TeraStor’s Near-Field Recording

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TeraStor Profile

- 140 employees, 100,000 sq. ft. facility in San Jose

Key Executives:
- Jim McCoy* CEO (founder of Maxtor, co-founder of Quantum)
- Gordon Knight* CTO (founder of Maxoptix & Optimem)
- Bill Dobbin* VP (founding CFO of Maxtor)
- Amyl Ahola Pres, COO (past CEO LMSI, WangDAT, VP Seagate)
- Hossein Mogadam Sr. VP Eng (former CTO of Seagate)
- Rick Wilmer VP Ops. (former VP of operations, Seagate)
- Richard Walker VP Mktg (former worldwide marketing manager, HP)
- Louis Llamas VP Sales (former VP Western Digital, Seagate)
- Skip Kilsdonk VP (former VP Maxtor)

* founder
Near Field Recording - Technology Evolution

- Optical flying head/First surface recording
  - Basic technology developed by Digital.
    - Extensive patent portfolio (26 patents)
  - Patents acquired by Quantum as part of their acquisition of the Digital storage business
  - Co-exclusive patent rights granted to TeraStor by Quantum

- Solid Immersion Lens (SIL) technology
  - Basic technology developed and patented at Stanford University
  - Exclusive patent rights granted to TeraStor by Stanford
Near-field Optics

- Spot Diameter without SIL $\approx 0.5\frac{\lambda}{NA}$
- Light entering SIL is not bent but is slowed by a factor of $n$ compared to air
- Wavelength of light in SIL $= \frac{\lambda}{n}$
- Spot diameter in SIL $\approx 0.5\frac{\lambda}{(NA \cdot n)}$
  » Diameter reduced by factor of $n$
Evanescent Coupling

- Provides energy transfer from the SIL to the surface of the media
  » Unlike conventional magneto-optical products, the laser is not focused on the surface of the media, instead it is focused at the bottom of the SIL

- Well understood from Near-field Scanning Optical Microscopy

- Allows image of small spot inside SIL to be pulled to the surface of the media.
NFR Components

- **Solid Immersion Lens**
  - Based on liquid immersion microscopy
  - Allows Numerical Aperture of much greater than 1 by using high index of refraction material
  - Shape of the SIL allow for tighter focus of light spot

- **First Surface Recording**
  - Places recording films in near-field proximity to the head

- **Flying Optical Head**
  - Provides tight focus tolerances within the near-field and eliminates focus servo found in conventional magneto-optical products

- **Crescent Recording**
  - Allows for bit densities of > 200,000 bits per inch with SIL
Architecture of TeraStor’s Near-Field Recording Technology

- Plastic Substrate Media
- Slider
- SIL Lens
- Objective Lens
- Air gap (fly ht.) <6µ” avg
- Fixed Optics Module
- Laser Beam
- Folding Mirror
- Stand Off
- Magnetic Coils
- Evanescent Coupling

Laser Beam

Plastic Substrate Media
Recording Area Compared

Magnetic    Optical    NFR

Track center

2.5 micron

0.6 micron

0.3 micron
NFR Media

- Uses conventional MO recording films
- Stamped plastic substrate and first surface recording allows media costs to be competitive with tape
- Vertical magnetic domains allow for smaller spots than magnetic recording
- Proven domain stability, no super-paramagnetic effects
  - Magnetic recording domains become unstable at room temperature somewhere between 20Gb/in² and 40Gb/in²
  - Magneto-optical media has been proven stable at densities beyond the superparamagnetic “limit” (AT&T 1992)
- Long shelf life approaching that of conventional magneto-optical products
- Infinite rewrite passes, unlike phase change media
TeraStor Disk Structure

MO recording films

Plastic single sided injection molded disk
TeraStor Disk Structure

**Traditional MO**
- Plastic Substrate
  - Dielectric
  - Magneto/Optical Storage Layer
  - Dielectric
  - Reflector

**Near Field Recording**
- Overcoat
- Dielectric
- Magneto/Optical Storage Layer
- Dielectric
- Reflector
- Plastic Substrate

Lube
The Two Stage Servo

- Combines movements of a primary actuator and laser scanning
- Radial run out taken out with rotary actuator
- Instantaneous near track seeks with galvanometer mirror
- High bandwidth micro-mirror galvanometer allows for order of magnitude increase in track densities over magnetic recording
- Improved track acquisition capability
- Improved shock resilience
## Technology Comparison

<table>
<thead>
<tr>
<th>Technology</th>
<th>Recording Mechanism</th>
<th>Cyclability</th>
<th>Data Rate</th>
<th>Areal Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near-Field MO</td>
<td>Vertical Magnetic Media</td>
<td>Infinite</td>
<td>&gt;160 Mb/sec</td>
<td>&gt; 10 Gb/in² today =&gt; &gt;200 Gb/in² today</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Far Field MO</td>
<td>Vertical Magnetic Media</td>
<td>Infinite</td>
<td>~48 Mb/sec</td>
<td>~ 2 Gb/in² today =&gt; &lt;20 Gb/in² today</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase Change</td>
<td>Amorphous Crystaline Molecular change</td>
<td>10,000 to 500,000 cycles</td>
<td>~ 24 Mb/sec today (slow process)</td>
<td>~ 2 Gb/in² today =&gt; &lt;15 Gb/in² today</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnetic</td>
<td>In-plane Magnetic Media</td>
<td>Infinite</td>
<td>&gt; 200 Mb/sec today</td>
<td>&gt; 4 Gb/in² today =&gt; &lt; 40 Gb/in² today</td>
</tr>
</tbody>
</table>
# Optical Comparisons

<table>
<thead>
<tr>
<th></th>
<th>Conventional*</th>
<th>Near-Field</th>
<th>Blue Laser</th>
<th>Blue laser</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Magneto-Optical</td>
<td>Magneto-Optical</td>
<td>Conventional*</td>
<td>Near-Field</td>
</tr>
<tr>
<td>Laser Wavelength</td>
<td>685 nm</td>
<td>685 nm</td>
<td>410nm</td>
<td>410nm</td>
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<tr>
<td>Numerical Aperture</td>
<td>0.65</td>
<td>0.65</td>
<td>0.7</td>
<td>0.33</td>
</tr>
<tr>
<td>Index of refraction of Sil</td>
<td>n/a</td>
<td>2</td>
<td>n/a</td>
<td>3**</td>
</tr>
<tr>
<td>Potential Spot Size</td>
<td>0.53 micron</td>
<td>0.26 micron</td>
<td>0.29 micron</td>
<td>.07 micron</td>
</tr>
<tr>
<td>Maximum Areal Density</td>
<td>4Gb/in²</td>
<td>16Gb/in²</td>
<td>13Gb/in²</td>
<td>238Gb/in2</td>
</tr>
</tbody>
</table>

* Conventional optics products include CD, DVD, ASMO, MO, and OAW

** SuperSIL shape
TeraStor Product Highlights

- High capacity removable cartridge drive
  - Announced 10GB, 20GB and future double sided family
  - Removable NFR media
  - Average seek times < 18ms.
  - Volume production Q1 1999

- Announced automation solutions coming from:
  - ATL Products
  - DISC
  - Overland Data
  - Exabyte
  - Spectra Logic
  - Overland Data
  - Plasmon IDE
  - Others to follow

- Storage Management software commitments from 17 UNIX, NT, and Novell backup and nearline application developers
TeraStor Partners

- Strategic Technology Partnerships:
  - Media
    - Imation
    - Tosoh
    - Maxell
  - Heads
    - Yamaha
    - Second source under negotiation
  - Electronics
    - Silicon Systems Inc (Texas Instruments)
    - Hitachi
  - Optics
    - Olympus
TeraStor Partners

- Contract Manufacturing Partnership
  - Mitsumi - Cebu Philippines

- Drive Manufacturing and Marketing License
  - Quantum
    - ensure multiple sources of competitive drives
    - create de-facto standard products
**Conclusions**

- Near-field recording with a Solid Immersion Lens combines the best advantages of magnetic and optical recording
  - many components from HDD vendors
  - Low cost plastic media
- Near-field recording is practical today
- Conventional far-field optical recording has fallen behind magnetic recording and cannot keep up (even for DVD-RAM, ASMO, and OAW)
- NFR technology can maintain a significant areal density advantage over magnetic recording for both fixed and removable media products