FMR Studies of High-Moment Materials at High Frequencies

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Advantages of High-Frequency, High-field FMR in Studies of High-Moment Films

The use of a high field and a high frequency allows one to achieve resonance when the magnetic field is perpendicular to the film plane. Spin waves are most easily observed in this orientation and fitting of spin wave data allows one to determine the exchange coupling constant.

Detection of magnetic species with slightly different g or Ms values is easier because the separation of the absorption lines is proportional to the applied field.

The variable temperature capabilities of the superconducting magnets makes it possible to study the temperature variation of magnetic properties, including FMR line widths.

The sample size for the 94 GHz FMR is small, and the sensitivity is very high, making it a particularly good system for studying patterned samples of high-moment materials.

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Cu/CoFe, FMR at 94 GHz

Perpendicular Anisotropy = 23390 Oe
\( \gamma = 2.93 \text{ MHz/Oe} \)
\( A = 1.75 \times 10^{-6} \text{ erg/cm} \)
FMR of FeTiN$_5$ at 93.9 GHz in 6T Superconducting Magnet

\[ H_{cal} (\text{Oe}) \]

\[ \beta \text{(deg)} \]

\[ \gamma = 2.88 \text{ MHz/Oe} \]

\[ 4\pi M_s = 14620 \text{ Oe} \]

\[ \text{H perpendicular to film} \]

\[ \text{Angle of H and M} \]

\[ \beta \text{(angle of H)} \]

\[ \text{(angle of M)} \]

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Measurement of Switching Characteristics of Patterned Soft Films: MOKE-Microwave Stripline system

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MOKE- Microwave Stripline System

Patterned Samples are placed on a microwave coplanar waveguide, and pulses of variable length (1-100 nsec), amplitude (0- 120 Oe) and repetition frequency (.01 – 100 kHz) can be applied.

The magnetization state is detected by a MOKE system.

Switching of 50 nm thick NiFe samples 2 x 10 µ has been detected.
CPW-MOKE system for the study of fast switching of patterned films

Cross section of CPW

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Patterned NiFe Measured by MOKE

Pattern size: 2 x 10 um
Thickness: 50nm

Hc = 8.3 Oe
Hk = 139 Oe
The Effects of Ti on the Diffusion of Nitrogen in FeXN Films

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Ti and Nitrogen Diffusion

The diffusion of N atoms in FeXN films can cause phase changes and unstable anisotropy.

Multilayer films of Fe, Ti, FeTi, and FeTiN have been studied before and after annealing.

We have done structural studies by XRF and depth profile studies by XPS techniques.

Our preliminary findings show that Ti has a large effect on N diffusion and Ti tends to stabilize the $\alpha$-phase of FeN and prevent formation of Fe$_4$N.
Diffusion of N in FeXN materials causes nitrogen loss, phase change and unstable anisotropy.

Rotation of Hk caused by nitrogen diffusion in FeTaN.

<table>
<thead>
<tr>
<th></th>
<th>ENTHALPY KJ/MOL</th>
<th>DIFFUSION LENGTH (DT)^{1/2}(A) 373K, 100 MIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe₄N</td>
<td>-10</td>
<td>α(bcc) Fe 2000</td>
</tr>
<tr>
<td>TiN</td>
<td>-338</td>
<td>α(hcp) Ti 0.002</td>
</tr>
<tr>
<td>AlN</td>
<td>-318</td>
<td></td>
</tr>
<tr>
<td>Cu₃N</td>
<td>Subject to randomization</td>
<td></td>
</tr>
</tbody>
</table>

X-N affinity and N diffusion in pure nitrides.

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Effect of Ti in the stability of \( \alpha \) phase FeTiN

- Addition of Ti in FeN film stabilizes the \( \alpha \) phase, prohibits the formation of \( Fe_4N \) phase

- But N can still diffuse over a long distance, even to the adjacent layer
Study of N diffusion by XPS depth profile

N (and O) in FeTiN layer is absorbed by Ti layer

N diffuse from FeTiN layer to FeTi layer resulting a uniform distribution

N doesn’t diffuse from FeTiN layer to Fe layer

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