High Performance Data Storage via Volume Holography

William L. Wilson
InPhase Technologies
2000 Pike Road, Longmont Co 80501

Phone: +1-720-494-7429 FAX: +1-720-494-9606

E-mail: WilliamWilson@inphase-tech.com

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Opportunity & Overview

Vision

InPhase's Tapestry™ technology will be the dominant choice for capturing, editing, archiving, distributing and securing digital image content.

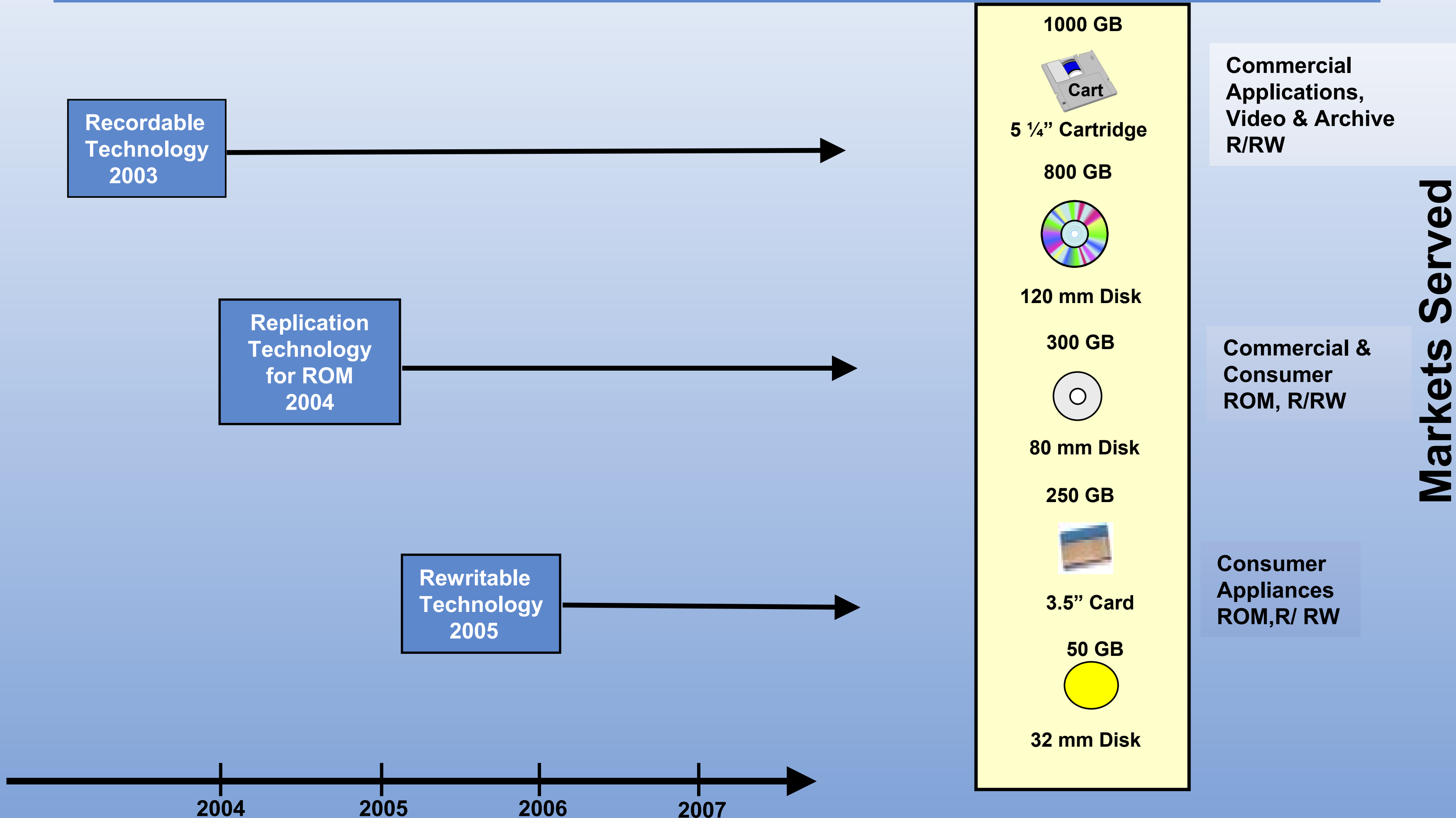
Mission

Bring holographic storage media and drives to market.

History

Founded by Bell Labs media and holography scientists in December 2000.

Disruptive Vision: Revolutionalize the removable storage industry by becoming the underlying technology for all devices and media - **$ 60B opportunity**



What is holographic storage?

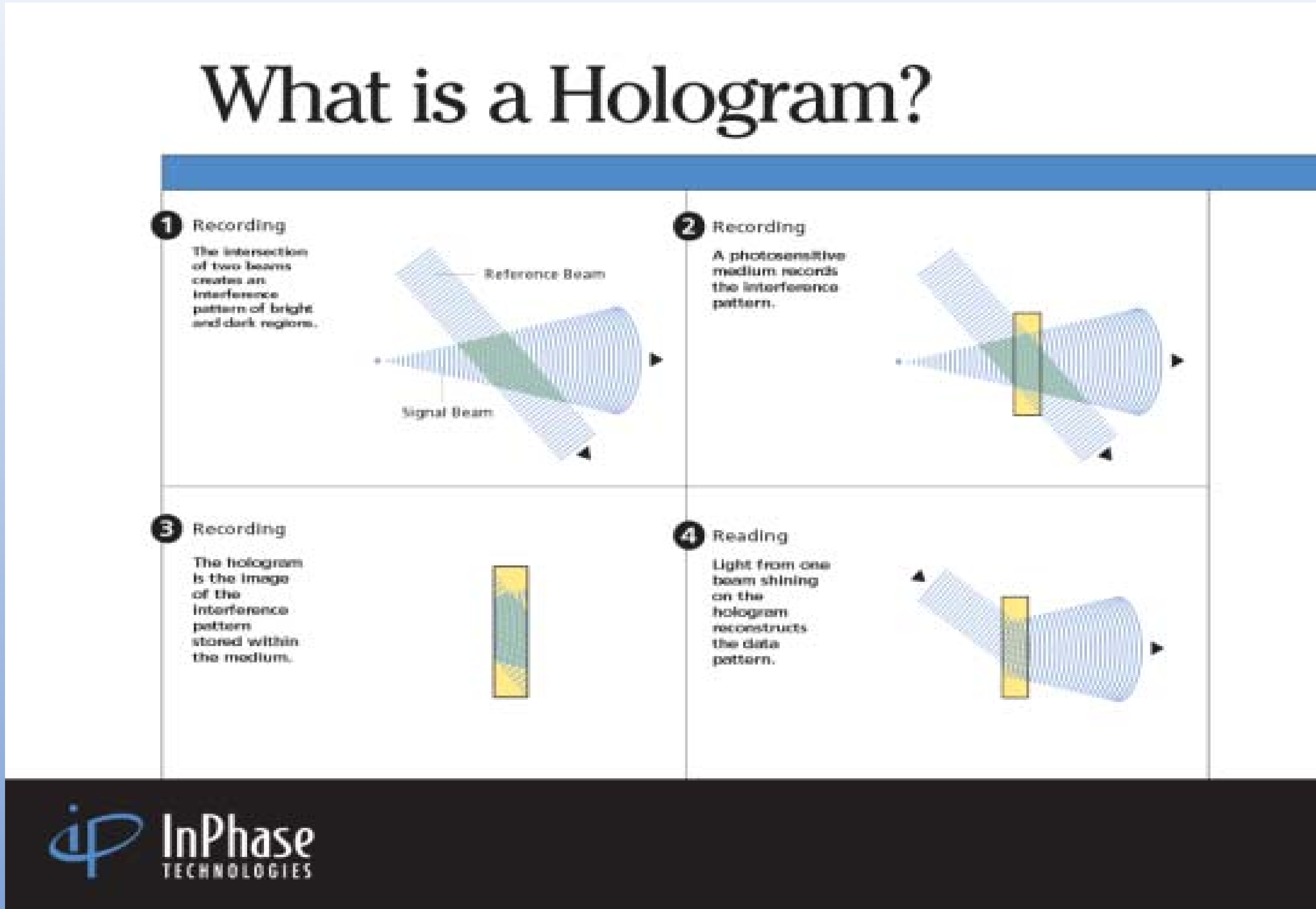
Holography stores data in an optical pattern of a million bits. The data are recorded and read with a single flash of light. Thousands of holograms can be stored in the same location in the media.

What is it's value?

Lowest Total Cost of Ownership of any high capacity, high performance removable storage, and the flexibility to address broad markets today, and tomorrow.

Why InPhase?

It is the only company in the world with media and drive expertise, intellectual property, and resources to successfully commercialize the technology. (~80 patents and filings, and a staff of >50)


What is a Hologram?
1 Recording
The intersection of two beams creates an interference pattern of bright and dark regions.
Reference Beam
Signal Beam
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.
InPhase
TECHNOLOGIES

Why Holographic Storage?

- **High Capacity & Performance**
    - Highest optical density - 100 Gbits per sq. in. for initial product
    - 4X faster than Transfer rates of other optical technologies
    - Random Access
- **Robust Content Protection**
    - More difficult to pirate due to volume recording
- **Long Archival Life**
    - 50 years
    - Very tolerant to dust, scratches, and surface defects
    - Not effected by electric or magnetic fields
- **Low Cost**
    - Lowest cost per gigabyte for removable storage
    - Inexpensive media manufacturing process
- **Broad Design Flexibility**
    - Card or Disk formats – enabled by parallel read/write
    - Optical Mastering possible (ROM), recordable, rewritable

Tapestry - a new paradigm in storage

	Existing storage	Tapestry
Capacity	Bit Size Bit Density	Media thickness Multiplexing technology Page characteristics
Transfer Rate	RPMs Linear bit density	Page record/recovery Media sensitivity Media dynamic range Laser power
Reliability	NFR increases susceptibility to dust, scratches, head crashes, E&M	Holographic not susceptible

InPhase Breakthroughs

Required Components	Past Problems	InPhase Breakthroughs
Recording material	Commercially viable materials that had high density and were manufacturable did not exist	2 Chemistry Media • For manufacturing properties • For recording properties
High Volume Manufacturing	Optically flat media expensive to manufacture.	ZeroWave™ mfg process Low cost DVD like process
Recording Methods	Complex with limited densities.	Patented recording methods that enable high density
Channels and error correction codes	Serial storage channels.	Developed modulation, coding, and filtering for robustness and capacity.
Environmental stability	Changes to Media volume caused by temperature sensitivity.	Methodology that allows wide operating temperature (± 30°C)

Tapestry 100

- **Media**
  - Recordable
    - 5 ¼ inch media in a cartridge
    - Chip in cartridge for file system
    - Library ready
  - ROM
    - Bare 120 mm disc
    - Does not require Cartridge
    - Uses same media formulation as Recordable

Different Media Formats

- **Drive**
  - Recordable
    - 5 ¼ inch full height, extended depth.
    - 100 GB, 20 MB/sec
    - Library ready

InPhase Recordable Media and Drive

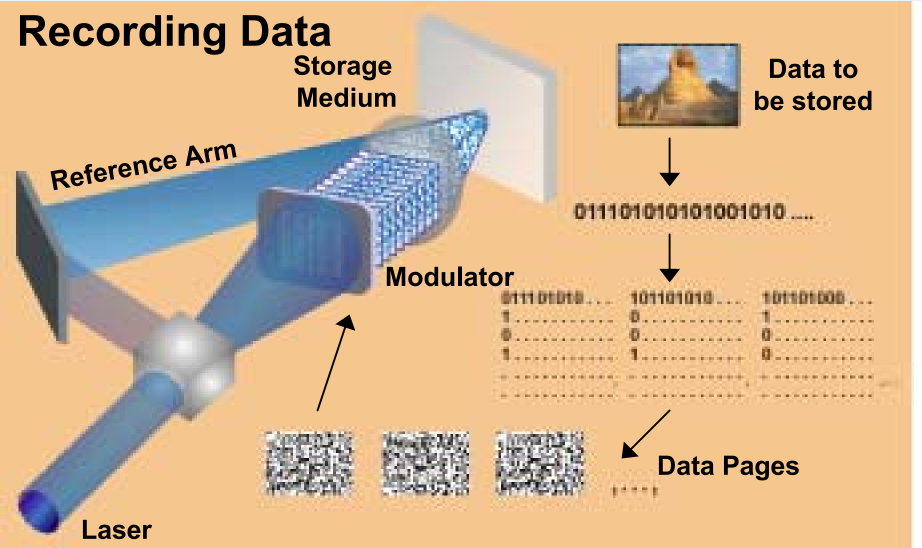
Technology Overview

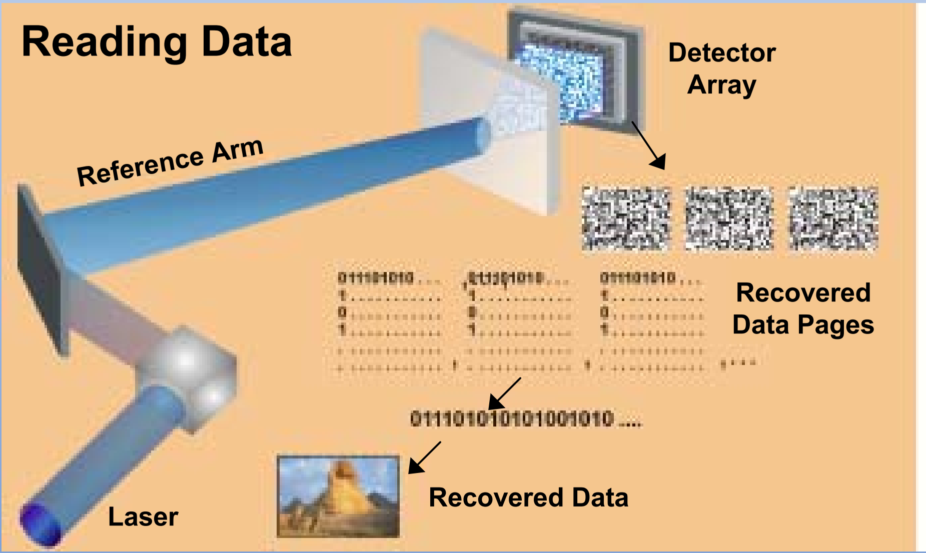
Holographic Data Storage

Feature	Benefit
▪ Parallel access (million vs. one bit data transfers)	▪ Fast data transfer rates
▪ Volumetric Storage (Overlap many data pages in one location)	▪ Ultrahigh storage densities
▪ Removable Media	▪ Transportability

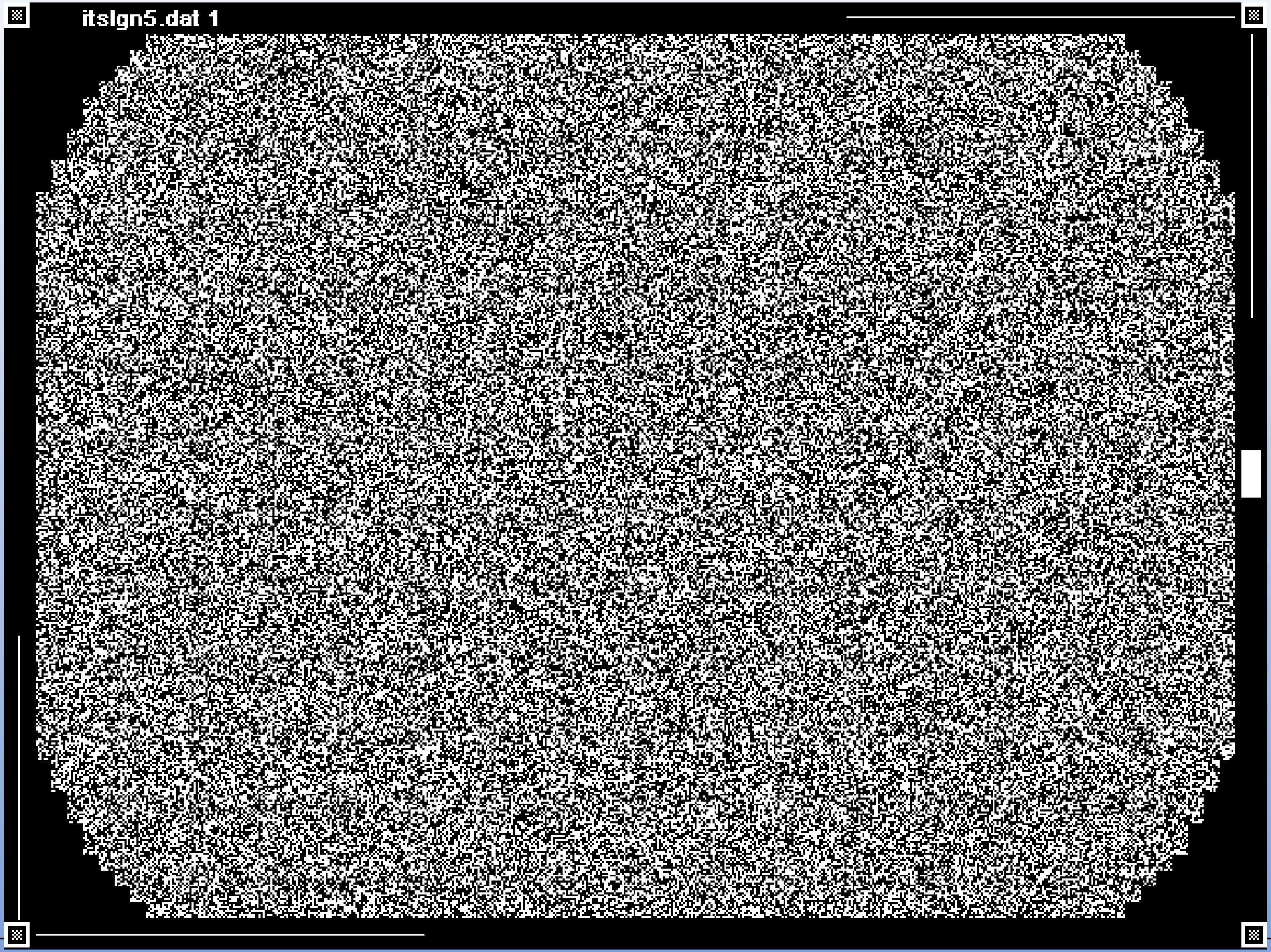
Record by crossing signal beam with a reference beam

Readout by presenting reference beam to the media



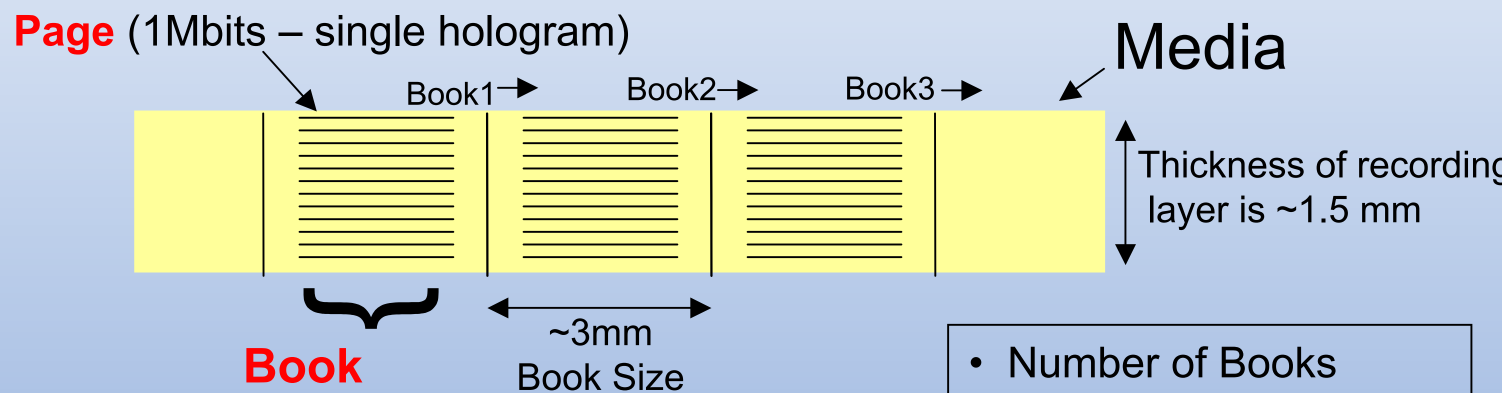


Sample Data Page (1 million bits)



Recording through the Volume

Logical View



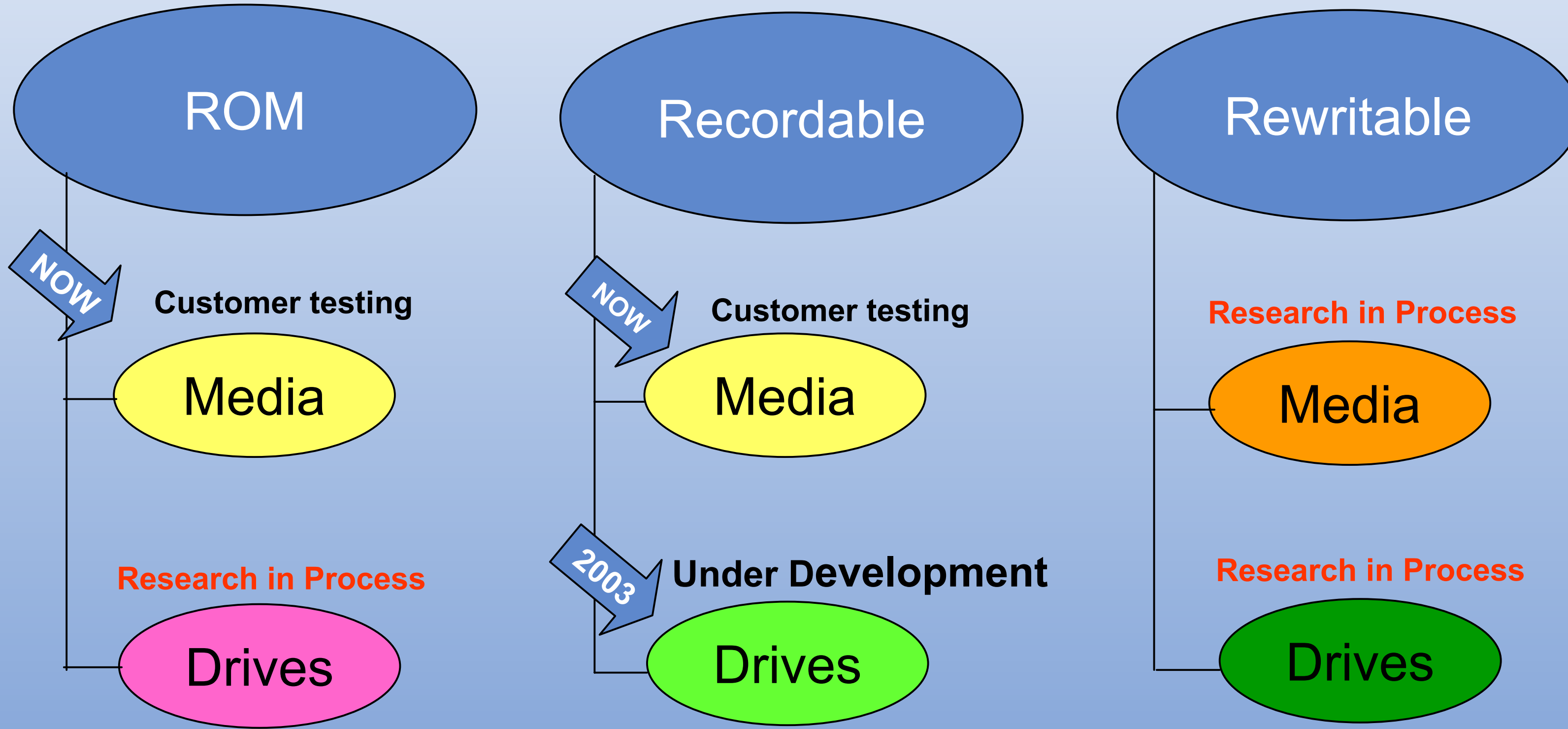
~1000 Pages
Stacked in same volume
Each with a unique Reference angle

- Number of Books in a disc is ~ 1500
- First record Book1 then Book2 etc

Physical View

- Physically each page (hologram) takes the whole volume of the book
- The thickness of the recording layer allows each page to be readout and stored uniquely by changing the reference beam angle for each page.

Technology Development Focus



Media Overview

Requirements for Media for Holographic Data Storage

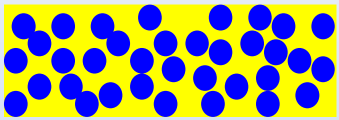
Dynamic Range - High storage densities & rapid read rates
Photosensitivity - Rapid write rates
Millimeter Thickness - High storage densities
Dimensional Stability - High fidelity data recovery
Optical Flatness - High fidelity imaging of data pages
Low Scatter - Low levels of noise in data recovery
Processing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

Selected candidate Materials for Recording

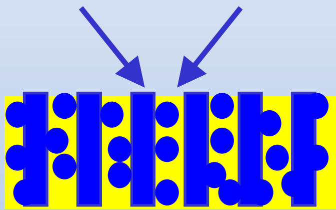
	Dynamic Range	Photo Sensitivity	Dimensional Stability	Thickness	Optical Quality	Non-volatile/ Post-Processing	Media Cost
InPhase Tapestry Media	✓	✓	✓	✓	✓	✓	✓
Photorefractive crystals (eg LiNbO3)	X	X	✓	✓	✓	X	X
Photorefractive polymers	X	X	X	X	-	X	X
Inorganic Glasses	X	X	✓	✓	-	-	X
Biological /Photochromic	X	X	-	-	-	X	X
Conventional Photopolymers	-	✓	X	X	X	✓	-

Grating formation in conventional photopolymer media

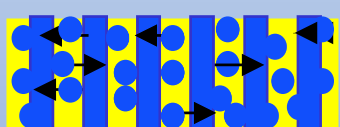
Mechanism



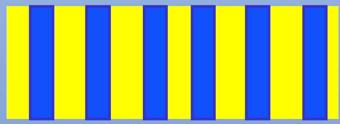
System consists of monomers dissolved in a matrix.



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 (Δn).

Advantages

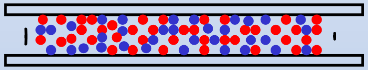
- High photosensitivity
- Permanent holograms
- Low cost

Concerns

- Recording-induced dimensional & bulk refractive index changes
- Thickness
- Optical Quality & Scatter

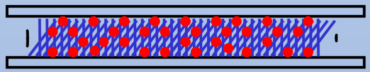
InPhase's Tapestry™ Recording Material

Proprietary Two Chemistry Approach

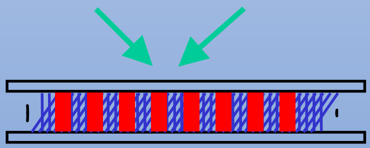


Resin consists of matrix precursors and imaging components

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



In-situ formation of cross-linked matrix

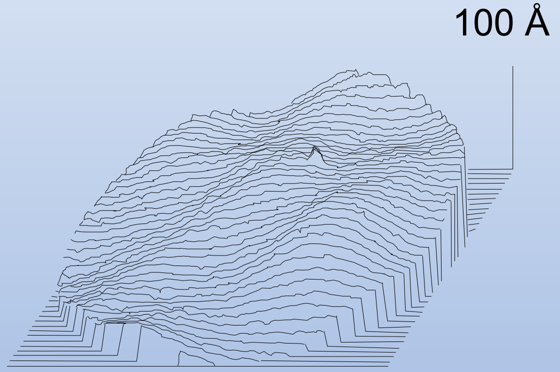


Writing chemistry is independent of host formation chemistry

- ✓ **In-situ matrix formation**: thick, optically flat formats with good mechanical robustness
- ✓ **Cross-linked matrix**: stable holographic gratings - long archival life
- ✓ **Compatible matrix and monomer systems**: optical clarity and low levels of light scatter
- ✓ **Independent matrix and monomer systems**: no cross-reactions- maximizes refractive index contrast.

InPhase Zerowave™ Media Manufacturing Process

Excellent optical quality & thick media

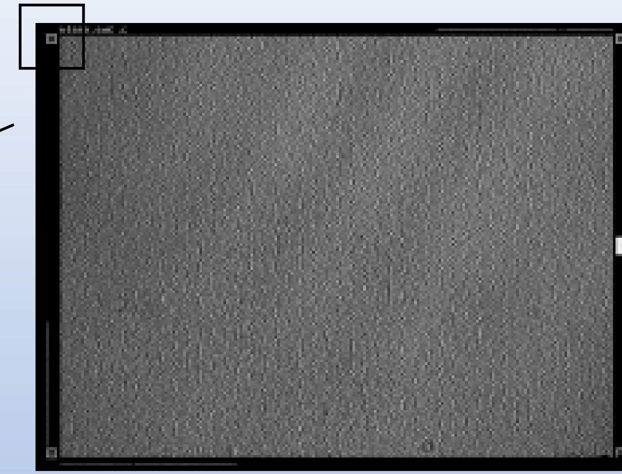


3” x 3”, 1 mm-thick media

Proprietary DVD-like media fabrication method allows for

Routine fabrication of media with better than $\lambda/4$ / cm^2 flatness enables high fidelity data storage and recovery

Optical Quality:
Pixel Matching with Low Bit Error Rates

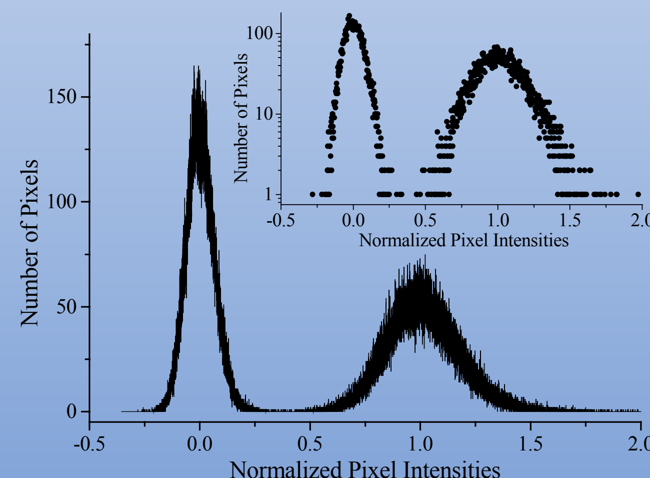


Data Page 800x600

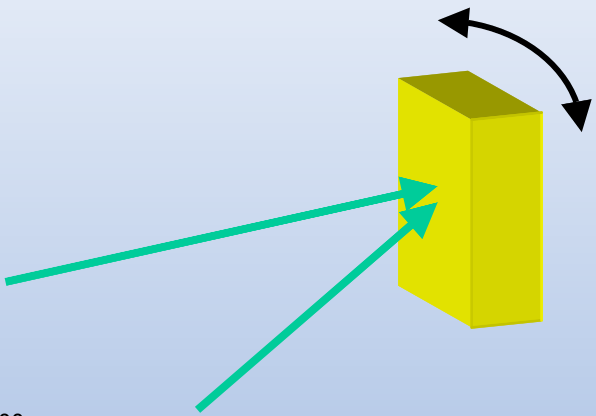
Expanded view of
corner pixels

Histogram of pixel intensities,
a measure of fidelity of data recovery.

Raw BER ~ 10^{-6}



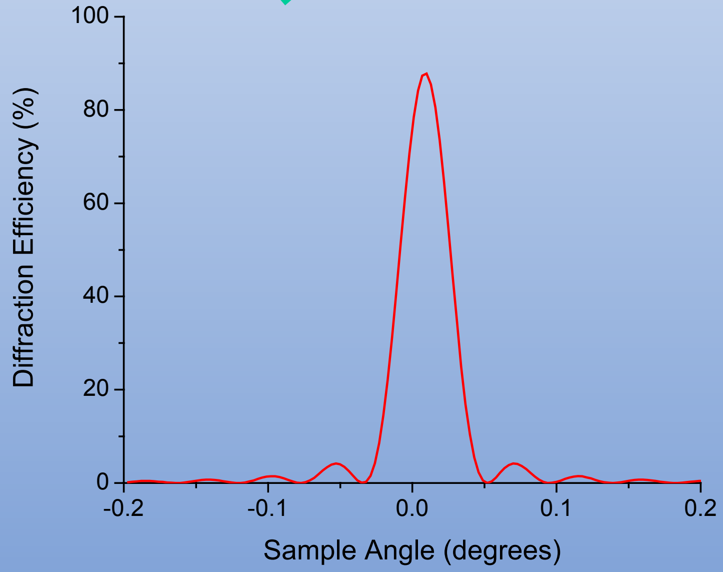
Measurements of Dynamic Range

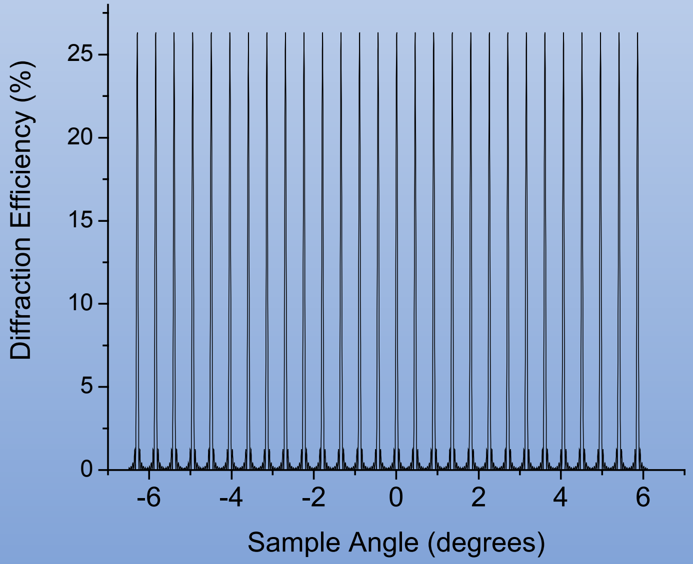


Measure of Dynamic Range: M/#

M/# = (Number of Holograms) * (Ave. Diff. Eff.)$^{1/2}$

M/# ~ Δn * (thickness)



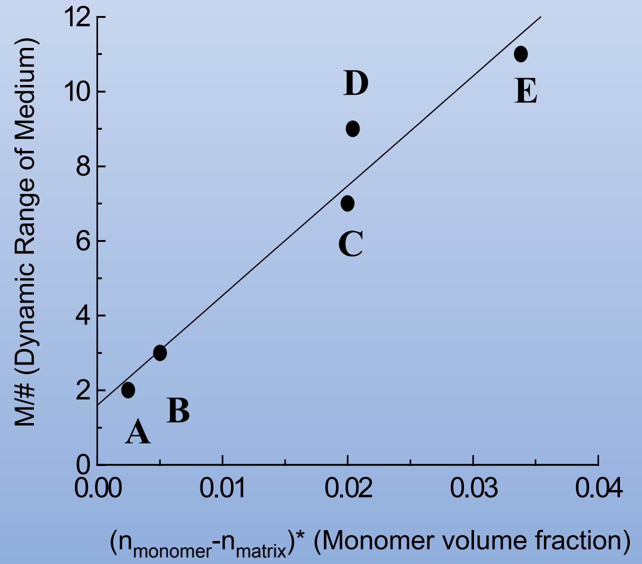


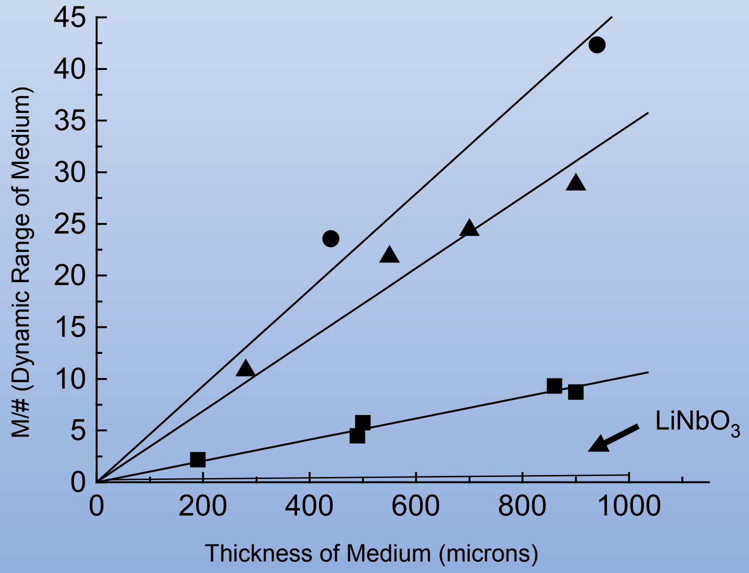
High Dynamic Range Photopolymer Media

Independent Matrix & Writing Chemistries Yield High Dynamic Range Media:
Tunable Dynamic Range with Controlled Dimensional Change

Dynamic range can be systematically optimized by using writing monomers of increasing refractive index and size.

Concentration of writing monomers is adjusted to achieve equal levels of Bragg detuning (dimensional stability) throughout the series.

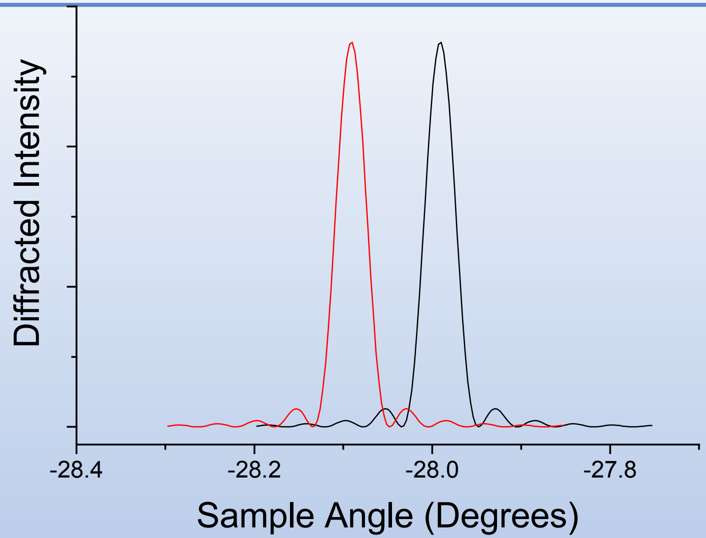


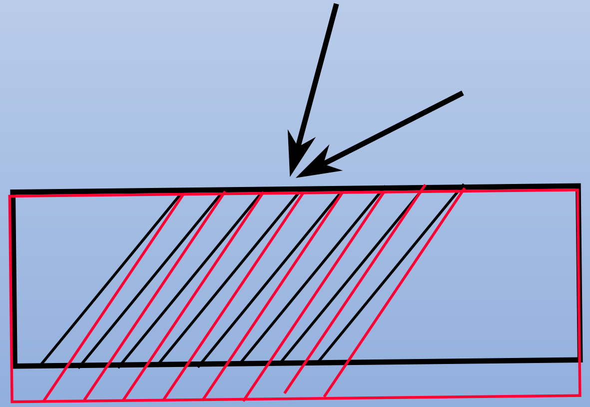


M/# of a series of 200 μm thick media fabricated with writing monomers A-E

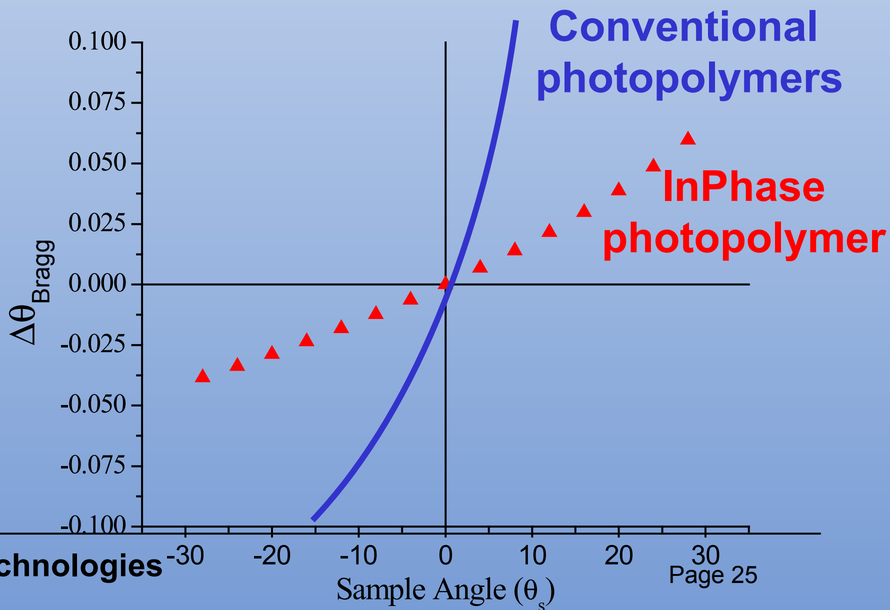
Dimensional Stability

Changes in dimension (shrinkage) distort holographic gratings leading to detuning of the gratings' Bragg angles

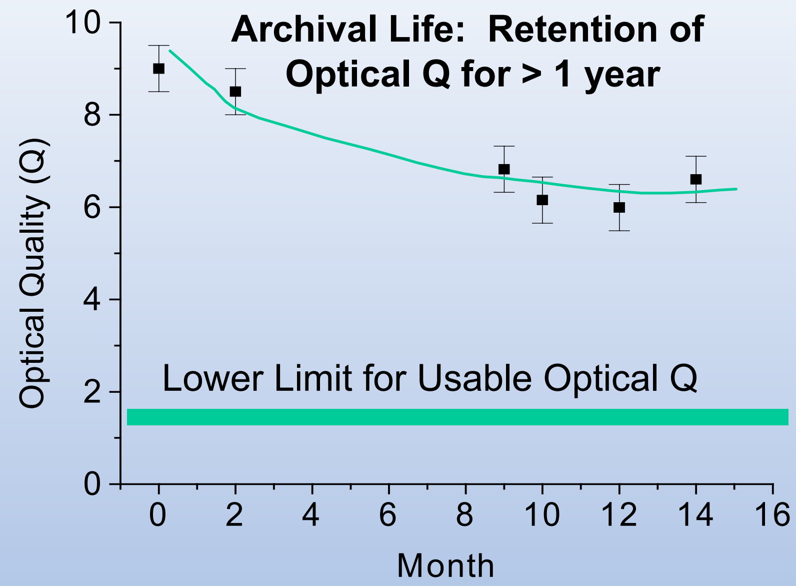




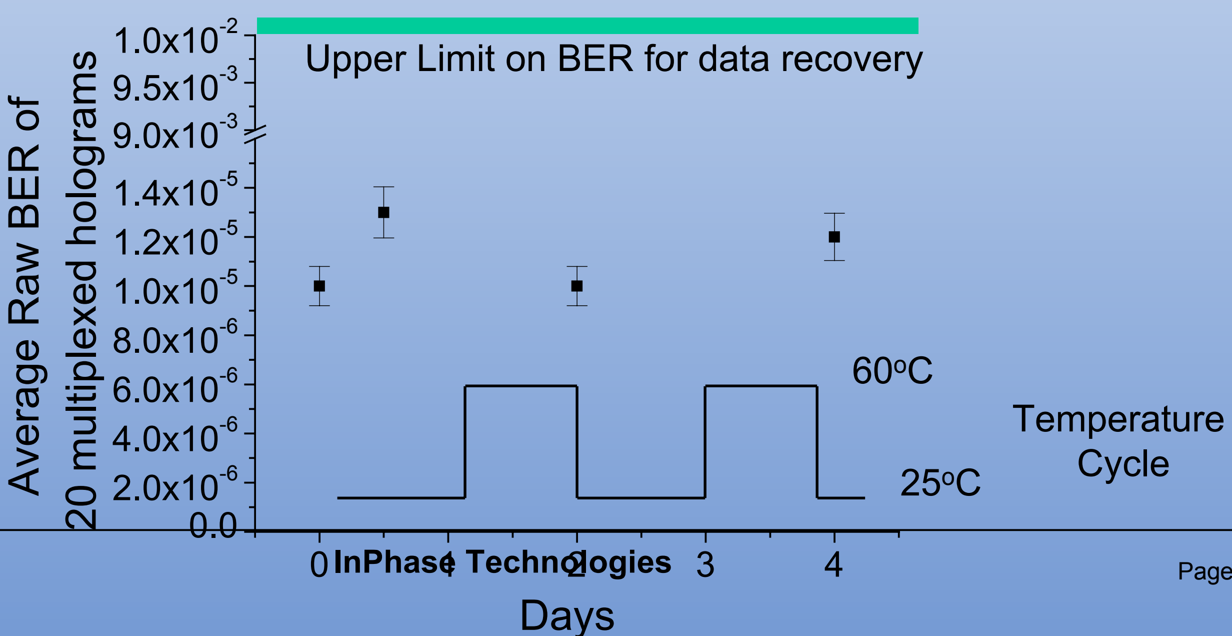
Recording-Induced Bragg Detuning



Archival Life



Archival Life: Accelerated aging tests of retention fidelity of data recovery

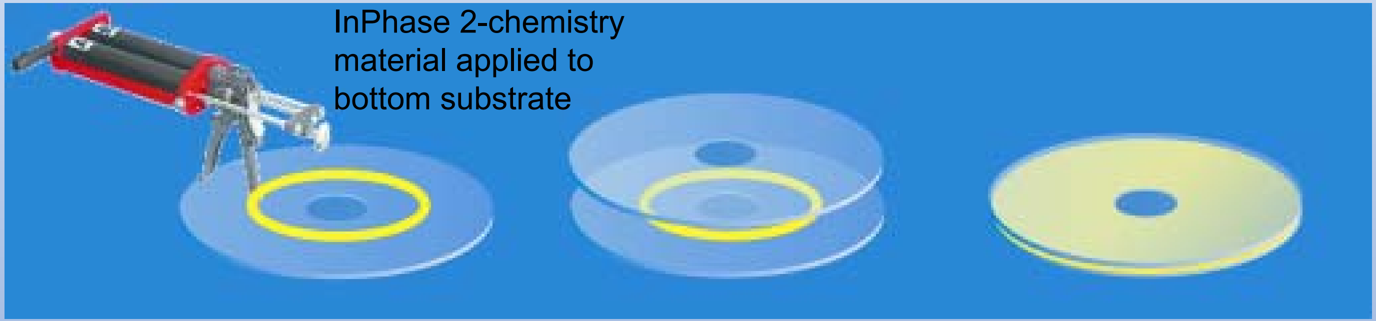


Present Status Photopolymer Media

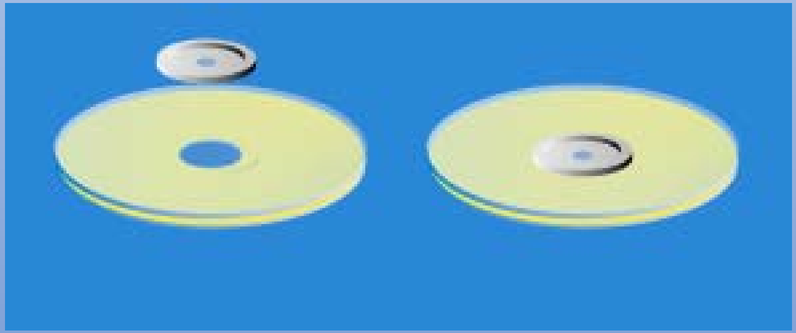
	Goal	Current Media
Dynamic Range (M/# at 1mm)	10-15	>20
Photosensitivity ($\Delta n/(mJ/cm^2)$)	$>1.2\times10^{-6}$	9×10^{-6}
Millimeter Thickness	$\geq$1 mm	>1 mm
Shrinkage	$\leq$ 0.1%	$\leq$0.1%
Optical Flatness	$\leq\lambda/2$ /cm	$<\lambda/4$ /cm
Low Scatter (of ref. power)	$\leq10^{-6}$	$< 10^{-6}$
Works in Red, Green, and Blue λs	✓	✓
Heat/Solvent-Free Processing	✓	✓
Non-volatile readout	✓	✓
Shelf-life of media	>3 year	tested >6 months
Archival life of stored data	>30 years	tests underway

Media Manufacturing

Plastic substrates fabricated via DVD molding process



Substrate-polymer-substrate sandwich formed via DVD-like bonding process



Hub attached

Media Summary Status

- **Currently selling media to customers building holographic drives**
  - **ROM products**
  - **Recordable products**
- **Contract with automation company to develop media manufacturing system for volume production**
- **Rewriteable media under development**

Drive Overview

Recordable/Rewritable Technology Roadmap

	2003	2004	2005	2006	2007
Recordable Specs	100 Gb/in^2 20 MB/s	200 Gb/in^2 40 MB/s	400 Gb/in^2 80 MB/s	800 Gb/in^2 160 MB/s	1600 Gb/in^2 250 MB/s
Drive Configuration	• Angle Mux ~1000 pages • Blue Laser	• Custom SLM, Detector • Grayscale	• 2000 pages by using 2 wavelengths	• Custom laser • 4 λ's	• 8 λ's • Or more angles used
Re-Writable Specs			200 Gb/in^2 30 MB/s	400 Gb/in^2 60 MB/s	800 Gb/in^2 120 MB/s
Drive Configuration			• Custom SLM, Detector • Grayscale	• 2000 pages by using 2 wavelengths	•Custom laser • 4 λ's

Initial product target specifications

• Capacity (native):	100 GBytes
• Transfer rate (read and write)	20 MB/sec
• Average seek time:	250 msec
• Maximum seek time:	500 msec
• Interface (at FRS):	SCSI-II
• Cartridge load time:	5.5 sec
• Cartridge unload time:	3.5 sec
• MTBF	100K POH's
• MTTR	30 min
• MSBF (Mean Swaps between failure)	>750K cycles

Test Beds for Media, Servo, and Channel

Program risks and opportunities:

- No known “show-stoppers” at this time.
- Test Beds & Prototypes will identify and explain technology unknowns
- Blue Laser supplier not identifies yet, but optical path is independent of the laser supplier
- Timely identification of the OMA and Drive MFG partners.

InPhase Summary

- **Large markets are demanding advanced removable storage**
  - Holographic storage has compelling value proposition
- **InPhase has a commercial media**
  - Proprietary photopolymer system with two chemistry approach
  - Innovative, DVD like, manufacturing process
  - Applicability to markets outside of storage (such as photonics)
- **Strong IP portfolio and management team**
- **Technology roadmap for significant improvements**
  - This is a technology with legs
  - Re-writable roadmap opens even larger markets