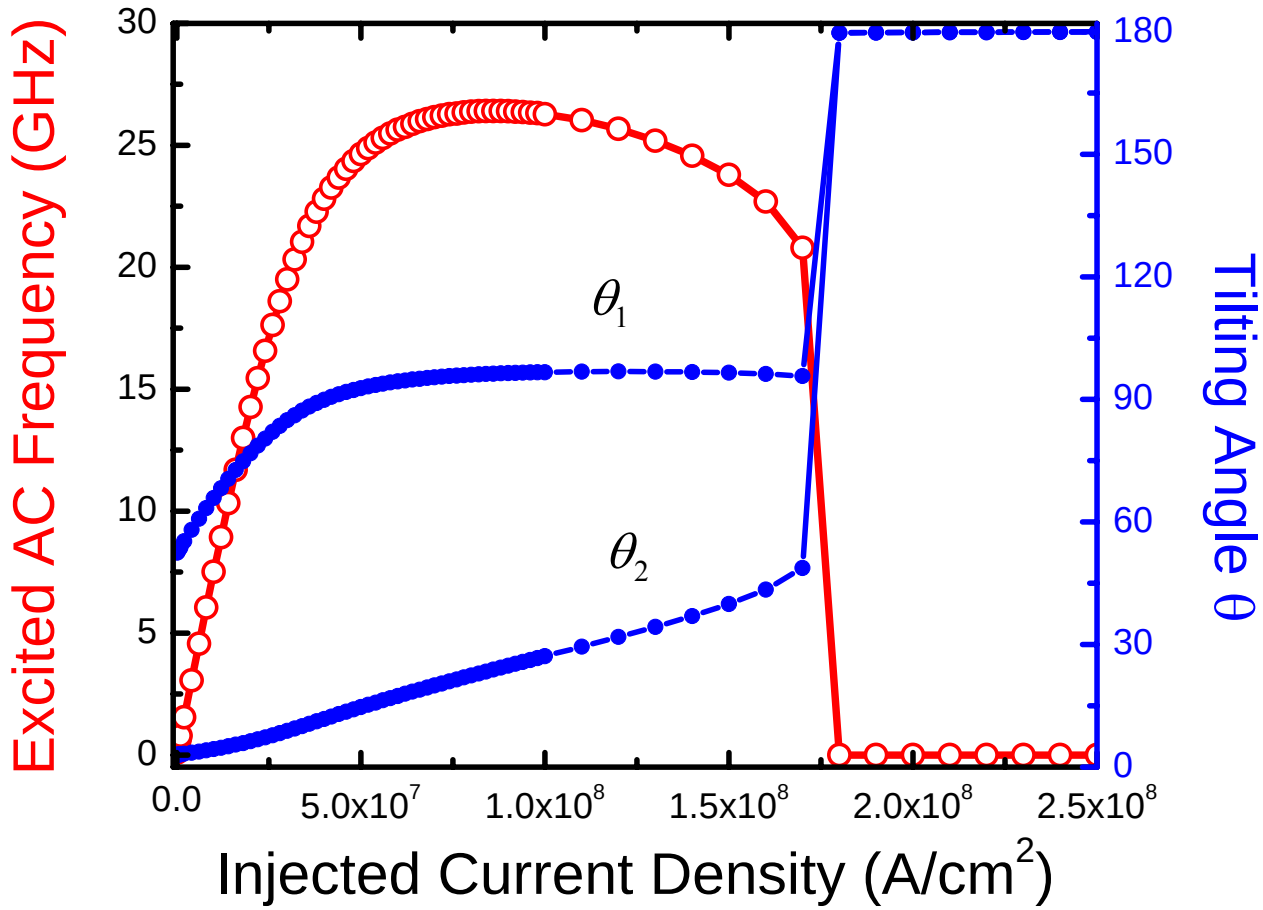



# Frequency Tuning by Current

Ku = 5 x $10^6$ erg/cc

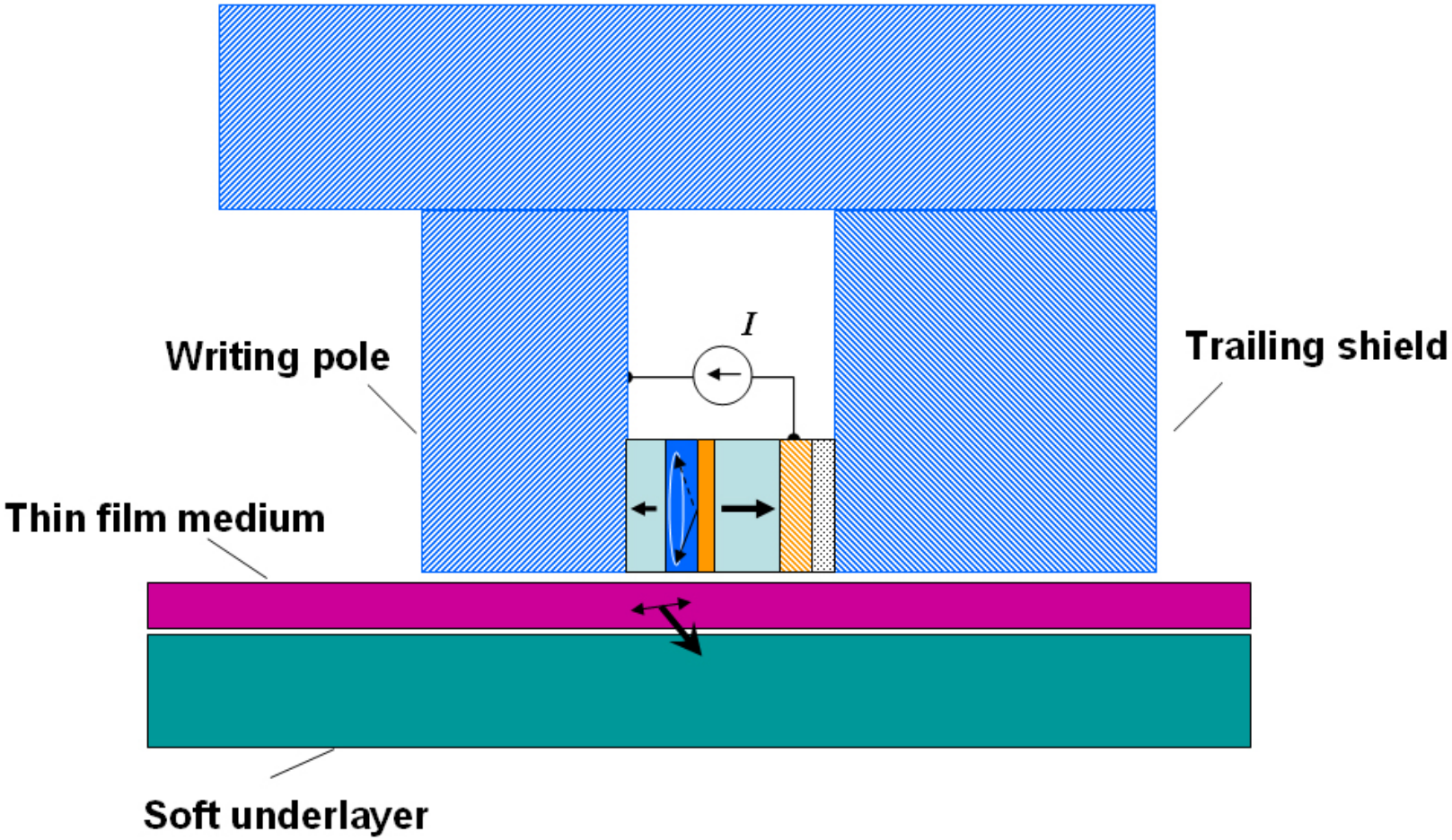



Frequency Tuning Window




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

# Novel Write Head Design



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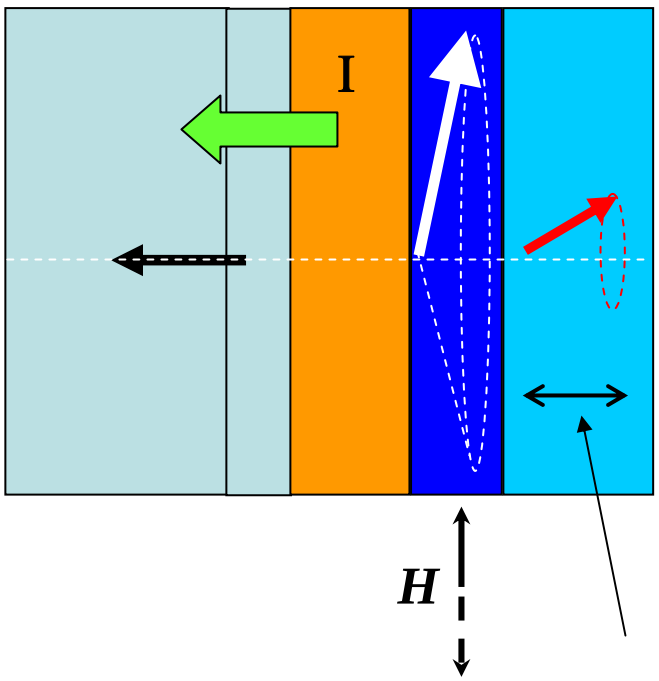
# Generating AC Field

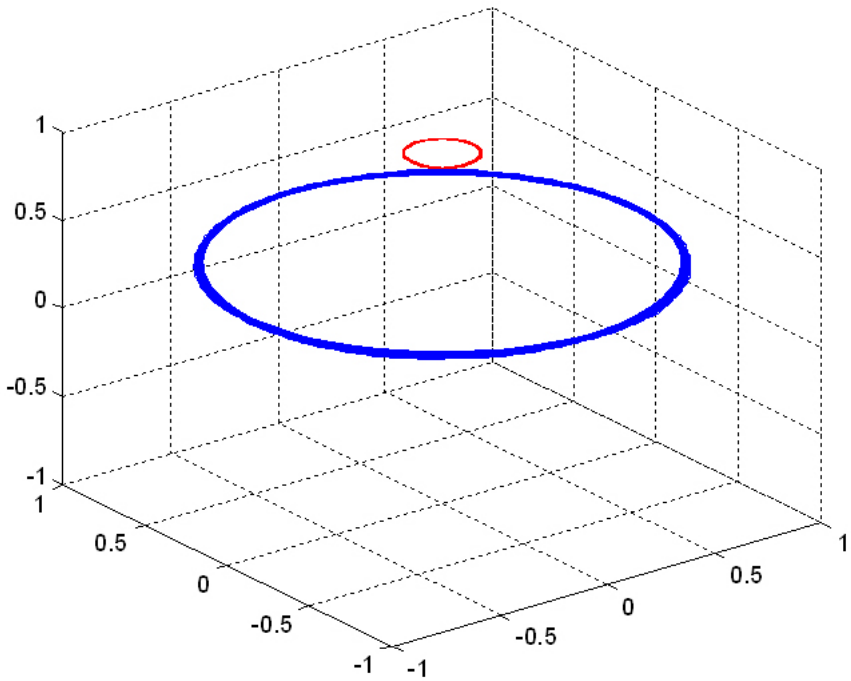
Field Generating Layer (FGL)

$Fe_{65}Co_{35}$ $4\pi M_s$=2.5T $\delta$ =10 nm

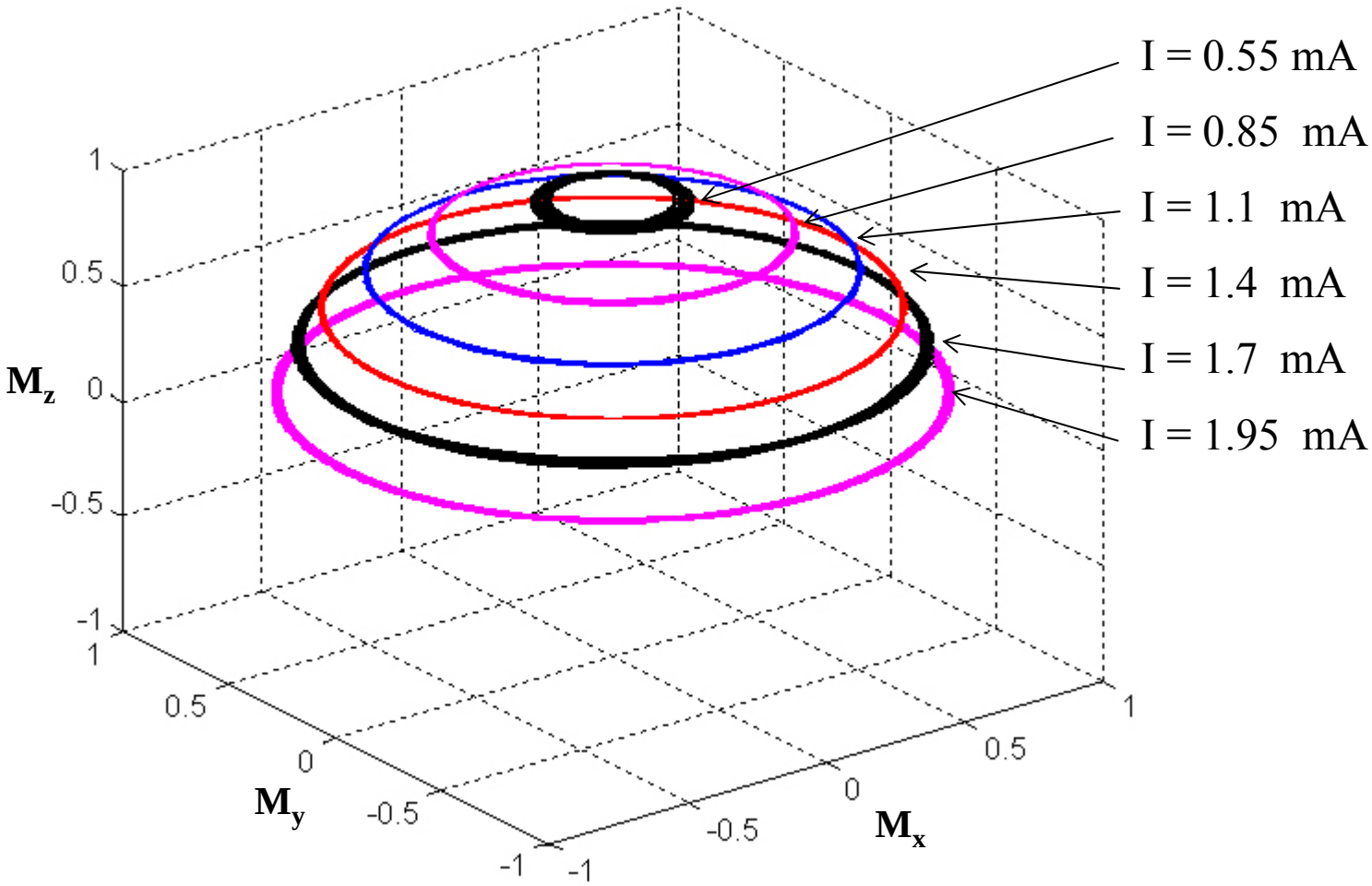



$K_U$=1.5x$10^8$ erg/$cm^3$

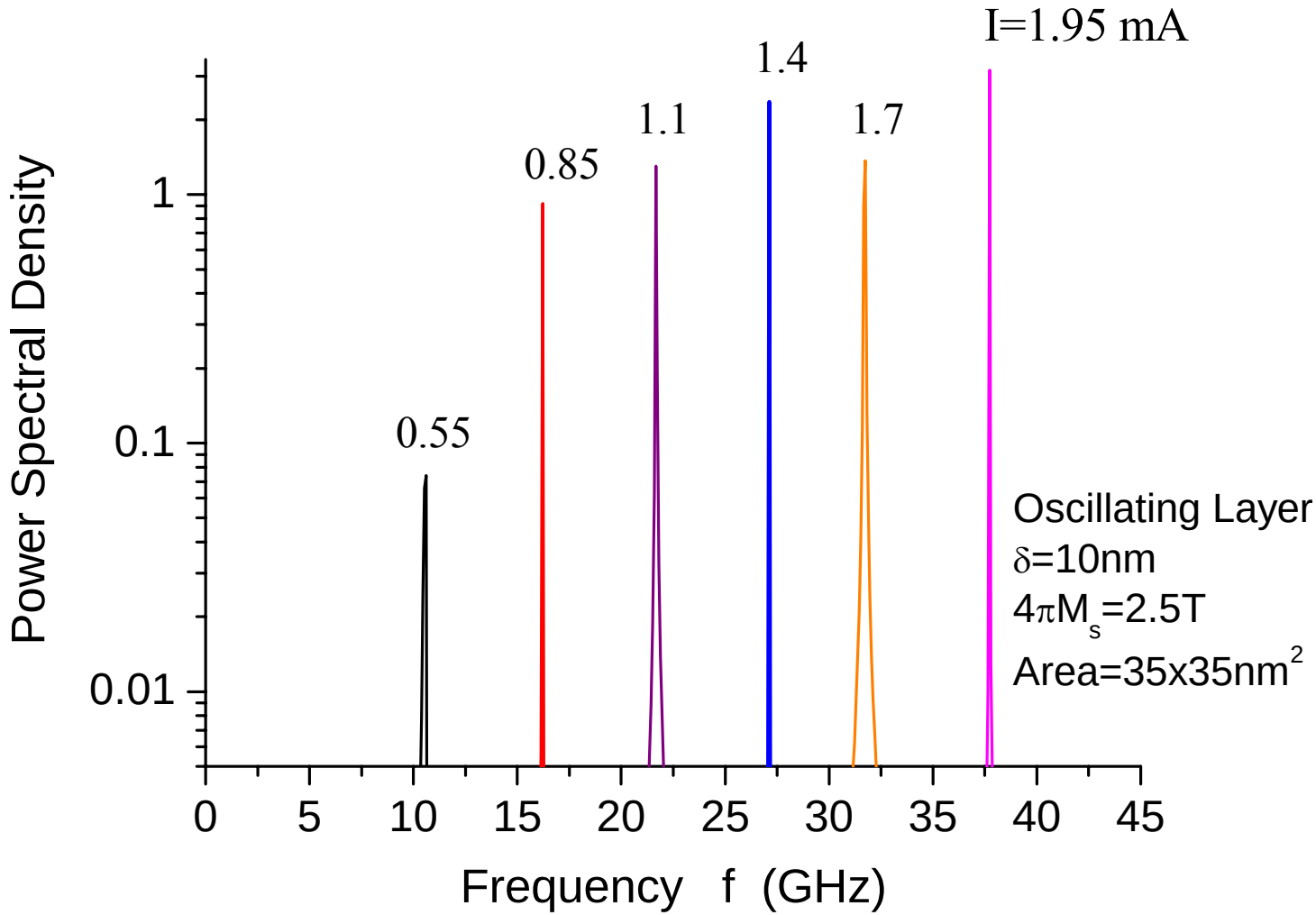
Calculated Magnetization Precession



# Precession in FGL

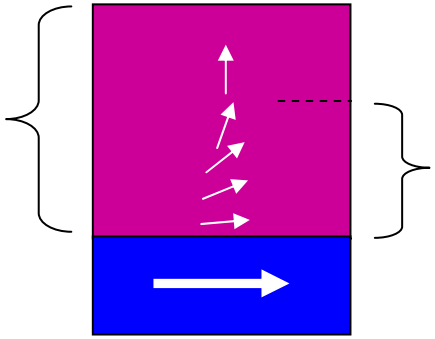


# Power Spectral Density



# Interlayer Exchange Coupling

*Perpendicular layer*



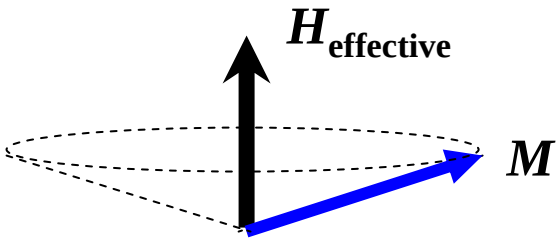
$$\gamma_{\text{wall}} = 2\sqrt{AK}$$

$$\delta_{\text{wall}} = \sqrt{\frac{A}{K}}$$

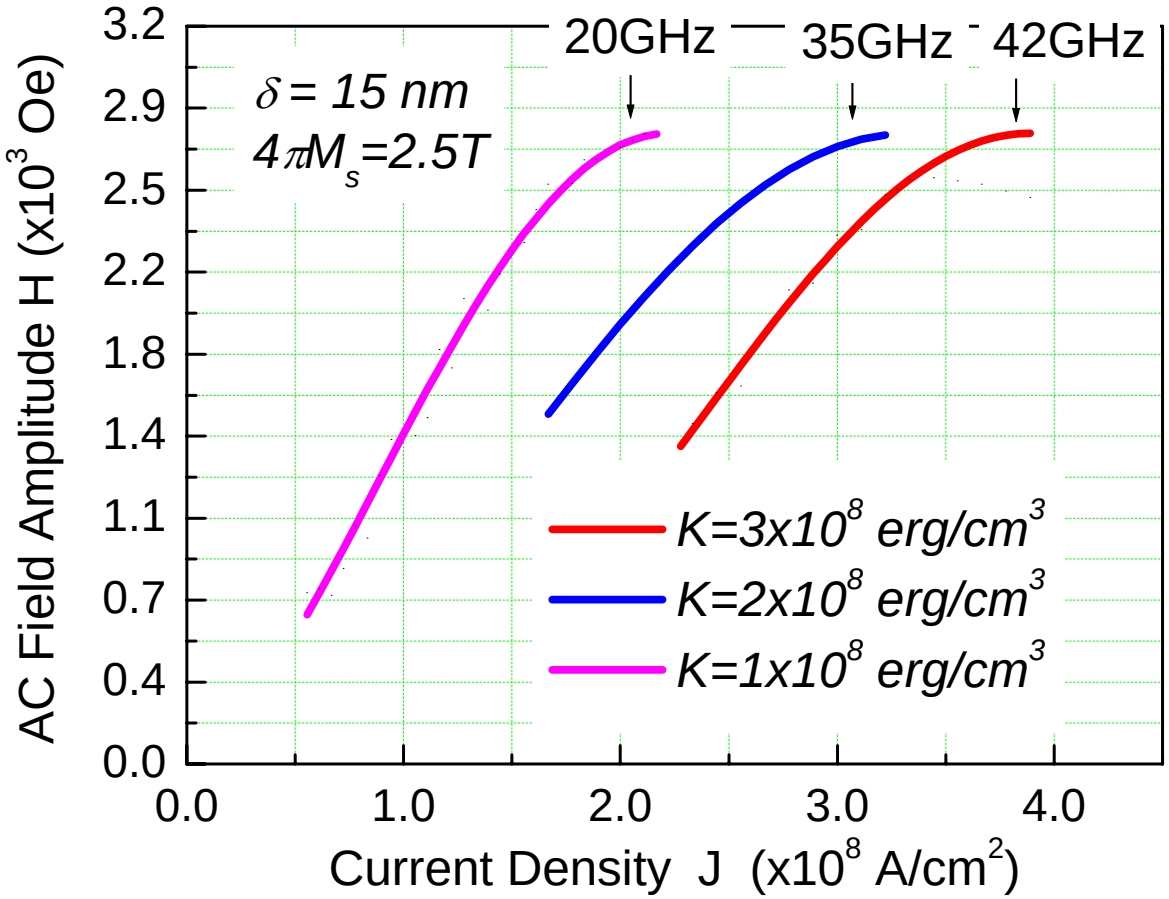
***The effective interlayer exchange coupling on FGL is:***

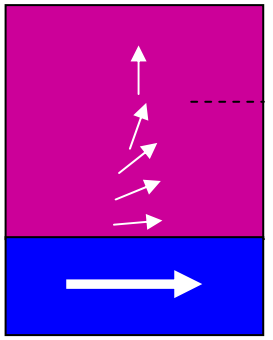
$$\sigma = 2\sqrt{AK}$$

$$H_{\text{effective}} \approx H_{\text{exchange}} = \frac{\sigma}{M_S \cdot t_{FGL}}$$

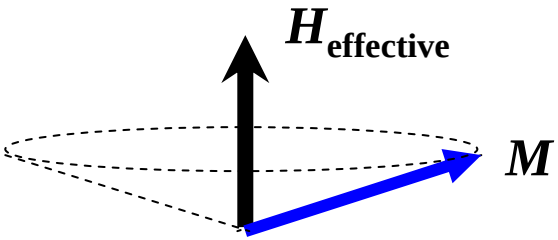


# Field and Injected Current



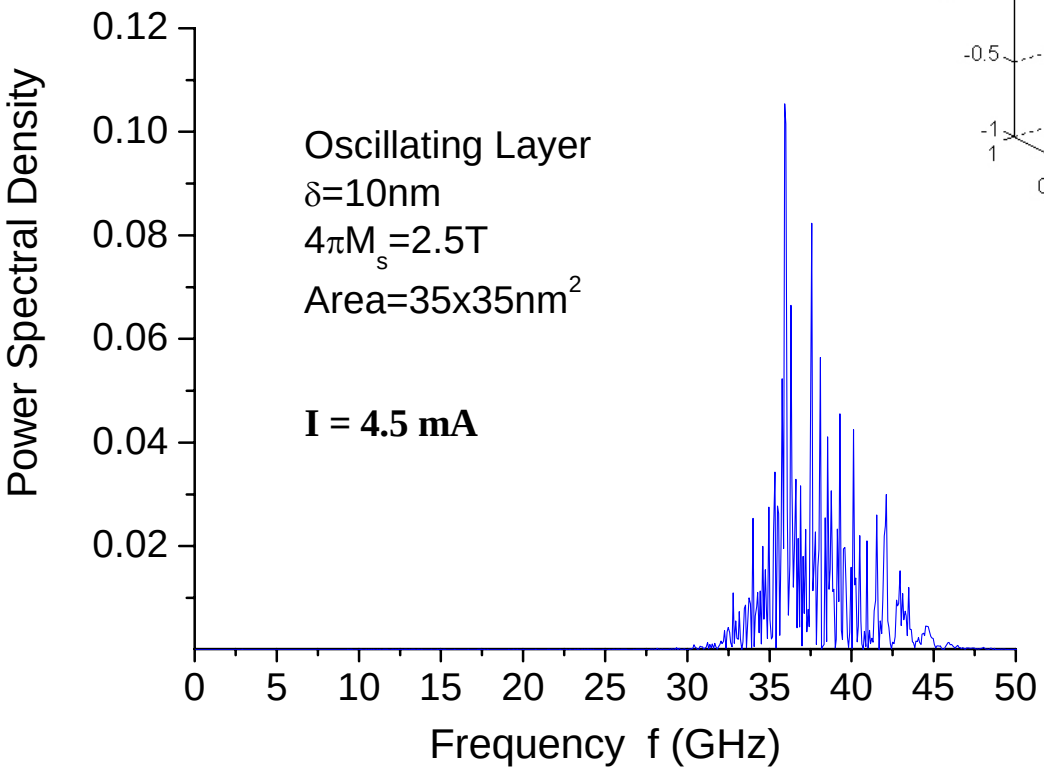
$$\gamma_{\text{wall}} = 2\sqrt{AK}$$

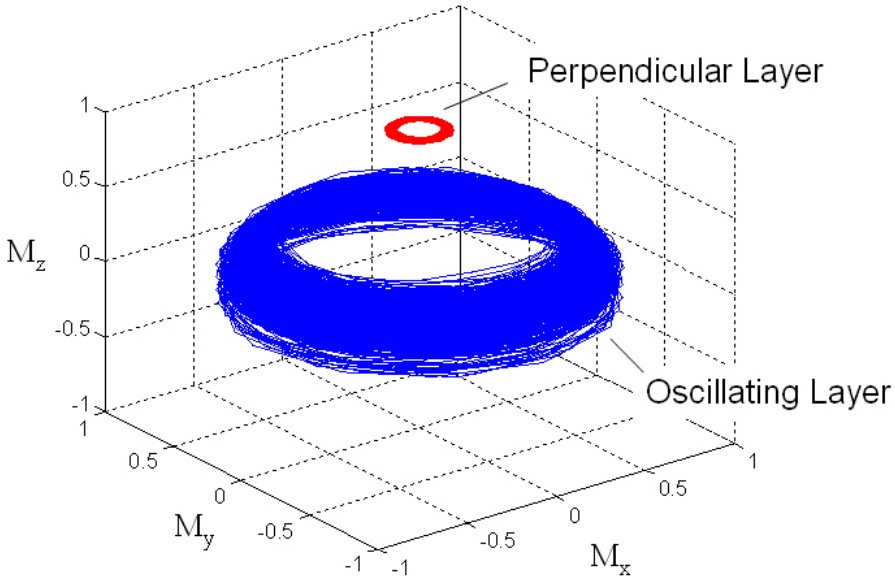



$$H_{\text{effective}} \approx \frac{\sqrt{AK}}{M_S \cdot t_{FGL}}$$

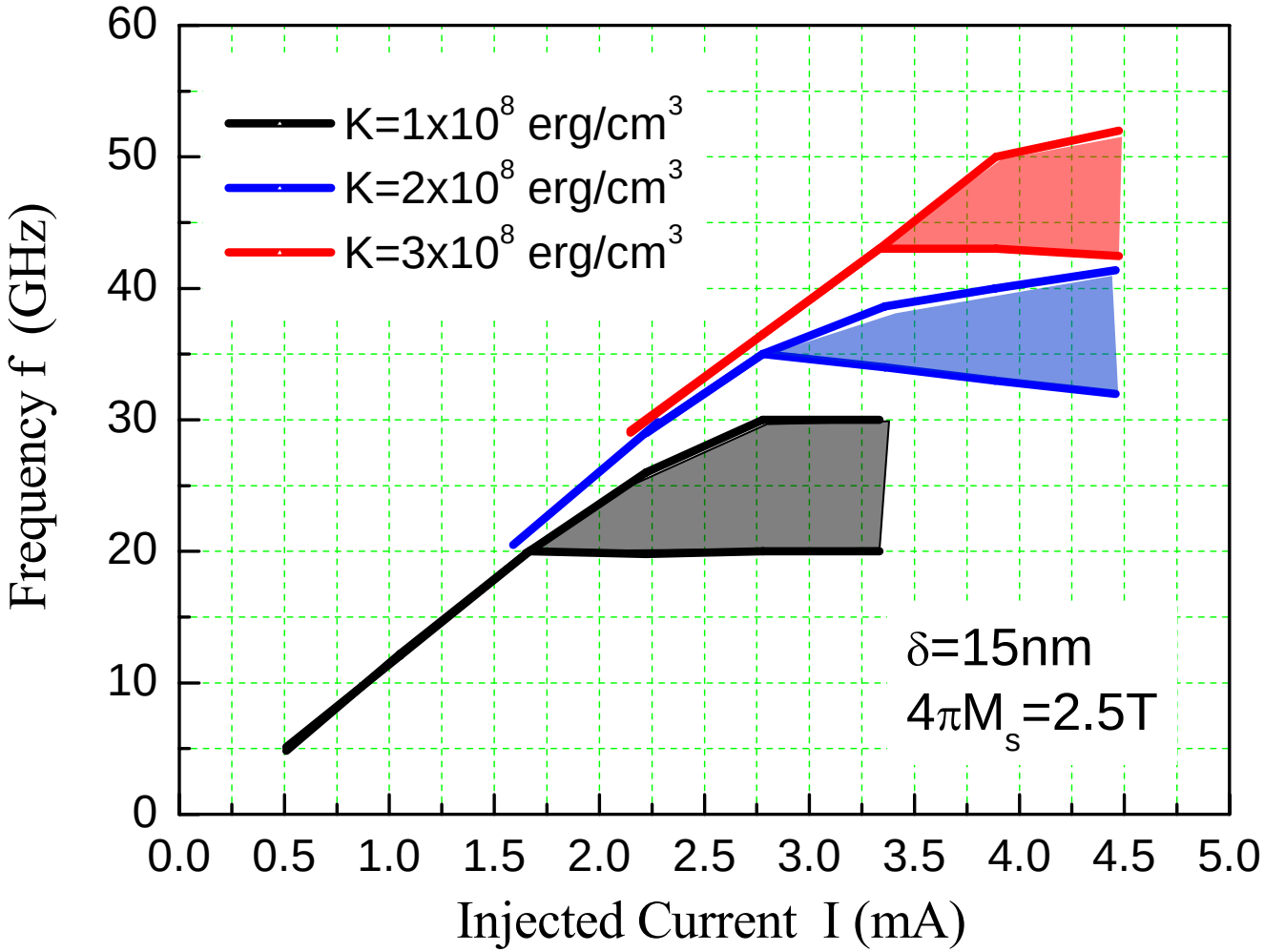
# Higher Modes Excitation

When the current is too large, the magnetization precession becomes spatially non-uniform.

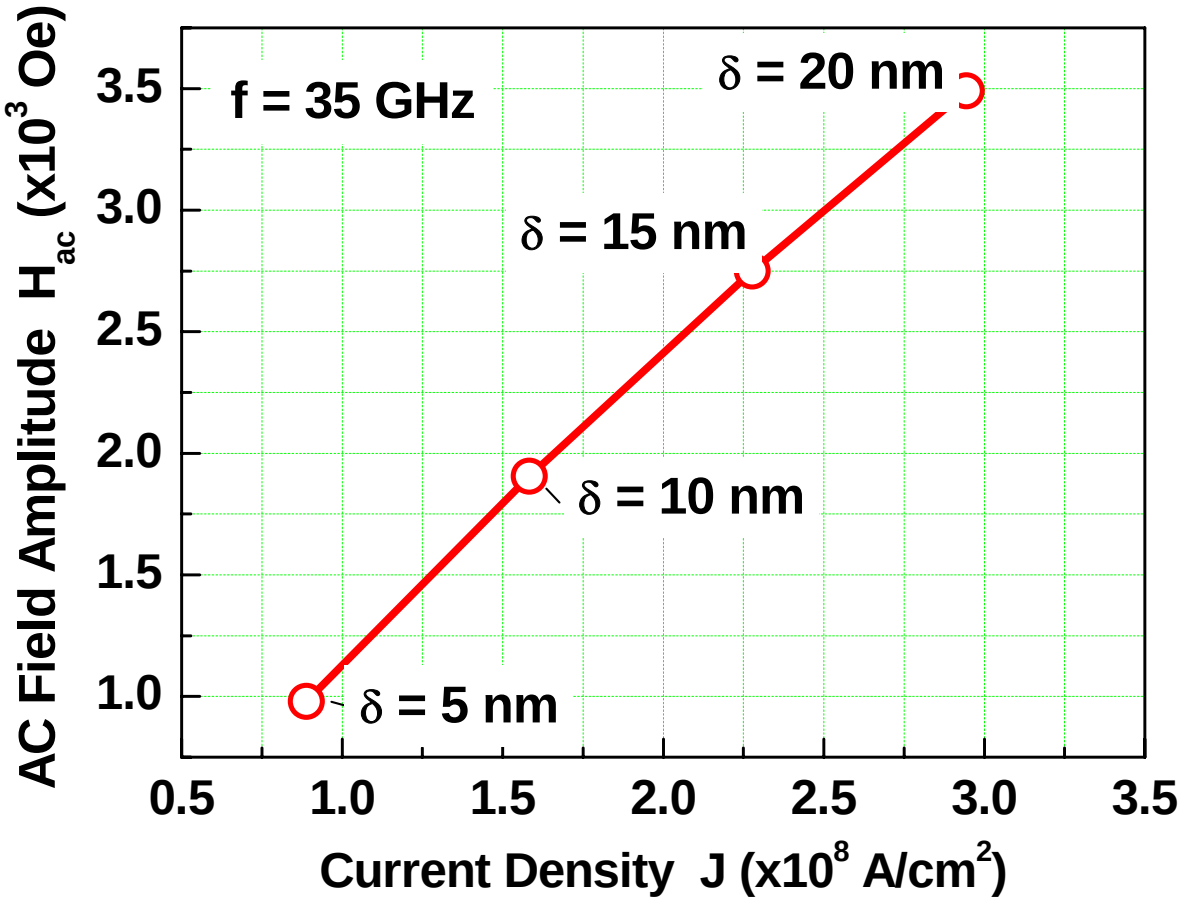


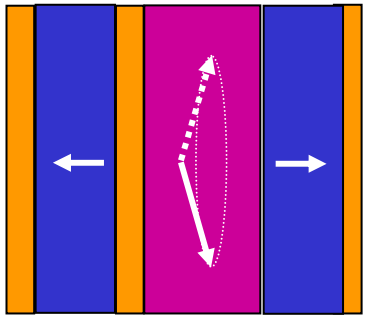



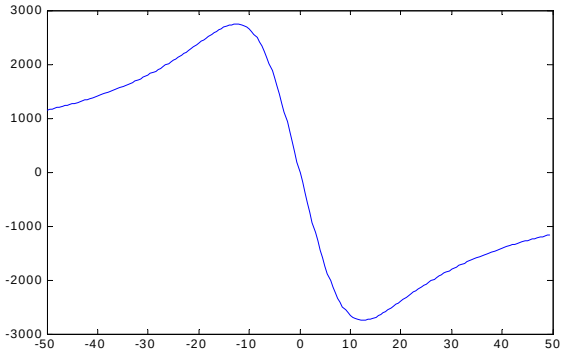
# Frequency and Current



# AC Field Strength





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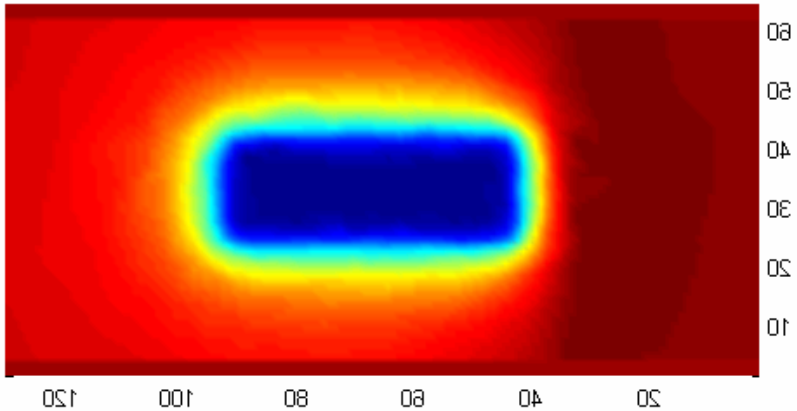
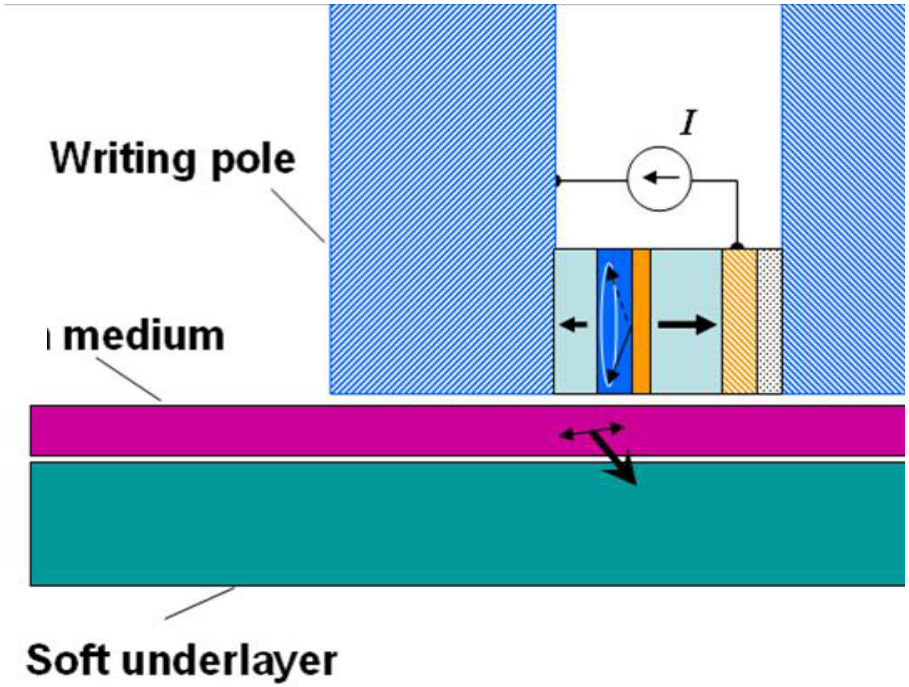
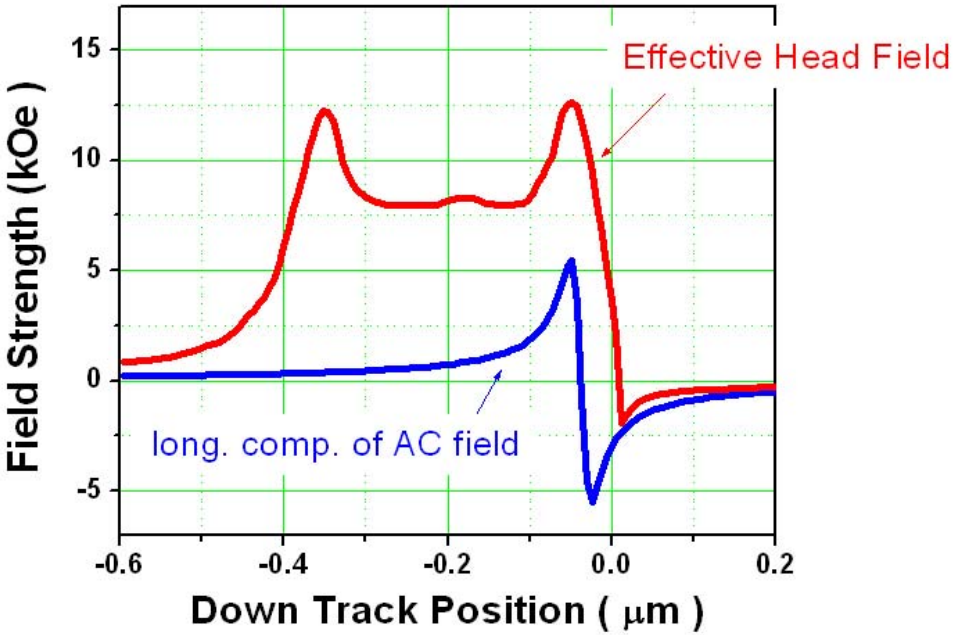
# Recording Fields

Physical write head track width: 120 nm

Trailing Shield present



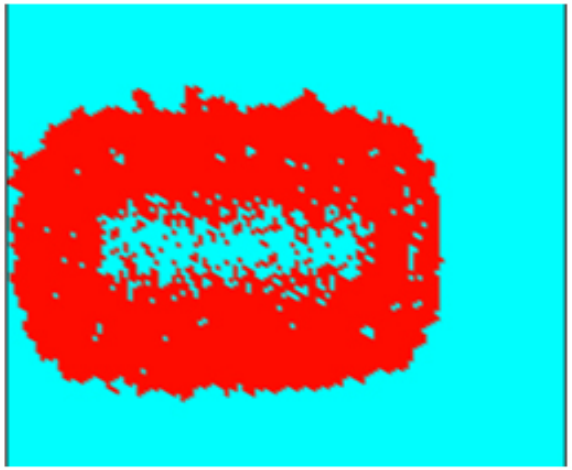


# Recording Footprint

***Write head field:*** ***Rise time 0.2 ns, Duration 1 ns, Magnitude 12 kOe***

Conventional:



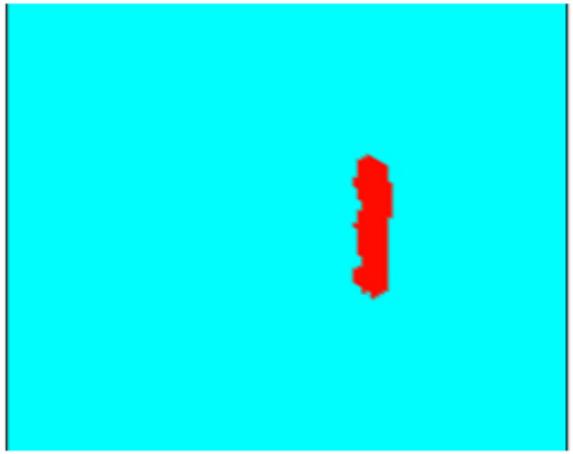
(a)

***$M_s$ = 300 emu/cc***

***$H_k$ = 8 kOe***

***$H_{AC}$ = 0.0***

MAMR:



(b)

***$M_s$ = 300 emu/cc***

***$H_k$ = 30 kOe***

***$H_{AC}$ = 3 kOe***

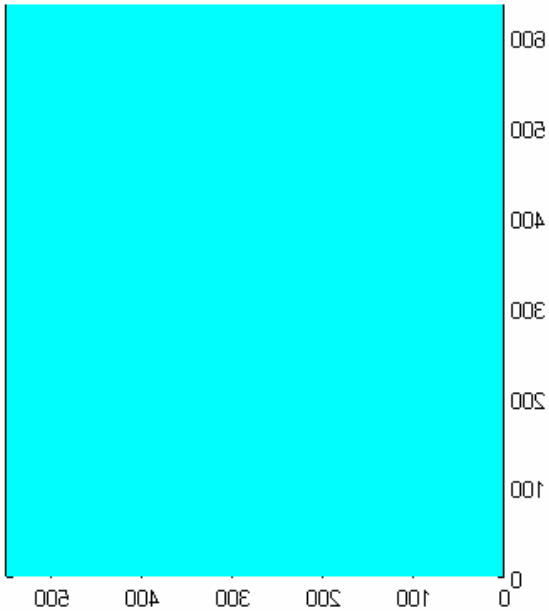
***f = 32 GHz***

***No dispersion***

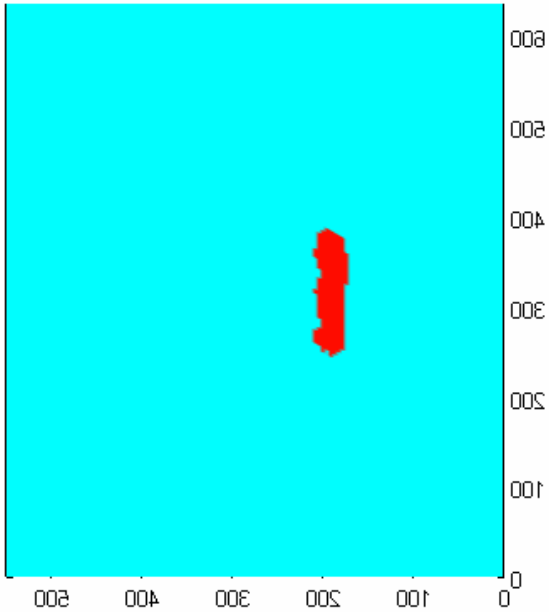
# AC Field Frequency

$M_s$ = 300 emu/cc , $H_k$ = 30 kOe $H_{AC}$ = 3 kOe $H_{head}$ = 12 kOe

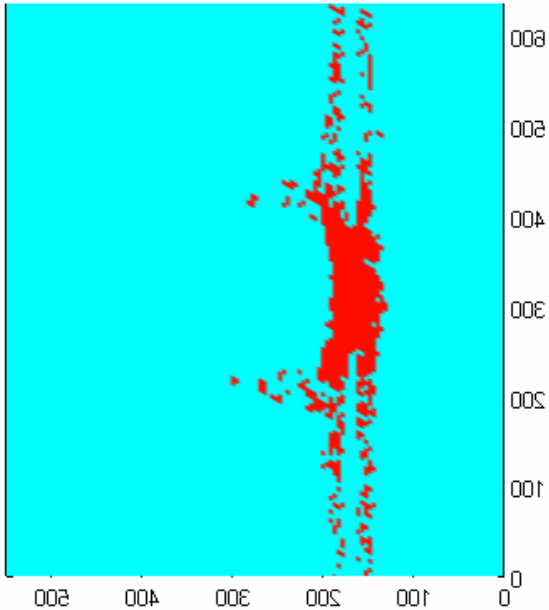
f = 24 GHz




f = 32 GHz




f = 60 GHz

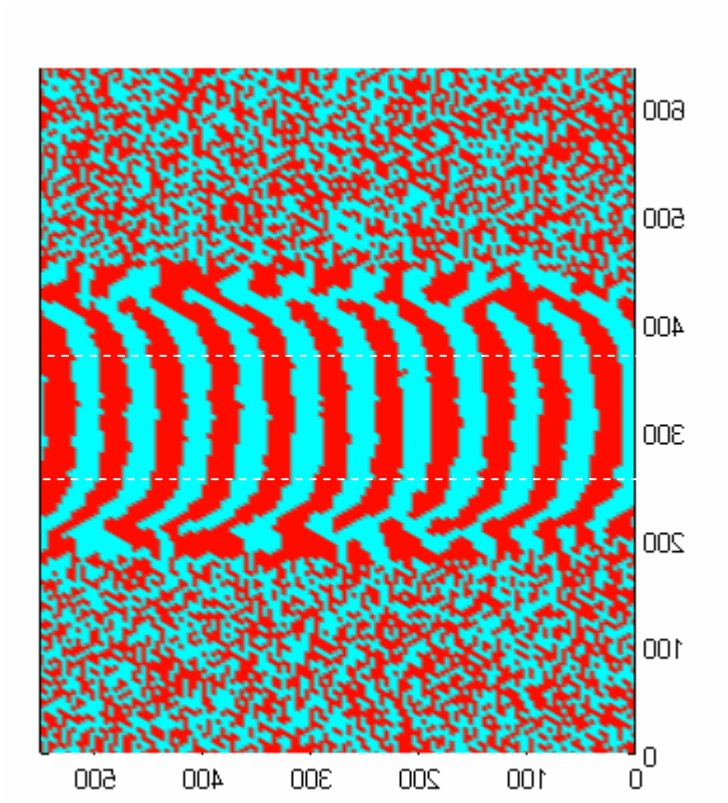


# Comparison at 1 MFCI

Conventional Recording

$H_{head}$ = 12 kOe

$H_k$ = 10 kOe

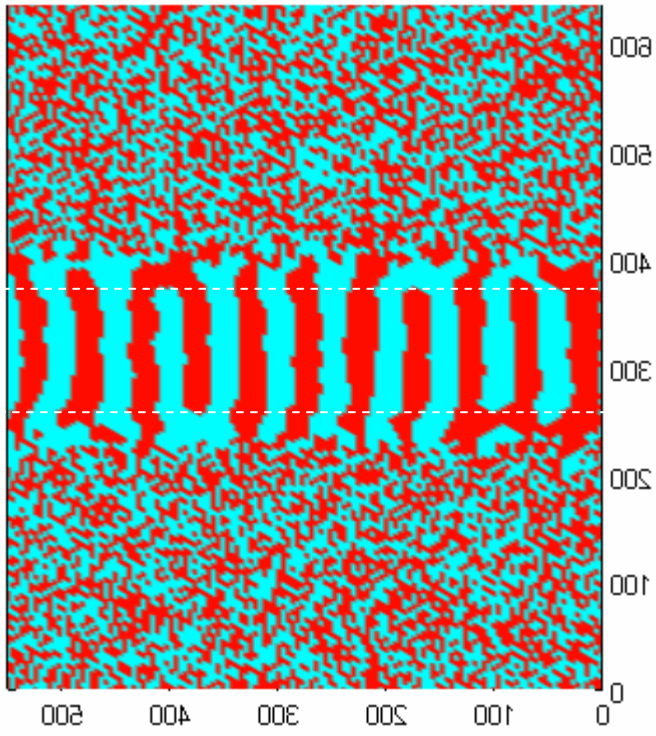



MAMR:

$H_{head}$ = 12 kOe

$H_k$ = 30 kOe

$f = 32\ GHz \quad H_{ac} = 3000\ Oe$

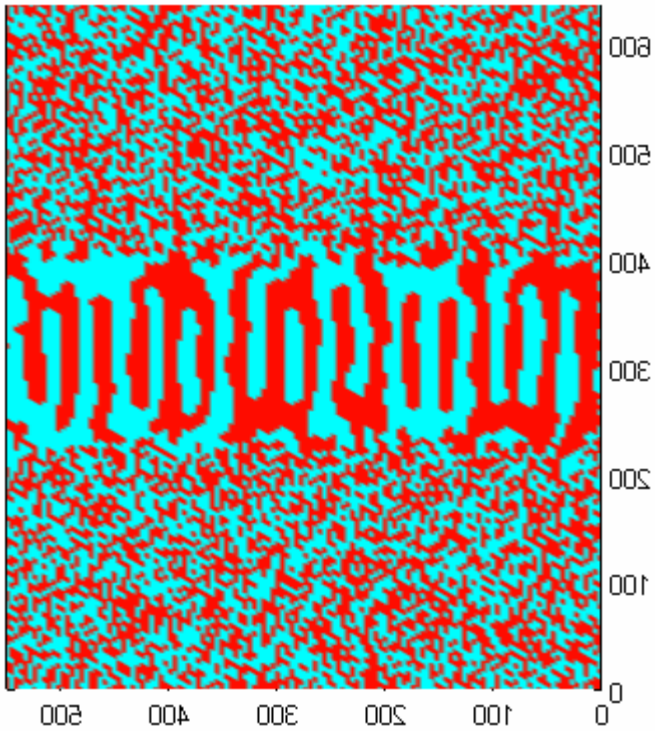


# MAMR @ 1.6 MFCI

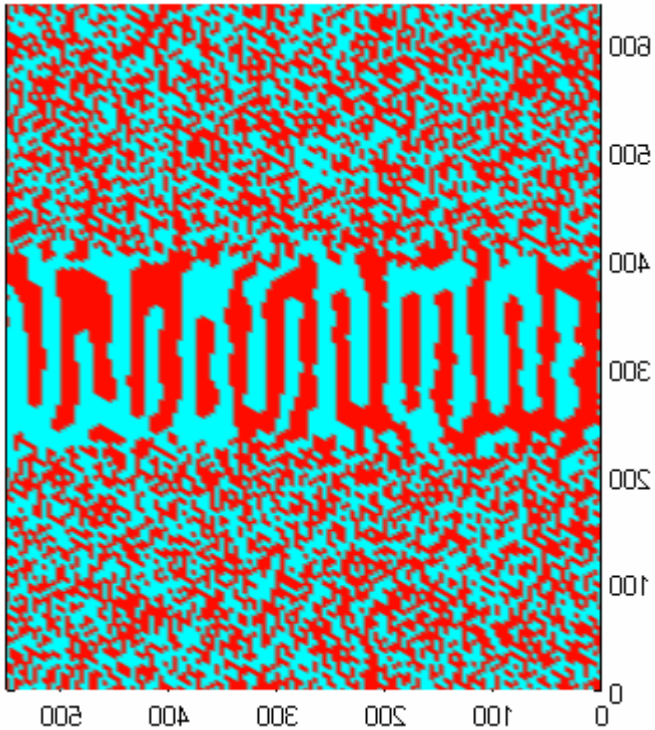
**Head:** $H_{\text{head}} = 12\ kOe$ $H_{ac} = 3\ kOe$ $f = 32\ GHz$

**Medium:** $H_{\text{k}} = 30\ kOe$ $D_{\text{grain}} = 5\ \text{nm}$ $\delta = 10\ \text{nm}$ $C^{*} = 0.05$

*0 °easy axis and 0 % $H_k$ dispersion*




*3 °easy axis and 3% $H_k$ dispersion*



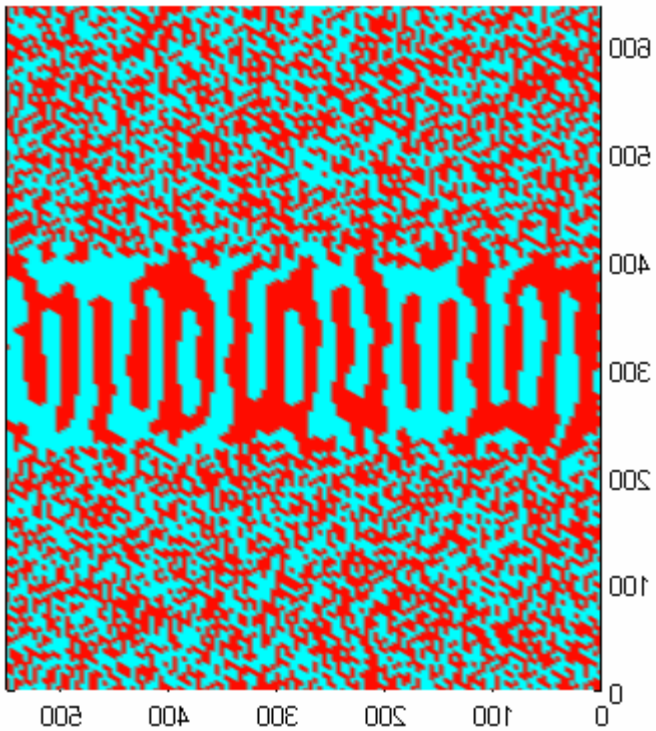
# Exchange Coupling

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

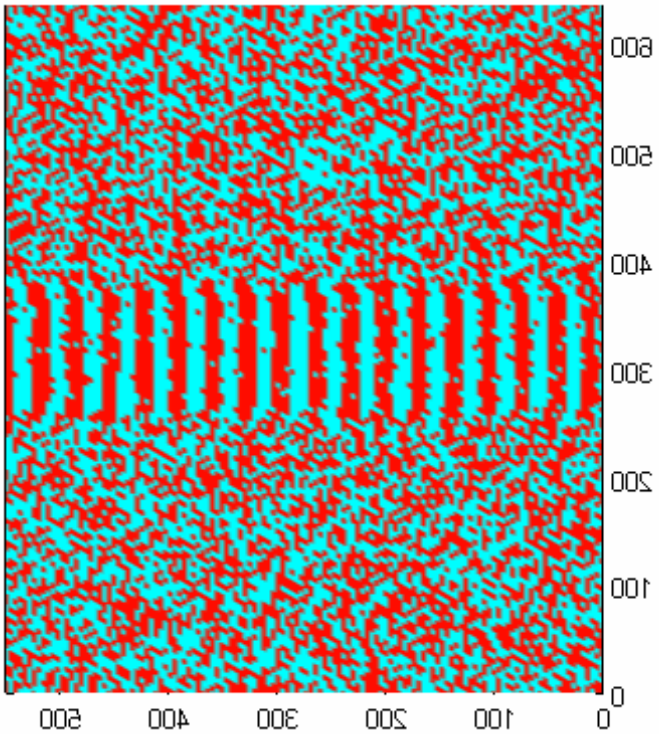
**Medium:** $H_{\text{k}} = 30\ kOe$ $D_{\text{grain}} = 5\ \text{nm}$ $\delta = 10\ \text{nm}$

**MAMR @ 1.6 MFCI**

$C^* = 0.05$

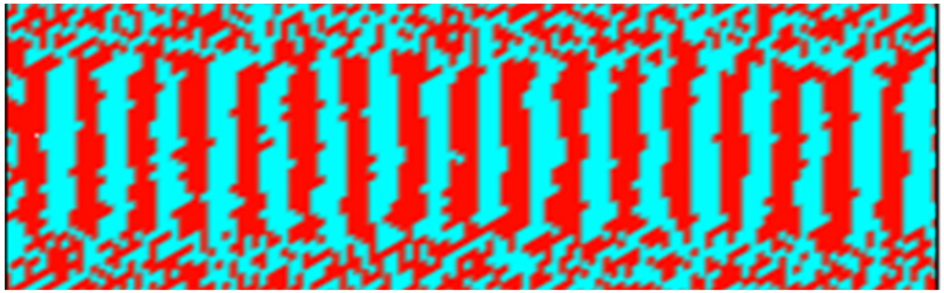



$C^* = 0.0$

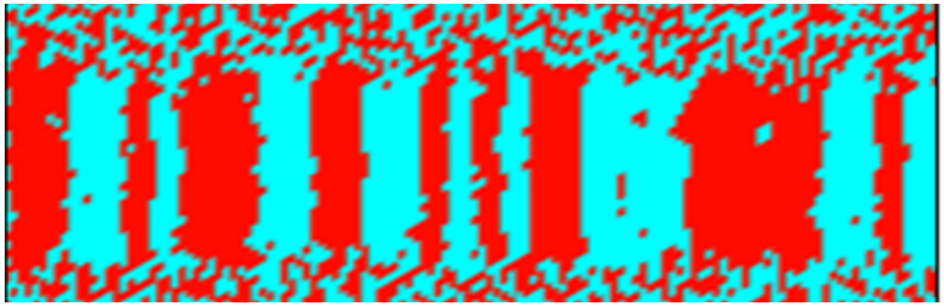


# Random Bits

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1



All "1"s pattern



Random bits

0 0 1 0 1 1 1 0 0 1 0 1 0 1 0 1 1 1 1 1 0 1 0 0 0 1 0 0 0 0 1 0 1 1 1

- No nonlinear transition shift is observed.

# Summary

- *An in-plane ac field at the FMR frequencies results 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.*