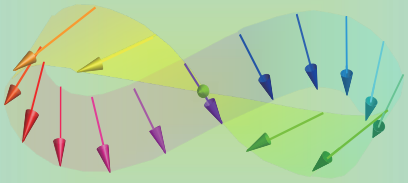
Information Storage and Spintronics 07



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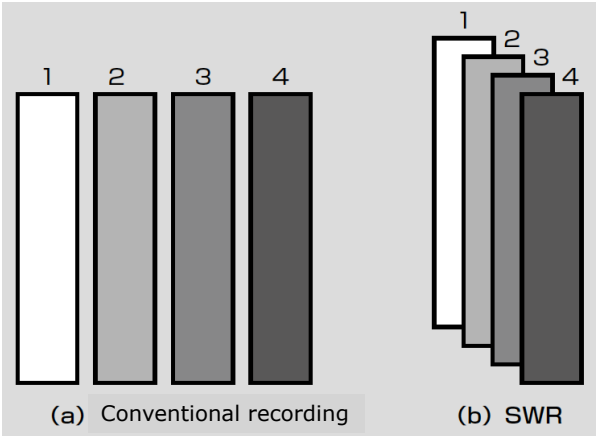
Department of Electronic Engineering

THE UNIVERSITY of York

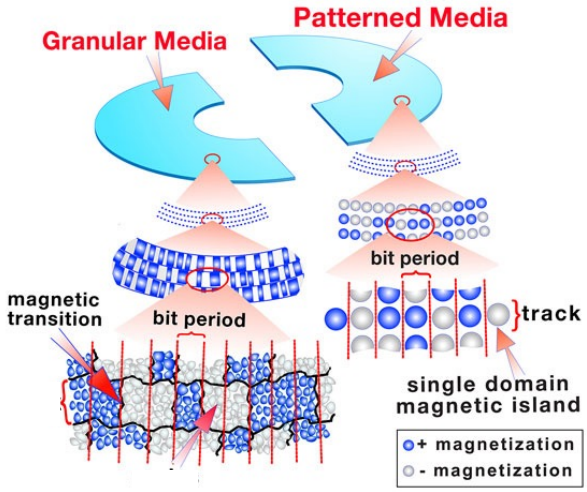
10:00 Monday, 24/October/2022 (SLB 102)

Quick Review over the Last Lecture

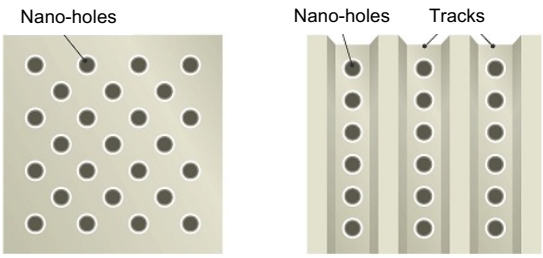
Shingled write recording : *



Bit patterned media (BPM) : **



Discrete tracks : ***



* S. Matsuo, H. Uwazumi and N. Hara, *Fujidenki Gihou* **85**, 316 (2012);
** http://news.cnet.com/2300-1008_3-6108692.html;
*** http://www.tdk.co.jp/

07 Optical Storages

- Read-only
- Writable
- High density
- Physical phenomena
- Phase change

Optical Storage

Read-only : *

Writable (once only) :

Writable (multiple) :

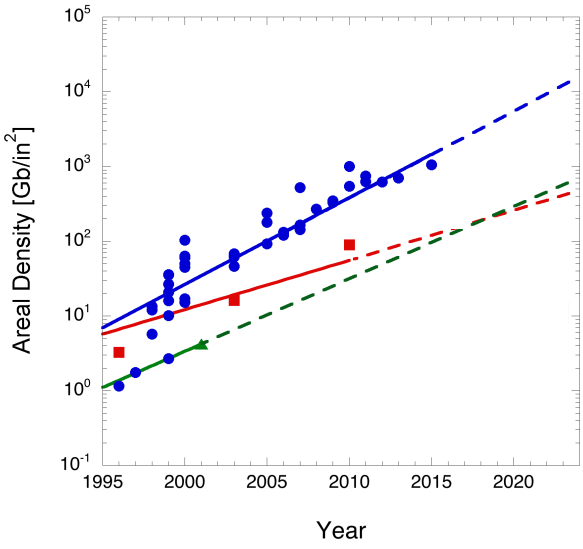
High density :

* https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiQpNDA-__jAhVFoVwKHWGIDssQFjAAegQIARAC&url=http%3A%2F%2Fhome.sato-gallery.com%2Feducation%2Fkouza%2FRyukoku_lecture.ppt&usg=AOvVaw0UTNH3qZH_LSTZ0vsF3Hxx/

Properties of Optical Storage

Advantages of optical storage : *

- Removable
- Large capacity, High density — Not as high as HDD
- Random access — Not as fast as HDD
- Fidelity — Not as good as HDD



* https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiQpNDA-__jAhVFoVwKHWGIDssQFjAAegQIARAC&url=http%3A%2F%2Fhome.sato-gallery.com%2Feducation%2Fkouza%2FRyukoku_lecture.ppt&usg=AOvVaw0UTNH3qZH_LSTZ0vsF3Hxx/

Physical Phenomena Used

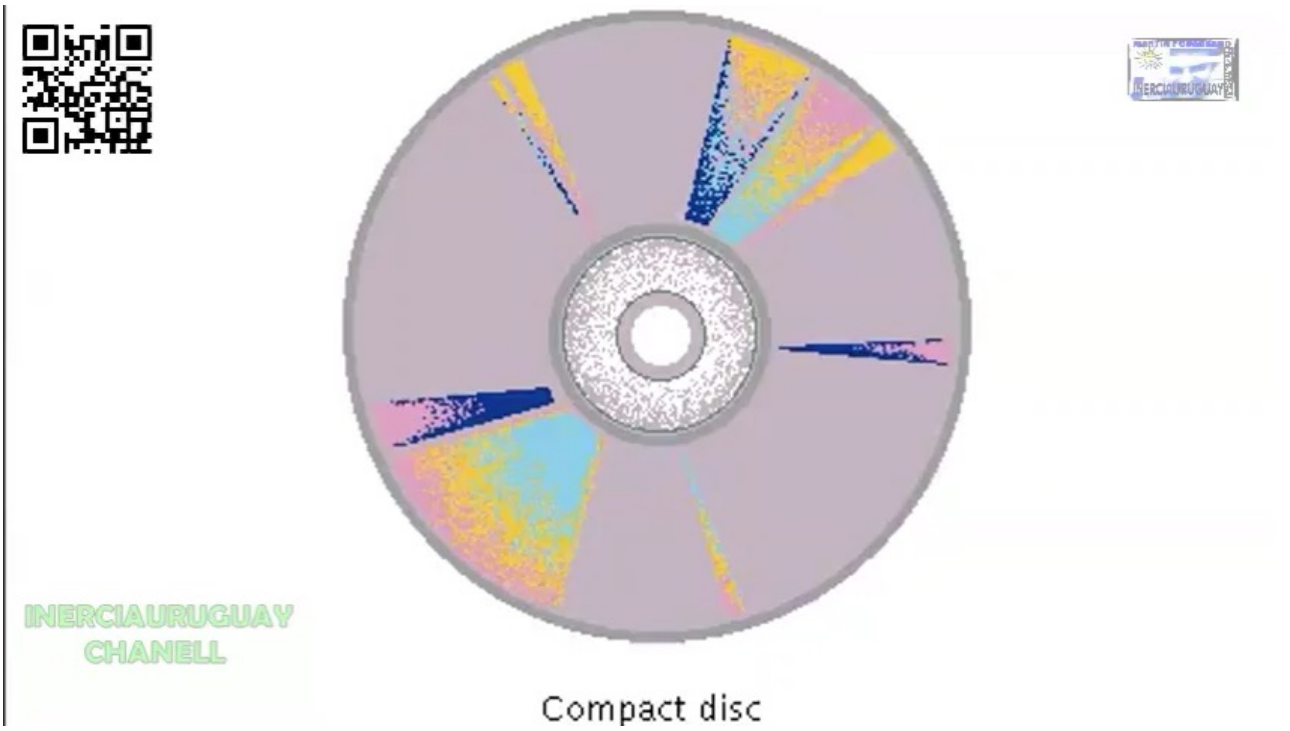
Various phenomena are used for optical storage : *

- Recording bit formation – CD-ROM, DVD-ROM
- Chemical reaction of organic dye – CD-R, DVD-R
- Amorphous phase change - CD-RW, DVD-RAM, DVD-RW, DVD+RW
- Ferromagnetic-paramagnetic phase change – MO, MD
- Photorefractive effect – Holographic memory

* https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiQpNDA-__jAhVFoVwKHWGIDssQFjAAegQIARAC&url=http%3A%2F%2Fhome.sato-gallery.com%2Feducation%2Fkouza%2FRyukoku_lecture.ppt&usg=AOvVaw0UTNH3qZH_LSTZ0vsF3Hxx/

Principles of CD

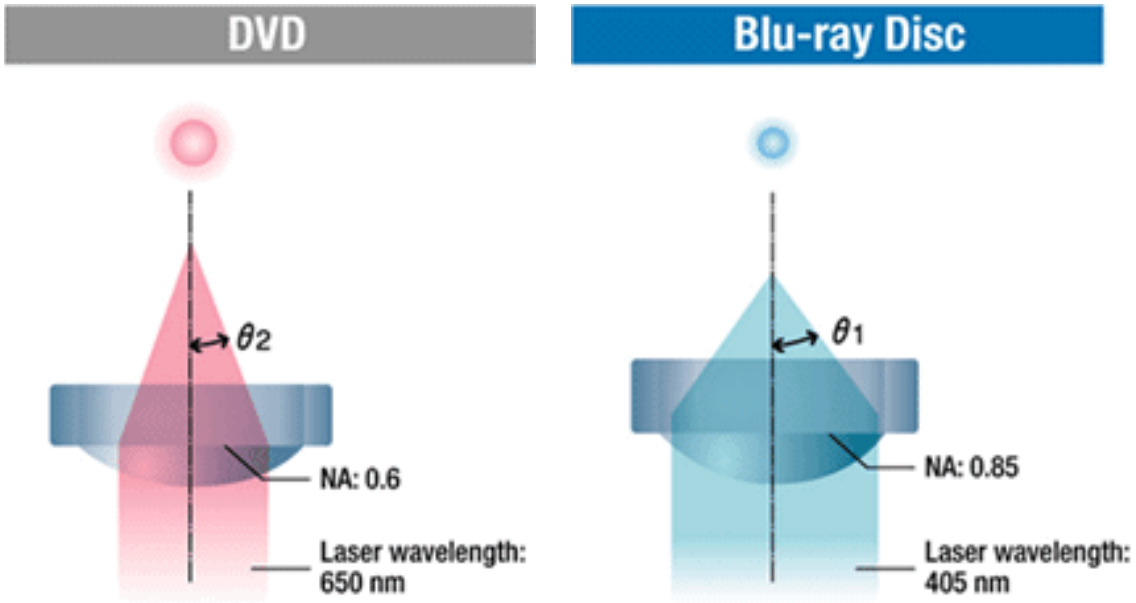
CD operation : *



* http://www.youtube.comwatchv=MPQEIGo4AHI

Numerical Aperture for Optical Storage

Numerical aperture (NA) : *



The NA is expressed by ,

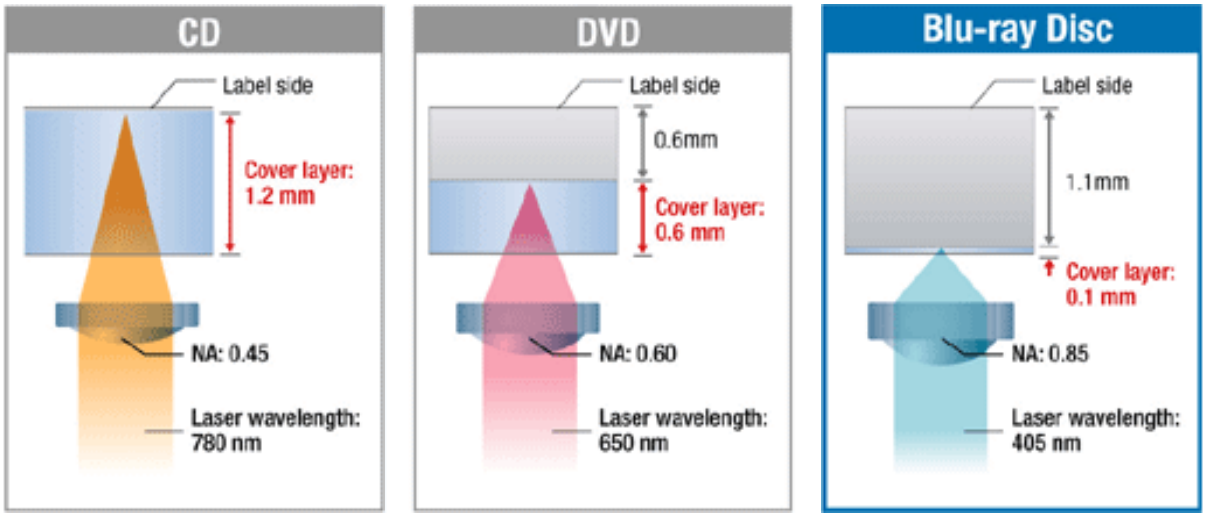
where *n* : the refraction index (in air).

The larger the NA, the greater the *θ* value (>) and the smaller the laser spot size.

* https://azkurs.org/whats-the-blu-ray-disc-why-was-the-blu-ray-disc-created.html

Numerical Aperture and Wavelength

NA and the corresponding laser wavelength : *

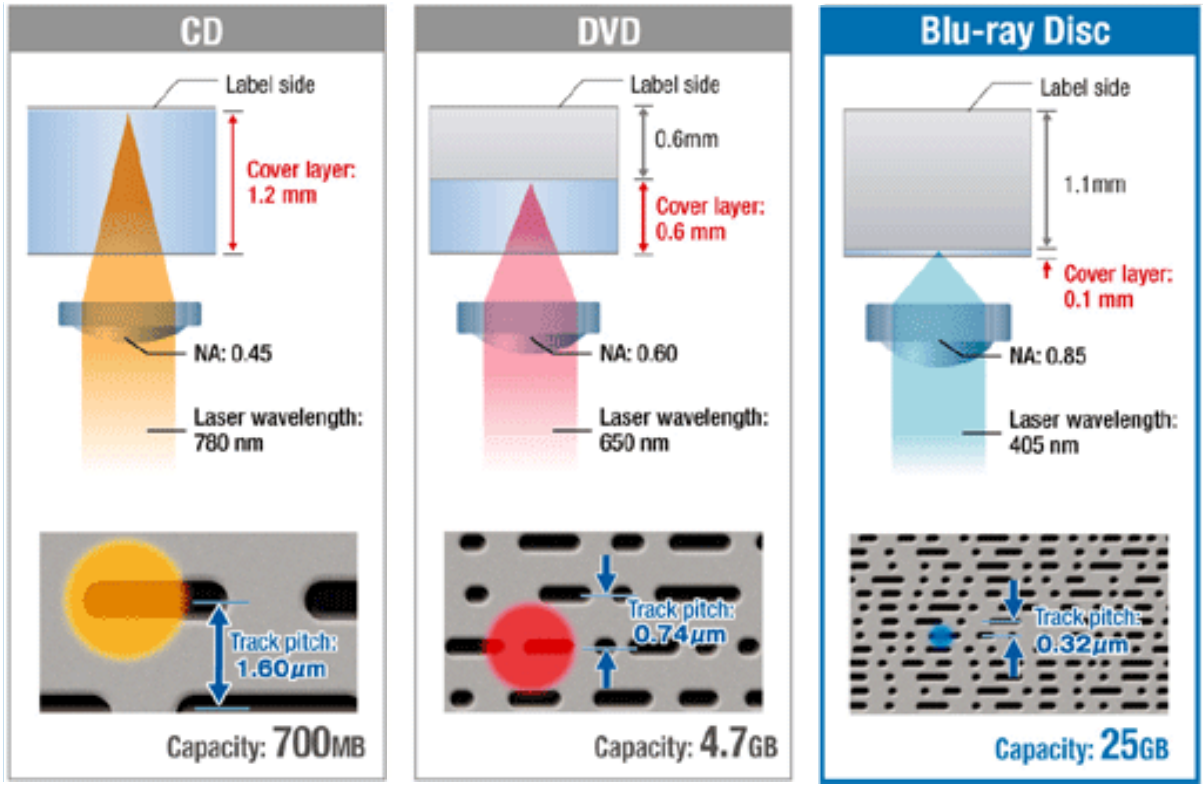


By increasing NA, laser spots can become smaller for higher storage density.
The corresponding laser wavelength also becomes shorter.

* https://azkurs.org/whats-the-blu-ray-disc-why-was-the-blu-ray-disc-created.html

Numerical Aperture and Spt Size

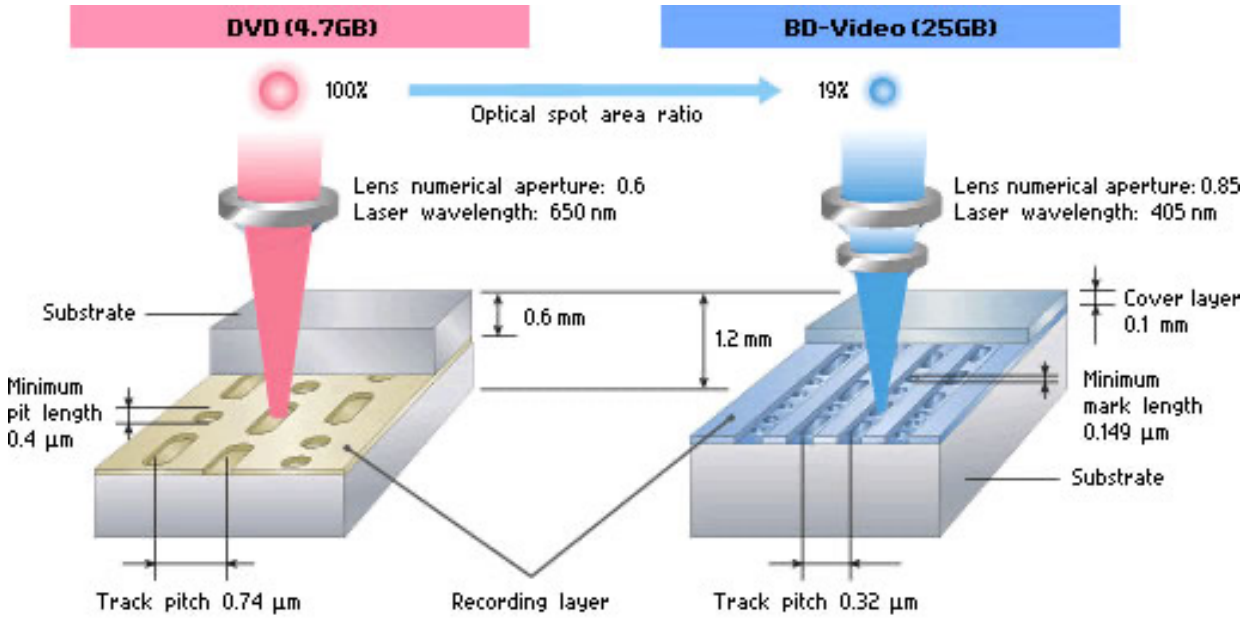
NA and the corresponding laser spot size : *



* https://azkurs.org/whats-the-blu-ray-disc-why-was-the-blu-ray-disc-created.html

Increase in Storage Density

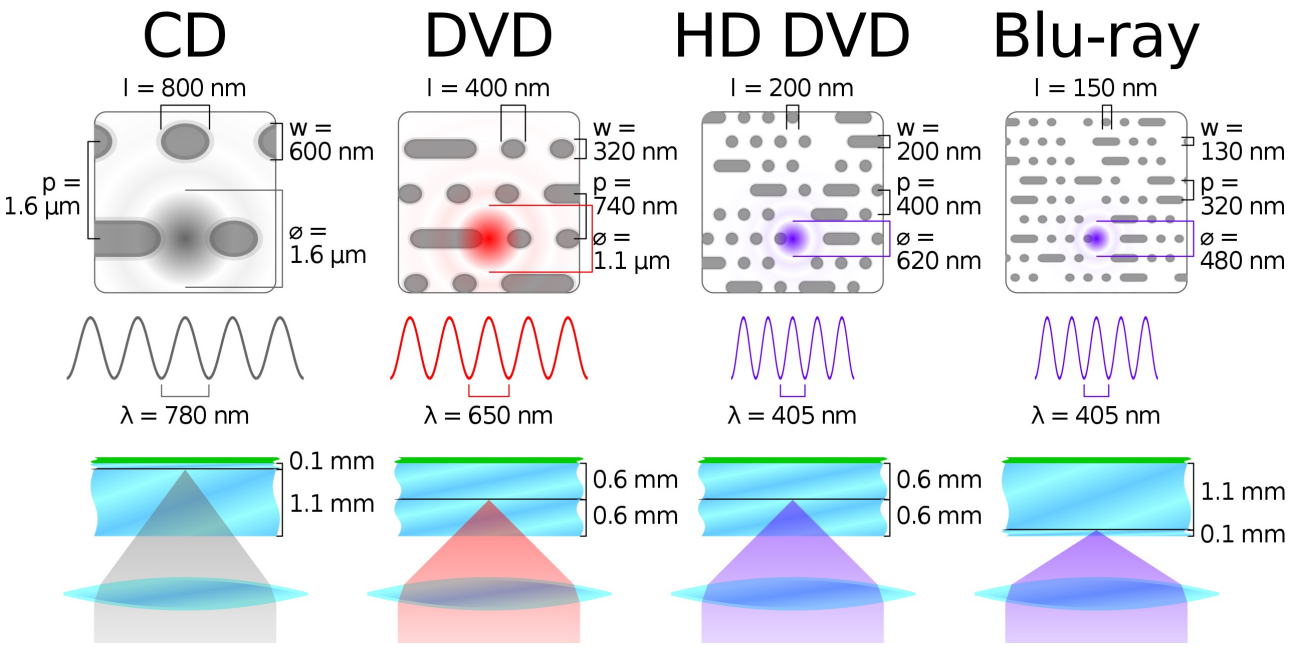
Comparison between DVD and BD : *



* https://azkurs.org/whats-the-blu-ray-disc-why-was-the-blu-ray-disc-created.html

Bit Size Comparison

Data bits used for optical storage : *

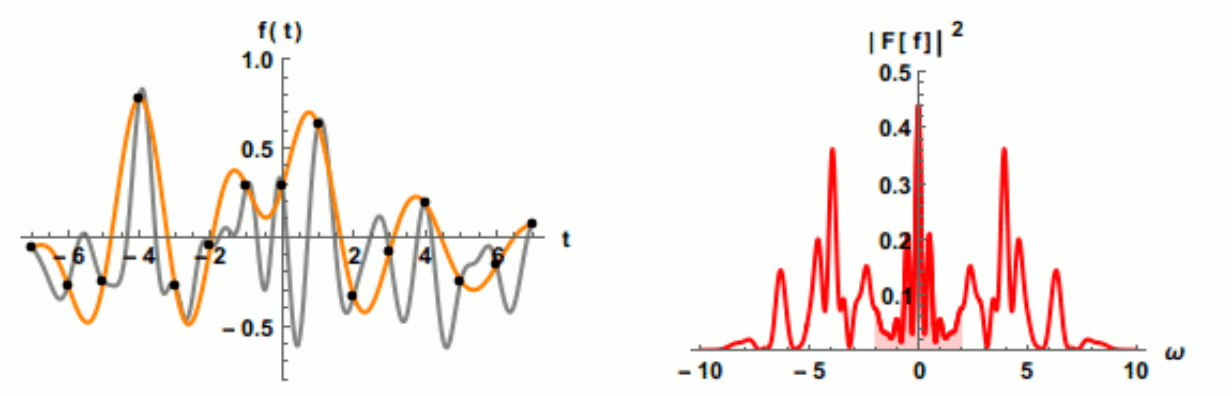


* http://www.wikipedia.org/;

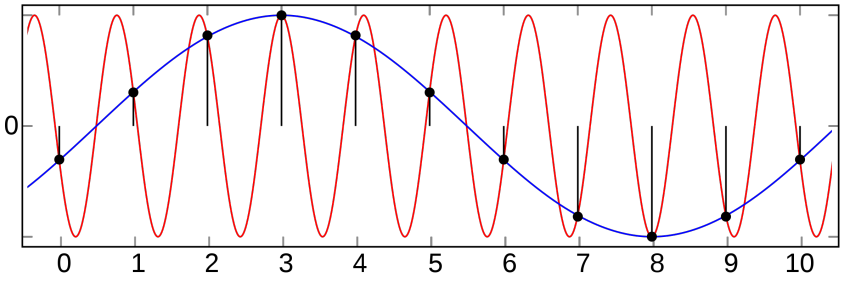
** https://azkurs.org/whats-the-blu-ray-disc-why-was-the-blu-ray-disc-created.html

Nyquist-Shannon Sampling Theorem

Data sampling : *



For accurate data reconstruction, sampling up to frequency as the required value is needed due to folding noise.



** http://www.wikipedia.org/

Optical Storage Capacity

	LaserVision	LaserDisc/ CD-Video	Video-CD	DVD-Video	Blu-ray Disc	Ultra HD Blu-ray
Launch	1978	1986	1993	1996	2006	2016
Laser wavelength	780 nm (infra-red)	780 nm	780 nm	650 nm (red)	405 nm (blue)	405 nm
Sides	2	2	1	1 or 2	1	1
Layers	1	1	1	1-2	1-2	1-3
Substrate thickness	1.25mm	1.25mm	1.1mm	0.6mm	0.1mm	0.1mm
Numerical Aperture			0.50	0.60	0.85	0.85
Track pitch			1.5 Âµm	740 nm	320 nm	225 nm?
Data bit length			800 nm	400 nm	150 nm	80 nm?
Capacity			700 MB	4.7 GB or 8.5 GB	25 GB or 50 GB	33 GB, 66 GB or 100 GB

* http://yoeri.geutskens.com/blog/ultrahdbluray-history.html

Amorphous Phase Change

Additional writing process : *

Rapid quenching of chalcogenide glass in an amorphous phase.

Laser heating promotes crystallisation → reflection.

Rewriting process :

Initial crystallised phase by slow quenching below $T < 400^{o}C$.

Written phase by rapid quenching above $T > 600^{o}C$.

DVD-RAM – GeSbTe (> 100,000 times writing cycles).

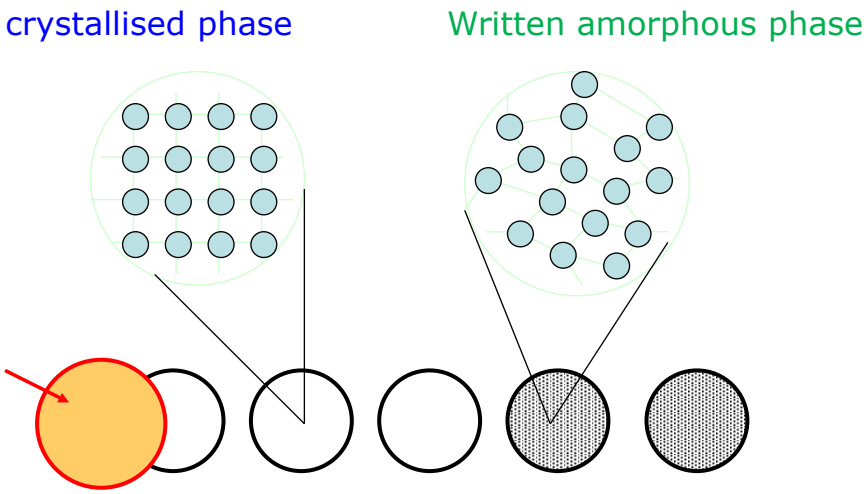
DVD-RW – AgInTe (> 1,000 times writing process).

Slow data transfer speed (11 ~ 47 Mbps).

* https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiQpNDA-__jAhVFoVwKHWGIDssQFjAAegQIARAC&url=http%3A%2F%2Fhome.sato-gallery.com%2Feducation%2Fkouza%2FRyukoku_lecture.ppt&usg=AOvVaw0UTNH3qZH_LSTZ0vsF3Hxx/

Phase Change Processes

Initialisation and writing processes : *



* https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiQpNDA-__jAhVFoVwKHWGIDssQFjAAegQIARAC&url=http%3A%2F%2Fhome.sato-gallery.com%2Feducation%2Fkouza%2FRyukoku_lecture.ppt&usg=AOvVaw0UTNH3qZH_LSTZ0vsF3Hxx/

Magneto-Optical Storage

Writing process : *

Laser-induced heating to promote magnetic phase change above the Curie temperature.

Reading process :

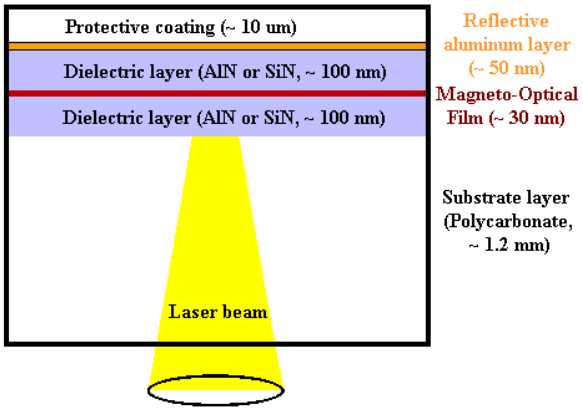
Detection of the polarisation rotation through the Faraday effect.

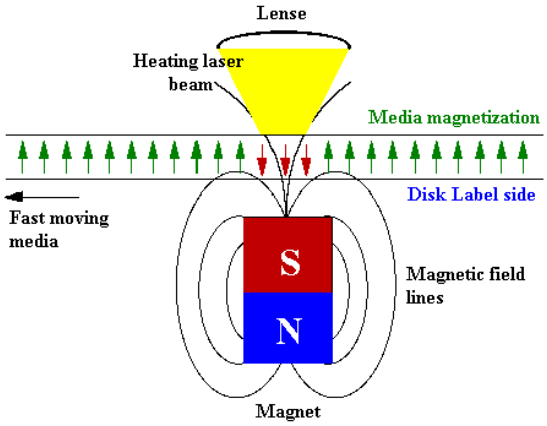
TbFeCo (> 10,000,000 times writing cycles).

* https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiQpNDA-__jAhVFoVwKHWGIDssQFjAAegQIARAC&url=http%3A%2F%2Fhome.sato-gallery.com%2Feducation%2Fkouza%2FRyukoku_lecture.ppt&usg=AOvVaw0UTNH3qZH_LSTZ0vsF3Hxx/

Magneto-Optical Disc

In 1971, Honeywell proposed magneto-optical recording : *

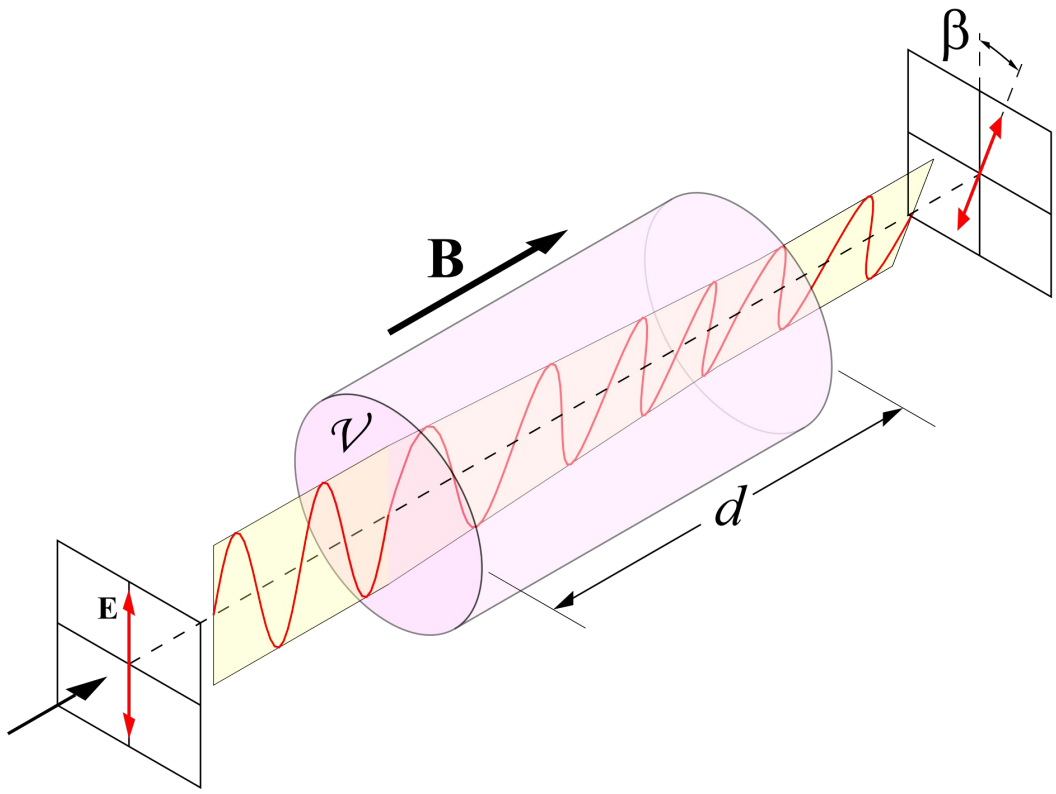




* http://ffden-2.phys.uaf.edu/211.fall2000.web.projects/J%20Kugler/mo.html

Faraday Effect

Rotation of a linearly polarised direction by a magnetic moment : *



* http://www.wikipedia.org/

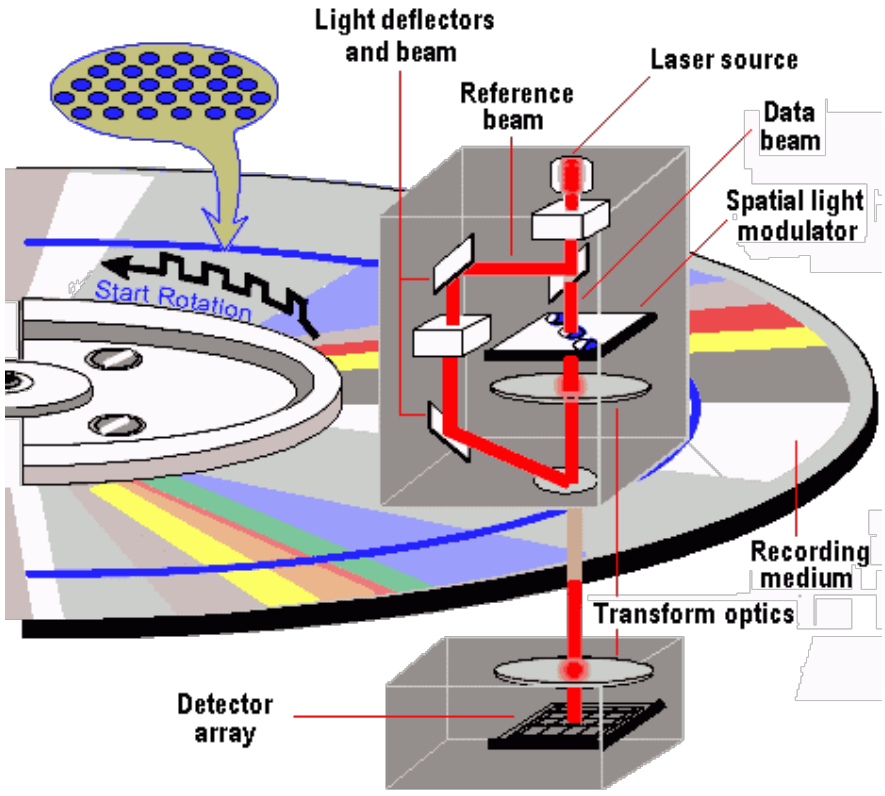
Comparison among Optical Storage

Name	Capacity	Experimental[Note 1]	Years[Note 2]
LaserDisc (LD)	0.3 GB		1971–2001
Write Once Read Many Disk (WORM)	0.2–6.0 GB		1979–1984
Compact Disc (CD)	0.7–0.9 GB		1982–today
Electron Trapping Optical Memory (ETOM)	6.0–12.0 GB		1987–1996
MiniDisc (MD)	0.14 GB		1989–today
Magneto Optical Disc (MOD)	0.1–16.7 GB		1990–present
Digital Versatile Disc (DVD)	4.7–17 GB		1995–present
LIMDOW (Laser Intensity Modulation Direct OverWrite)	2.6 GB	10 GB	1996–present
GD-ROM	1.2 GB		1997–present
Fluorescent Multilayer Disc		50–140 GB	1998-2003
Versatile Multilayer Disc (VMD)	5–20 GB	100 GB	1999-2010
Hyper CD-ROM	1 PB	100 EB	1999?-?
Ultra Density Optical (UDO)	30–60 GB		2000-present
FVD (FVD)	5.4–15 GB		2001-present
Enhanced Versatile Disc (EVD)	DVD		2002-2004
HD DVD	15–51 GB	1 TB[citation needed]	2002-2008
Blu-ray Disc (BD)	25 GB 50 GB 100GB (BDXL) 128 GB (BDXL)	1 TB	2002-present
Professional Disc for Data (PDD)	23 GB		2003-2006
Professional Disc	23–128 GB		2003–present
Digital Multilayer Disk		22-32 GB	2004–2007
Multiplexed Optical Data Storage (MODS-Disc)		250 GB–1 TB	2004–present
Universal Media Disc (UMD)	0.9–1.8 GB		2004–2014
Holographic Versatile Disc (HVD)		6.0 TB	2004–present
Protein-coated Disc (PCD)		50 TB	2005–present
M-DISC	4.7 GB (DVD format) 25 GB (Blu-ray format) 50 GB (Blu-ray format) 100 GB (BDXL format) [19]		2009–today
Archival Disc	0.3-1 TB		2014–present
Ultra HD Blu-ray	50 GB 66 GB 100 GB		2015–present

* http://www.wikipedia.org/

Holographic Storage

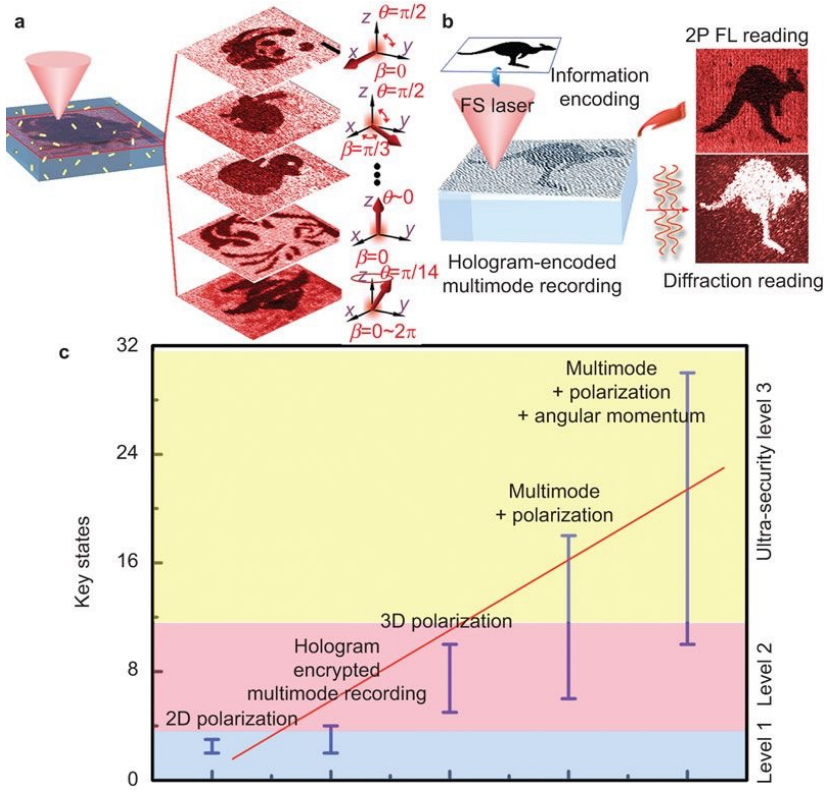
Holographic storage has been proposed : *



* https://www.pctechguide.com/removable-storage/holographic-data-storage

Three-Dimensional Optical Storage

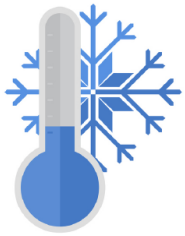
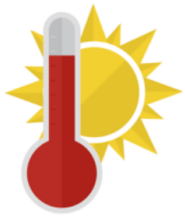
3D optical storage : *



* M. Gu *et al.*, *Light: Sci. Appl.* **3**, e177 (2014).

Cold Storages

Definition of cold storages : *

	Cold	Hot
		
Access Speed	Slow	Fast
Access Frequency	Seldom or Never	Frequent
Data Volume	Low	High
Storage Media	Slower drives, LTO, offline	Faster drives, durable drives, SSDs
Cost	Lower	Higher

* https://www.backblaze.com/blog/whats-the-diff-hot-and-cold-data-storage/

Comparison of Cold Storages

Optical storages are advantageous for long time storage : *

MEDIA ▸	HDD	TAPE	NAND	OPTICAL		
	7200 RPM	LTO	3D QLC	Blu-ray	Archival disc	MDISC[1]
Data durability without power	< 4 years	> 30 years	< 1 year	~ 50 years	~ 100 years	~ 1,000 years
Raw capacity per cartridge or drive	12 TB	6 TB	~ 128 TB[3]	1.2 TB	4.8 TB	1.2 TB
Roadmap maximum raw capacity	20 TB	330 TB	~ 256 TB	1.2 TB	12 TB	1.2 TB
Form factor	3.5-inch	2.5-inch	2.5-inch	5.1" x 0.8" x 5.2"		
Immutability	SW-WORM	SW-WORM	SW-WORM	Built into media		
Encryption	Yes	Yes	Yes	Yes		
Backwards compatibility	Unlimited	Gen 2 or >	Unlimited	Unlimited		
Maximum transfer performance (MBps)	~ 261	~ 300-750[2]	~ 500	~ 30	~ 360	~ 30
Erasure code compatibility	Yes	No	Yes[4]	Yes		
Deduplicable	Yes	No	Yes	No		
Compressable	Yes	Yes	Yes	Yes		
Removable cartridge or drive	No	Yes	No	Yes		
Acquisition cost per GB—relative	Low	Lowest	Medium[5]	Medium	Low	Medium
TCO cost per GB—relative	Medium	Low	Low-Med	Low	Lowest	Low

* https://techtarget.itmedia.co.jp/tt/news/1802/12/news02.html#l_aa8260_kaigai.jpg