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DEPARTMENT OF PHYSICS

High capacity optical data storage for active archives

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SPIE Photonics West

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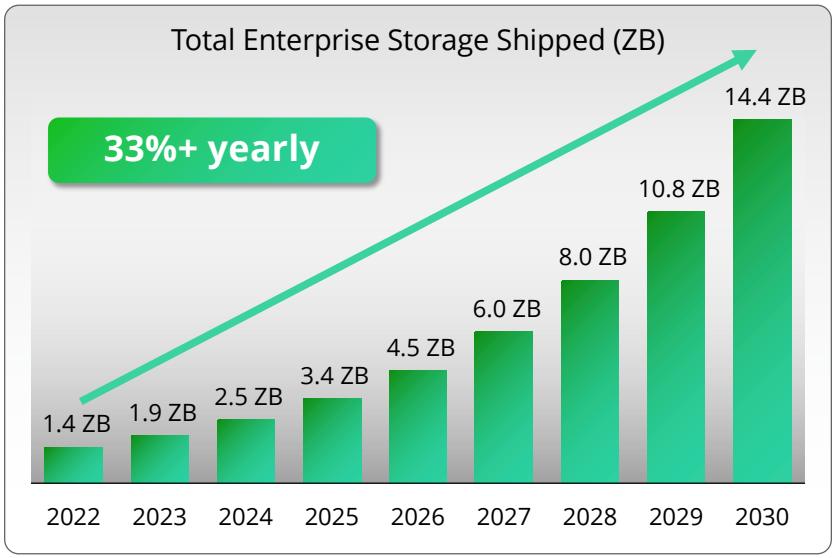
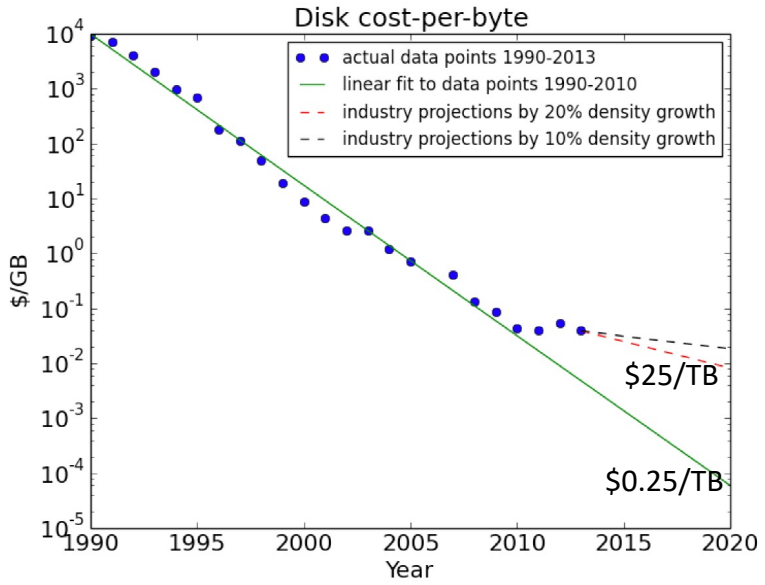
The Datapocolypse



14 ZBs = $125B+



Gupta et al. 2014 IEEE 22nd International Symposium on Modelling, Analysis & Simulation of Computer and Telecommunication Systems; DOI: 10.1109/MASCOTS.2014.39

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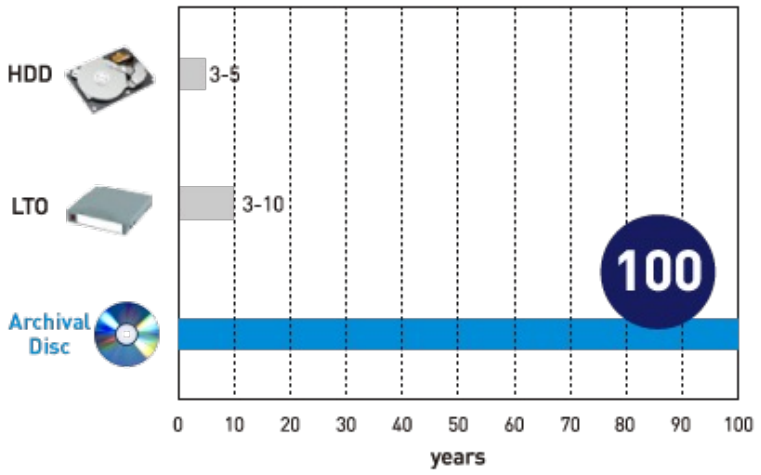
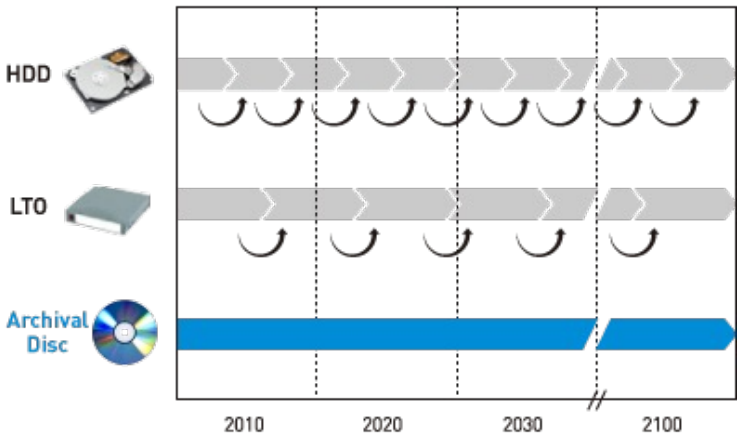
Optical Storage Value Proposition

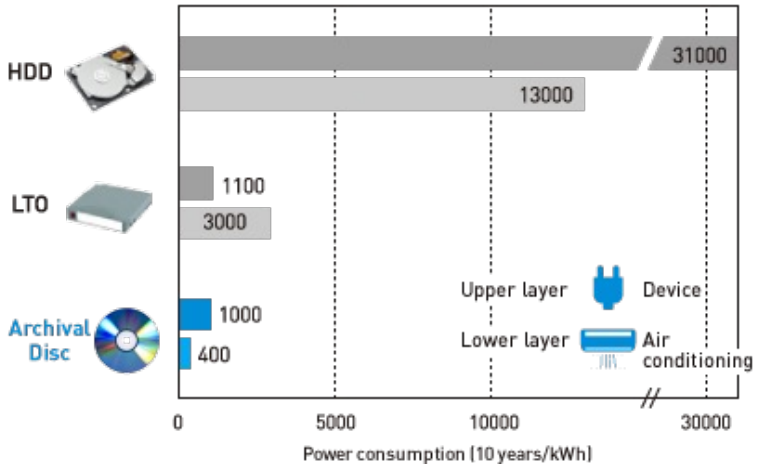
Longevity



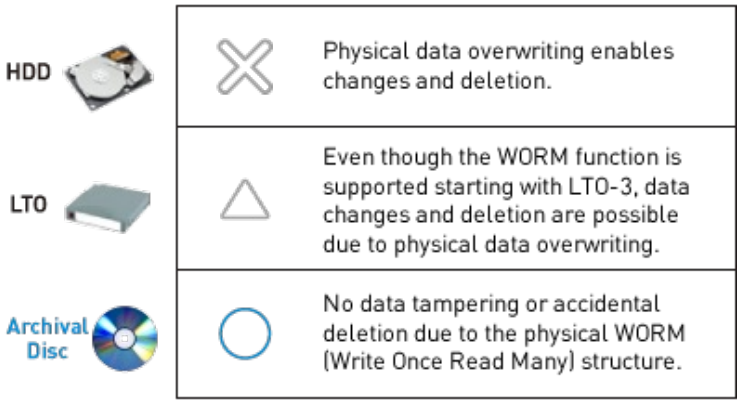
Data Migration



Power Consumption



Data Authenticity



https://panasonic.net/cns/archiver/optical_technology/index.html

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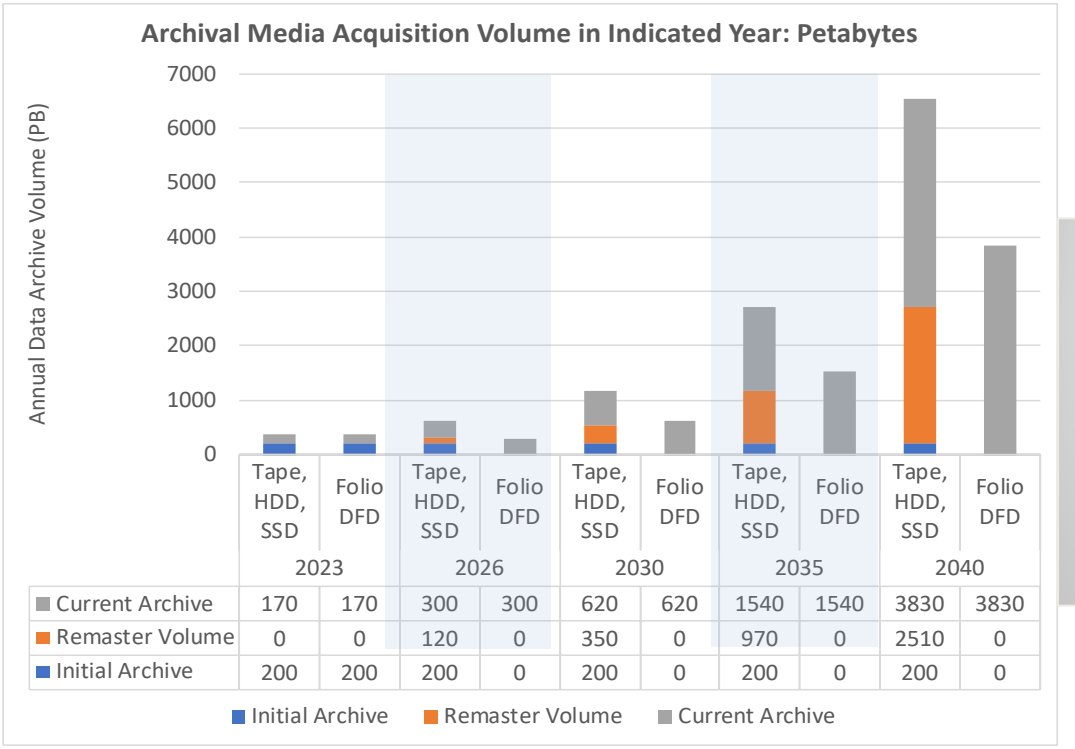
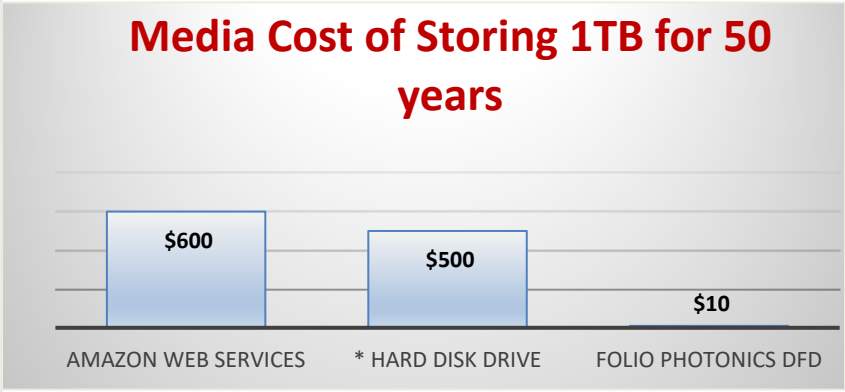
Remastering impact



	2023		2026		2030		2035		2040	
	Tape, HDD, SSD	Folio DFD	Tape, HDD, SSD	Folio DFD	Tape, HDD, SSD	Folio DFD	Tape, HDD, SSD	Folio DFD	Tape, HDD, SSD	Folio DFD
Current Archive	170	170	300	300	620	620	1540	1540	3830	3830
Remaster Volume	0	0	120	0	350	0	970	0	2510	0
Initial Archive	200	200	200	0	200	0	200	0	200	0



AWS $1.00/mo

20% y/y volume growth
200 PB original archive

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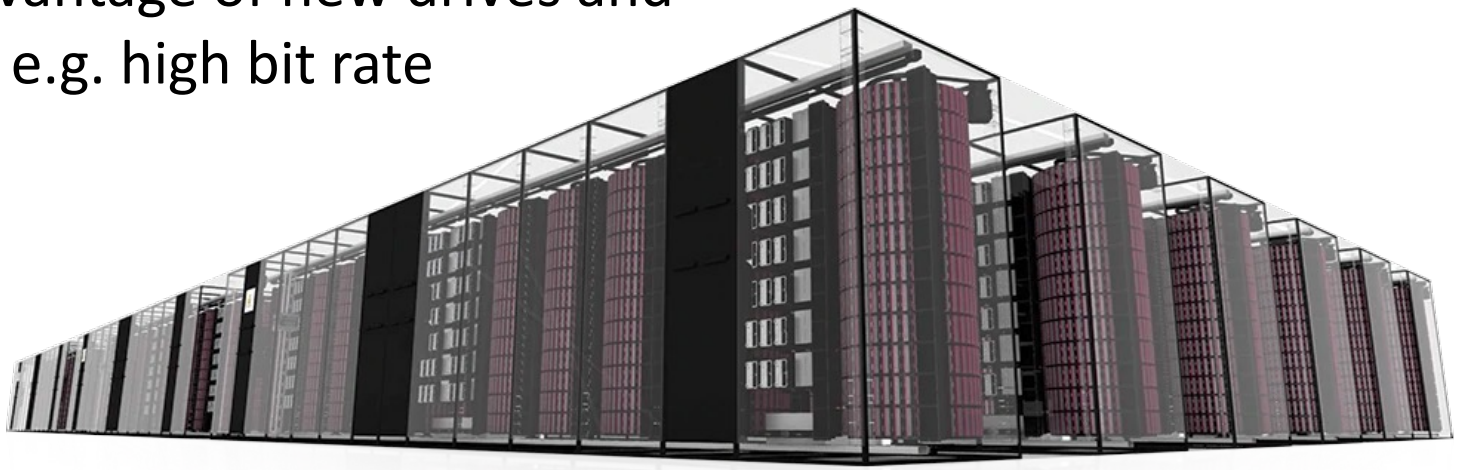
Optical data archiving systems

- Robotic library systems
- Several vendors at various scales
- Uses Blu-ray based technology
  - BDXL discs (200GB)
  - Sony/Panasonic Archival Disc (500GB)
    - Roadmap stops at 1 TB
- Takes advantage of new drives and systems: e.g. high bit rate



https://pro.sony/ue_US/products/petasite-scalable-library/optical-disc-archive-petasite-ex-solutions

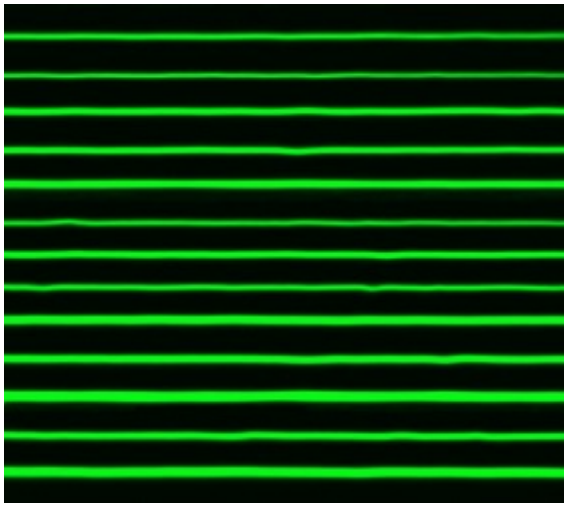
Optical Storage Advantage

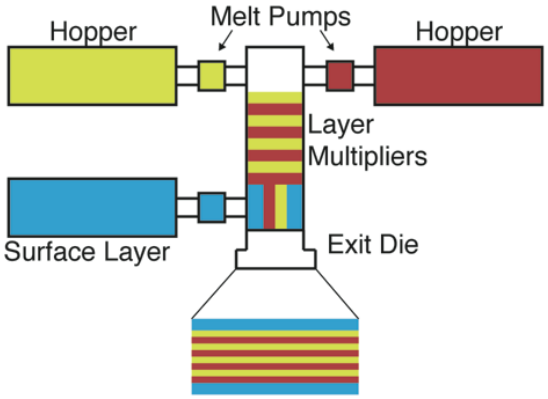
- Advantages of optical
  - Long lifetime: reduction of remastering
  - Energy efficient
  - Secure
  - Random access
- Main Challenge
  - **Limited capacity of BR-based technology: high media cost due to manufacturing technology limitations**
- Approaches to high capacity
  - Holographic
  - 5D Recording
  - Multilevel/multiplex
  - Extending the multiple layer roadmap

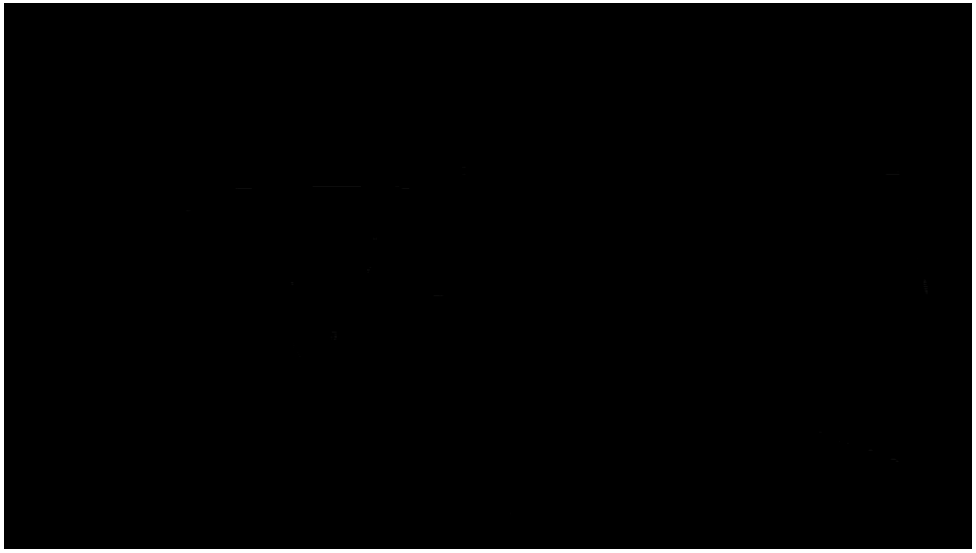
Co-Extrusion

Co-extruded multilayer polymer film

- Roll-to-roll process → extremely low cost
- Fluorescent storage scheme
  - Incoherent light → closely pack layers with no crosstalk
- Nanoscale active layer thickness
  - Sufficiently transparent
  - Write within the 1-photon absorption band
  - Blu-ray laser compatible







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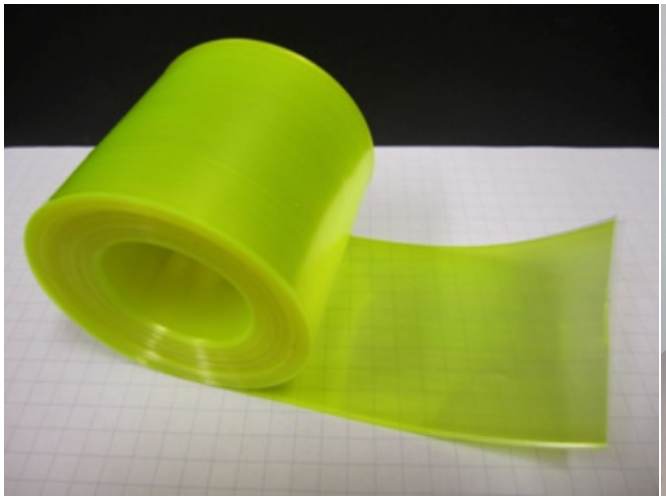
Disc construction

1. Co-extrusion of multilayer film
2. Coating protective hard coat on multilayer film, UV curing
3. Lamination of multilayer film on standard disc substrate
4. Laser cutting/edge sealing

Rolls of multilayer films



Folio Discs

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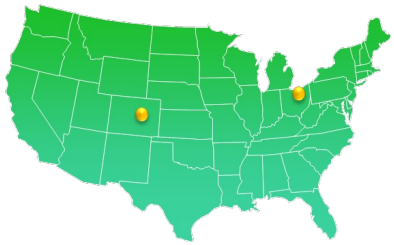
Introducing Folio Photonics

Developed at Case Western Reserve University with support from the National Science Foundation Center for Layered Polymer Systems

NSF | CASE WESTERN RESERVE UNIVERSITY EST. 1826

US-Based Company



Solon, OH
HQ, R&D, Film/Disc Manufacturing

Longmont, CO
Drive/Optics R&D

19 full-time employees with 8+ Ph.D.'s & 12+ Masters

6 Patents (2 Granted 4 Pending)
Across Media, Manufacturing, Optics and Drive

Steven Santamaria, CEO
- Seasoned technology executive with a history of successfully commercializing innovation
- 14 years at Intel

Kenneth D. Singer, Ph.D., Founder, CIO
- Expert in nonlinear optics with 200+ publications and several patents
- Experience at Bell Labs

Irina Shiyanovskaya, Ph.D., CTO
- Over 50 publications and 11 patents in optics, organic electronics, flexible displays and photophysics
- Technical advisor to Fortune 500 companies

Clayton Reeves, CFA, VP Fin & Strategy
- Background in investment banking, venture capital and M&A
- Experience with technology startups
- Led finance diligence on recent $1B exit

Board of Directors include:

Steven Santamaria, CEO, Felix Brueck Board Chairman, McKinsey (Rtd), **Bob Pavey** Morgenthaler Ventures (Rtd), **Ronn Richards** CEO, Cleveland Foundation, **Tim Schigel** Refinery Ventures, **Adam Sharkawy** Material Impact, **Ken Singer** Founder/CIO, **Joe Taylor** CEO, Panasonic USA (Rtd)

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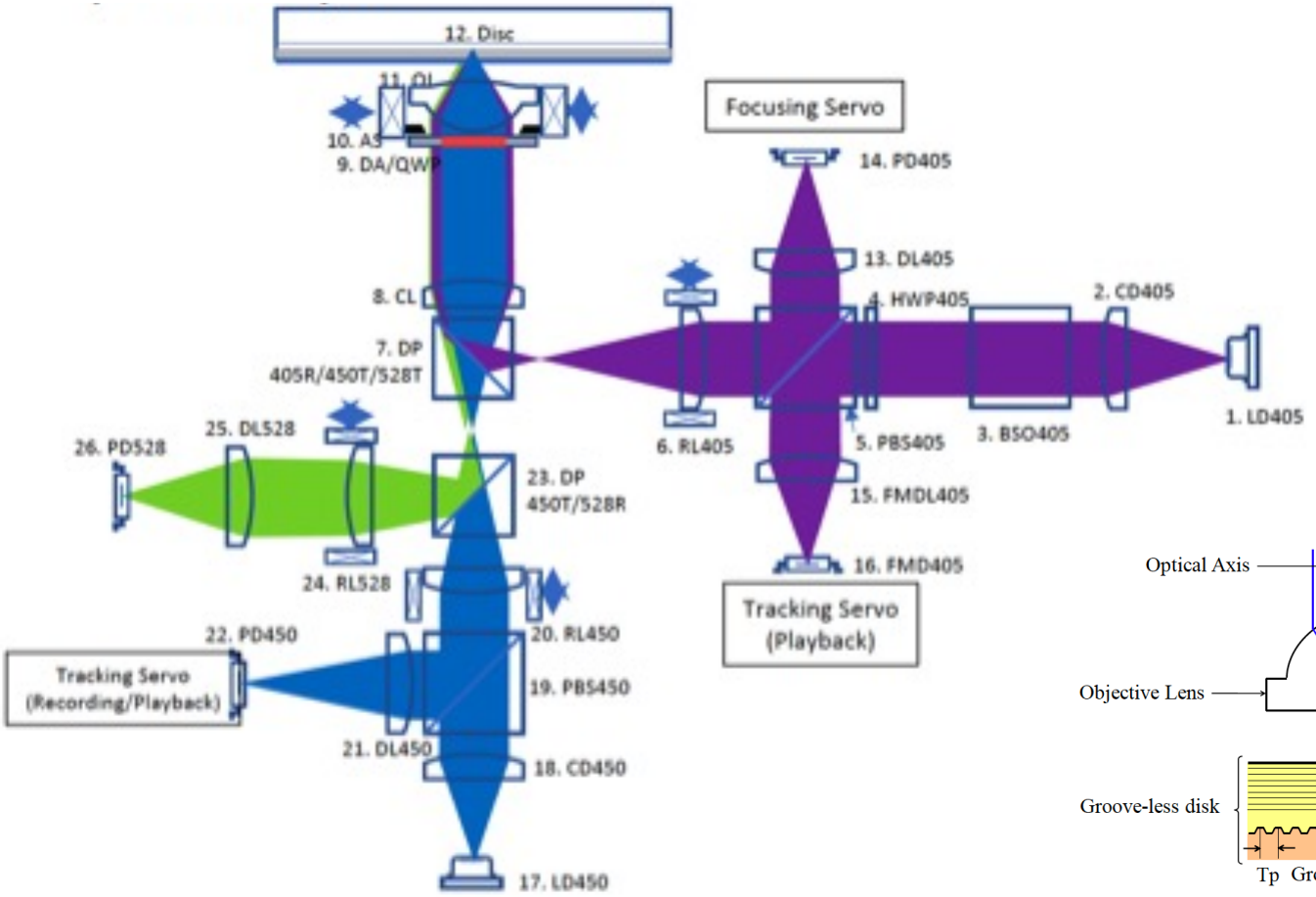
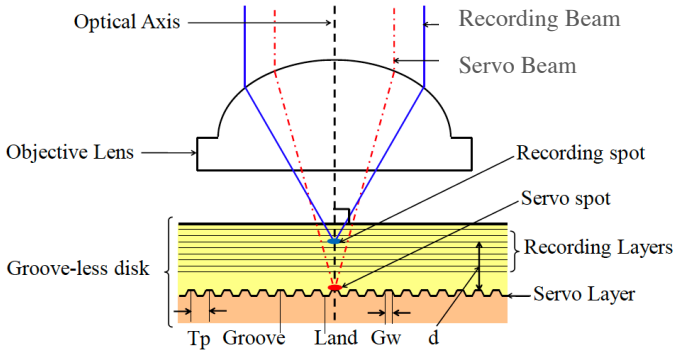
Optical pickup unit





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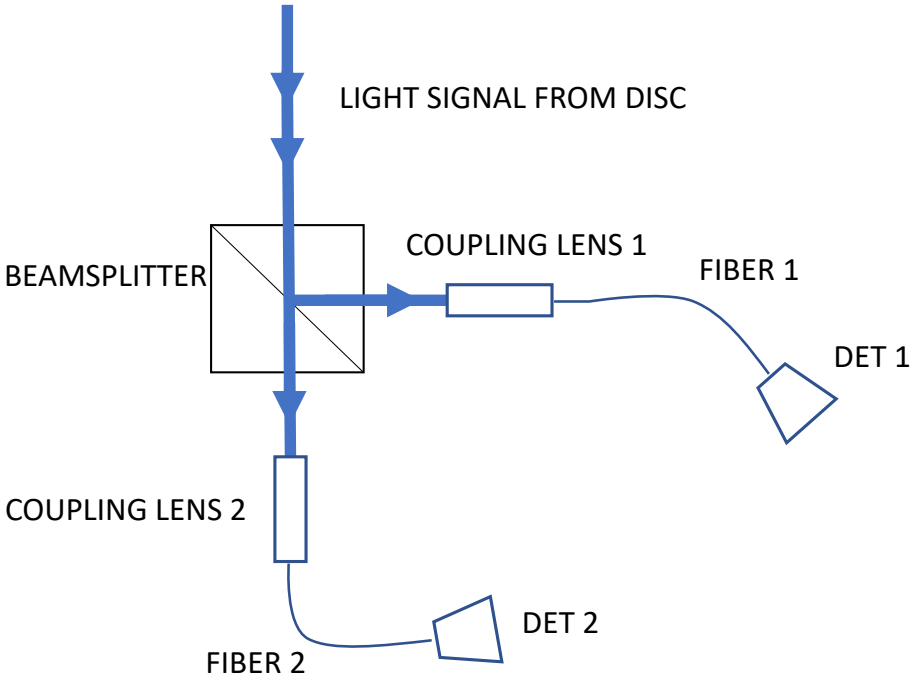
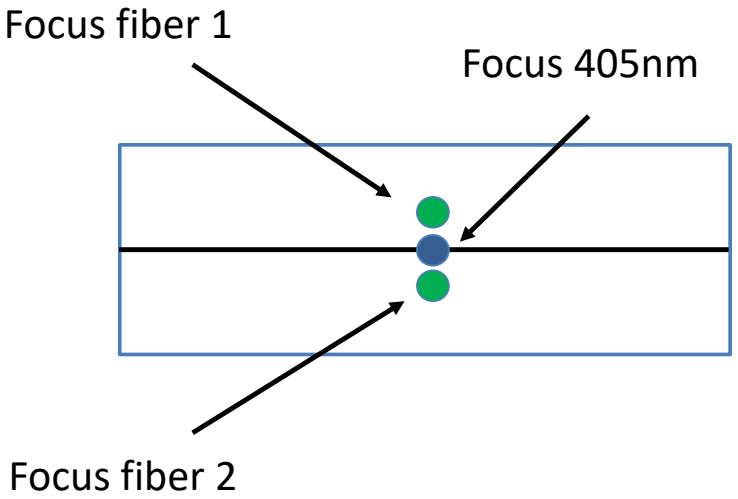
Push-pull focus error signal

Fluorescent signal

- Confocal fiber-optic detection
- Three planes in object space



Object space at disc



Focus error signal = DET 1– DET 2

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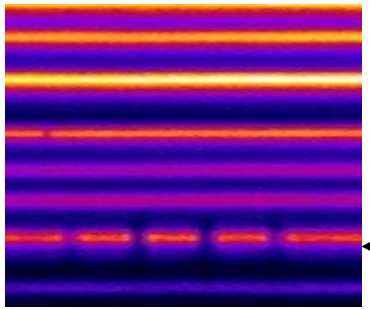
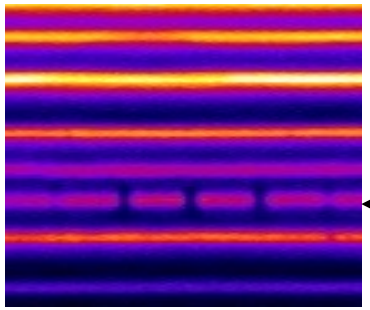
No interlayer crosstalk

- **The written data have no interlayer crosstalk or shadow in the adjacent layers**
- No interference of reflected fluorescence signals due to incoherent nature of the fluorescence

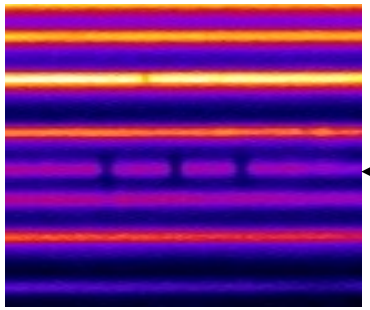
- Confocal scanning microscope images of the data written in 16 layer film
  - Buffer layer thickness - 6 μm
  - Active layer thickness - 600 nm



Bits only in 7th layer



Bits only in 6th layer



Bits only in 5th layer

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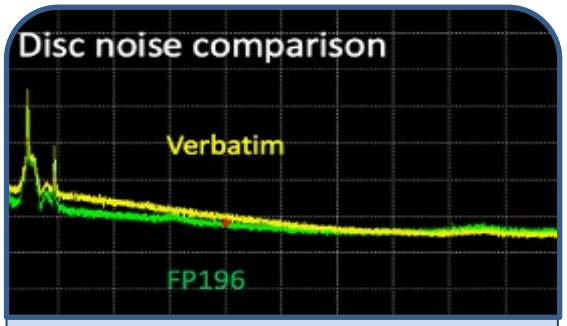
Single Layer Disc

Low Media Noise



Comparable to Commercial Discs

Importance:
- Demonstrates Folio media quality
- Enables better signal/mark quality

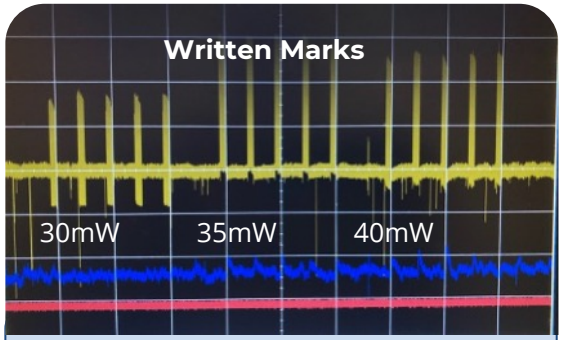
High CNR Values

Comparable to Commercial Discs

Folio Disc: CNR 50-52 dB
Verbatim Disc: CNR 52-53 dB

Importance: Demonstrates dynamic optical performance of materials/media

Low Writing Power



Low laser power on a disc:
- ***35mW at 1x***
- ***45mW at 2x***

Importance: Proves feasibility for sufficient power to write on all 8-layers at commercial speed

Proves: Materials Capability

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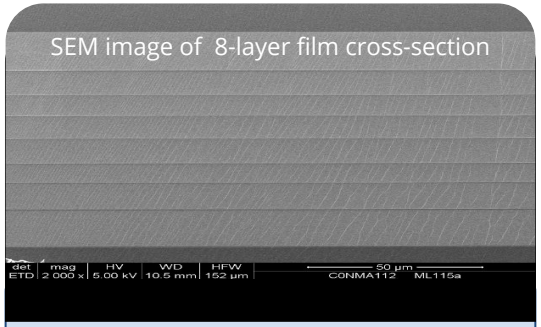
Multilayer results

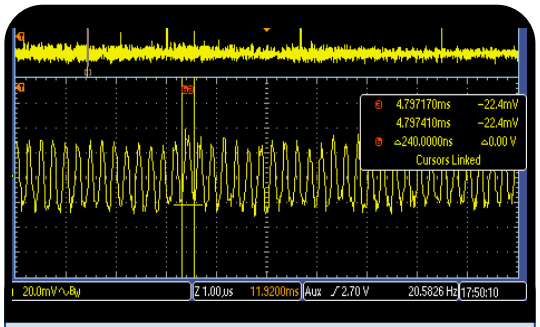
Multi-layer Film to Disc Manufacturing



The buffer & active layer thickness varies ~5% within the layer and ~10% across the film depth

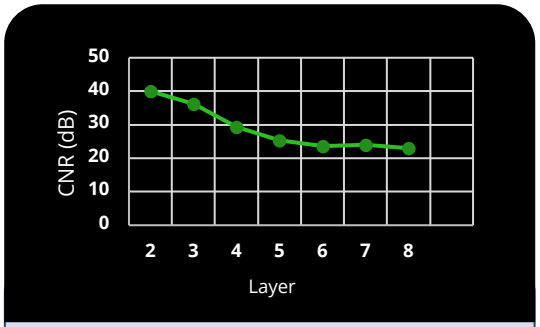
Demonstrates scalable multi-layer manufacturing processes that project to new S-curve in data storage

Dynamic Reading & Writing to 7 Layers



Demonstrates the ability to read & write data to 7 layers of a Folio disc **with no interlayer crosstalk**

Layer-by-Layer CNR



This initial data demonstrates the suitability of Folio's materials to achieve quality signals for dynamic writing and reading

Proves: Process and ML Film Capabilities

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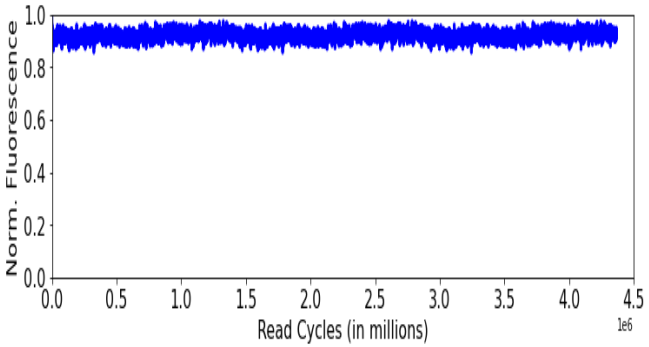
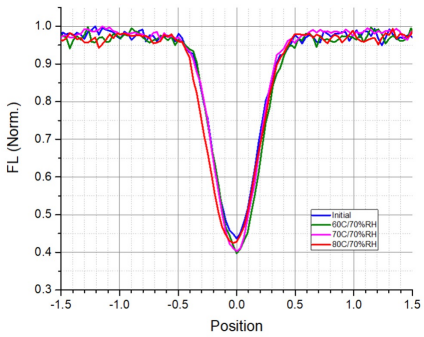
Materials durability

Photostability



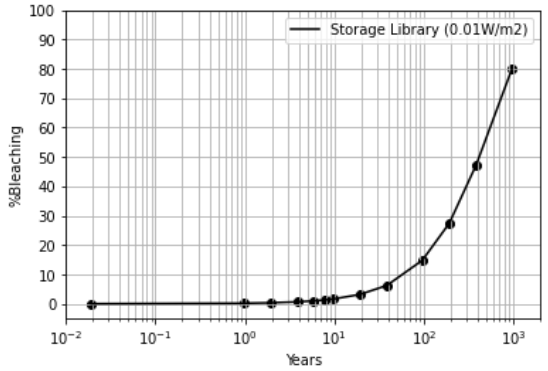
No changes in signal intensity after 4.5 M read cycles

Thermal Stability



Written data mark preserved after 1000h test at elevated temperatures and humidity

Longevity



Estimated 126-year lifetime at 25C/ 70%RH in the library conditions – written mark contrast change

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Conclusions

- Strong value proposition for optical storage
- New approach to optical data storage for enterprise archive
  - Economics driven by media lifetime and cost/GB
  - Low-cost roll-to-roll fabrication of multilayer optical data storage media
  - Writing mechanism within the single photon absorption band compatible with current Blu-ray™ technology for low-cost drive and backward compatibility
- Robust
  - Temperature and photostability
- Dynamic testing
  - Low media noise in data channel
  - Multilayer write and read

Acknowledgements

Case Western Reserve University:
- **Ken Singer**
  - Anuj Saini, Cory Christenson

Folio Photonics Inc
- **Irina Shiyanovskaya**, Steve Santamaria, Ron Kadlec