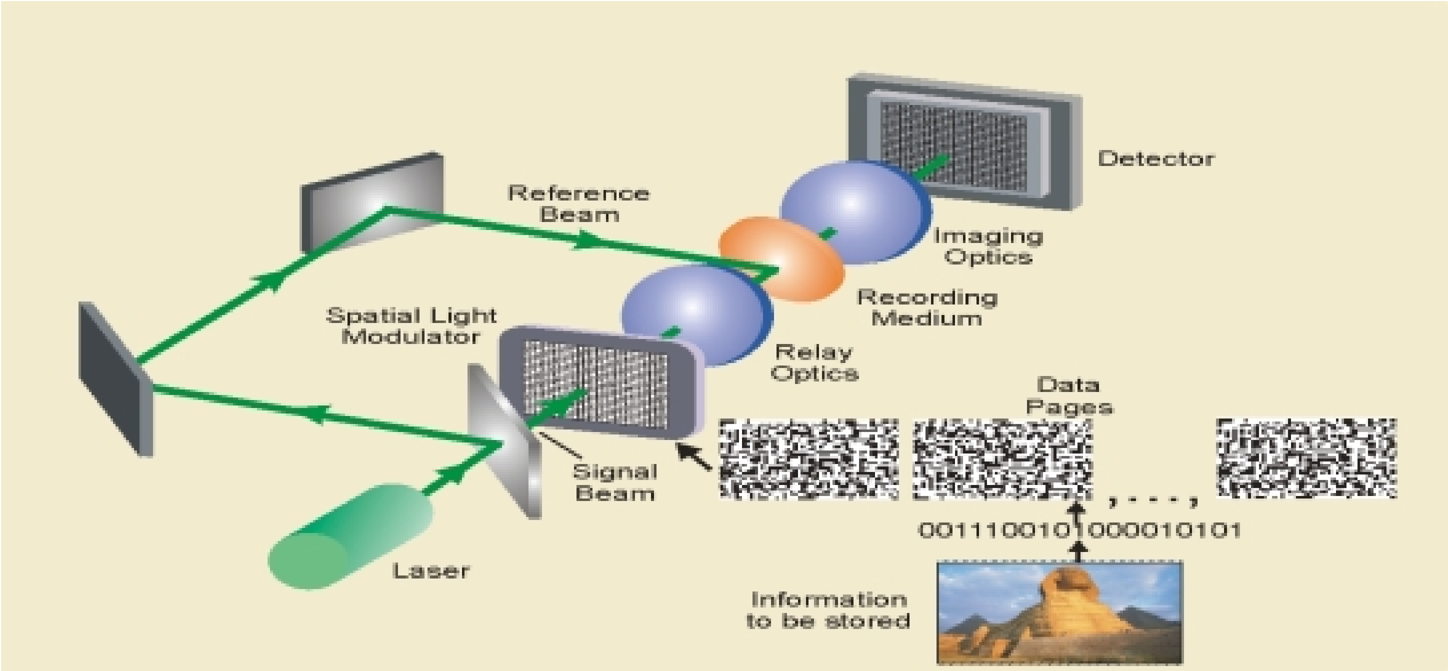
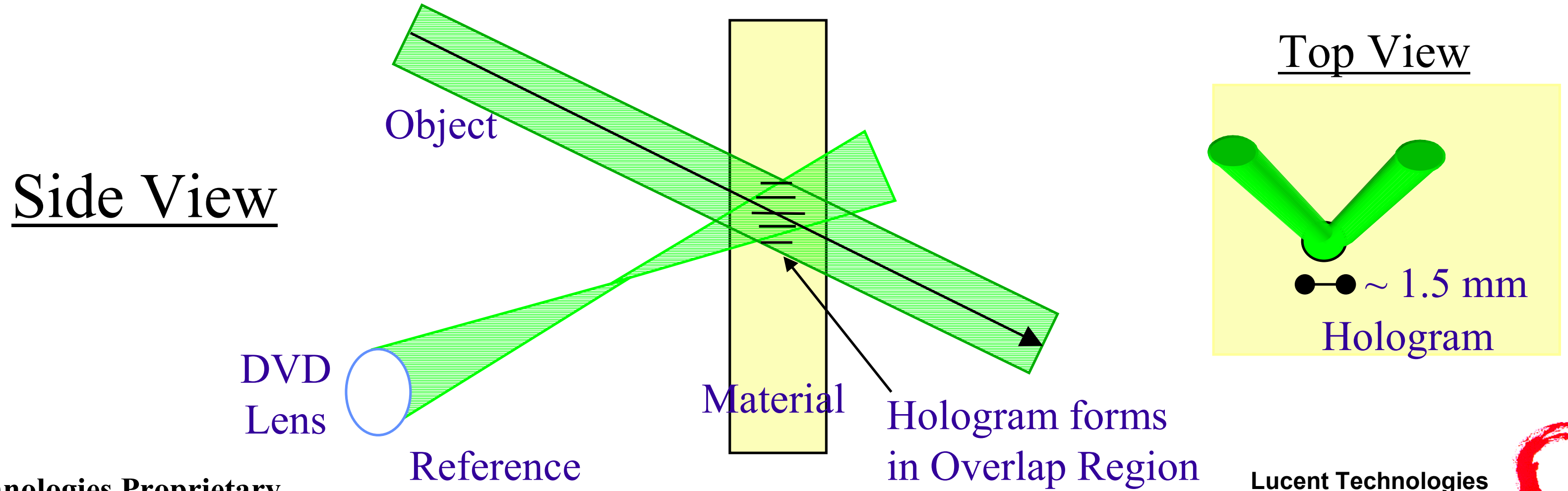
Holographic Recording

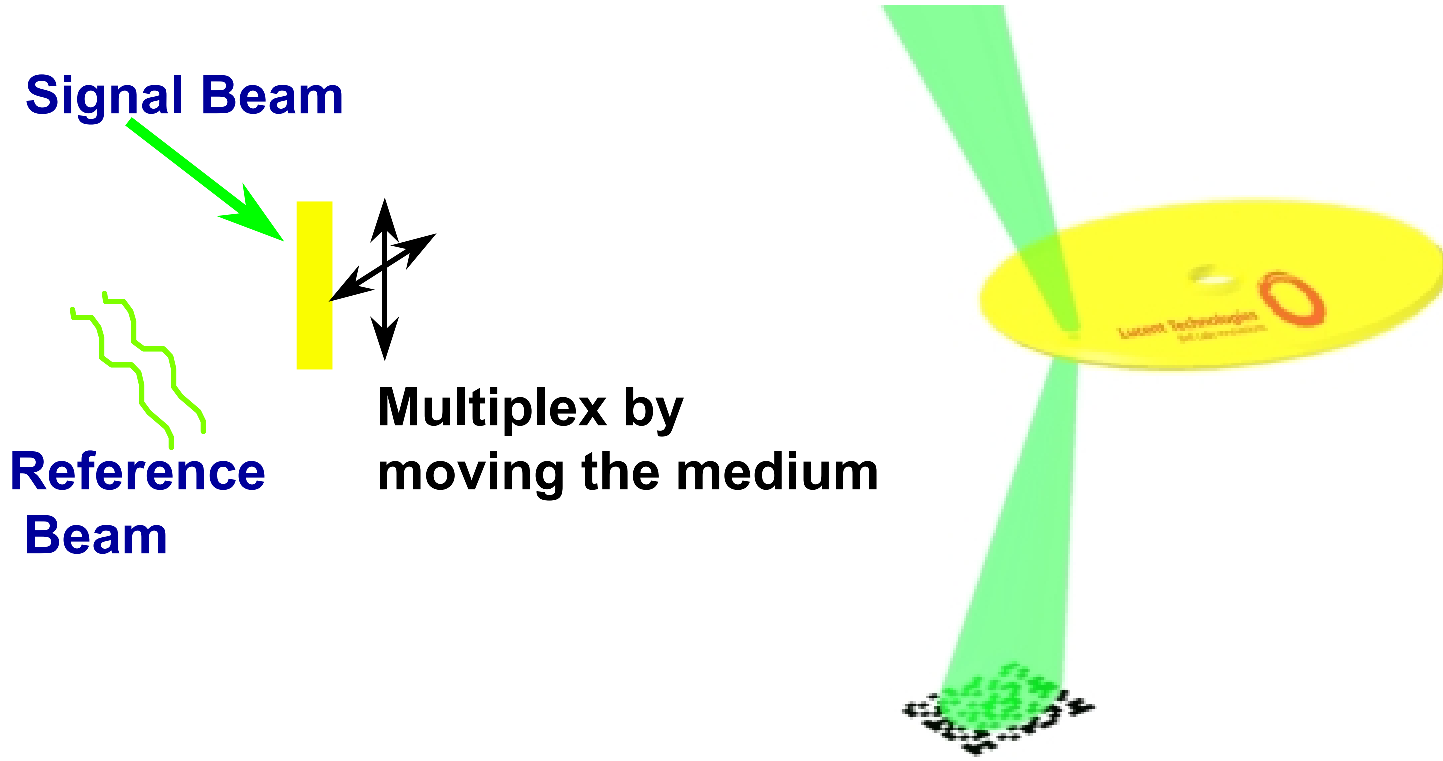




Past Problems with Holography

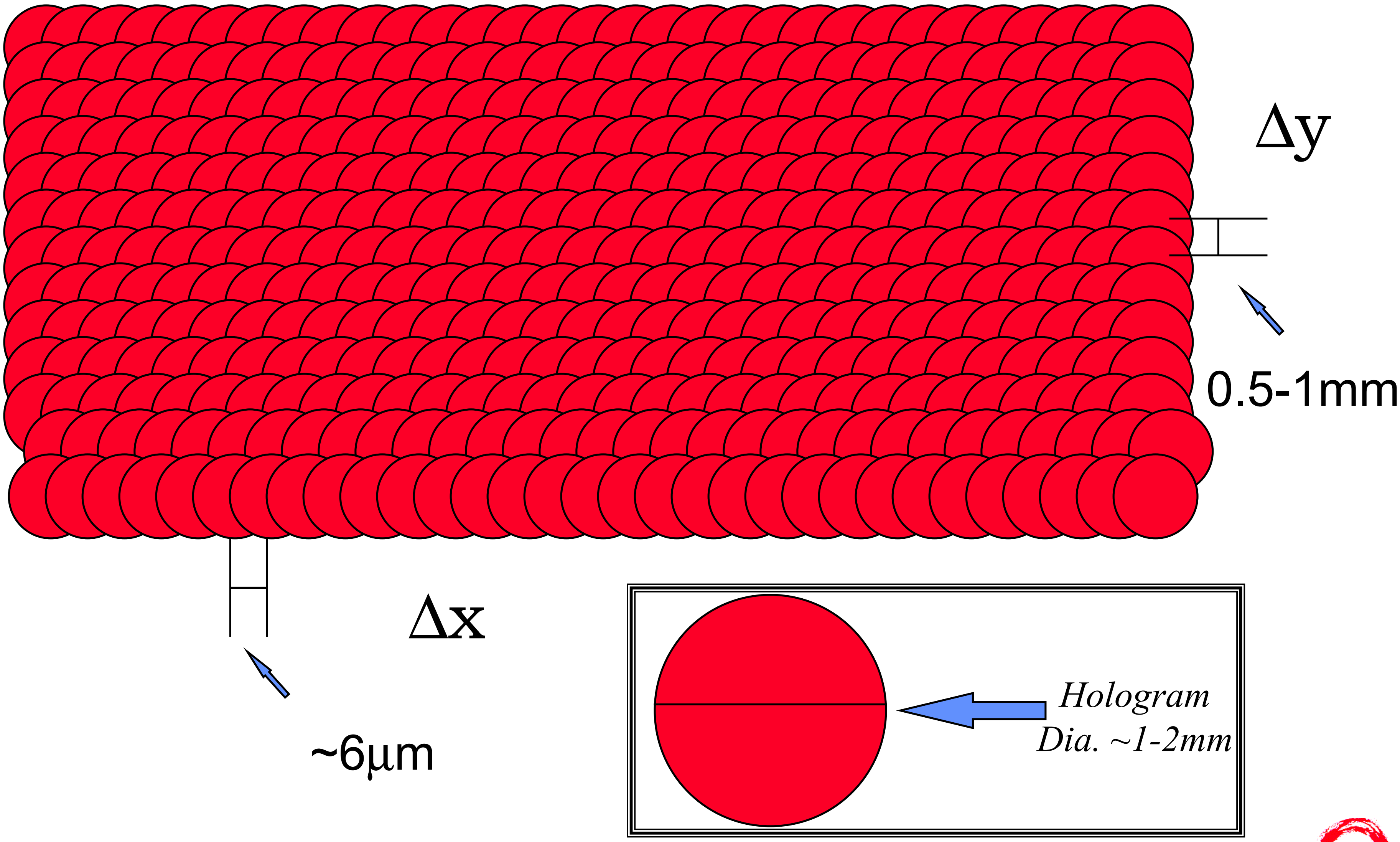
- Material - No acceptable material and requirements only vaguely known
- Methods - Complex and difficult, limited density
- Laser - Extremely costly and unreliable
- Detector - Cost and performance
- SLM - Performance: slow frame rates otherwise unknown

Multiplexing

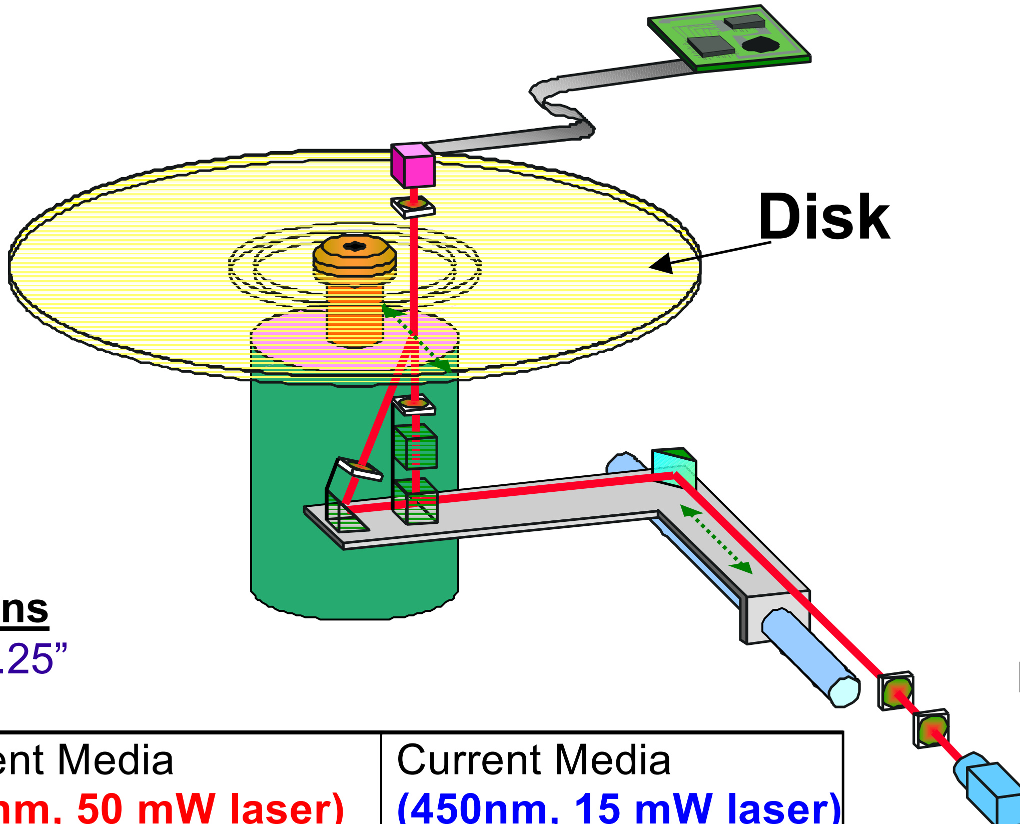


- Simple to implement
- Leverages existing technology
- Higher densities in thinner media (350 b/um2)

Array of Stored Holograms



First Generation Drive



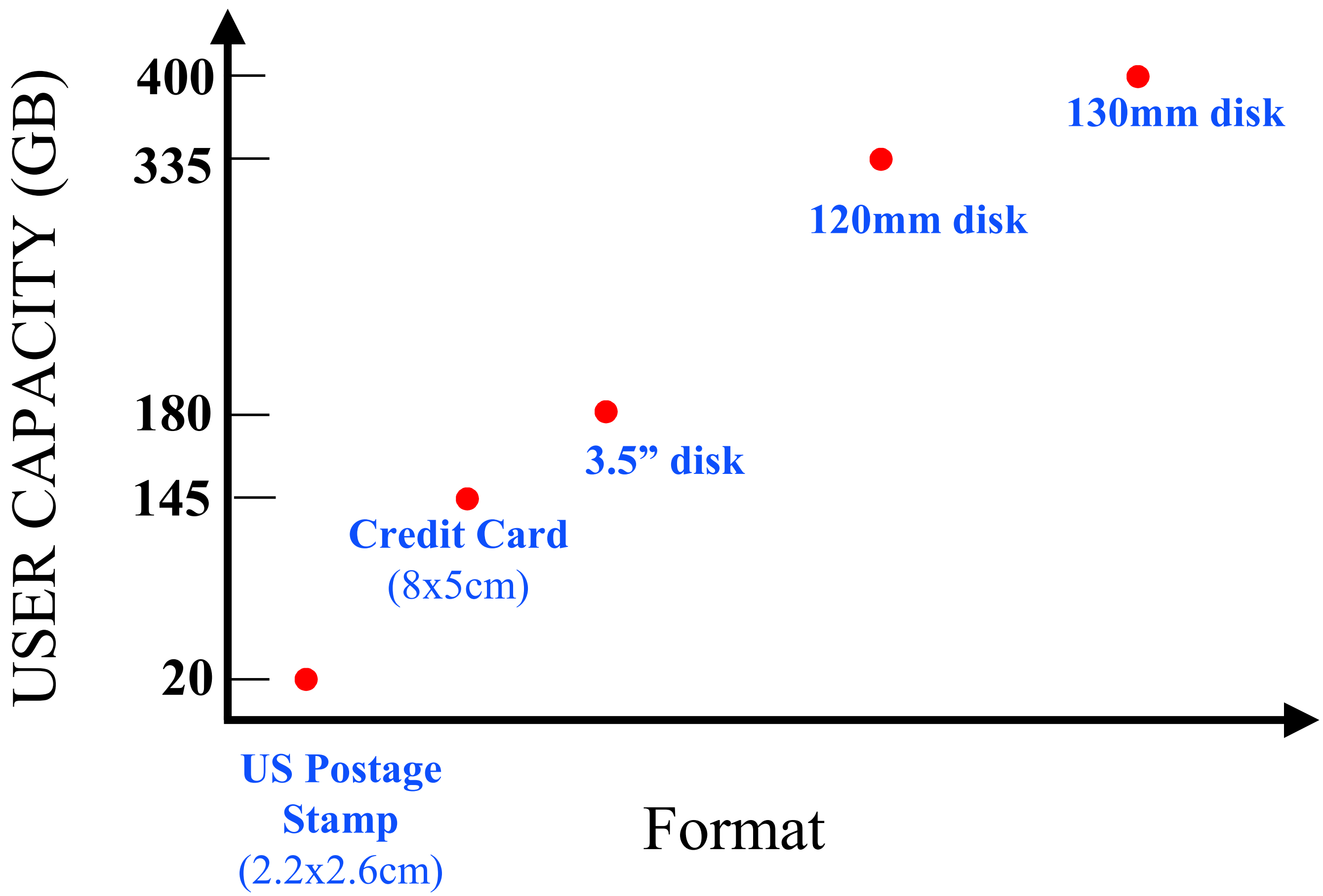
WORM Drive Specifications

Low Cost Removable Disk 5.25"

	Current Media (650nm, 50 mW laser)	Current Media (450nm, 15 mW laser)
User Capacity (per disk)/(Channel Density)	**150 GB** **(106 Gbits/in^2)**	**400 GB** **(300 Gbits/in^2)**
Write Rate (MBytes/sec)	**20**	**20**
Read Rate (MBytes/sec)	**70**	**40**

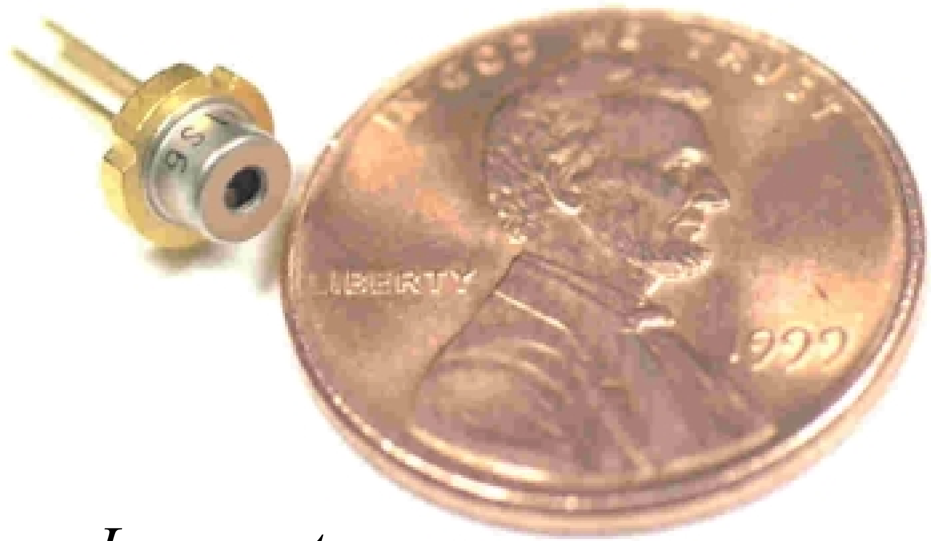
Capacity vs Format

(Blue laser)

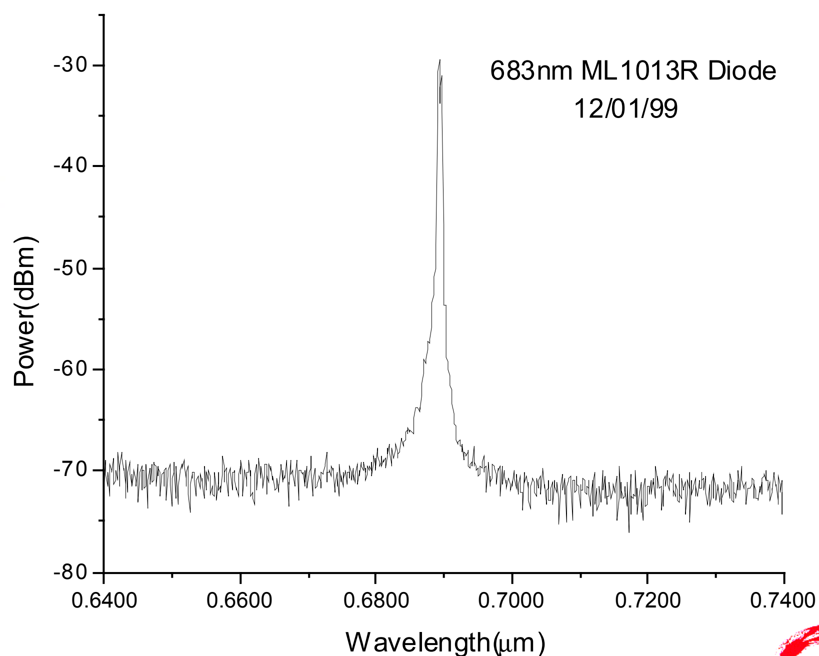


Component Summary

High Power Semiconductor Q-well Lasers
(developed for DVD-RAM)



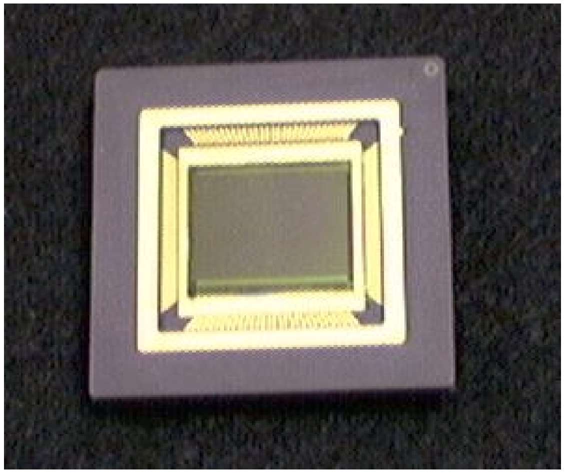
***50mW single mode, single frequency*



- *Low cost*
- *High reliability*
- *Low power consumption*

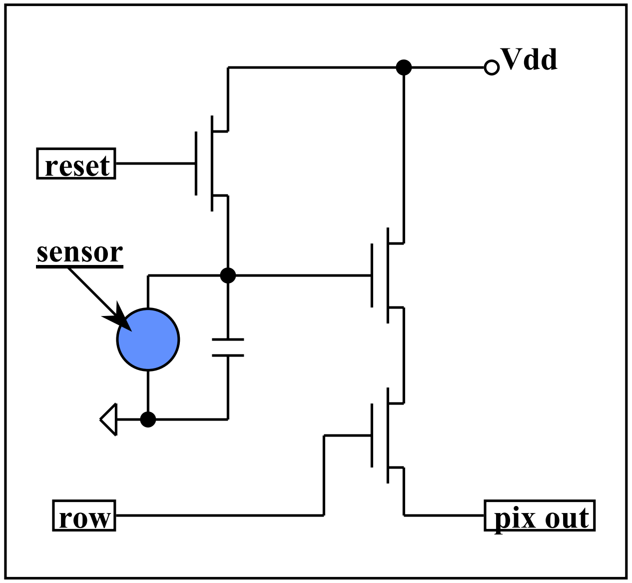
Component Summary

- **Detectors - CMOS Active Pixel Sensor Arrays**
  - **Custom detector functioning**
  - **Cheaper to produce than CCDs =>$300 going to $30**
  - **Lower power, Less heat, Lower noise**
  - **Optimization of data throughput**



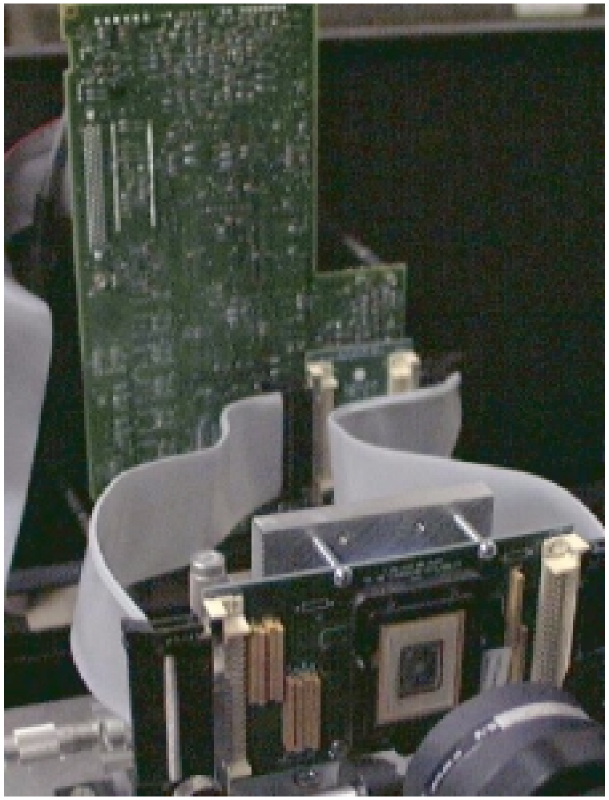
Developed for digital camera market.

Schematic of a single pixel



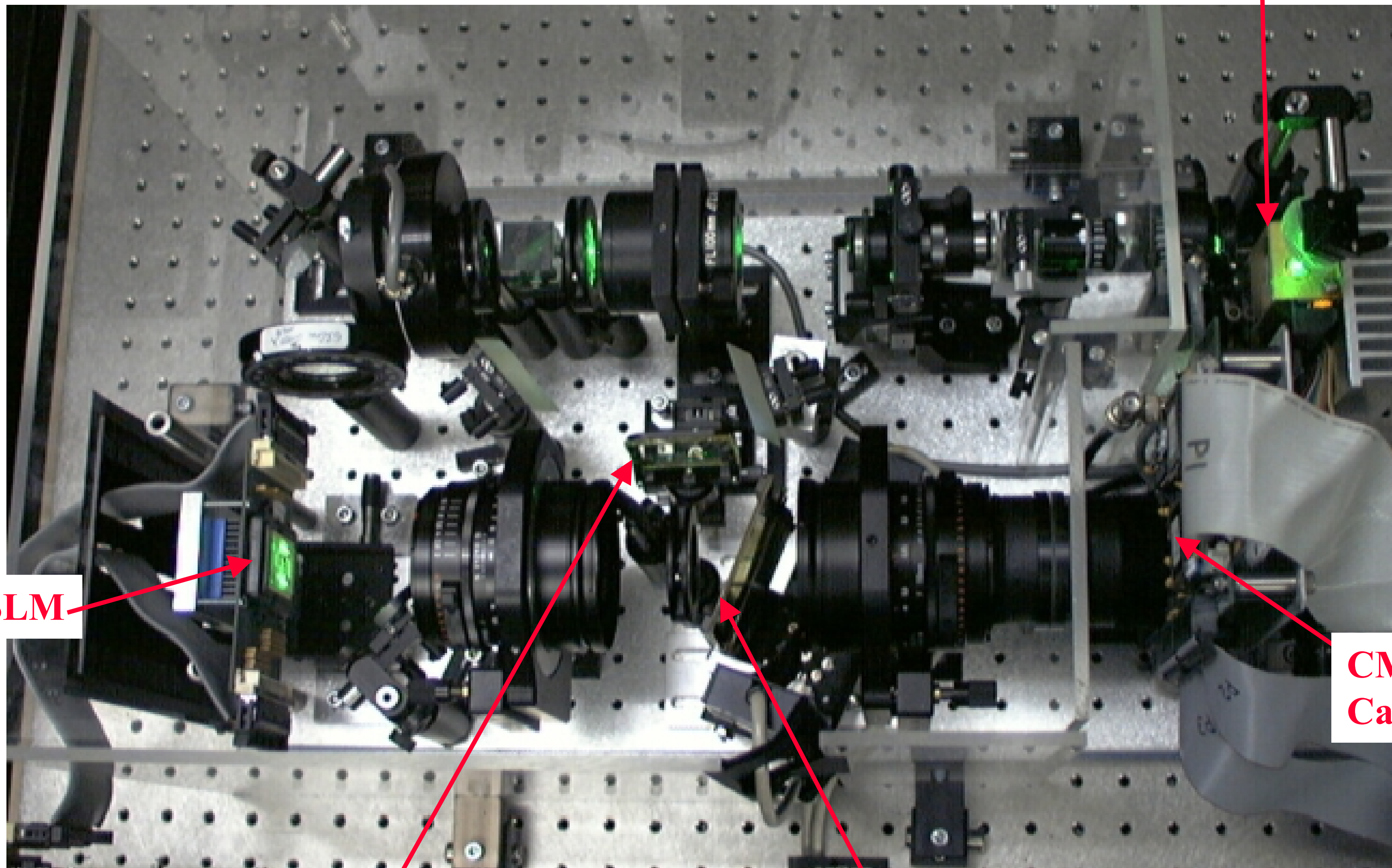
Component Summary

- **SLM - DMD, Ferroelectric, LC -Silicon**
  - **2,000 frames/sec**
  - **80% light throughput, 30-50% 0th order**
  - **Contrast, ~1000:1**
  - **1280 x 1024 pixels**



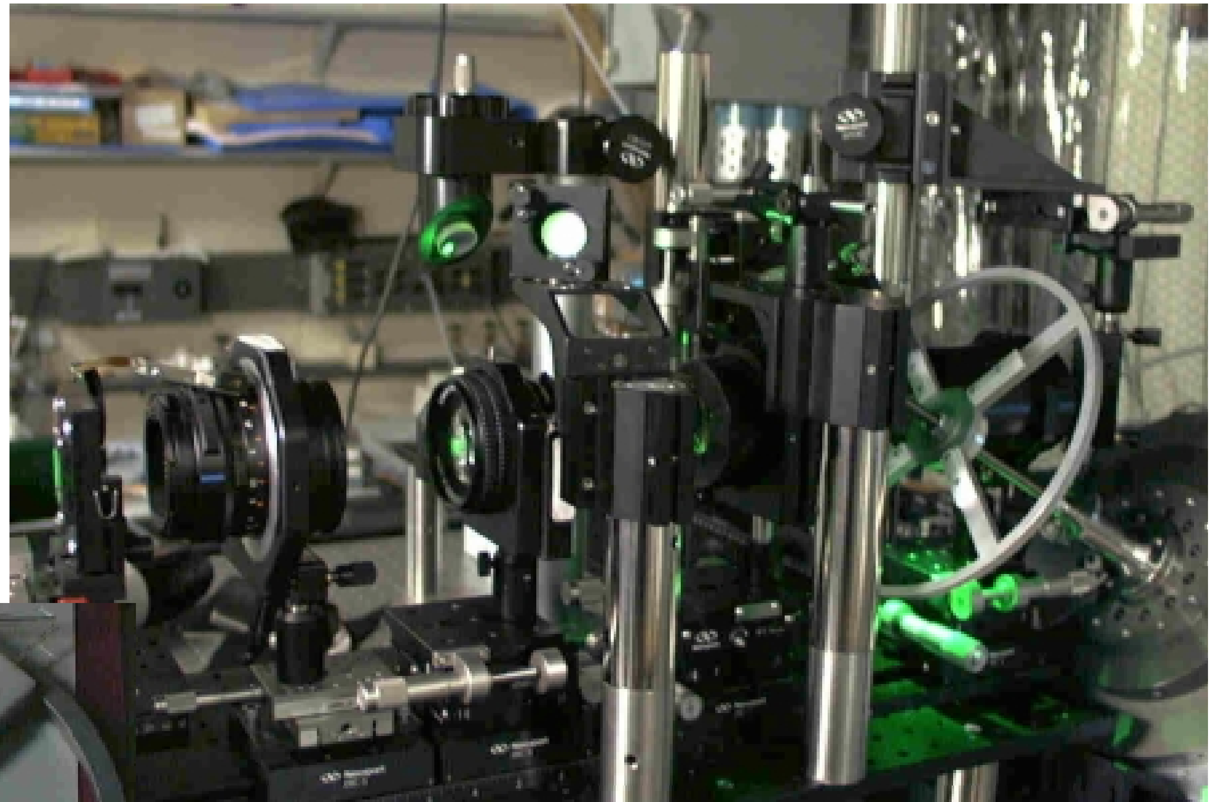
Developed for display market.

X-Y Setup



1 x 2 foot area

Rotation Setup



Experimental drive

First “disks”

Past Problems with Holography

- Material - No acceptable material and requirements only vaguely known
- Methods - Complex and difficult, limited density
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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

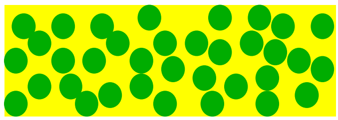
Long shelf-life of media

Long archival life of stored data

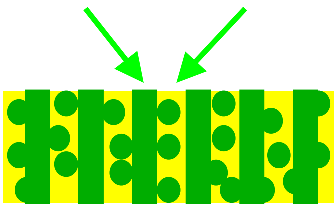
Environmental/thermal stability

Grating Formation in Conventional Photopolymer Systems

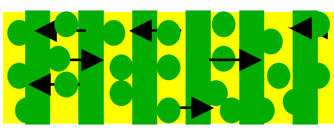
Mechanism



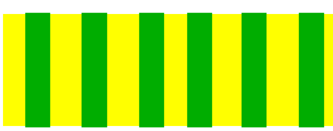
System consists of monomers dissolved in a matrix.



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.

Advantages

- High photosensitivity
- Permanent holograms
- Low cost

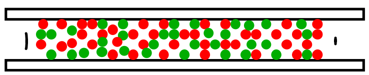
Problems

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

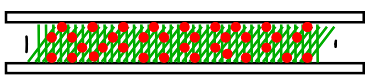
Bell Labs Proprietary Photopolymer System

Two Chemistry Approach

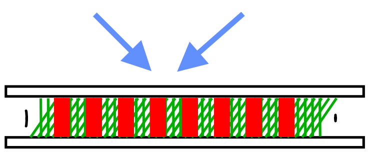
Media are fabricated from independently polymerizable
and compatible matrix and imaging components



Resin consists of matrix precursors and imaging components



In-situ formation of cross-linked matrix

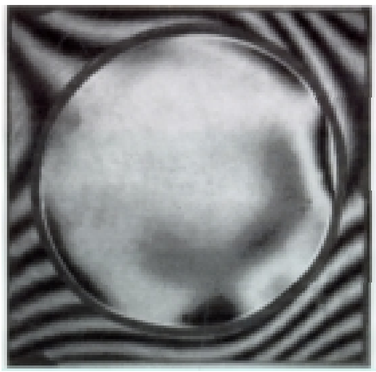


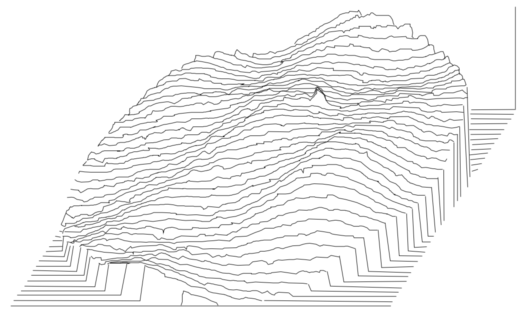
Writing chemistry is independent of host formation chemistry

- **In-situ matrix formation**: thick, optically flat formats 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.

Optical Quality & Thick Media: In-Situ Matrix Formation:

Transmission Interferogram of Media

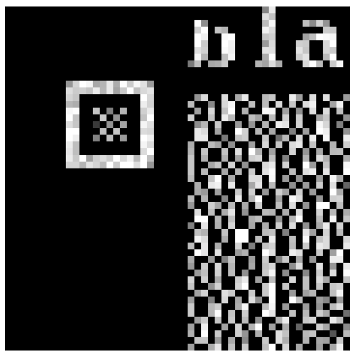




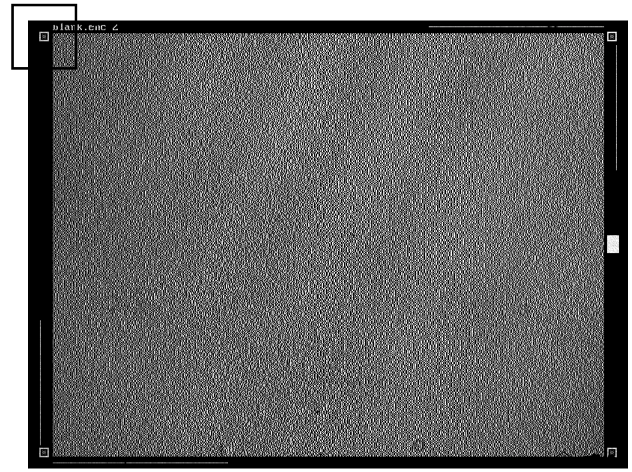
3" x 3", 1 mm-thick media

Routine fabrication of media with better than λ/4 / cm flatness enables high fidelity data storage and recovery

☑ Optical Quality:
Pixel Matching with Low Bit Error Rates



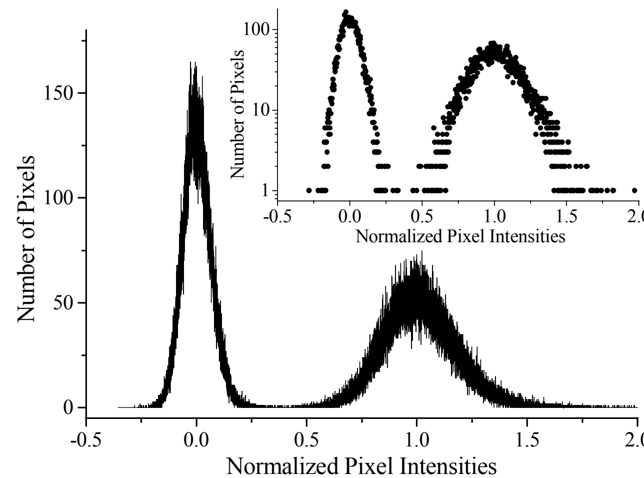
Expanded view of
corner pixels



Transmitted 800x600
data page

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

Raw BER ~ 10^{-6}



Lucent Technologies Proprietary

Lucent Technologies
Bell Labs Innovations

Dynamic Range:

Tunable Dynamic Range with Controlled Dimensional Change

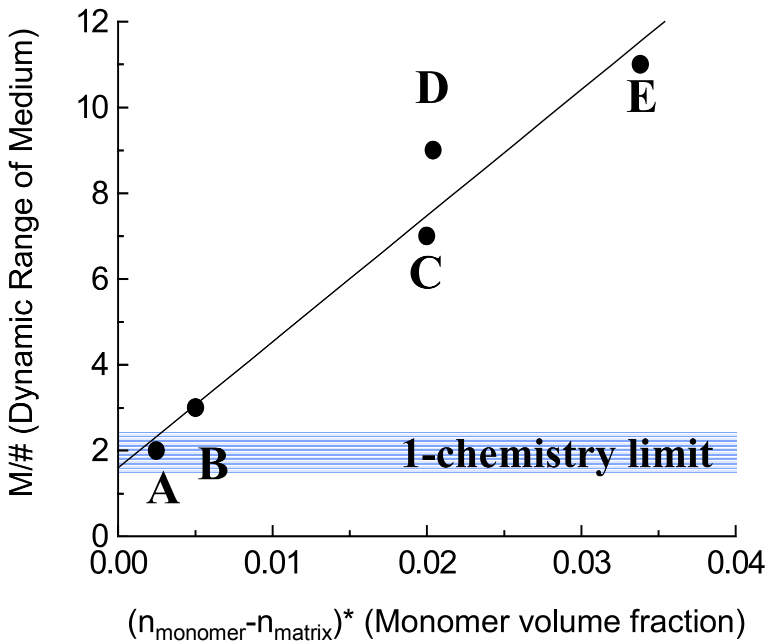
Measure of Dynamic Range: M/#

$M/\# = N * (\eta)^{1/2}$

$M/\# = (\Delta n) * (\text{thickness})$

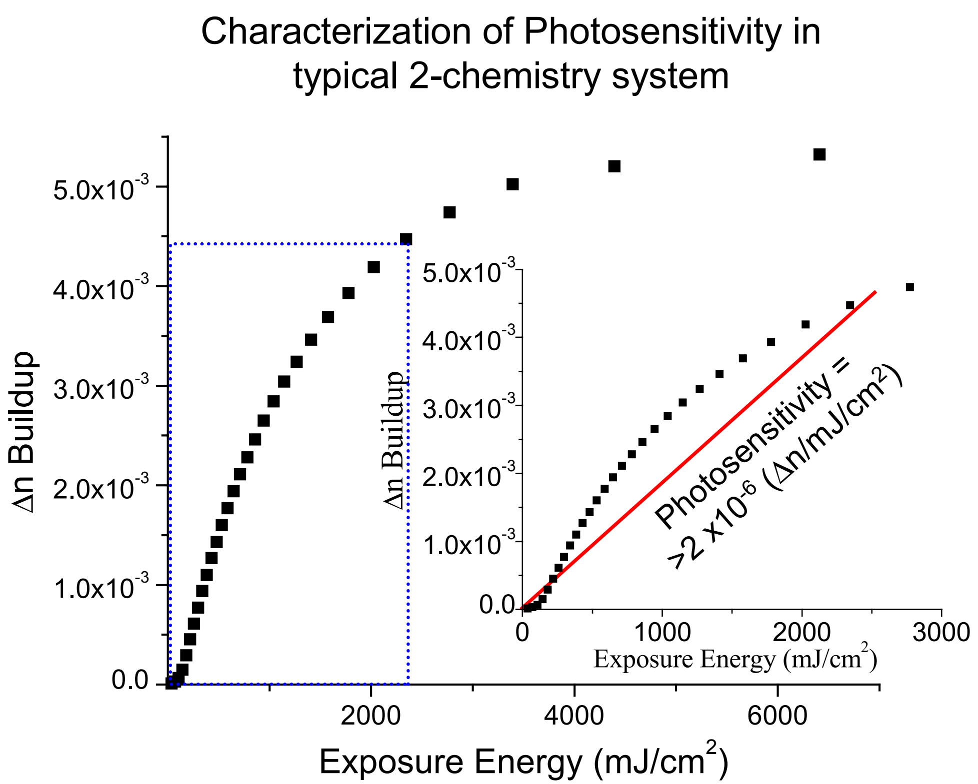
Require media with **M/#'s > 10**
with ~0.1% dimensional change.

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



☑ Photosensitivity:

Sensitivity to enable rapid write rates

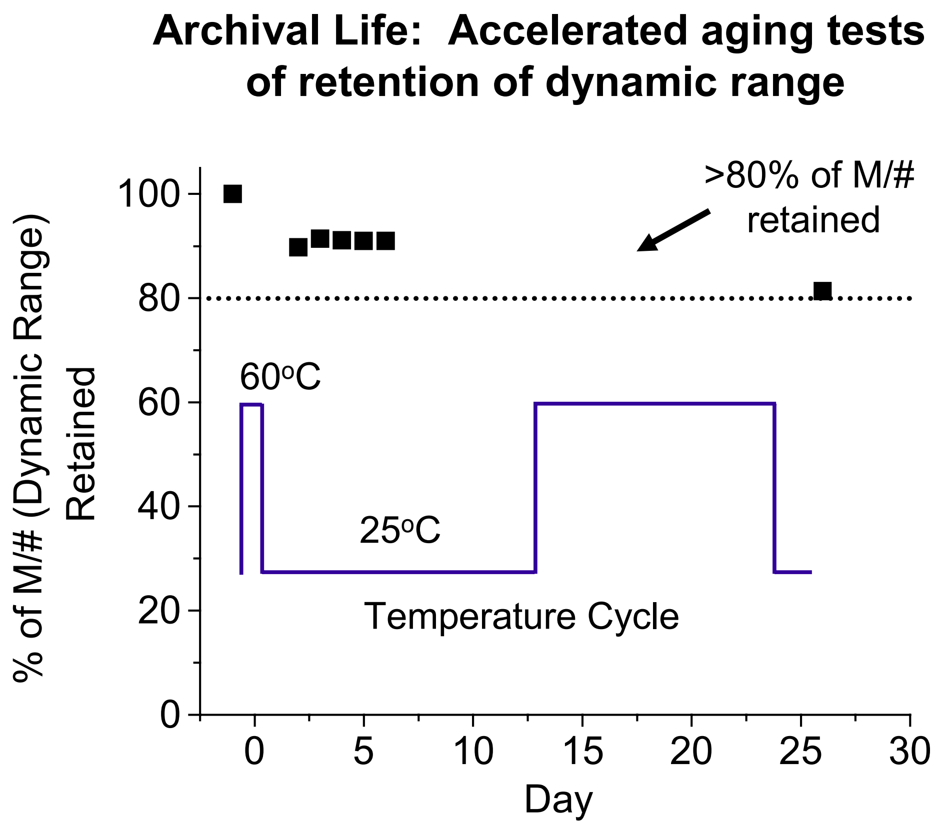


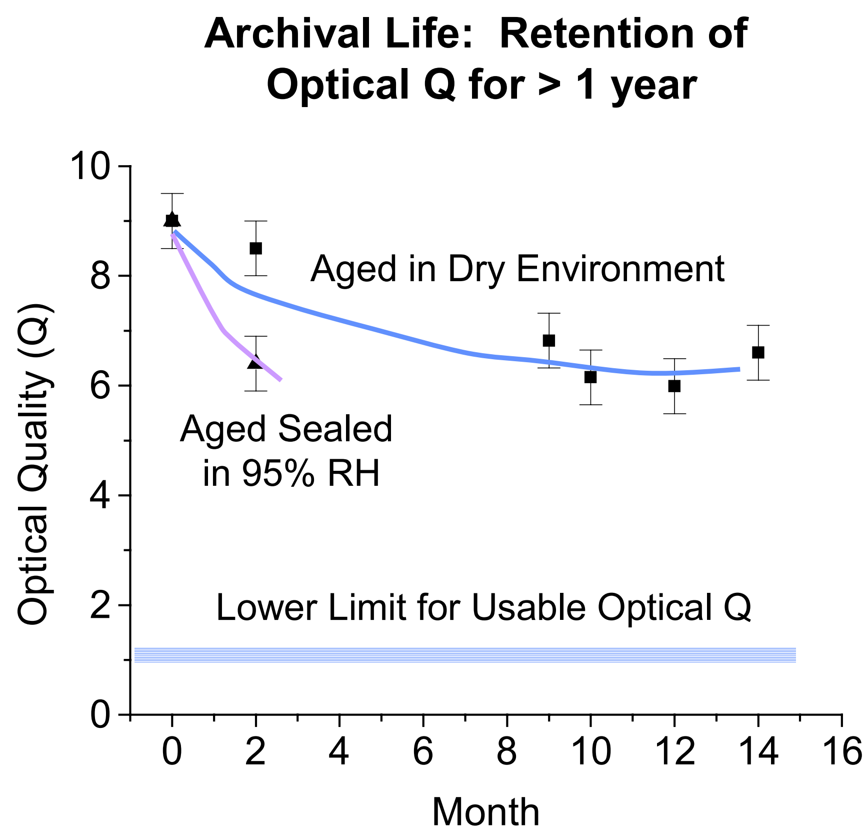
To enable 20 MB/s write rates:

$\Delta n/(mJ/cm^2) \geq 1.2 \times 10^{-6}$

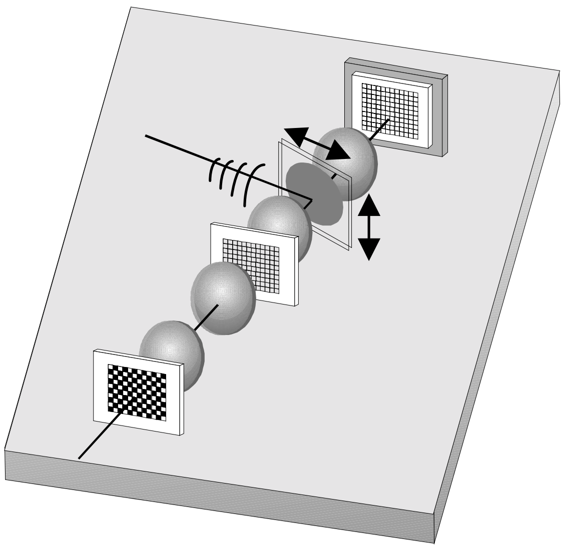
Range of Bell Labs Systems:
$1.5 - 9 \times 10^{-6}$

Archival Life:

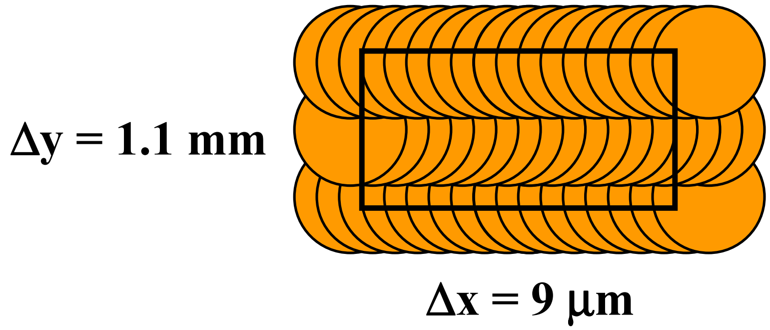


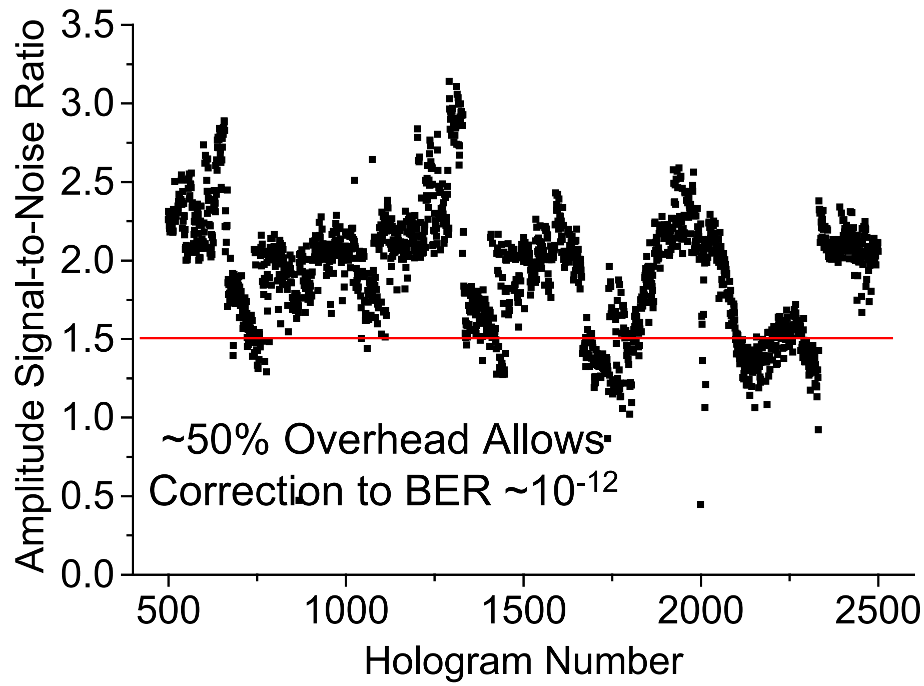


Digital Data Storage Capabilities:



Spherical wave multiplexing used to record 4000 480 kbit data pages.





At 48 bits/um^2 density

Present Status Photopolymer Media

	Density Experiment	Improved	Goal
Storage Density	48 bits/μm^2	being tested	$\geq$300 bits/μm^2
Dynamic Range (M/# at 1mm)	3-4	>20	10-15
Photosensitivity ($\Delta n/(nJ/cm^2)$)	0.18	9	1.2
Millimeter Thickness	1 mm	1 mm	1 mm
Shrinkage	0.1%	0.1%	0.1%
Optical Flatness	<λ/4 /cm	<λ/4 /cm	<λ/2 /cm
Low Scatter (of ref. power)	$<10^{-6}$	$<10^{-6}$	$\leq 10^{-6}$
Heat/Solvent-Free Processing	✓	✓	✓
Non-volatile readout	✓	✓	✓
Shelf-life of media	tested >7 months	in test	>1 year
Archival life of stored data	tests underway		>30 years
Environmental/thermal stability	may require compensation		

Summary

- Fundamental technology has been developed for a very high performance storage device.
- Need to develop product level proof of concept prototype (18 mo.)
- Starting company to focus the development.
- Partnering with industry leaders to start this process. - Imation and a couple of drive companies.