Thin Film Head Fabrication in the PMR Era

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Veeco Data Storage Technology

IDEMA PMR Symposium
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Outline

- Thin Film Head Technology Drivers
  - Areal density growth & slider form factor
  - PMR roadmap & architectural trends
- Wafer Processing for PMR
  - Perpendicular write-pole deposition
  - Perpendicular write-pole definition
- Slider Processing for PMR
  - Shape, stripe height & throat height control
  - Fly-height & head media spacing reduction
- Summary of Process Solutions
Thin Film Head Technology Drivers
CE and SFF HDD growth is driving areal density growth

Rapid adoption of PMR for high capacity SFF Drives
Areal Density Growth

Growth of Areal Densities for Conventional Recording

- **Thermal Stability Limited Region**
- **“Superparamagnetic” effect**
- **Source: HGST, Diskcon 2006**
- Simple scaling allowed for increasing areal density for many years at 30% CGR
- “Superparamagnetic” effect now posing a significant challenge
- Perpendicular + other new technologies introduced
- Acceleration to 60-100% CGR thin-film head, media, channels

PMR technology now mainstream to maintain 40% CAGR

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**Multiple Technology Transitions**

**Concurrent Adoption**

*PMR, TMR & Femto Sliders*

**Areal Density Growth**

125 → 500 Gb/in²

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*Femto, PMR and TMR place new demands on process equipment*

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# PMR Roadmap

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Areal Density (Gb/in²)</td>
<td>125</td>
<td>175</td>
<td>245</td>
<td>350</td>
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<tr>
<td>Track Width (nm)</td>
<td>115</td>
<td>100</td>
<td>80</td>
<td>65</td>
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<tr>
<td>High Bₚ Pole</td>
<td>Plating / Laminated</td>
<td>Damascene / Laminated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Throat Height (nm)</td>
<td>100</td>
<td>90</td>
<td>75</td>
<td>60</td>
</tr>
<tr>
<td>Stripe Height (nm)</td>
<td>120</td>
<td>100</td>
<td>90</td>
<td>70</td>
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<tr>
<td>Magnetic Spacing (nm)</td>
<td>20</td>
<td>18</td>
<td>15</td>
<td>12</td>
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<tr>
<td>DLC Thickness (nm)</td>
<td>2.4</td>
<td>2.0</td>
<td>1.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Height Control σ (nm)</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>PTR / PTP σ (nm)</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>

*Shrinking geometries & tightening control requirements*
Perpendicular Writer Options

Cusp

Trail

Spartan

Floating Front Shield

Front Shielded

Wrapped

Field & field gradient tradeoffs
guide selection

Source: Mao & Murdock, Seagate

Increasing process complexity

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Perpendicular Write-Pole Formation
Write-Pole Requirements

PMR Write-Pole

- Decreased track-width → Narrower pole width
- High coercivity media → High $B_s (> 2.4T)$ materials
- Reduced remnant erasure → Laminated stack

- Side track erasure → Tapered pole shape
Evolution of Write-Pole Formation

**Method I**
- PR
- Al2O3 or DLC Hard Mask
- Laminated PVD Pole

**Method II**
- PR
- RIBE Hard Mask Etch
- IBE Pole Etch

**Method III**
- PR
- RIBE Hard Mask Etch
- RIBE Trapezoidal Trench Etch
- IBE Trapezoidal Pole Slimming
- CMP Stop Layer
- Al2O3
- Deposit Pole
- CMP
High Moment Stack for Write-Pole

- Multi-target planetary PVD tool for laminates
  - Velocity profiling ➔ uniformity < 1% (3σ) & ~0.02 nm control
  - Upto 13 sputtering targets & ion beam assist
  - High throughput, low CoO architecture
Bilayer & Multi-layer Write Pole Stacks

CoFe$_{70}$250Å/Ru (Cr)/CoFe$_{70}$250Å

CoFe/Ru/CoFe

CoFe/Cr/CoFe

NiFe$_{25}$Å/[CoFe$_{50}$350Å]$_m$/Ru8.5Å$_{n-1}$/ [CoFe$_{50}$350Å]$_m$/NiFe$_{25}$Å/Ru20Å

m=4
n=2
m=2
n=4
m=1
n=8

H$_{ce}$ = 8.3 Oe
B$_{re}$/B$_{se}$ = 0
H$_k$ = 30 Oe
H$_{ch}$ = 1.8 Oe
B$_{rh}$/B$_{sh}$ = 0.06
H$_{ex}$ = 10.8 Oe
IBE for trapezoidal slimming
- Controllable side-wall angle $\sim 8 - 10^\circ$ from normal
  - Multi-angle etch process
  - Static and sweep etch
- CD uniformity
  - Low beam divergence and steering angle

RIBE process for hard mask etch
- Selectivity of Alumina : pole material
- Vertical sidewalls

RIBE process for trench formation
- Selectivity of Alumina : mask material & Alumina : stop material
Sidewall Symmetry & CD Control
Beam Collimation – Divergence & Steering

Beam Steering impacts glancing angle

Static Etch & CD Etch Uniformity

Uniformity of Beam Divergence impacts CD Etch Profile

Beam Divergence impacts CD Etch Profile

High etch rate
Low etch rate
Nexus 420 for Pole Etch

- Collimated ion source
  - Low divergence & steering angles
- Improved etch uniformity & CD control (< 2.5 % ΔCD)

![Graph showing divergence and steering angles]

Divergence angle of 2.4 +/- 0.3 degrees across 6” diameter

Beam steering < 0.5°
Intermediate Energy Pole Process

- Pole process at 600 to 800 V regime developed
  - Similar uniformity and divergence
  - Etch rate 80 - 90% of high rate process
RIBE for Trench or Hard Mask Etch

- Developed CHF$_3$ based RIBE process
  - ER of Al$_2$O$_3$ : NiFe > 7:1
  - ER of Al$_2$O$_3$ : NiCr > 10:1
  - Selectivity over full angle range

![Graphs showing ER and selectivity over CHF$_3$ percentage]
PMR Pole Monitoring

FIB-SEM cross-section

Advanced writer structure

Veeco x3D AFM
PMR Pole Production Monitoring

Plan view

ABS plane

Pinching

Line Width Variability

20

25

30

35

40

45

50

0 200 400 600 800 1000

Position Along Line (nm)

Line Width (nm)

Scan1

Scan2

Nominal 28 nm

Nominal 43 nm

500 nm range

High Resolution (10 nm spacing)

x3D Imaging Technology

- High Lateral Resolution
- 3D Monitoring
  - Line Edge Roughness
  - Pole Pinching & Narrowing
  - Photoresist Profile
- High Throughput
- Non Destructive
Slider Processes for PMR
Slider Process Challenges for PMR

Head Media Spacing
- PTR
- Crown & camber

Head Performance
- Stripe height
- Throat height
- PTR
- Sensor smearing

Performance Metrics
- Fly height, stiction

Shape Control
- Straightness
- Perpendicularity
- Rowbar bow
- Pullouts

Yield Metrics
- Throat & stripe height, PTR, debris

- ~ 40% total

Flyheight Control
- Triple cavity etch
- Cavity shape
- CD & depth

Defects
- Pressure ridges
- Debris
- Pullouts

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Slicing, Lapping & Dicing for PMR

- μ-radian Angle Adjustment Control Technology provides Reader/Writer Offset
- Sensor Height Control Technology provides Stripe Height Control
- Low lapping pressure improves Flatness, Surface Finish and PTR
- Dual-pass dice manages dice edge stress & Particles
- Sensor Height Control Technology provides Stripe Height Control
- Wedge angle control provides Parallelism
- Backside grind sets Perpendicularity between the ABS & overcoat
- Double Sided Machining Process to reduce row bar stress
Grind & Slice for Shape Control

- Thin blade deflects during slicing
- Solution:
  - Edge grind backside of rowbar for perpendicularity
  - Establishes reference for subsequent processing
Stripe & Throat Height Control for PMR

- Reader & writer ELG feedback for height control
- Wedge angle control for parallelism

<table>
<thead>
<tr>
<th>Gb/in²</th>
<th>Stripe Height (nm)</th>
<th>Stripe Height 1σ (nm)</th>
<th>Throat Height 1σ (nm)</th>
<th>Perpendicularity</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>150</td>
<td>7.5</td>
<td>20</td>
<td>±0.375°</td>
</tr>
<tr>
<td>240</td>
<td>70</td>
<td>3.5</td>
<td>10</td>
<td>±0.15°</td>
</tr>
</tbody>
</table>
Overcoat Thickness Reduction

- **Reduce Variability**
  - Carbon and Si
    - WIW 2-3 $\Rightarrow$ 1.5 Å
    - RTR 4-5 $\Rightarrow$ 2.5 Å
  - Pre-clean
    - Uniform etching

- **Improve pre-clean process**
  - Reduce sensor recession
    - 1.5 nm $\Rightarrow$ < 1 nm

- **Reduce Si/Carbon Thickness**
  - 10 Å Si/10 Å C $\Rightarrow$ 13 Å total

- $\Delta = -4$ Å
  - Improved in-situ thickness monitoring
  - Pulsed FCA source
  - Long-throw PVD Silicon

- $\Delta = -5$ to 10 Å
  - Tunable Low Energy ion source
  - Interface Control Module

- $\Delta = -5$ to 8 Å
  - Dual Source FCA

- $\Delta$ in HMS $\Rightarrow$ -15 Å
Low Energy Ion Beam Etching

Etch Profile for Different Tilt Angles
Ub=100V, Ib=150mA, Us=700V

-0 deg (1.9%)
-35 deg (2.1%)
-55 deg (1.5%)
-75 deg (1.8%)

CPP sensor smear removal & ABS smoothening with controlled PTR & uniformity

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Pulsed FCA ta-C Film Properties

- Precise control of film thickness
  - Linearly dependent on number of pulses
- Film density \( \sim 2.95 - 3.03 \text{ g/cm}^3 \)
  - Higher than DC FCA \( \sim 2.8 \text{ g/cm}^3 \)
- Optical properties (n, k) are similar to DC FCA
  - Films have the same microstructure
- Film stress -4 to -6 GPa (\( \sim 25 \text{ nm DLC} \))
  - Similar to DC FCA
- Particulate levels are similar to DC FCA
- Uniformity < 5% 3\( \sigma \)
  - Shape the plume with focusing / deflection coils
ta-C Uniformity Tuning
Plasma Beam Shaping/Deflection

Deposition Profile Optimization By Beam Shaping

**Convex**

**Concave**

- Source conditions: 1000 pulses, focusing coils -2.5A.
- 20% loss in dep. rate when tuning uniformity due to offsetting the plume

<table>
<thead>
<tr>
<th>Deflection Current [A]</th>
<th>Uniformity +/- %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>13.8 %</td>
</tr>
<tr>
<td>2</td>
<td>6.6 %</td>
</tr>
<tr>
<td>3</td>
<td>13.3 %</td>
</tr>
</tbody>
</table>
PFCA Uniformity: ~2A Range

WIW Uniformity
Range: ~2A

RTR Uniformity
Range: ~0.5A
Next Generation Overcoat Tool
Overall System Configuration

- Separate modules for pre-clean and deposition processes
AFM PTR Monitoring

• Proven Automated PTR Measurements
  • Automated Tip Exchange*
• Flat XY Scanner
  • < 2 nm Leveling Error over 100 μm
  • Improved GR&R to < 0.15 nm 1σ
  • Throughput improvement > 30%
• Optimized Data Storage Performance
  • Magnetic Force Microscopy
  * Patented

Leveling Error < 2 nm

Veeco Vx200-PTR

AFM PTR MFM Image
Optical PTR Monitoring

- High Speed PTR @ < 6 Sec/Site
- Improved Accuracy Through Compensation
  - > 20% Yield Enhancement
- Optical Solution for AFM Monitoring

• Less Scrap
• Tighter Control
• Higher Yields

AFM to Optical Correlation

Uncompensated

Compensated

2.28% Protrusion

0.66% Protrusion
Air Bearing Etch: Background

- Advanced ABS must provide:
  - Small and stable spacing between slider and disk
  - High air-bearing stiffness
  - Low sensitivity of spacing on disk velocity and skew angle
  - Low sensitivity of flying behavior (attitude)
  - Negative pressure pocket
  - Tri-pad designs
  - Multiple etch depths
    - Cavity > 1 - 2 μm
    - Shallow ~ 1 - 200 nm
    - Super Shallow ~ 20 nm
  - Stringent uniformity, shape, depth & CD control requirements

* Source: Hitachi GST * Source: UCSD-CMRR
NEXUS® Slider IBE Systems Overview
Application Configurable Product Line

- **NEXUS® 420Si**
  - Application: Shallow & Super Shallow Step
  - Improved Etch Depth Control

- **NEXUS® 350Si**
  - Application: Cavity and Shallow
  - Process Matching with RF-350S
  - Field Upgradeable to 420Si

- **NEXUS® 350SE**
  - Application: Deep Cavity and Cavity
  - Low COO, High Throughput, Small Footprint
  - TEC fixture
  - RIE Replacement Tool
NEXUS 420Si Process Performance
Typical Etch Profiles

- Increased Device Yield Through Improved Etch Depth Control
  - Rotated WIW Etch Uniformity < 2.0%, 3σ
  - RTR Uniformity: < 2.0%, 3σ
  - Wide process window
ABS Metrology

- Critical to Fly-Height Control
  - Slider Flatness
  - Local Flatness Deviations
  - Slider Waviness
  - Etch Step Sizes
  - Trailing Edge Roll-off

Source: HitachiGST Web Site.

Veeco HD8100
2X Dicing for PMR

1X DICE
Hard blade
3 - 4 nm \( R_a \)
5 \( \mu \)m chipping

- Pressure ridges created as face of harder blade enters ABS side of slider

2X DICE
Soft blade
1 - 2 nm \( R_a \)
1 \( \mu \)m chipping

- Soft cutting action of polish blade removes chips and pits along outer slider walls and 99% of pressure ridges

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<table>
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<tr>
<th>Manufacturing Step</th>
<th>Process</th>
<th>System</th>
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</thead>
<tbody>
<tr>
<td>Sensor Deposition</td>
<td>High ratio TMR</td>
<td>Nexus-MT</td>
</tr>
<tr>
<td>Sensor Etch</td>
<td>Highly Uniform Collimated Etching</td>
<td>Nexus 420</td>
</tr>
<tr>
<td>Isolation Layer Deposition</td>
<td>High quality alumina films</td>
<td>Nexus IBD-DS / Nexus ALD</td>
</tr>
<tr>
<td>Hard Bias Deposition</td>
<td>Collimated Deposition for lift-off</td>
<td>Nexus IBD-DS</td>
</tr>
<tr>
<td><strong>Write Pole Deposition</strong></td>
<td>High Moment Laminated Poles</td>
<td><strong>Nexus-MT</strong></td>
</tr>
<tr>
<td><strong>Write Pole Shape</strong></td>
<td>High Collimation Etching with good CD control</td>
<td><strong>Nexus 420</strong></td>
</tr>
<tr>
<td>Rowbar Formation</td>
<td>Grinding the backside of the row for perpendicularity</td>
<td>ADS160gs</td>
</tr>
<tr>
<td>Lapping</td>
<td>Wedge angle control, (\mu)-radian angle adjustment control for parallelism</td>
<td>ASL200</td>
</tr>
<tr>
<td>Overcoat Deposition</td>
<td>Pulsed FCA with Interface Control for thin overcoats</td>
<td>Nexus DLC-X</td>
</tr>
<tr>
<td>ABS Etch</td>
<td>Shallow/Cavity/Deep Cavity for low fly heights</td>
<td>Nexus 350Se/420Si</td>
</tr>
<tr>
<td>Slider Formation</td>
<td>2X Dicing Process for reduced particulates</td>
<td>ADS160gs</td>
</tr>
</tbody>
</table>
Veeco Process Solutions For PMR

- CD control for PMR and Sensor Etch
- Asymmetry control for narrow TW
- Isolation, and seed for TMR & PMR
- Alumina and metal layers
- Sub 20 Å overcoat for low HMS
- Sub 100nm shallow step for low HMS

- PVD-MT
- IBD-DS
- IBE
- IBE Si
- IBE Se
- ALD
- PVD-1
- CWH
- Nexus
- Slider
- ADS160
- ASL200
- Optium

Slice, grind & dice
Rough, fine & kiss lap

- Shallow & deep cavity etch
- TMR/CPP & HMM
- Wafer
### Metrology Solutions for the PMR Age

Veeco Provides Metrology Solutions for each process step …..

<table>
<thead>
<tr>
<th>Manufacturing Step</th>
<th>Metrology</th>
<th>System</th>
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<tbody>
<tr>
<td>Write Pole Shape</td>
<td>Pole Critical Dimensions</td>
<td>X3D</td>
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<tr>
<td>Wafer test</td>
<td>Read pole magneto-resistance</td>
<td>QSW3000</td>
</tr>
<tr>
<td>Rowbar lapping</td>
<td>PTR control / monitor</td>
<td>HD8100 Vx200 PTR</td>
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<tr>
<td>DLC deposition</td>
<td>PTR control / monitor</td>
<td>HD8100 Vx200 PTR</td>
</tr>
<tr>
<td>ABS Etch</td>
<td>Etch depth Rowbar shape</td>
<td>HD8100</td>
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<tr>
<td>Slider Formation</td>
<td>Slider shape</td>
<td>HD8100</td>
</tr>
<tr>
<td>HSA</td>
<td>Suspension shape</td>
<td>SAT probe HD8100</td>
</tr>
</tbody>
</table>

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Veeco Metrology Solutions for PMR

Veeco’s Unique Position…

Optical Industrial
- HD Optical Profiler
- SAT Probe
- Dektak
- RTI
- QSW

NanoBio Research AFM
- Dimension 3100 / 5000

Auto AFM
- Vx200-PTR
- x3D Pole Monitor

Nanotech

Microtech

Lateral Dimension

1,000,000nm

100,000nm

10,000nm

1,000nm

100nm

10nm

1nm

0.1nm

Silicon Atom
0.2nm dia

PMR Width CD

Pole Tip Recession (PTR)

80nm

2 nm

Nanotech

METROLOGY APPLICATIONS

Suspension Shape

ABS Surface Shape, Cavity

10 mm

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*Thanks for your attention!*