DTM and BPM Pattering Considerations Using S-FIL: Double Side Imprinting and Imprint Mask Replication Processes through Pattern Transfer

September 18, 2008
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Outline

- Imprint patterning considerations for manufacturing
- Template fabrication: the master template
- Template replication: the working template
- Imprint patterning
  - S-FIL and Drop-on-Demand imprinting
  - Double side patterning
  - Material usage
- Pattern transfer
HDD Patterned Media Fabrication

- Current disk fabrication has roughly six process steps assuming sputter as one step.
  - Sputter may be as many as twelve steps

- Pattern media will require at least 6 new steps.
  - Assuming descum and pattern transfer etch as one step

- These new steps will require new process know how, including inspection and metrology techniques not currently used in media fabrication.

- New infrastructure and tools are required
  - Infrastructure
    - Master templates and template replication
    - Imprint and etch processes
  - Tools
    - Planarization processes
    - New inspection and metrology tools
HDD Patterned Media Process Flow

1. Wash  
2. Sputter  
3. CoC  
4. Lube  
5. Burnish  
6. Fly test

Conventional Media

- Wash
- Planarize
- Adhesion promoter

Patterned Media

- Imprint
- Pattern transfer
- Descum/ion mill

Debug Inspection & Metrology (Sampling)

Mask Supplier

Template Replication

Master Template Fabrication
Step and Flash® Imprint Lithography

Imprint fluid, Drop-On-Demand™

Thin template is bowed so initial contact in the center of the disk

Capillary forces pull template into conformal contact with the disk

Expose with UV light to cure the imprint resist

Separate template from disk

Etch
Template Mastering with Rotary E-beam

- Fabrication of Master Templates for Patterned Media requires high resolution patterning over large areas
  - Sub-20 nm resolution
  - Very low pattern distortion
- Patterns are concentric lines, arcs, and dot arrays

Rotational speed: ~ 100 to 3000 rpm
Direction: CW or CCW
Linear translation in one radial direction

ZEP520A resist patterning
25 nm holes, 50 nm pitch = 250 Gb/in2
Conventional Cr Approach: Pitch Feasibility

- 64 nm Pitch
- 56 nm Pitch
- 48 nm Pitch
- 40 nm Pitch

Magnification: 150k

DNP

Resist
Chrome
Quartz
Full Surface Disk: S-FIL Template

- E-beam exposure by Elionix
- 150 mm Template fabrication by Hoya
- ID = 15 mm, OD = 31 mm
DTM imprints: Servo & Data Patterns (120 nm track pitch)

- E-beam exposure by Elionix
- 150 mm diameter template fabrication by Hoya
- Imprints of template by Molecular Imprints
DTM Imprints: Data tracks at 100 nm pitch

SEM images from IMPRINTS

Track pitch is 100nm 250 KTPI

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Std deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line Width, nm</td>
<td>50.01</td>
<td>2.50</td>
</tr>
<tr>
<td>LWR &lt;3σ&gt;, nm</td>
<td>3.90</td>
<td>0.70</td>
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<tr>
<td>Pitch Left, nm</td>
<td>101.22</td>
<td>3.73</td>
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<tr>
<td>Pitch Right, nm</td>
<td>101.32</td>
<td>3.17</td>
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</table>
High Resolution BPM Templates

SEM images from TEMPLATE

24 nm pitch dots
~1.1 Terabits per square inch
**Template Replication Process Flow**

- **Process flow / Lithography**
  - E-beam written master – 2 possible tones:
    - Feature proud: liftoff
    - Field proud: direct etch
  - Nanoimprint / RIE pattern transfer to create:
    - Template replicated from master template (Either tone: S-FIL/S-FIL/R)

<table>
<thead>
<tr>
<th>“Master” Template</th>
<th>“Working” Template</th>
<th>Imprinted Disks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mask maker generates one master by rotary-stage e-beam</td>
<td>Replicate master to “working template”</td>
<td>Fabricate imprinted disks from working templates</td>
</tr>
</tbody>
</table>

*Made by imprint*
**Template Replication Steps**

1. **Pattern Media area**
   - Disk alignment
   - Master or Submaster template (not to scale)

2. **Mesa*: Imprint area**
   - Tool Alignment
   - Pre-mesa, pre-patterned Working template substrate (not to scale)

3. **Mesa Area***
   - Disks & Tool Alignment
   - Final working template (not to scale)

*Template mesa is required for fluid control at the disk edge*
100 nm pitch DTM Template Replication Results

SEM images of imprints

Template Master  Submaster   Working Template
**Random Site Analysis: Master vs. Working Template Imprints**

### 100nm pitch Master Template

<table>
<thead>
<tr>
<th>parameter</th>
<th>mean</th>
<th>standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line Width, nm</td>
<td>57.95</td>
<td>0.72</td>
</tr>
<tr>
<td>LWR, nm</td>
<td>4.00, 3σ</td>
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</tr>
<tr>
<td>Line Space, nm</td>
<td>44.52</td>
<td>1.73</td>
</tr>
<tr>
<td>Pitch, nm</td>
<td>102.50</td>
<td>1.74</td>
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<tr>
<td>Slope Angle Left, degree</td>
<td>93.17</td>
<td>0.42</td>
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<tr>
<td>Slope Angle Right, degree</td>
<td>94.47</td>
<td>0.80</td>
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<tr>
<td>LER Left, nm</td>
<td>3.06, 3σ</td>
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</tr>
<tr>
<td>LER Right, nm</td>
<td>3.82, 3σ</td>
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</table>

### 100nm pitch Working Template

<table>
<thead>
<tr>
<th>parameter</th>
<th>mean</th>
<th>standard deviation</th>
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<tbody>
<tr>
<td>Line Width, nm</td>
<td>57.08</td>
<td>0.64</td>
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<tr>
<td>LWR, nm</td>
<td>4.27, 3σ</td>
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</tr>
<tr>
<td>Line Space, nm</td>
<td>44.24</td>
<td>1.54</td>
</tr>
<tr>
<td>Pitch, nm</td>
<td>101.43</td>
<td>1.53</td>
</tr>
<tr>
<td>Slope Angle Left, degree</td>
<td>93.86</td>
<td>0.59</td>
</tr>
<tr>
<td>Slope Angle Right, degree</td>
<td>94.90</td>
<td>0.86</td>
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<tr>
<td>LER Left, nm</td>
<td>3.29, 3σ</td>
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</tr>
<tr>
<td>LER Right, nm</td>
<td>3.89, 3σ</td>
<td></td>
</tr>
</tbody>
</table>

- CD analysis shows good agreement between master and working replicate
Bit Patterned Media template status: hole template to imprint pillars
Double Side Disk Imprint Tool: Imprio 2200

Imprint Process Features

- Throughput: 180 disks/hr
- Resolution: Defined by Template
- Resist usage: ~100 nl/disk
- Double side imprinting
- Cleanliness: ISO Class 2
- Full automated
I220 Tool Performance

Throughput

Concentricity Error

Throughput Alignment

2.5
3
3.5

Concentricity Error

0.5
1
1.5
2
2.5
3
3.5

Alignment

Takt Time Versus Tool Generation

• Alignment system alignment capability already below 5 microns
• Takt time is at 20 seconds per imprint for Imprio 2200
Double Sided Imprints in Full Patterned Disk Test Pattern
Pattern Variability Managed by Drop-on-Demand

Drop-on-demand dispense accommodates disk feature density variations (servo patterns, discrete tracks & bit patterns)

More drops for denser patterns on disk

Thin, uniform RLT by drop on demand

90 nm Holes in oxide

84 nm pitch lines in oxide

Microscopic view of the servo pattern on the master disk surface
Drop-on-Demand Enables Uniform Residual Layers

Simultaneously Imprinting Large & Small Features (Example: 15 nm residual layer, independent of pattern density)

Template Volume Map MII Drop Generation

More drops in dense patterns on disk
Fewer drops in less dense patterns on disk
Drop on Demand Enables Thin Residual Layers

- Thin residual layers are template tone and feature density independent with drop on demand
  - Bright field templates
  - Dark field templates
- Local volume control of the imprint resist relative to the template volume is the key factor
- Imprint residual layers can be < 5 nm
- Images were taken after HF etch back of oxide to show layers
The materials are a key enabler of high throughput, imprint longevity, resolution and etch selectivity
Low cost from drop on demand
- ~100 nano liters per imprint (Pattern dependant)
- Zero waste
Imprint Longevity: >3000 Imprints Demonstrated on Step and Repeat Tool

- Nanoscale performance achieved by materials and tool
  - Demonstrated no degradation of 40 nm imprinted features after >3000 imprints
  - No template treatment between imprints
- No gross damage
  - No template breakage due to low imprint forces and liquid contact
- Imprint longevity enabled by materials and tools
  - Good adhesion of the imprint material to the substrate is required for 1000’s of imprints
  - Low imprint forces at room temperature
  - Well controlled template separation
Adhesion Layer by Vapor Priming

- ValMat© is used to provide high adhesion of the imprint material to most HDD substrates
- ValMat© film thickness is ~1 nm
- ValMat© adhesion is > 30lbft thus enhancing imprint longevity
- Batch vapor priming processing allows:
  - High throughput
  - Low material usage
  - Uniform coverage
  - Minimal substrate handling
  - Low cost
ValMat Provides Good Adhesion to Many Substrates

Uniformity $< 1 \text{ nm } 3\sigma$ as measured on Candela

ValMat provides good adhesion to Si, SiNx, SiO$_2$, Ta and other metal films
Pattern Transfer into Hard Mask Materials for DTM and BPM

Discrete Track Structures

- **CD**: Imprint
  - LWR (3σ): 36.2 ± 1.1 nm
  - 2.9 nm

- **Descum**: 34.6 ± 1.4 nm
  - 2.5 nm

- **Oxide Etch**: 34.7 ± 1.0 nm
  - 2.8 nm

- **Clean**: 36.7 ± 1.4 nm
  - 2.9 nm

Bit Patterned Structures

- **50 nm pitch Imprinted Pillars**

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IDEMA®
Conclusions

• Full disk surface master templates have been demonstrated by commercial companies
• Full disk surface template replication processes have been demonstrated.
• Full surface double sided imprint patterning of disks has been demonstrated at pilot scale throughputs.
• Imprint patterns at 50 nm pitch (BPM) and 64 nm pitch (DTM) have been demonstrated with good feature fidelity.
• Low material usage processes and equipment for patterning full surface disks by S-FIL are available.