MASS STORAGE AND RETRIEVAL AT ROME LABORATORY

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OUTLINE

- Why mass storage for the USAF?
- Why optical?
- Types of optical memory
  - Two-photon
  - Holographic
  - Others
- System considerations
- Outlook (short & long term)
- Summary

WHY MASS STORAGE FOR USAF

- Mission planning/intelligence
- Future requirements:

  ~ 350 TB on-line, 20 PB off line

  digital images, maps, etc.

  Access time

  data < 1 week ==> 5 seconds

  data < 2months==> 30 seconds

  data < 10 years==> ~ minutes
- Typical network: 10-100 users

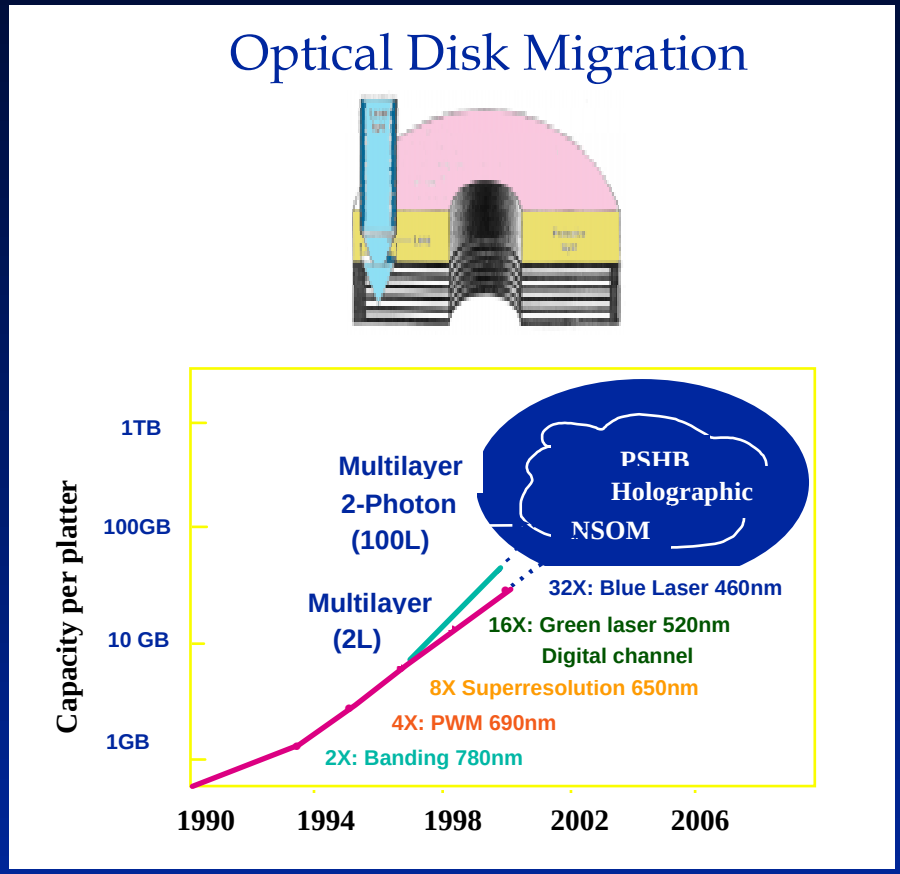
WHY OPTICAL STORAGE?

- Resolution ~ λ

  Blue laser diode??
- 2–D Now...3-D Soon??
- Parallel Recording/readout
- Large Working Distance

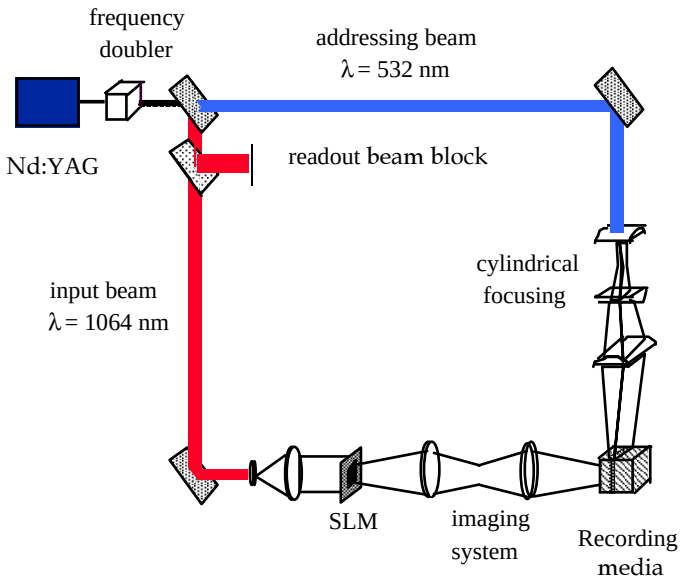
  No head crashes

  Dust & scratches okay??
- Key Components: MIA ??

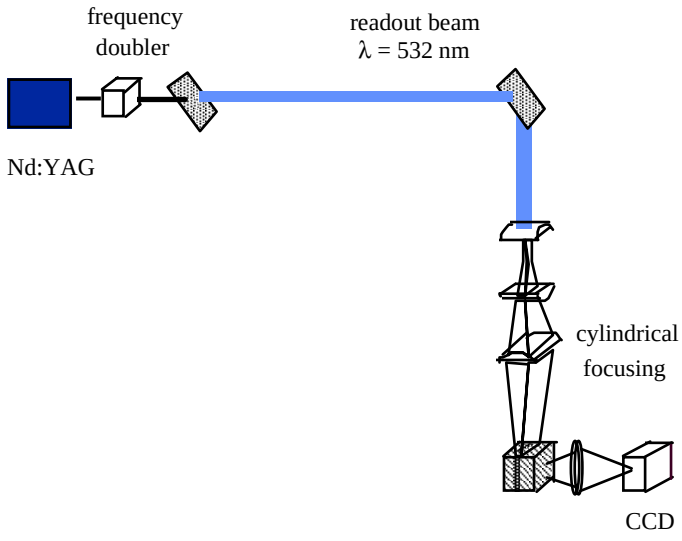


TWO-PHOTON STORAGE

Recording Setup



Readout Setup



TWO-PHOTON STORAGE

Advantages

- Tb/cm^3
- Parallel input/output
- Cheap materials
- High quantum efficiency
  read w/ LED

Disadvantages

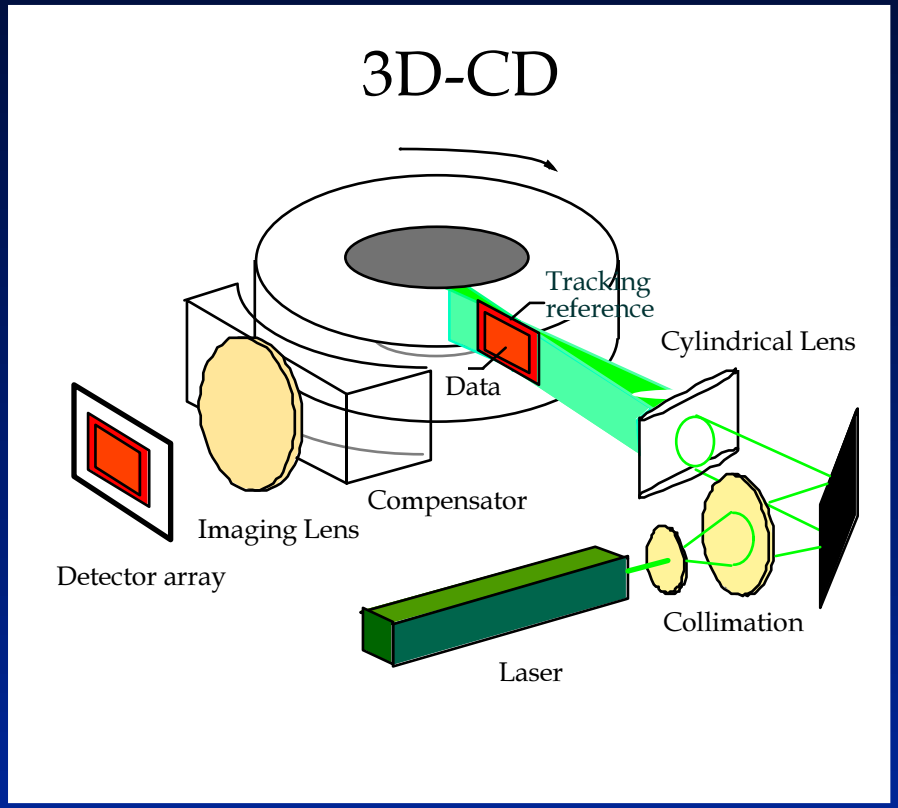
- High laser intensities (write)
- SLM/CCD's ??
- Dynamic focusing ??
- Parallelism vs. density

Current Status

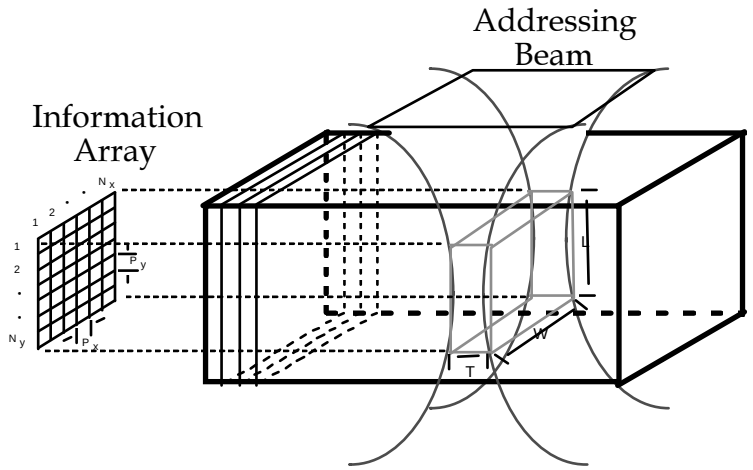
- ROM demo system built
  - Chrome mask input
  - Minimal density
  - (~1Gb/cm^3 shown)
  - Good early BER
  - Spirobenzopyran cm^3
- Work on R/W/E media
- Work on 3D-CD system
- Numerical modeling
- Thermal, pressure & aging studies

3D-CD

- Rotating volumetric disc
- Data stored as “spokes” vs. “planes”
- Eliminates dynamic focusing
- Loss of density vs. cube
- Tracking & focusing servos being studied
- Compensator ==> prevent spherical aberration
- Disc fabrication done



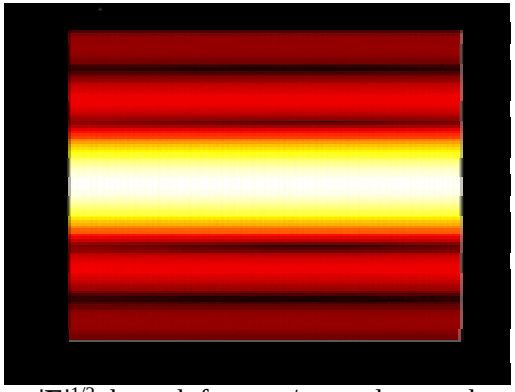
PARALLELISM vs. DENSITY



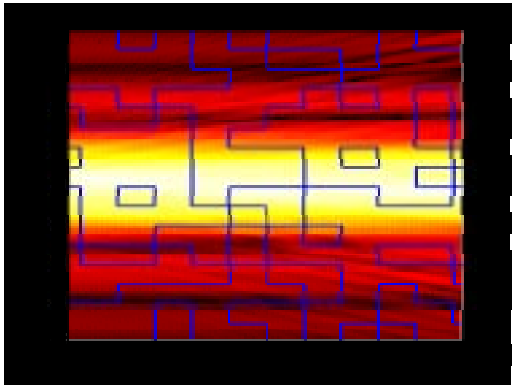
Data Format	Pixel Size P_x x P_y µm x µm	Array Size N_x x N_y	Addressing Beam Dimensions			MVD (bits/cm ^{3})
			Width $W = P_x N_x$ µm	Length $L = P_y N_y$ µm	Thickness µm	
Bit	1 x 1	1 x 1	1	1	1	1×10^{12}
Vector	5 x 5	256 x 1	1280	5	2	20×10^{9}
	5 x 5	1 x 256	5	1280	33	1.2×10^{9}
Image	5 x 5	16 x 16	80	80	8.2	4.9×10^{9}
	5 x 5	128 x 128	640	640	23	1.7×10^{9}
	10 x 10	1024 x1024	10240	10240	93	0.1×10^{9}

NUMERICAL MODELING

- Physical/geometrical optics, vector EM (FDTD) models used
- System analysis
  - Scattering effects
  - Non-linear effects
  - Aberrations
- System design
  - Optics/mechanics/electronics Equalization/signal processing
- Material models being developed
  - Sensitivity
  - R/W/E



$|\mathbf{E}|^{1/2}$ through focus w/o any data marks



$|\mathbf{E}|^{1/2}$ through focus w/ data marks (Δn=4xSP)

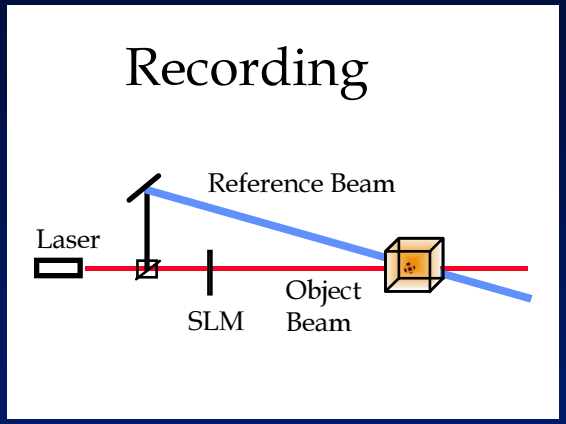
HOLOGRAPHIC STORAGE

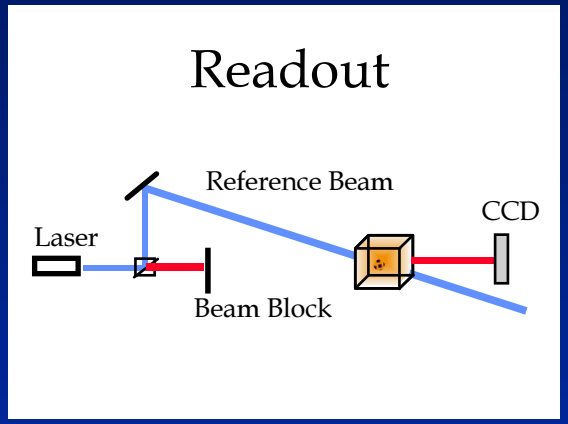
- Recording

  Record interference of reference & object beam

  Data encoded on object beam
- Readout

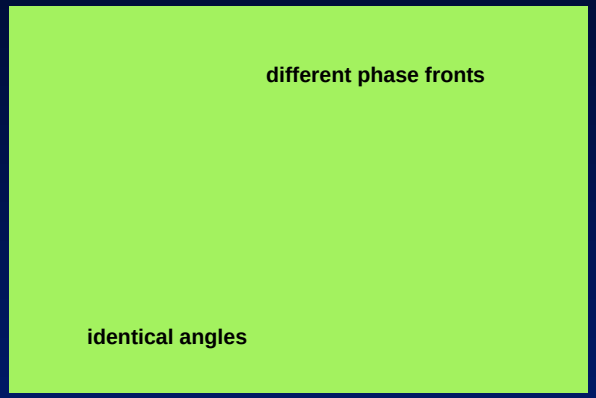
  Reference “replays” object
- Thick vs. thin hologram
- Thick ==> multiplexing
- Crystals vs. Polymers





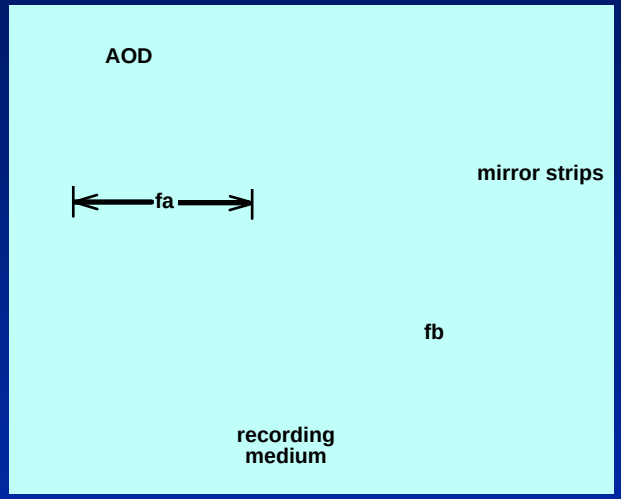
MULTIPLEXING TECHNIQUES

PHASE MULTIPLEXING



ANGLE MULTIPLEXING

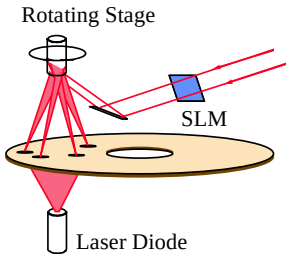
SPATIAL MULTIPLEXING



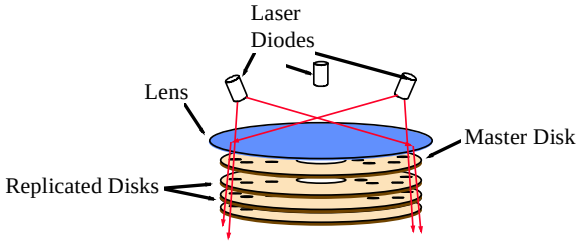
- Multiplexing==>3rd dimension
- Mechanical parts required??
- Thick crystals==>better Bragg selectivity
- Diffraction efficiency $\propto 1/(\#\ \text{holog})^2$
  - More holograms==>longer read time
  - Complex recording schedule
- Possible encryption method??

PHOTOPOLYMER DISK

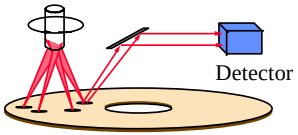
Recording



Replicating



Reading



HOLOGRAPHIC STORAGE

Advantages

- Tb/cm^3
- Parallel input/output
- Established technology
- Linear recording

Disadvantages

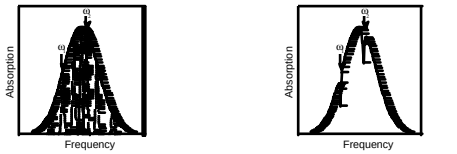
- Material issues
- Fixing of hologram
- Beam steering
- Complex recording schedule
- Low diffraction efficiency

Current Status

- ROM demo system built
  - 160,000 holograms
  - Angular multiplexing
  - $LiNbO_3$
- Polymer disks
  - 2.8 Tb/disk
  - 17 ms access time
- Optical processing/correlation??
  - no electronic processing

OTHER PROGRAMS

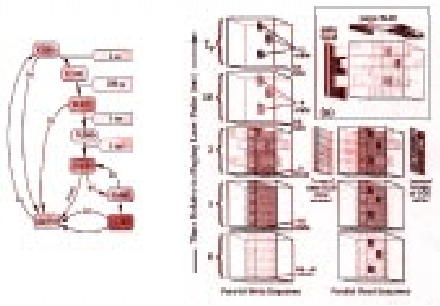
Spectral Hole Burning



Before illumination

After illumination

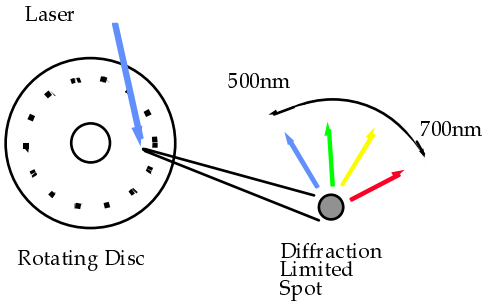
Bacteriorhodopsin (bR)



Photocycle

Timed Read & Writing Sequences

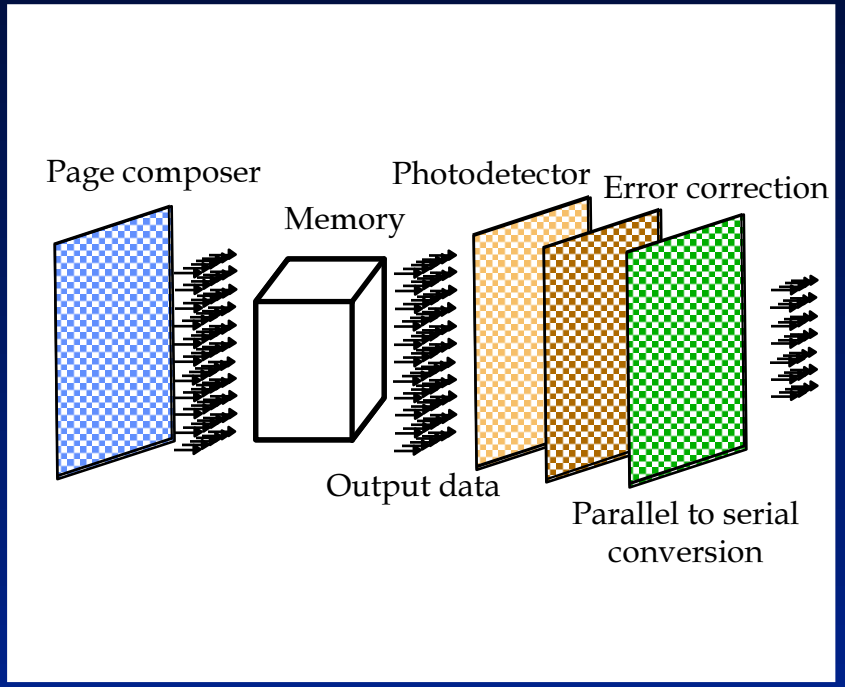
DNA Data Storage



- PSHB
  - *x*, *y* & λ dimensions
  - Room temperature operation??
- bR
  - Protein found in SF bay
  - Ultra cheap media
- DNA
  - *x*, *y*, *z* & λ dimensions
  - Detection & recording uncertain
  - Nanotechnology--2000+

DATA TRANSPORT

- 1024 x 1024 ==> serial data
- 1-10 Gb/s data rate desired
- Where to partition data??
- ECC: 2D or 1D??
- Transport: optical or electronic??
- Optical: free space vs. fiber??
- For Now **HIPPI-6400**

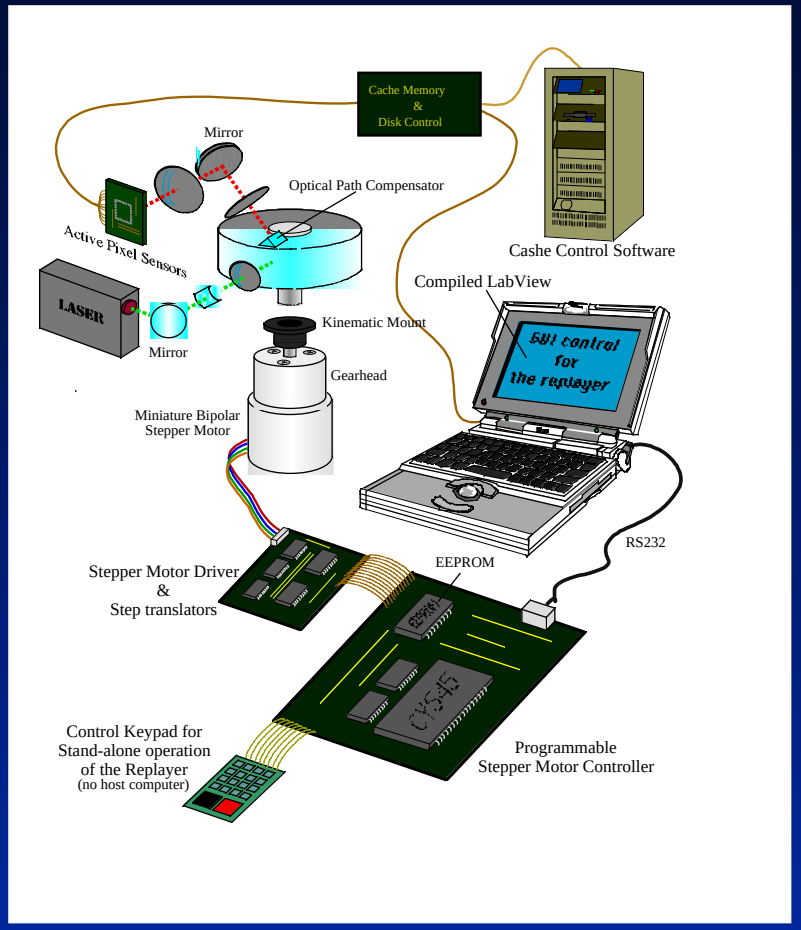


DATA CACHING

- Cache page(s) of data
- Reduce access time to user(s)

  Hide ms access time of memory

  Effectiveness==> type of data
- SRAM==> Short term
- Optoelectronic==> long term
- ECC at cache level ??
- Ultimately--cache for R/W/E



THE OUTLOOK

- **Short Term**

  Two-photon
  - ROM--1 year
  - WORM--2 years
  - R/W/E-- 3-5 years

  Holographic
  - Materials needed
  - Data fixing

  In general need
  - SLMs
  - Better CCD's
  - Dynamic focusing

- **Long Term**

  Free space I/O transport

  Smart pixel arrays

  VCSEL arrays??

  2D ECC hardware

  DNA storage
  - colors +gray levels

  bR
  - Very cheap & easy

SUMMARY

- 100 Gb/cm^2 to 1 Tb/cm^2 WORM w/i 2-3 years
- Parallelism vs. density
- Need 1-10 Gb/s data I/O
- Error-correction issues
- Key issues are materials, components and network integration

"Our ability to retrieve previously collected intelligence was such that it was generally easier to retask the platform than to find the product in the theater data base"

Lessons Learned--Desert Storm

MGen. Kenneth Israel, USAF

Director, DARO