Overview of Sputtering Technologies for Thin-Film Head Applications

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Collaborators and Sponsors

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Hard-Biased MR/Spin Valve Head
## Materials Used in Thin-Film Head Fabrication

**APPLICATION**
- Undercoat/Overcoat/Gap
- Poles
- Coils
- Shields (MR)
- MR Layer
- Soft Adjacent Layer (SAL)
- Hard Bias/Contacts
- AF material (for pinning or exchange bias)
- Spacer between MR/SAL
- Protective Coating
- GMR Multilayers

**MATERIALS**
- $\text{Al}_2\text{O}_3$, AlN
- CoZrNb, FeN, FeCoBC, Ni$_{45}$Fe$_{55}$
- Permalloy
- Permalloy
- NiFe, NiFeRh
- Cr/CoPt, Cr/CoPtCr, FePt, Ta/Au/Ta, Rh
- FeMn, NiO, NiCoO
- Ta, Ti, Al$_2$O$_3$, SiO$_2$
- Carbon (DLC)
- NiFe/Ag, NiFeCo/Ag, NiFeCo/Cu
Thin-Film Head Layer Requirements

• GMR Spin Valves and Multilayers
  – Monolayer control of film thicknesses
  – Clean, smooth interfaces for high GMR ratio and high $H_{ex}$

• Hard Bias Multilayers
  – High coercivity
  – High remanent magnetization
  – Collimators and/or spacers for liftoff requirements

• Soft Poles
  – Oriented, very soft magnetic material with very high saturation magnetization
Features of Process Tools

- In-Line and Cluster Tools
- Static Deposition Modules for Poles, Shields, MR Sensors, Hard Bias
  - Rotating Magnetron or Broad Erosion Circular Cathodes
  - Electromagnet for Orientation
  - Temperature Control
  - Bias
- Planetary Module for Nanoscale Control of Thickness and Repeatability in GMR Spin Valves and Multilayers
  - 6-10 Rectangular Cathodes
  - Permanent magnet orientation
  - Precise Thickness/Repeatability Control to less than 0.1 nm
    - Independent Sun and Planet Speed Control
    - Power Supply Control
  - Uniformity Control to better than 3%, $3\sigma$ over 200 mm wafers
    - Computer-simulated Cathode Design
    - Planetary motion, velocity profiling, apertures
  - Monolayer /Interface Control
    - Power turn-on/turn-off with substrate out of deposition zone
    - Short residence time between layers
    - Bias utilized to control interfacial properties
GMR Spin Valves and Multilayers

References

GMR Spin Valves

- FeMn-based spin valves optimized on cluster tool with planetary and static modules

- Monolayer deposition rate control with substrate bias and excellent vacuum conditions allow precise tailoring of interface smoothness, which directly affects SV performance

- Highly repeatable spin valves with excellent properties achieved: $\text{DR/R} > 9.4\%$, $H_{\text{ex}} > 470\text{ Oe}$
Spin Valve Structure

ΔR/R > 9.4%

H_{ex} > 470 Oe

Ta 5.0 nm
FeMn 7.5-15 nm
Co 2.5-3.5 nm
Cu 2.0-3.0 nm
Co 1.0 nm
NiFe 6.0 nm
Ta 5.0 nm
SiO_{2} substrate
Accuracy of Thickness Control in Planetary Deposition Mode

Sun speed and rotation counts used to control Cu film thickness
GMR Ratio vs. Cu Spacer Thickness
NiFe/Co/Cu/FeMn Top Spin Valve
GMR Ratio vs. Pinned Layer Thickness for NiFe/Co/Cu/NiFeCo/FeMn Spin Valve

Normalized $\Delta R/R$ (a.u.)

NiFeCo pinned layer thickness (Å)
GMR Ratio vs. Pinned Layer (Co) thickness
NiFe/Co/Cu/Co/FeMn Top Spin Valve
GMR Ratio vs. Pinning Layer Thickness
NiFe/Co/Cu/Cu/FeMn Top Spin Valve
Hysteresis Loop for Exchange Biased Top Spin Valve

Theoretical

Free layer

Pinned layer

Actual data

Magnetization

$H_{applied}$
Repeatability of Exchange Field

Repeatability (\%_3\sigma) = 3.0
Spin Valve GMR Ratio
GMR Repeatability Data for Top Spin Valve

Spin valve repeatability on Cymetra

Sample number

DR/R (%), Rs (ohms/sq), Rs unif. (% 3 sigma)

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## GMR Multilayer Structures

<table>
<thead>
<tr>
<th>Film Structure</th>
<th>( \Delta R/R )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(NiFeCo/Ag)</td>
<td>6.5% (following RTA)</td>
</tr>
<tr>
<td>(NiFe/Au)</td>
<td>7.5% (as-deposited)</td>
</tr>
<tr>
<td>(NiFeCo/Cu)</td>
<td>18% (as-deposited)</td>
</tr>
</tbody>
</table>
GMR Ratio for NiFeCo/Cu Multilayer
Low Angle X-Ray Diffraction Spectra for Au/NiFe GMR Multilayers

- DC Magnetron Sputtered Au/NiFe MLs (NiFe 1.5 nm and Au 0.5-3.5 nm).
- GMR Values of 7.4% Achieved As-Deposited.
- Coherent Smooth Interface Pattern Observed by Low-angle X-ray Diffraction and also by TEM.
GMR Ratio and Saturation Field vs. Au Thickness in (NiFe/Au) Multilayers
Hard Bias Films

References

- “High coercivity CoPtCr, CoPt films deposited at high power and high bias conditions for hard bias applications in MR heads”, G. Choe, S. Funada, A. Tsoukatos and S. Gupta, J. Appl. Phys. 81, 4894 (1997).
Lift-Off Process for Hard Bias/Contact Layer Deposition
Hard Bias / Contact Layers

• Magnetic Properties
  – CoPt with bias, no collimation
    • $H_c > 2000$ Oe; $M_r t > 4$ memu/cm$^2$
  – CoCrPt, no bias, collimation
    • $H_c > 1600$ Oe; $M_r t > 3$ memu/cm$^2$

• Uniformity, Repeatability
  – +/- 3%, 3 $\sigma$, within wafer
  – +/- 3%, 3 $\sigma$, wafer-to-wafer

• Collimated Deposition for Lift-off
  – Physical collimation
  – Long throw
B-H Loop of CoPt (60 nm)/Cr (20 nm) Deposited at High Power and Bias

![Graph showing magnetic properties](image)
Coercivity and $M_t$ Uniformity Data
Cr/Co$_{75}$Pt$_{12}$Cr$_{13}$ films

- Coercivity
  - Mean = 1700 Oe
  - U(3 Sigma) = 0.7%

- $M_t$
  - Mean = 3.19 memu/cm$^2$
  - U(3 Sigma) = 7%
Repeatability Runs: $\text{Cr/Co}_{75}\text{Pt}_{12}\text{Cr}_{13}$ Films

![Graph showing Coercivity, SQ, and Mrt for different runs.]

- **Coercivity (Oe):**
  - Mean = 1613 Oe
  - U(3 Sigma) = 8%

- **SQ:**
  - Mean = 0.81
  - U(3 Sigma) = 5.5%

- **Mrt (memu/cm²):**
  - Mean = 2.56 memu/cm²
  - U(3 Sigma) = 6.5%
Computer Simulation of Long-Throw vs. Traditional
Collimation Angle vs. T/S Spacing
Long Throw Deposition

I. Wagner

Ar Pressure = 0 mT

Target
RM34-Stadium
RM34-SYM4B

Target-Substrate Distance (Inches)
Computer Simulation of Physically Collimated Deposition

Angular distribution of collimated deposition

Modeled step coverage of collimated deposition

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Hard Bias Deposition for Lift-off
Traditional Process

Cr 7.5 nm / CoPtCr 80 nm
T/S distance: 2-4”
Pressure: 4/6 mTorr
Hard Bias Deposition for Lift-off
Long Throw, Low Pressure

Cr 7.5 nm / CoPtCr 75 nm
T/S distance: 8-10”
Pressure: <0.5 mTorr
Hard Bias Deposition for Lift-off
Physical Collimation

Cr 7.5 nm / CoPt 75 nm,
Collimator aspect ratio: 2:1, Pressure 1.8 mTorr
T/S distance 6”, Coll/Sub distance 1.25”
High $B_{\text{sat}}$ Materials

Reference

Oriented Soft Pole Layers

- FeCoBC, CoZrNb, FeTaN and Ni$_{45}$Fe$_{55}$ soft magnetic materials for very low coercivity and high saturation magnetization.
- DC magnetron process yields excellent film uniformity.
- Electromagnetic orienting field provides exceptional orientation.
- Minimal interaction of cathode and orienting magnetic fields allows independent control of film uniformity and film orientation.
Coercivity Along the Easy and Hard Axis for High $B_{sat}$ Materials for Poles (1 $\mu$m)
Dispersion at 90% of Saturation ($\alpha_{90}$) and Skew Data for High $B_{sat}$ Materials for Poles (1 µm)
Saturation Magnetization for High $B_{sat}$ Materials for Poles (1 μm)
Easy Axis Coercivity and Saturation Magnetization Uniformity for Oriented CoZrNb Films
Thickness Dependence of Anisotropy Field ($H_k$) and Easy Axis Coercivity ($H_{ce}$) for DC Magnetron Sputtered Oriented CoZrNb Films
Hysteresis Loop for Oriented FeTaN (70 nm)
Magnetic Properties of FeTaN vs. Nitrogen Ratio
Film Resistivity of FeTaN vs. Nitrogen Ratio
Hysteresis Loop for Oriented 45% Ni / 55% Fe (1.4 µm)
Influence of Deposition Conditions on Ni$_{45}$Fe$_{55}$ Films
## Processes Developed for Thin-Film Heads

<table>
<thead>
<tr>
<th>Application</th>
<th>Materials/Processes</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undercoat/Overcoat/Gap</td>
<td>( \text{Al}_2\text{O}_3, \text{AlN} )</td>
<td>Pinhole-free 30 nm films</td>
</tr>
</tbody>
</table>
| Poles/ MR Shields      | \( \text{CoZrNb, Laminated FeN, FeCoBC} \) | \( H_{\text{c-e}} < 0.2 \text{ Oe} \)  
\( M_{\text{sat}} > 2 \text{ T} \) |
| MR Sensor/ SAL         | \( \text{NiFe, NiFeRh} \)  | \( H_{\text{c-e}} < 1.5 \text{ Oe} \)  
\( \alpha_{90} < 1^\circ \) |
| Hard-Biased Bilayers   | \( \text{Cr/CoPt, Cr/CoPtCr} \) | \( H_{\text{c}} > 2000 \text{ Oe}, \)  
\( M_{\text{sat}} > 4 \text{ memu/cm}^2 \) |
| Exchange-Coupled Multilayers | \( \text{Ta/NiFe/FeMn} \)  
\( \text{NiFe/NiCoO} \) | \( H_{\text{ex}} > 200 \text{ Oe} \)  
\( H_{\text{c}} < 50 \text{ Oe} @ 5 \text{ nm} \) |
| Thin Spacers           | \( \text{Ta, Ti, Al}_2\text{O}_3, \text{SiO}_2 \) | Uniformity \( < 3\% \),  
\( 3\sigma \) |
| GMR Spin Valves        | \( \text{Ta/NiFe/Co/Cu/Co/NiFe/ FeMn/Ta} \) | \( \Delta R/R > 9.4\% \)  
\( H_{\text{ex}} > 470 \text{ Oe} \) |
Conclusions

• DC Magnetron Sputtering Processes Developed in Conjunction with Advanced Cathodes and Tools for MR and GMR Heads.

• Cooler Processes, Better Uniformity and Improved Magnetic Performance Achieved for a Large Range of Materials and Applications

• Examples shown of Production Processes Developed for:
  – Spin Valves
  – Hard Bias Layers
  – Soft Poles