Deposition Technologies for >500GB/in² PMR and HAMR Write Heads
Outline

- Background
- New technologies for PMR pole deposition
- Optical films for HAMR write heads
- Summary
### Background – Technology Roadmap

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>Technologies</strong></td>
<td>PMR, DFH</td>
<td>HAMR, Shingled (SWR), DFH</td>
<td>HAMR, Shingled (SWR), 2D read-back, BPM</td>
</tr>
<tr>
<td><strong>Key Areas</strong></td>
<td>Sigma reduction, Damascene writer, Reduced HOC</td>
<td>Light delivery, Near-field transducer</td>
<td>2D signal processing, Media patterning</td>
</tr>
</tbody>
</table>

**Technologies**
- PMR
- DFH
- HAMR
- Shingled (SWR)
- Near-field transducer
- 2D read-back
- BPM

**Key Areas**
- Sigma reduction
- Damascene writer
- Reduced HOC
- Light delivery
- Near-field transducer
- 2D signal processing
- Media patterning
Damasceene Processes for Advanced PMR Poles
Motivation for Damascene Processes

- Two types of process are used for PMR poles
  - Subtractive process (etch)
  - Additive process (Damascene)

Damascene Processes are Preferred as Geometries Shrink
Requirements for Damascene Pole Processes

- Key steps in the damascene process
  - Deposition of seed layer
  - Plating of magnetic materials
  - CMP

- Seed layer requirements
  1. Conformal
  2. Conductive / Low resistivity
  3. Void free plating of magnetic materials with desired properties
  4. Deposited at TFMH compatible temperatures (<200°C)
  5. Good thickness control
  6. Adhesion

- CVD deposition of Ru meets the above requirements

**Fabrication Sequence**

1. Etch
2. CVD Ru Deposition
3. Plate + CMP
Ru CVD for Damascene Writer Pole
Enabling Features

- CVD Ru is unique in being able to combine several key features
  1. Appropriate properties as a seed layer for plating
     - Conformal
     - Conductive / Low resistivity
  2. Appropriate as a seed layer for Magnetic properties of plated layer
     - Void free plating of magnetic materials
     - High Bs plated layer
  3. Provides ability to fine tune final track-width of the PMR pole
     - Good thickness control
     - Compensate for trench etch variation

- Ru CVD also used as a plating seed for wrap around shields
  - Enables narrower track-widths by reduced cross track interference
Ru CVD Chemistry

- Precursor: RuO₄
  - ToRuS Blend from Air Liquide
    - Mixture of RuO₄ in two fluorinated solvents
    - Liquid at room temperature
    - High Vapor Pressure
  - Rapid Reaction – practical deposition rates
  - Low Temperature Process (170°C)
  - Small molecule that nucleates on all tested surfaces

- Two step reaction
  - (heated wafer)
  - A. RuO₄ → RuO₂ + O₂ (not self limiting)
  - B. RuO₂ + 2H₂ → Ru + 2H₂O

- Accomplished as cyclic CVD in 4 steps
  - Steps 1,2: Reaction A: + Inert Gas Purge
  - Steps 3,4: Reaction B: + Inert Gas Purge

Repeat to get desired thickness
System Architecture

- RuO$_4$ decomposition reaction to RuO$_2$ is catalyzed by Ru but not self limiting
- Cross flow architecture requires self limiting reactions to achieve good WiW uniformity and precursor utilization
- Showerhead architecture allows for localized flow optimization to achieve optimum WiW uniformity and precursor utilization

NEXUS Ru CVD uses a showerhead design
Deposition Conformality

- Cross-section SEM
- ~400Å CVD Ru on SiO₂
- Deposition conformality similar at process temperatures from 170-200°C
- Deposition conformality similar for features of various sizes
- Conformality of adhesion enhancing under-layers can impact stack conformality
CVD Ru: Thickness Control, Resistivity

- Growth rate is linear with number of cycles
  - Thickness can be accurately targeted
  - Initial nucleation delay <7 cycles at 200°C

- Growth rate varies with temperature

- Resistivity change slightly with temperature
  - < 20µΩ-cm at 400Å on SiO₂ at 170-210°C

Good thickness control, appropriate electrical properties for plating
Ru CVD film stress ~2600MPa
Stress can be tuned to desired value by periodic plasma annealing
Stress driven more compressive with:
- More plasma anneals
- Higher power plasma anneals
- Lower pressure plasma anneals
Marathon Test Through Ampoule Life

- Data from one 3.6L ampoules with single process recipe on Lab Tool
- 150mm wafers, 190°C deposition temp
- 632 wafers processed within tight specifications (black line shows End Of Life)
  - Mean thickness at 401.6Å with 3σ variation of 1.45%
  - Ampoule Utilization at 83Å/cc

Good WTW and WIW repeatability across ampoule life < 2% 3σ Non-Uniformity up to 650 wafers
CVD Ru: Uniformity, Repeatability (200mm)

- 12-wafer lot on Lab Tool: WIW < 3% $3\sigma$, WTW ~1% $3\sigma$
- Multiple ampoules on Lab Tool: WIW ~3% $3\sigma$, WTW ~2.5% $3\sigma$
- Data through ampoule life: WIW <6% $3\sigma$, WTW < 2% $3\sigma$

Good uniformity and repeatability through multiple ampoules
< 6% $3\sigma$ WIW, < 2% $3\sigma$ WTW through ampoule life
Summary

- NEXUS CVD Ru meets the film properties required of a conformal seed layer for damascene processing of high areal density write poles and shields
  - Conformality: >0.98
  - Deposition temperature: <200°C
  - Resistivity: <20μΩcm
  - Uniformity: <3%3σ
  - Repeatability: <2%3σ
  - High efficiency of chemical use: >80Å/ml

- The showerhead architecture is ideal for the ToRuS based CVD Ru process

- The NEXUS CVD Ru system has been proven in production
  - Demonstrated >90% uptime
  - Stable film performance over lifetime of ampoule
Deposition of Optical Materials for HAMR Write Heads
HAMR Technology

- **Overview**
  - HAMR is the leading candidate for >1TB/in² areal densities for write heads

- **Concept**
  - At high areal densities, write heads cannot produce enough field to record data in high coercivity media
  - By heating the media locally, the coercivity can be reduced and the data recorded
  - HAMR write heads incorporate a laser light and near field transducer to locally heat the media

- **Challenges**
  1. Integration of light source and delivery mechanism
  2. Thermal management
  3. **Low loss optical materials for light transmission**

*HAMR is a key technology for >1Tb/in²*
HAMR: Waveguide Materials

- Laser with optical waveguide
  - Core/Cladding for waveguides
- Requirements
  - Low and high index films
  - Low optical loss / defect free
  - Good Throughput

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index</td>
<td>High $n$: $&gt;2$ (Ta$_2$O$_5$) (core)</td>
</tr>
<tr>
<td></td>
<td>Low $n$: $&lt;2$ (Al$_2$O$_3$) (cladding)</td>
</tr>
<tr>
<td>$k$</td>
<td>0 (below ellipsometer limit)</td>
</tr>
<tr>
<td>Optical Loss</td>
<td>$&lt;10$ dB/cm (cladding)</td>
</tr>
<tr>
<td></td>
<td>$&lt;5$ dB/cm (core)</td>
</tr>
<tr>
<td>Rate</td>
<td>100-500 Å/min (core)</td>
</tr>
<tr>
<td></td>
<td>500-1500 Å/min (cladding)</td>
</tr>
<tr>
<td>Uniformity</td>
<td>$&lt;3%$ R/M (200mm)</td>
</tr>
</tbody>
</table>
### PVD Deposition Technologies for Waveguide Films

<table>
<thead>
<tr>
<th>Technology</th>
<th>Property</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Loss</td>
<td>Uniformity (R/M 200mm)</td>
</tr>
<tr>
<td>IBD</td>
<td>&lt;0.5 dB/cm</td>
<td>&lt;3%</td>
</tr>
<tr>
<td>PVD1 Dielectric Mode</td>
<td>&lt;5 dB/cm</td>
<td>&lt;3% Ta₂O₅</td>
</tr>
<tr>
<td>PVD1 Metal Mode</td>
<td>&lt;10 dB/cm</td>
<td>&lt;3.5% Al₂O₃</td>
</tr>
</tbody>
</table>

- PVD processing has flexibility of hardware and deposition modes
  - Hot chuck capability (up to 400°C)
  - Dielectric and metal modes of deposition
  - RF diode / DC magnetron
**Ta$_2$O$_5$ Dielectric/Poisoned Mode Films**

- No measurable change in optical properties (ellipsometry) operating at different O$_2$ flows in poison mode
- Processes show acceptable loss properties

<table>
<thead>
<tr>
<th>Process</th>
<th>O$_2$ flow (sccm)</th>
<th>Power (W)</th>
<th>Deposition Rate (A/min)</th>
<th>U% 1σ% 200 mm</th>
<th>Index</th>
<th>Index U% 1σ%</th>
<th>Loss Results Db/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process A</td>
<td>Flow 1</td>
<td>3000</td>
<td>350</td>
<td>0.5</td>
<td>2.12</td>
<td>0.1</td>
<td>1.51</td>
</tr>
<tr>
<td>Process B</td>
<td>Flow 2</td>
<td>1250</td>
<td>145</td>
<td>0.5</td>
<td>2.12</td>
<td>0.07</td>
<td>1.54</td>
</tr>
<tr>
<td>Process C</td>
<td>Flow 3</td>
<td>1250</td>
<td>155</td>
<td>1.0</td>
<td>2.13</td>
<td>0.07</td>
<td>1.66</td>
</tr>
</tbody>
</table>
Closed-loop control with High Speed MFC partial pressure controller

- Target voltage continuously monitored
- High speed piezo MFC: oxygen flow adjusted to maintain target voltage
- Can now operate in “forbidden” range of voltages
- Rate ~ 50% of Al deposition rate achievable
Al₂O₃: Optical Loss

- Strong dependence of optical loss on wafer deposition temperature
- No significant changes observed using ellipsometry measurement
  - Measure extinction coefficient zero for all above films.
  - Loss not correlated to measured refractive index
    - Within 1.63-1.66 range
### Al₂O₃ Post Deposition Annealing

**Optical Loss vs. Annealing Time and Temperature**

<table>
<thead>
<tr>
<th>Annealing Time</th>
<th>Reference: 3.3 dB/cm (7 cm light streak)</th>
<th>Reference: 8.0 dB/cm (4-5 cm light streak)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 dB</td>
<td>Optimized Annealing Process</td>
<td></td>
</tr>
<tr>
<td>5 dB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 dB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 dB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 dB</td>
<td>Reference data (no anneal)</td>
<td></td>
</tr>
</tbody>
</table>

- **Appropriate post-deposition annealing (<2hrs)** results in low loss Al₂O₃

**Veeco has developed optimized annealing conditions that enable low temperature deposition of alumina with low-loss optical properties**
## Ta₂O₅ Thickness and Index Repeatability

### Ta₂O₅ – 2000 Å

<table>
<thead>
<tr>
<th>Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>WTW Thickness (1σ)</td>
<td>0.75% (300 A/min)</td>
</tr>
<tr>
<td>WIW Thickness (1σ)</td>
<td>0.75%</td>
</tr>
<tr>
<td>WTW Index (1σ)</td>
<td>0.08%</td>
</tr>
<tr>
<td>WIW Index (1σ)</td>
<td>0.24%</td>
</tr>
<tr>
<td>Index</td>
<td>2.13</td>
</tr>
<tr>
<td>Optical Loss</td>
<td>&lt;2dB/cm</td>
</tr>
<tr>
<td>Stress [MPa]</td>
<td>-147</td>
</tr>
</tbody>
</table>
### Al₂O₂ Thickness and Index Repeatability

#### Al₂O₃ Thickness Repeatability

![Graph showing Al₂O₃ Thickness Repeatability](image)

#### Ta₂O₅ Index Repeatability

![Graph showing Ta₂O₅ Index Repeatability](image)

#### Alumina – 1μm

<table>
<thead>
<tr>
<th>Data</th>
<th>Thickness [Å]</th>
</tr>
</thead>
<tbody>
<tr>
<td>WTW Thickness (1σ)</td>
<td>0.3% (1300 A/min)</td>
</tr>
<tr>
<td>WIW Thickness (1σ)</td>
<td>0.4%</td>
</tr>
<tr>
<td>WTW Index (1σ)</td>
<td>0.03%</td>
</tr>
<tr>
<td>WIW Index (1σ)</td>
<td>0.1%</td>
</tr>
<tr>
<td>Index</td>
<td>1.67</td>
</tr>
<tr>
<td>Optical Loss</td>
<td>&lt;5dB/cm</td>
</tr>
<tr>
<td>Stress [MPa]</td>
<td>-126</td>
</tr>
</tbody>
</table>
- Repeatable optical loss <5dB/cm obtained with $\text{Al}_2\text{O}_3$ 1$\mu$m / $\text{Ta}_2\text{O}_5$ 2000Å
  - 12 wafers measured (total of 48 wafers run)
- Four cassettes run over two days
HAMR Data Summary

- Ta$_2$O$_5$ process developed for low loss core layers
  - Loss: <2 dB/cm
  - Rate: 334 Å/min
  - U%: 0.7% 1σ
  - WTW% 0.7% 1σ

- Al$_2$O$_3$ for cladding layers
  - Loss: <2dB/cm (with post deposition annealing – max temp 200°C)
  - Rate: >1000 Å/min
  - U%: 0.4% 1σ
  - WTW%: 0.3% 1σ

- Bi-layer Al$_2$O$_3$/Ta$_2$O$_5$ films show <5dB/cm loss

- SiO$_2$ films in development