Progress of the Development of High Performance Removable Storage at InPhase Technologies for Application to Archival Storage

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InPhase Background

- InPhase Technologies was created to commercialize holographic media and systems technology developed at Bell Labs (Lucent)
  - Incorporated September 2000; setup in Longmont, CO in January 2001

- We are applying this technology to address the limitations of conventional removable media products (magnetic, optical, and Flash)
  - Removable media with huge storage capacity, high transfer rates, and random access

- InPhase owns or has exclusive access to >40 Bell Labs patents in high capacity polymer media and in holographic multiplexing techniques
  - Continue to maintain technology leadership and enlarge patent portfolio (21 patent disclosures since inception)

- We are working with storage industry partners to create storage and distribution systems using our holographic media and drive technology
Product Development

- **Recordable**
  - Media
  - Under Development 2006
  - Drives
  - Customer testing NOW

- **ROM**
  - Media
  - IP development in Process 2007
  - Drives
  - Customer testing NOW

- **Rewritable**
  - Media
  - Research in Process 2005/6
  - Drives
  - Modify recordable drive 2007

**InPhase Technologies**
InPhase Timeline

1994: Photopolymer media development
1996: Zerowave Media Manufacturing
1997: Multiplexing Techniques
1998: InPhase Technologies spun Out of Lucent, Bell Labs
1999: Demo 200 Gb/in2
2000: Temperature compensation
2001: Media Interchange
2002: Rewritable Media
2003: ROM Replication/ Polytopic Mux
2004: Media Interchange
2005: Rewritable Media
2006: Demo 200 Gb/in2
2007: Prototype Drive

Drive Tester Revenue
Media Revenue
Volume drive and media shipments
Rewritable drives and media
ROM drives and media
What is a Hologram?

1. Recording
   The intersection of two beams creates an interference pattern of bright and dark regions.

2. Recording
   A photosensitive medium records the interference pattern.

3. Recording
   The hologram is the image of the interference pattern stored within the medium.

4. Reading
   Light from one beam shining on the hologram reconstructs the data pattern.
Holographic Data Storage - Recordable

**Feature**
- Parallel access to data
- Multiplex data pages in one location
- Removable Media

**Benefit**
- Fast data transfer rates
- Ultrahigh storage densities
- Transportability

Record by crossing signal beam with a reference beam
Readout by presenting reference beam to the media
Media does not need to spin
Why Holographic Storage for Digital Content?

- **high capacity & performance**
  - Highest optical densities and fast parallel transfer rates
  - Random access – time to data

- **low cost**
  - Media up to 8 X less expensive than tape

- **50 year archive life**
  - No special handling required

- **broad design flexibility**
  - Chip/credit card for consumers
  - Disk for professionals
  - Blue, red, and green media

- **robust content protection & security**
  - Custom encryption
Grating Formation in Conventional Photopolymer Media

**Mechanism**

- System consists of monomers dissolved in a matrix.

- Holographic exposure produces a spatial pattern of photoinitiated polymerization.

- Concentration gradient in unreacted monomers induces diffusion of species.

- Diffusion produces a compositional gradient, establishing a refractive index grating ($\Delta n$).

**Advantages**

- High photosensitivity
- Permanent holograms
- Low cost

**Concerns**

- Recording-induced dimensional & bulk refractive index changes
- Thickness
- Optical Quality & Scatter
Requirements For Holographic Storage Media

High Storage Capacity

Rapid Write/Read Rates

Dynamic Range - High storage densities & rapid read rates
Photosensitivity - Rapid write rates
Millimeter Thickness - High storage densities
Dimensional Stability - High fidelity data recovery
Optical Flatness - High fidelity imaging of data pages
Low Scatter - Low levels of noise in data recovery
Processing - Heat/Solvent Free
Non-volatile readout
Long shelf-life of media
Long archival life of stored data
Environmental/thermal stability
InPhase Photopolymer Media

Two Chemistry Approach

Media are fabricated from independently polymerizable and compatible matrix and imaging components

Resin consists of matrix precursors and imaging components

In-situ formation of cross-linked matrix

Writing chemistry is independent of host formation chemistry

In-situ matrix formation: thick, optically flat formats

Cross-linked matrix: stable holographic gratings

Compatible matrix and monomer systems: optical clarity and low levels of light scatter

Independent matrix and monomer systems: no cross-reactions to dilute refractive index contrast. Allows optimization of dimensional stability.

Media suitable for all holographic Storage paradigms!

Optics Letters, 24(7), 487 (1999)
Our system’s basic geometry

- Camera
- SLM data page of 1.2 mega pixels
- Photopolymer Medium 1.5mm thick
- Phase conjugate read out

Angle multiplexing within a book
Density with a polytopic filter

Traditional minimum book spacing

Book spacing with a polytopic filter
Additional polytopic filter benefit

Polytopic filter placement freedom

Nyquist filtering during recording
System architecture - write

- Laser @ 407nm
- Isolator + shutter
- 52 mW
- POLYTOPIC FILTER
- SLM
- CAMERA
- Disk
- λ/2
- λ/2
- λ/2
- Rm
- 25°
System architecture - read

- Laser @ 407nm
- Isolator + shutter
- SLM
- POLYTOPIC FILTER
- Camera
- Disk
- 25°
Higher densities

200Gbit/in²

x40 DVD¹(1L), x8 Blue-Ray (¹L)

@ 24Mb/s write user transfer rate
@ 37Mb/s read user transfer rate

# of pixels per page = 1,144,640
# of pages per book = 252

Layout of our demonstrations:

L1  L7  L13  L2  L8
L3  L9  L14  L4  L10
L5  L11 L15  L6  L12

Reading of book #14

<table>
<thead>
<tr>
<th>Hologram #</th>
<th>SNR</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>1.00E-13</td>
</tr>
<tr>
<td>50</td>
<td>2.10E-12</td>
</tr>
<tr>
<td>100</td>
<td>4.10E-12</td>
</tr>
<tr>
<td>150</td>
<td>6.10E-12</td>
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<td>200</td>
<td>8.10E-12</td>
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Diffracted power in µW

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<th>Book #</th>
<th>0.0E+00</th>
<th>1.0E-06</th>
<th>2.0E-06</th>
<th>3.0E-06</th>
</tr>
</thead>
</table>

SNR

0  0.5  1  1.5  2  2.5  3  3.5
0  1  2  3  4  5  6  7

Hologram #
### Recordable Technology Roadmap

<table>
<thead>
<tr>
<th>Spec</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
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<tbody>
<tr>
<td>Specs</td>
<td>300 Gb/in²</td>
<td>800 Gb/in²</td>
<td>1600 Gb/in²</td>
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<tr>
<td></td>
<td>20 MB/s</td>
<td>80 MB/s</td>
<td>120 MB/s</td>
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<tr>
<td># of pages per book</td>
<td>131</td>
<td>370</td>
<td>753</td>
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<tr>
<td>Reference Beam Sweep (degrees)</td>
<td>10</td>
<td>25</td>
<td>30</td>
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<tr>
<td>Hologram pitch (θ, r) (mm)</td>
<td>0.82, 0.48</td>
<td>0.82, 0.48</td>
<td>0.82, 0.48</td>
</tr>
<tr>
<td>NA of object beam</td>
<td>0.65</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td>Bragg Null</td>
<td>2nd</td>
<td>2nd</td>
<td>1st</td>
</tr>
<tr>
<td>SLM Pixels</td>
<td>1200x1200</td>
<td>1200x1200</td>
<td>1200x1200</td>
</tr>
<tr>
<td>Camera Pixels (4/3 OS)</td>
<td>1696x1664</td>
<td>1696x1664</td>
<td>1696x1664</td>
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<tr>
<td>Wavelength (nm)</td>
<td>407</td>
<td>407</td>
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<td>Material Thickness (mm)</td>
<td>1.5</td>
<td>1.5</td>
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<tr>
<td>M# of media @1.5mm</td>
<td>33.3</td>
<td>90</td>
<td>135</td>
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InPhase delivers the World’s first Holographic Drive Proto

- completed October 2004

media

- 2-chemistry photopolymer
- Write Once Read Many (WORM)
- 130 mm disk
- 407 nm wavelength sensitive
- 1.5 mm thickness of material
- 5.25” cartridge

drive

- records and reads data to/ from entire 130 mm disk
- WORM
- Integrated control system
- Works through SCSI interface
Prototype Drive (internal view)
“Inside the box” video
Prototype in audio playback
Roadmap for Professional Products

media
- backward read compatible
- theoretical capacity of 17 TB

drive
- camera and slm
  - higher sensitivity/ faster
  - more pixels per page
- laser
  - higher power for improved performance
- firmware
  - more pages per book
  - more complex recording schedule
Customer’s TOTAL COST OF OWNERSHIP

POWER

SPACE

MEDIA

DRIVE
15 Year TCO for Media, Drive, Space, Power for 100 TB

Assumptions: 1 drive for every 200 pieces of media
Drives replaced 1 time
Data on tape migrated to new media every 5 years
Data migration cost, labor & system expenses
Warehouse Sq Ft. cost = $10.00
KWH = $.08
Partnerships move from “technology to solution”

Development Partners

- Drive Mechanics
  - ALPS
- SLM
  - Displaytech
- Laser
  - SONY
- Detector
  - Fillfactory
- OMA
- Large Company
- Media
  - maxell
- Chemicals
  - Bayer MaterialScience

Manufacturing Partners

- Drive
  - (Under discussion)

Customers & Integration Partners

- OEM
  - Drives, Media, Archival Solutions
- Robotics
  - ASACA
  - BDT
  - MASSTECH
  - PEGASUS
- Software & Solution Integrators
- Large Company

Strategic Components