Rewritable holographic memory

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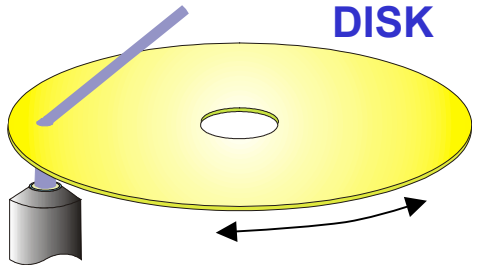
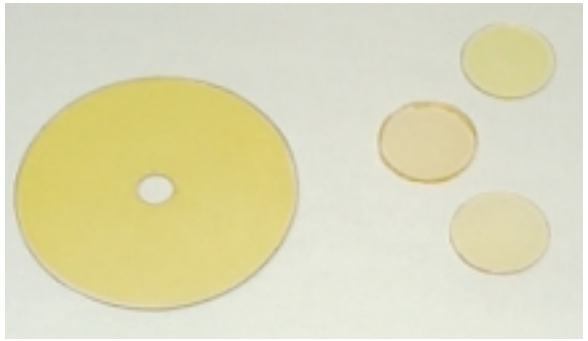
Outline

- Rewritable versus ROM/WORM holographic memories
- Can holographic memories replace magnetic disks?
- Compact HRAM module
- Recording material

Holographic Memory

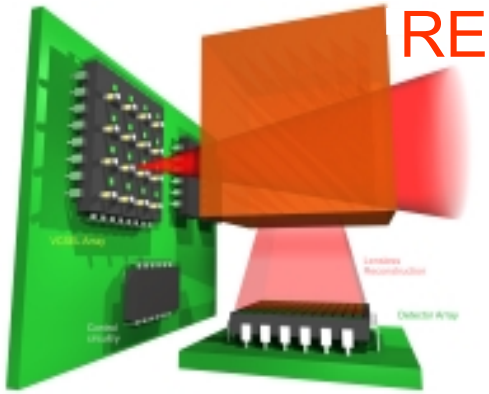
ROM/WORM



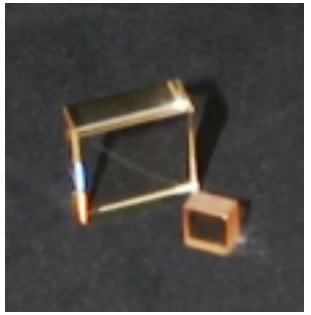


Photopolymers

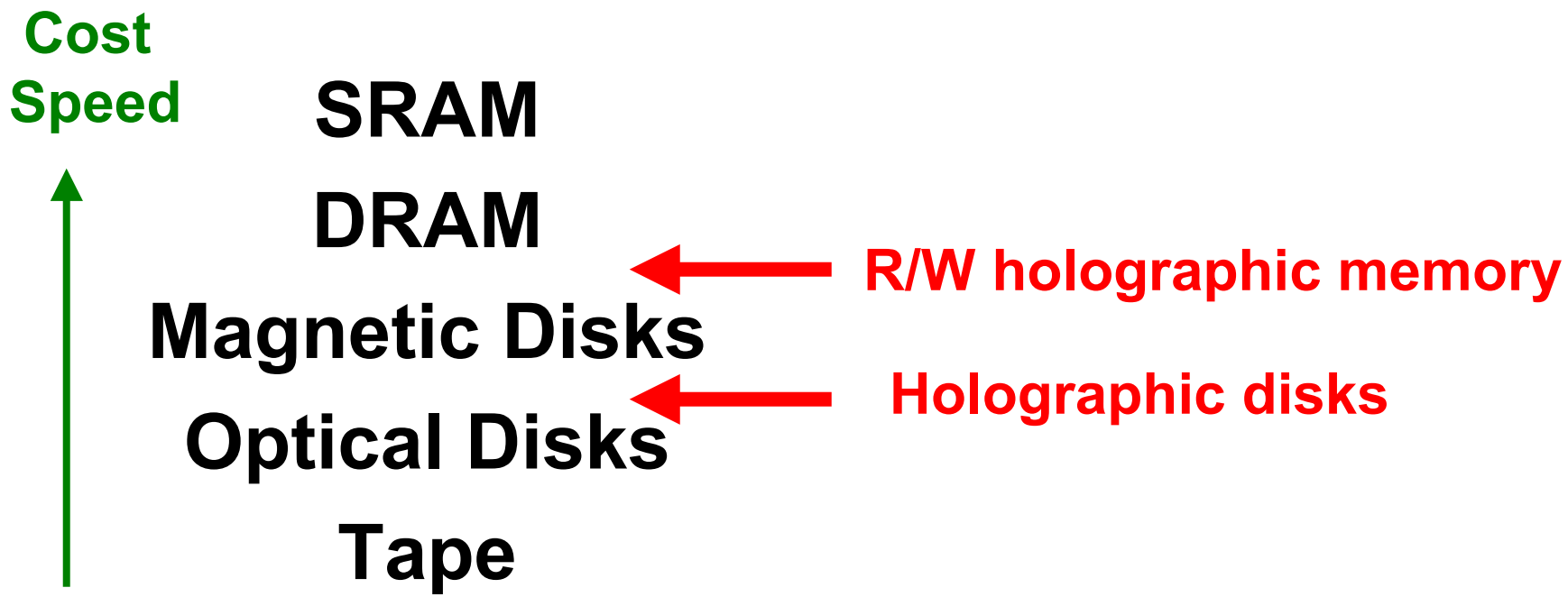
REWRITABLE



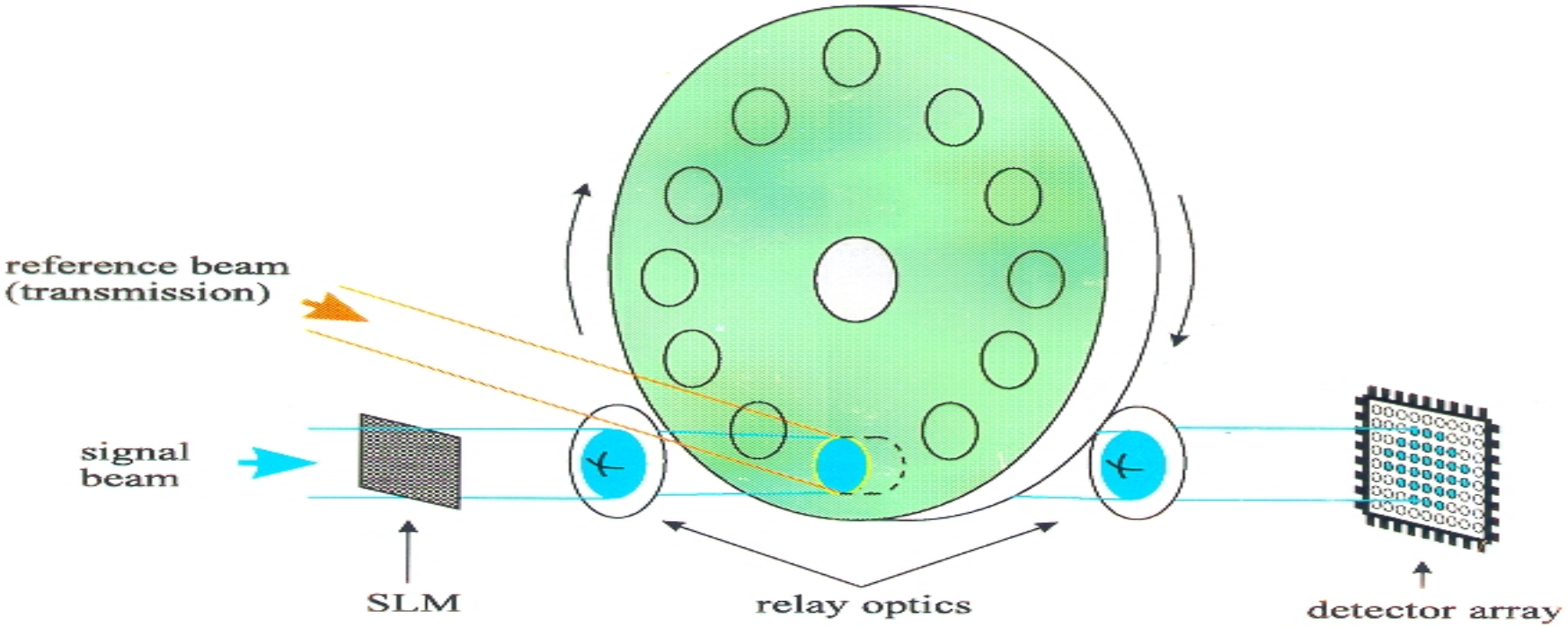
Photorefractives

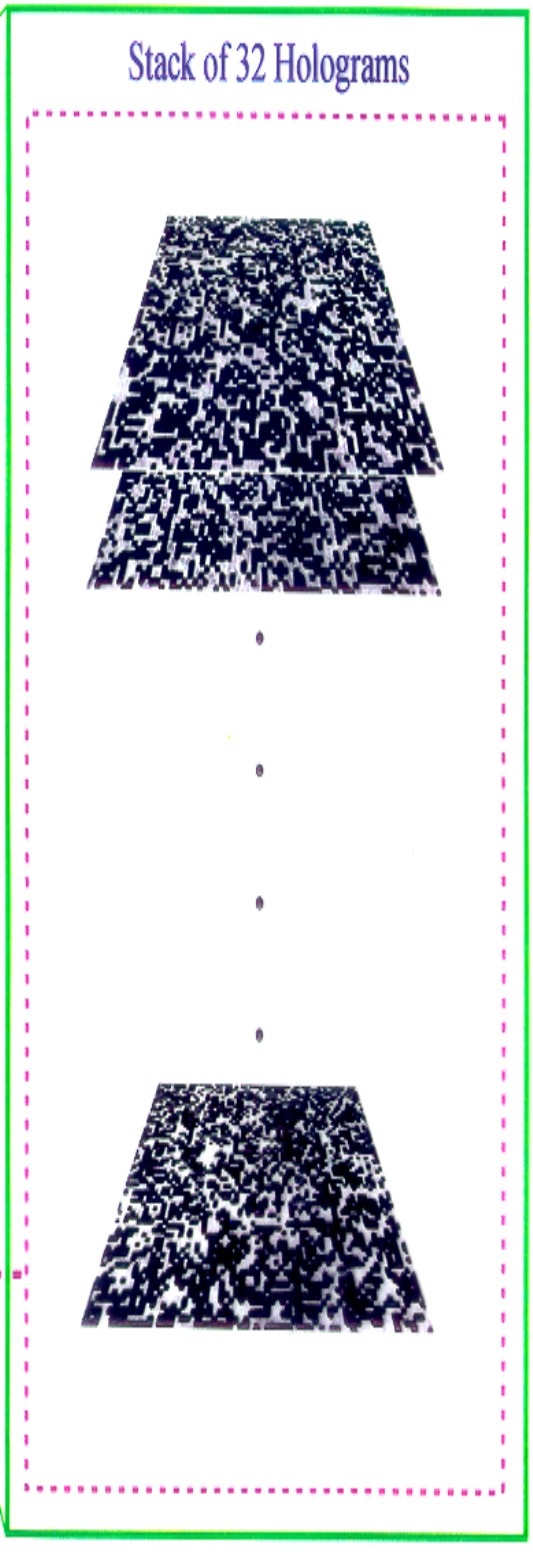


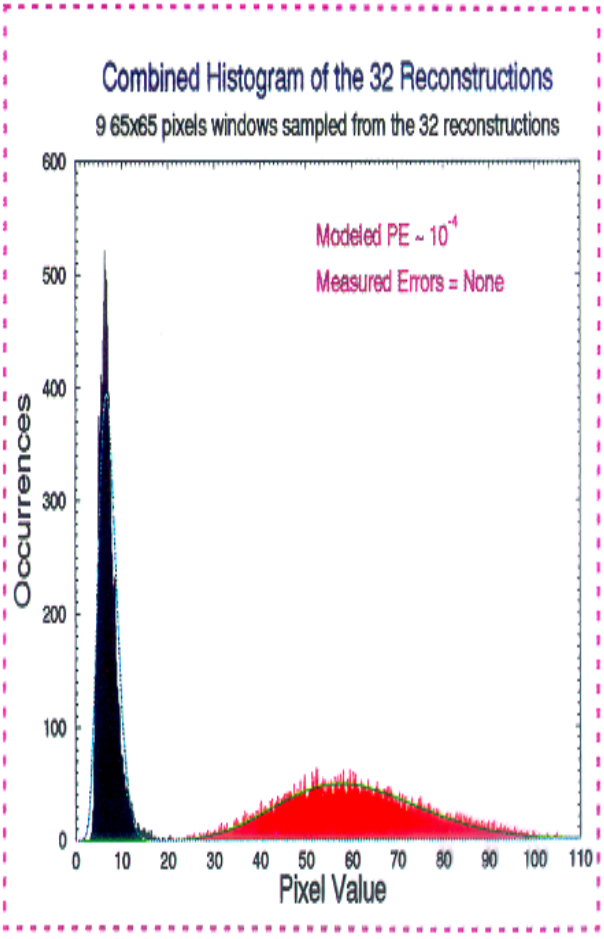
Memory Hierarchy



Holographic 3-D Disk



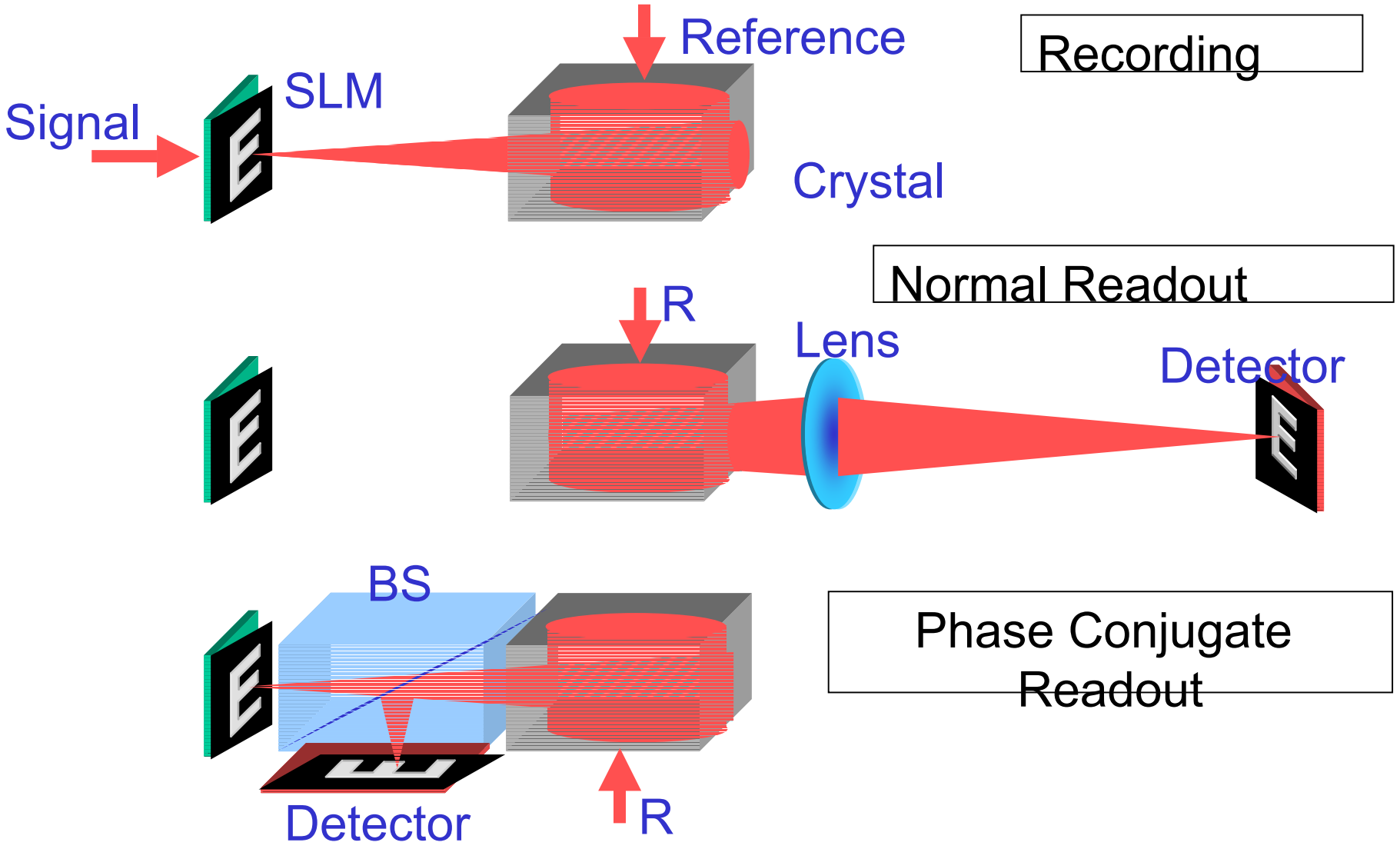

Stack of 32 Holograms


Combined Histogram of the 32 Reconstructions
9 65x65 pixels windows sampled from the 32 reconstructions
Modeled PE ~ 10^-4
Measured Errors = None
Occurrences
Pixel Value
0
100
200
300
400
500
600
0
10
20
30
40
50
60
70
80
90
100
110

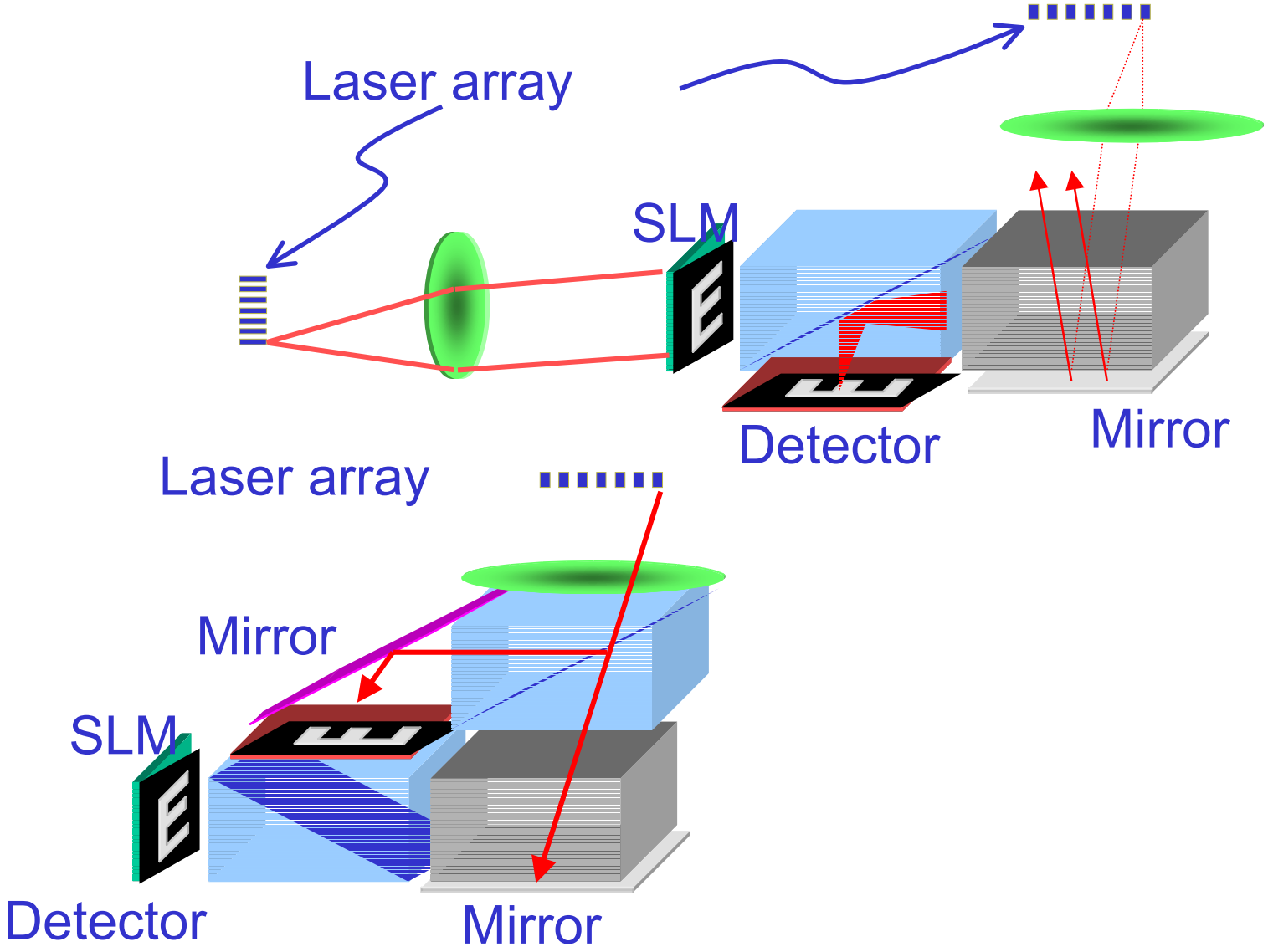
Rewritable holographic memories should be:

- **Faster** than magnetic disks
- **Cheaper** than DRAM

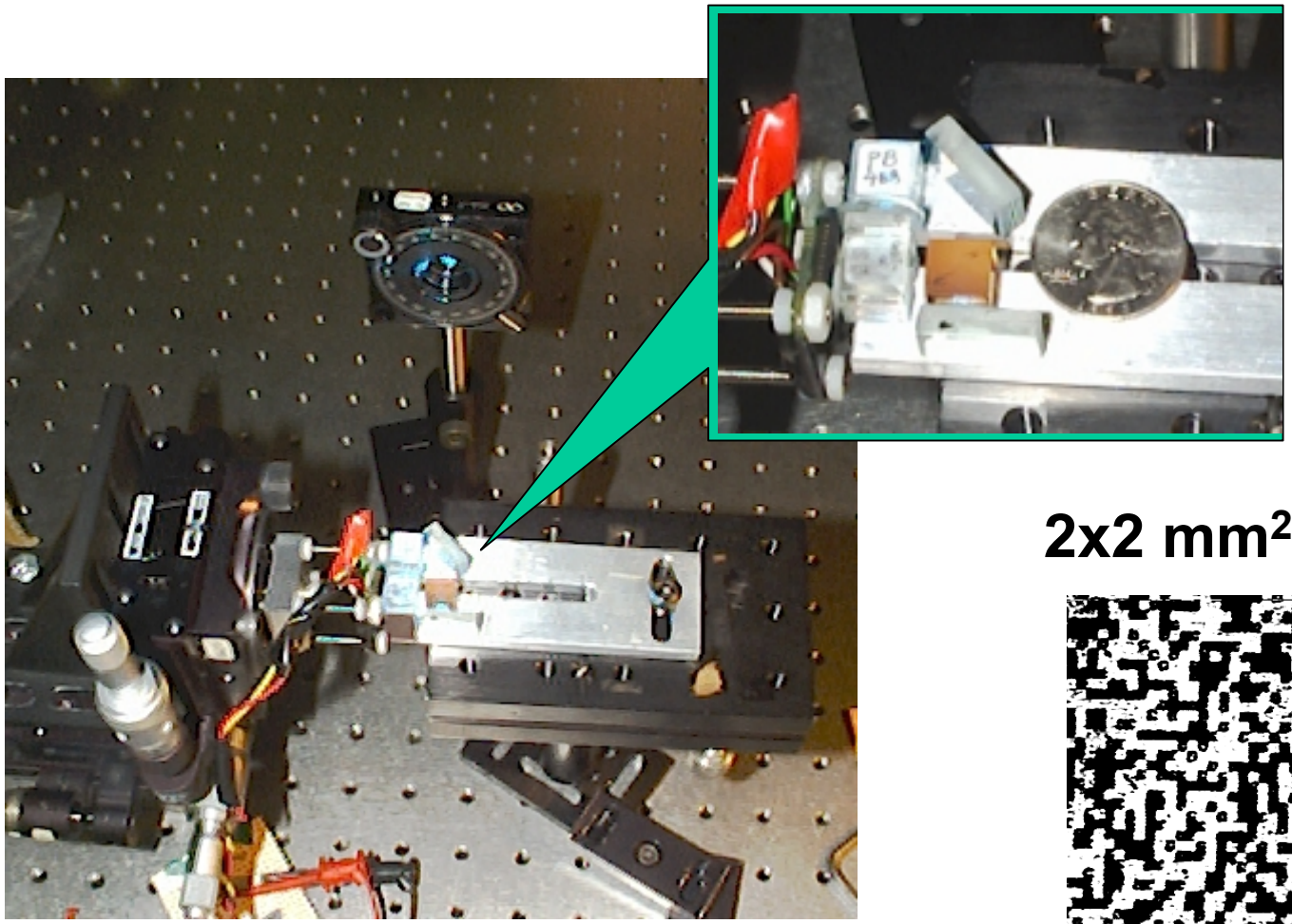
Phase Conjugate Readout



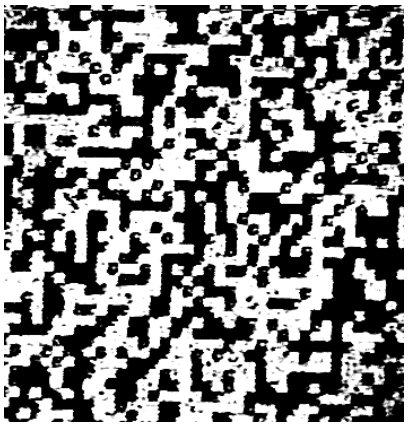
Holographic Multiplexing and Compact Module



Demo Setup and Reconstruction



2x2 mm^2 pixels



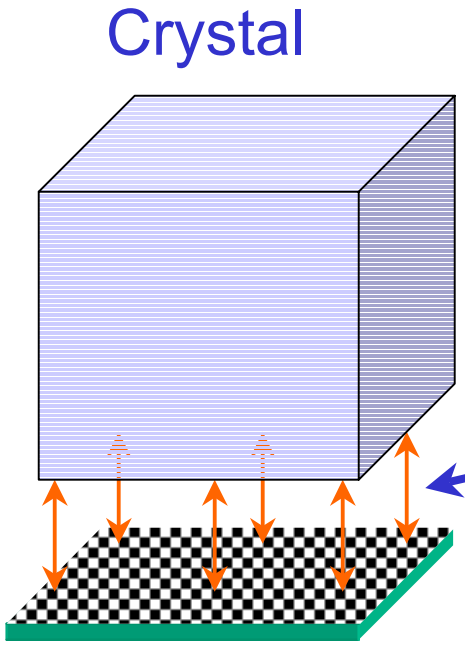
HRAM random access time

Photon budget

- number of pixels — *N=3,000*
- laser power — *I* =100 mW
- medium — *M/10*
- number of holograms — *M=1,000*
- number of photons — N_p=300

$$\tau = \frac{h\nu \, N_p M^2 N^2}{I \cdot (M/\#)^2} < 100\mu s$$

Recording and Readout Rate



$$\text{Recording Rate} = \frac{N^2}{\tau_{record}}$$

$$\text{Readout Rate} = \frac{N^2}{\tau_{read}}$$

$\tau_{record} = 100\ \text{msec}, \quad \tau_{read} = 100\ \mu\text{sec}$

N^2 channels

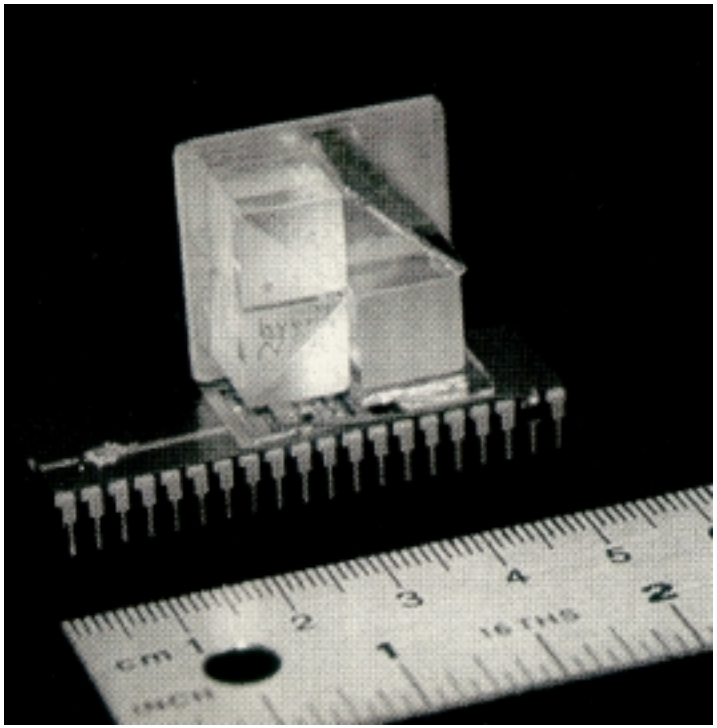
For $N^2 = 8 \times 10^6 = 1$ MB,

Recording: 10 MB/sec

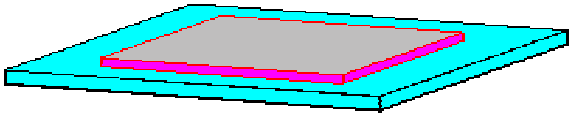
Readout: 10 GB/sec

HRAM Module

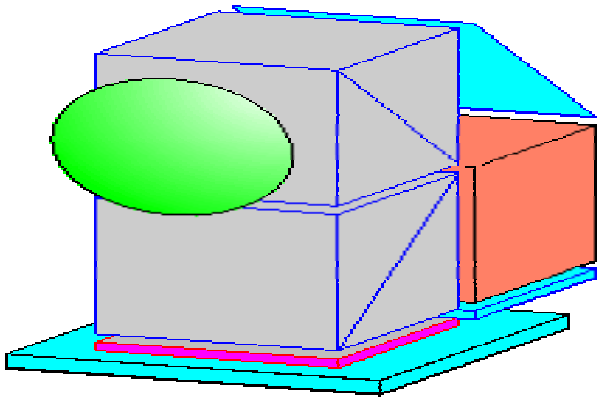
Capacity	**1 GB**
Access time	**100μs**
Recording bandwidth	**10 MB/s**
Readout bandwidth	**10GB/s**
Size (cm)	**1x2x2**



Cost Comparison



DRAM

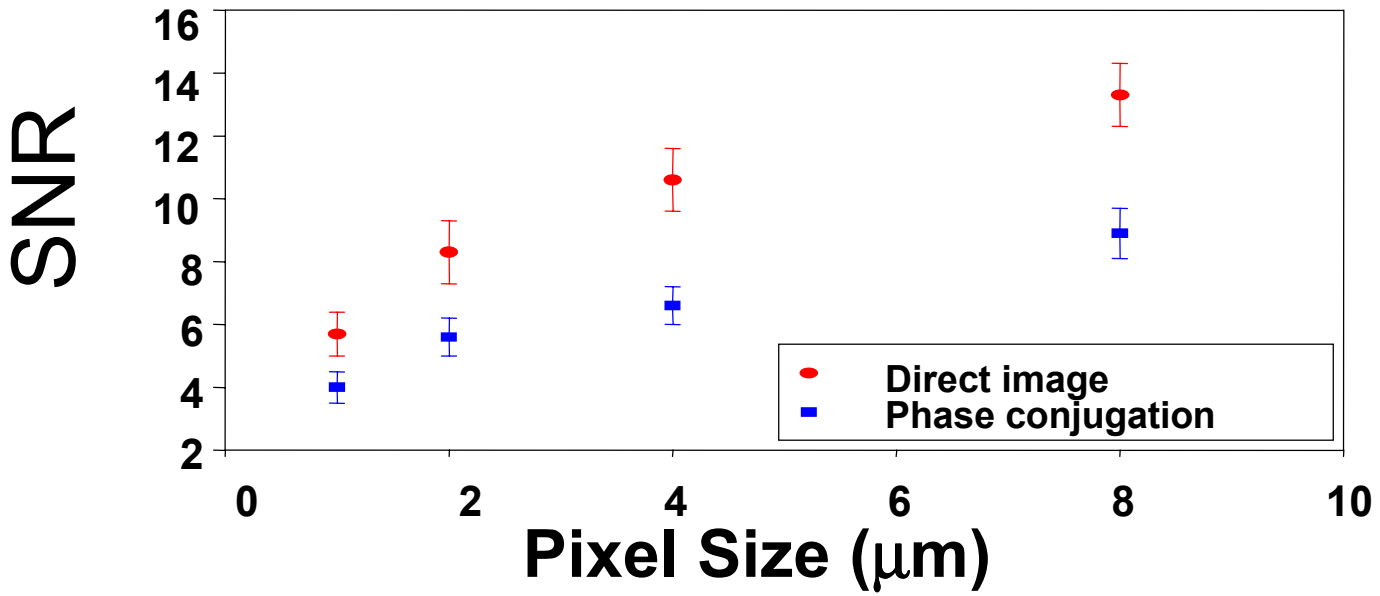


HRAM(**M pages**)

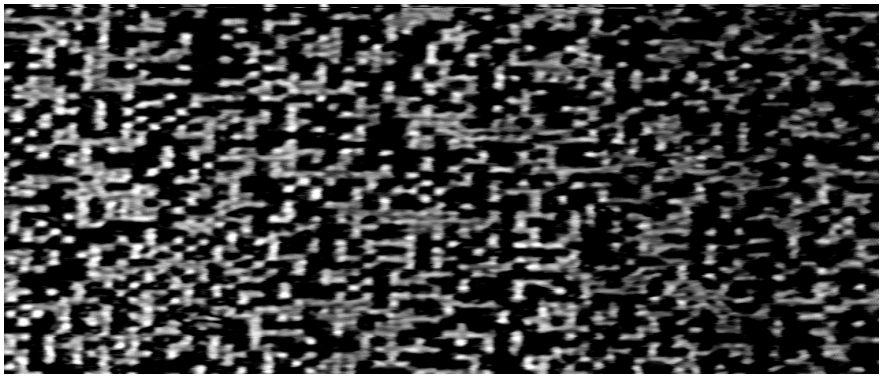
$$\frac{\text{Cost of HRAM}}{\text{Cost of DRAM}} = \underbrace{\frac{\text{Cost}_{\text{optics}} + \text{Cost}_{\text{Si}}}{\text{Cost}_{\text{Si}}}}_{\approx 2} \cdot \underbrace{\frac{\text{SLM pixel area}}{\text{DRAM cell area}}}_{25} \cdot \underbrace{\frac{1}{M}}_{10^{-3}} = \frac{1}{20}$$

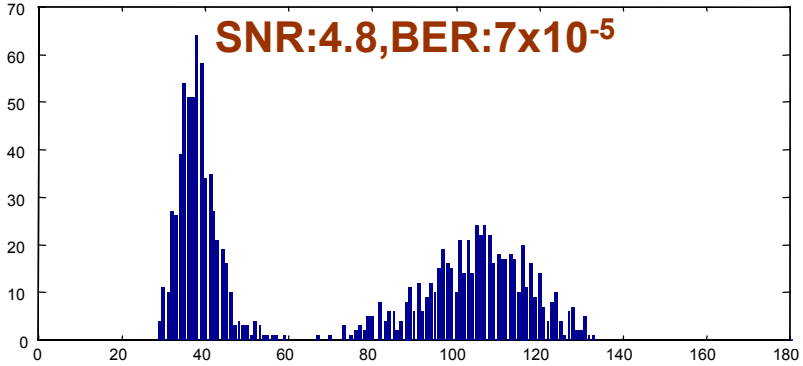
	1998	2006
DRAM cell(/bit)	1 x 1 μm^2	0.04 μm^2
HRAM pixel(/bit)	5 x 5 μm^2	1 x 1 μm^2

SNR vs. Pixel Size

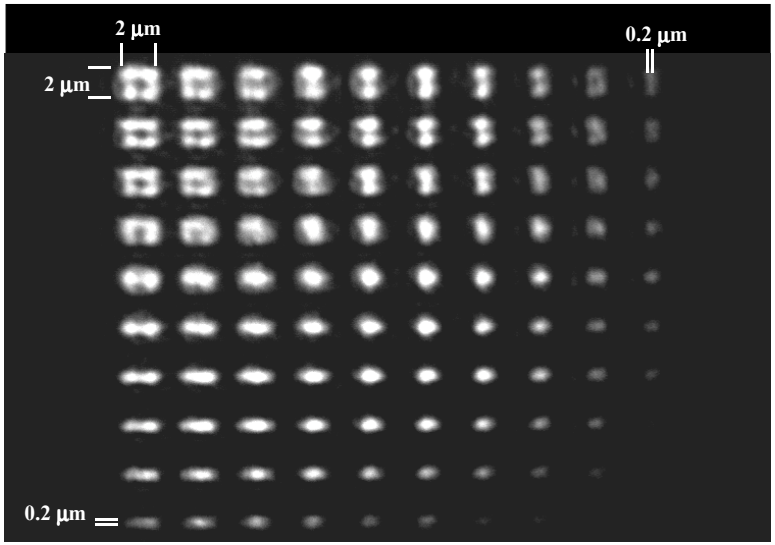


1x1μm² pixel reconstruction



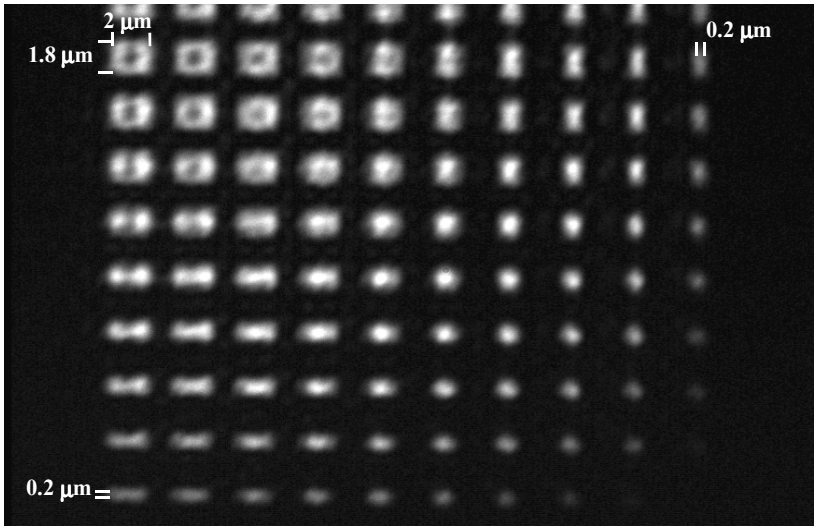


Mask With Various Pixel Sizes



Microscope image:
(Nikon lens, NA0.65)

Phase Conjugate
Reconstruction:
(Nikon lens,NA 0.65)



Components

- SLM

  MicroDisplay: 1024x768,
  pitch 12.5 micron
  frame rate: 30-180 Hz

- Detector

  Photobit: 1040x1040
  pitch: 10 micron
  frame rate: 500 Hz

- Laser diode

  SDL: 30 mW, 630nm

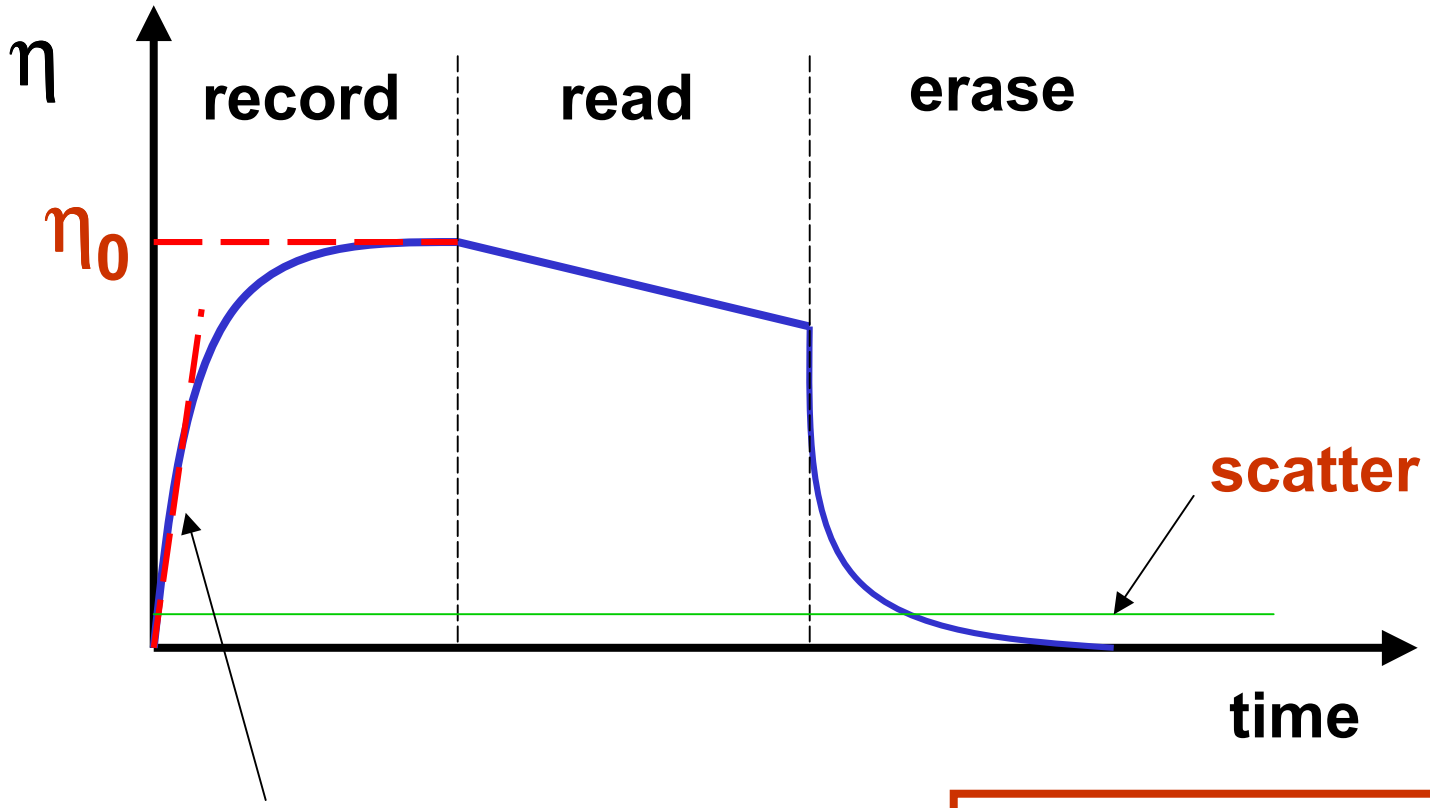
HRAM components

	Currently available	Requirement (1 GB module)
SLM	1000x1000 10 μm	3000x3000 3 μm
Detector	1000x1000 5 μm	3000x3000 3 μm
Laser	Single laser plus mechanical scanning	Laser array or wavelength tunable
Material	M/1, S=0.1cm/J, Volatile, non-persistent	M/10, S=1cm/J Nonvolatile, persistent

Multiplexing Laser

	Pro	Con
VCSEL array	Fast switching	Low power
Electrically tunable laser diode	Simple; compact	Availability at visible wavelength; cost
Single laser plus MEMS scanning	High power	Speed ?
Hybrid (eg. 100 lasers + MEMS, one or multiple wavelengths)	High power, Fast scanning	Expensive? Bulky?

Recording and erasure characteristics



Sensitivity

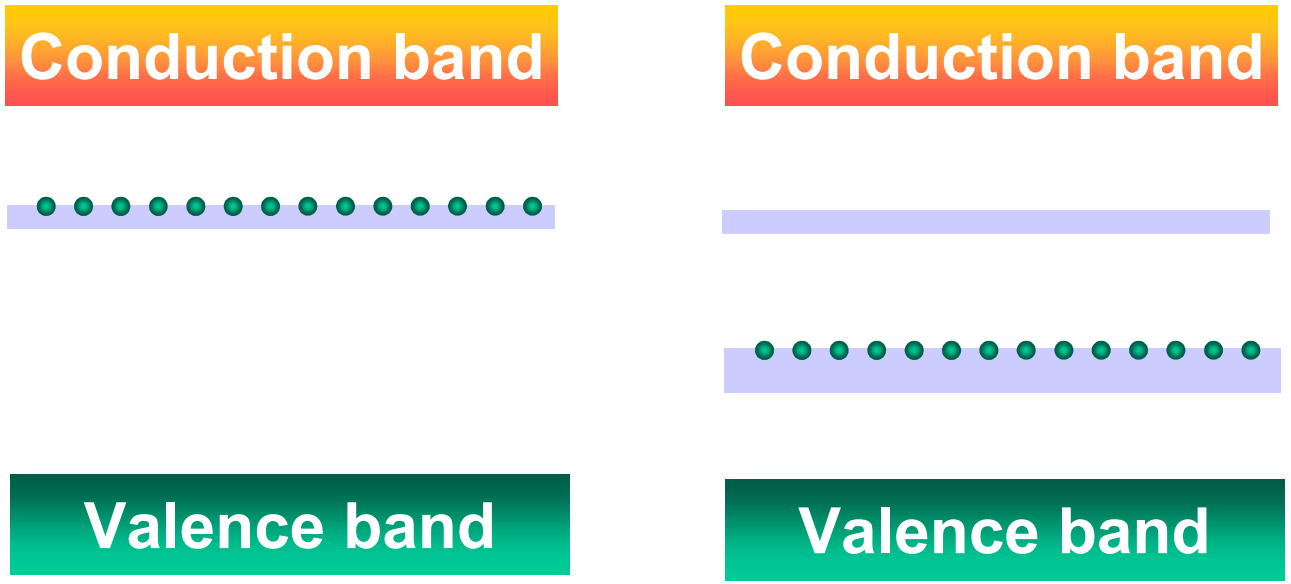
$$S = \frac{d\sqrt{\eta}/d\,t}{I\,L} \quad \textbf{(cm/J)}$$

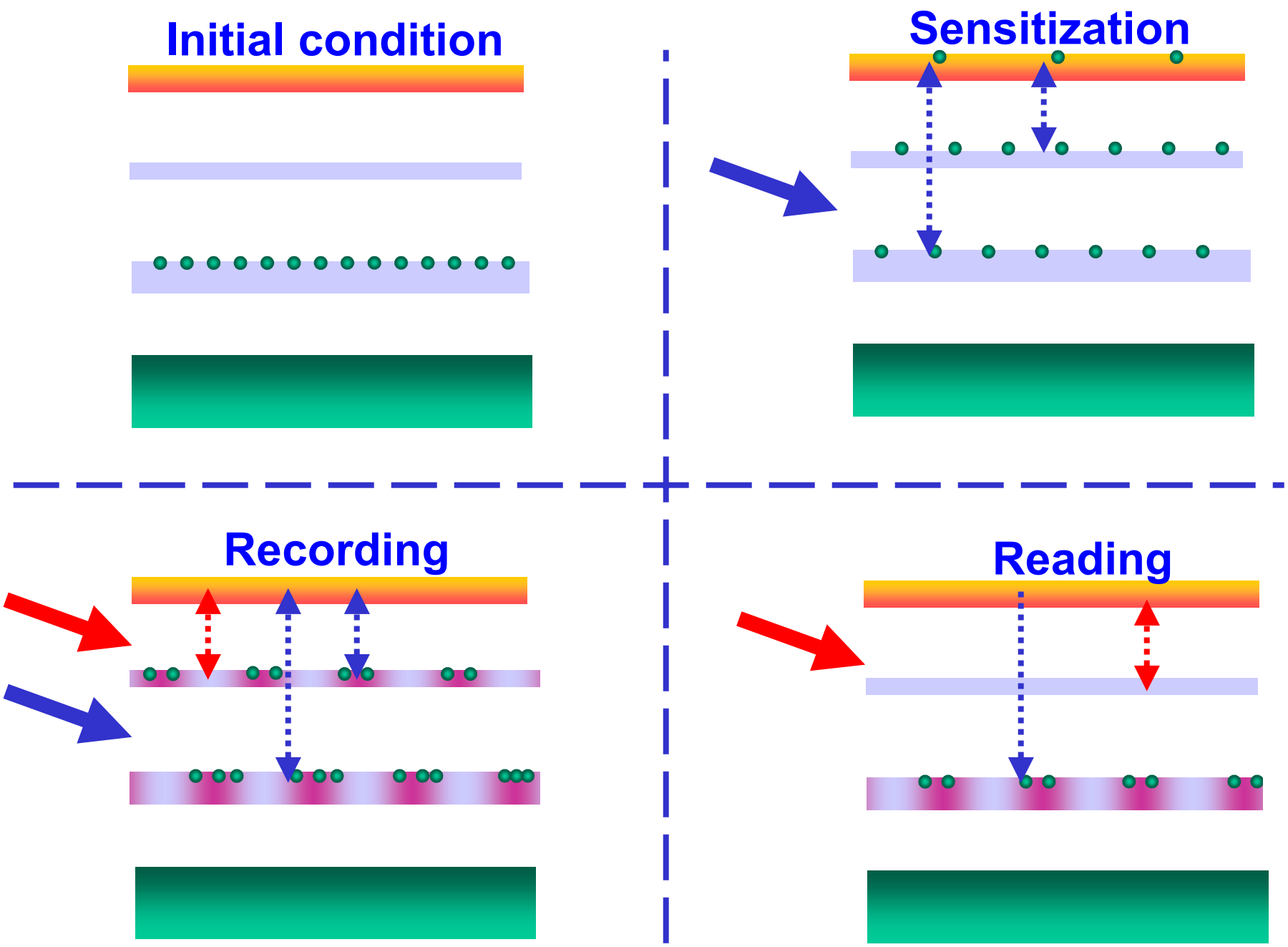
$$\eta = \left(\frac{M/\#}{M} \right)^2$$

$$M/\# = \frac{\sqrt{\eta_0}\,\tau_e}{\tau_w}$$

Material Requirements

Resolution:	**pixel size < 3 μm**
Sensitivity:	**recording time = 100 msec**
S=1 cm/J	**@ I= 100 mW/cm2**
Dynamic range:	**read-out time = 100 μsec**
M/#=10	**@ M=1,000 holograms**
Persistence:	**decay time > 100,000 sec**


Conduction band
Valence band
Conduction band
Valence band


Initial condition
Sensitization
Recording
Reading

Conclusion

- Small pixel area is important for a competitive HRAM
- Compact, modular design using phase conjugate read-out
- Doubly-doped lithium niobate is a promising recording material