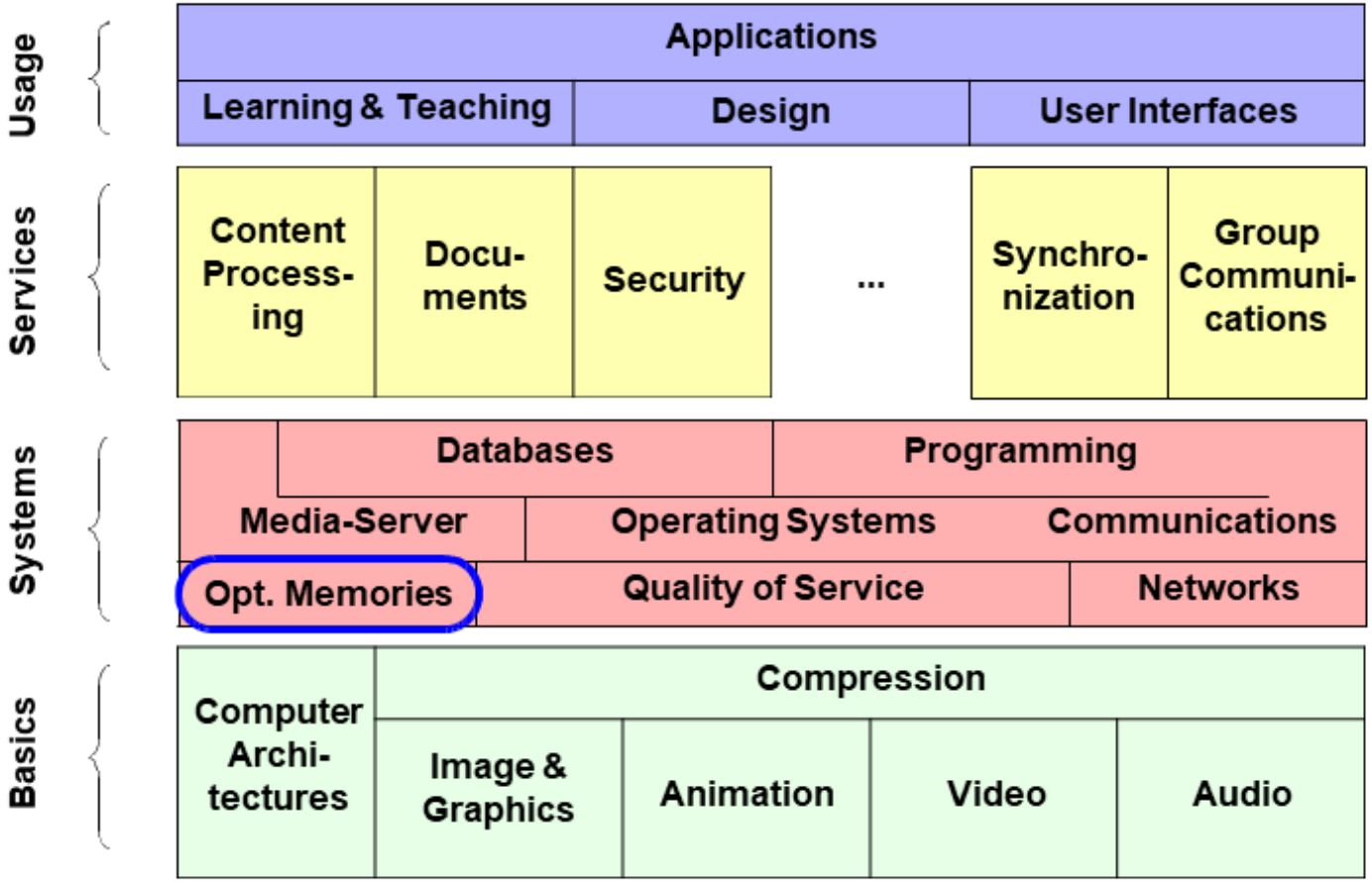
OPTICAL STORAGE MEDIA

UNIT 6

6.1. Basic Technology

Scope



6.1. Basic Technology (cont..)

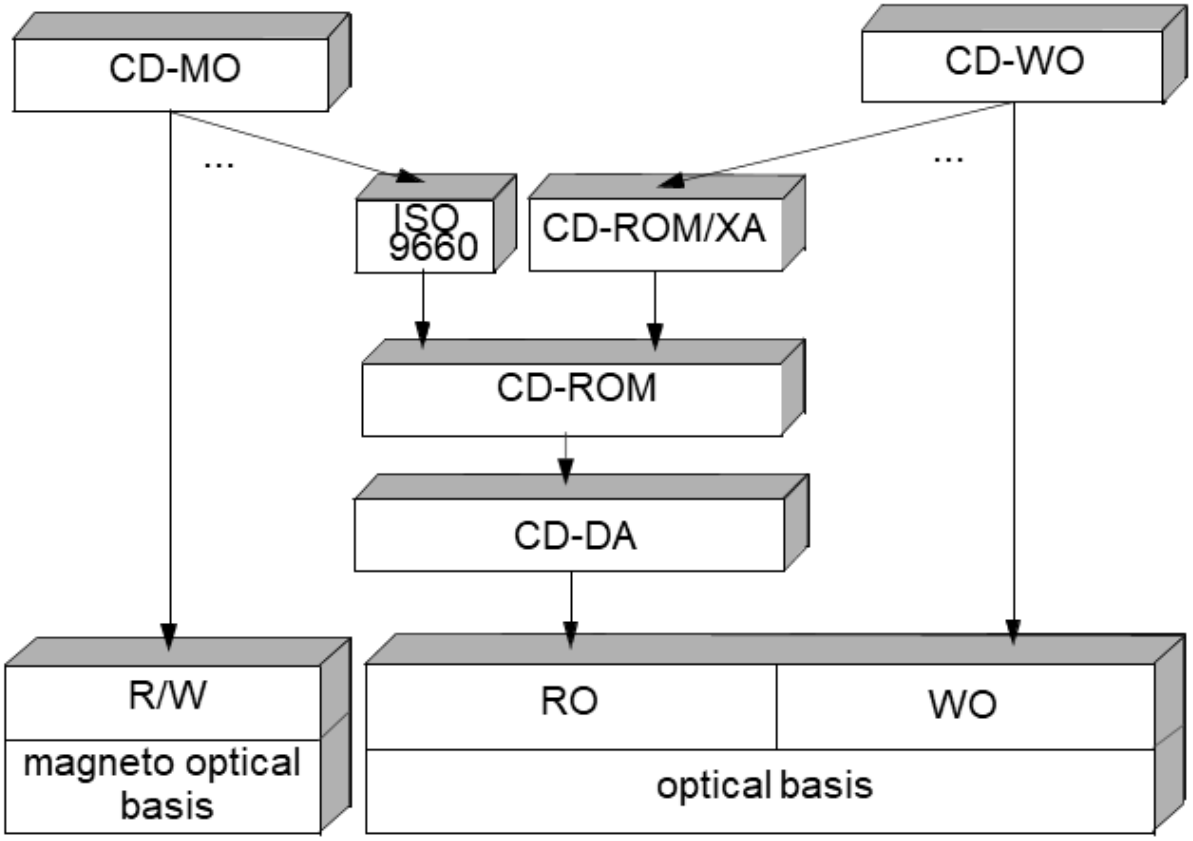
- **Optical storage** is the **storage** of data on an optically readable **medium**.
- Data is recorded by making marks in a pattern that can be read back with the aid of light, usually a beam of laser light precisely focused on a spinning **optical disc**.
- **Optical storage**, electronic storage medium that uses low-power laser beams to record and retrieve digital (binary) data.
- In optical-storage technology, a laser beam encodes digital data onto an optical, or laser, disk in the form of tiny pits arranged in concentric tracks on the disk's surface

6.1. Basic Technology (cont..)

- Optical storage media offer a higher storage density at a lower cost.
- Current magnetic data storage carriers take the form of floppy disks or hard disks and are used as secondary storage media.
- An optical disc drive is a device in a computer that can read CD-ROMs or other optical discs, such as DVDs and Blu-ray discs.
- Optical storage differs from other data storage techniques that make use of other technologies such as magnetism, such as floppy disks and hard disks, or semiconductors, such as flash memory and RAM.

6.1. Basic Technology (cont..)

Compact Disc and in addition Digital Versatile/Video Disk



6.1. Basic Technology (cont..)

History

1973	Video Long Play (VLP) - published
1983	Compact Disc Digital Audio (CD-DA) - available: • Red Book Standard
1985	Compact Disc Read Only Memory (CD-ROM): • Yellow Book Standard for physical format • High Sierra Proposal • ISO 9660 Standard for logical file format
1986	Compact Disc Interactive (CD-I) - announcement: • Green Book
1987	Digital Video Interactive (DVI) - first presentation
1988	CD-ROM Extended Architecture (CD-ROM-XA) announcement
1990	CD Write Once (CD-WO), CD Magneto Optical (CD-MO): • Orange Book
1996	Digital Video Disk DVD

6.2. Fundamentals

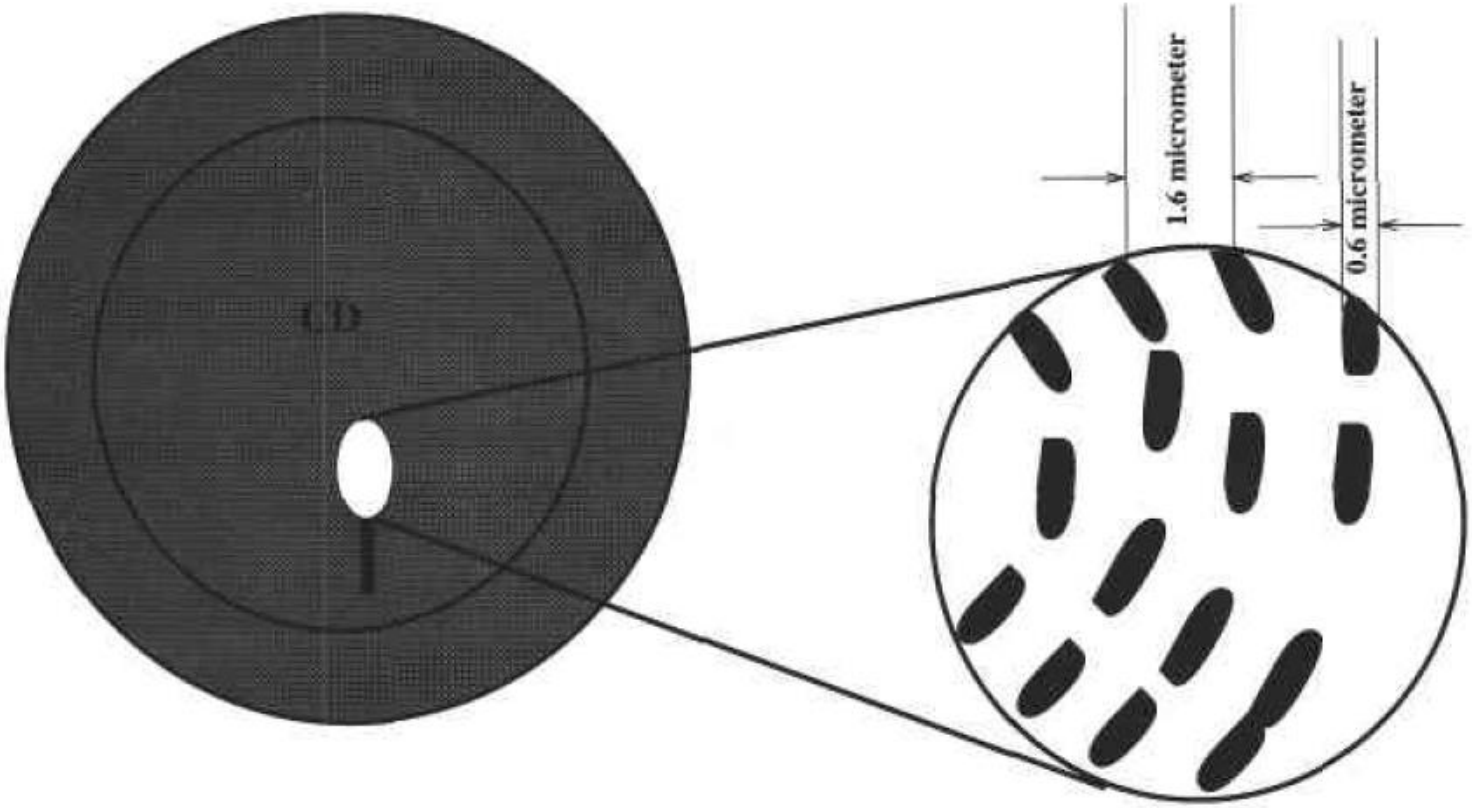


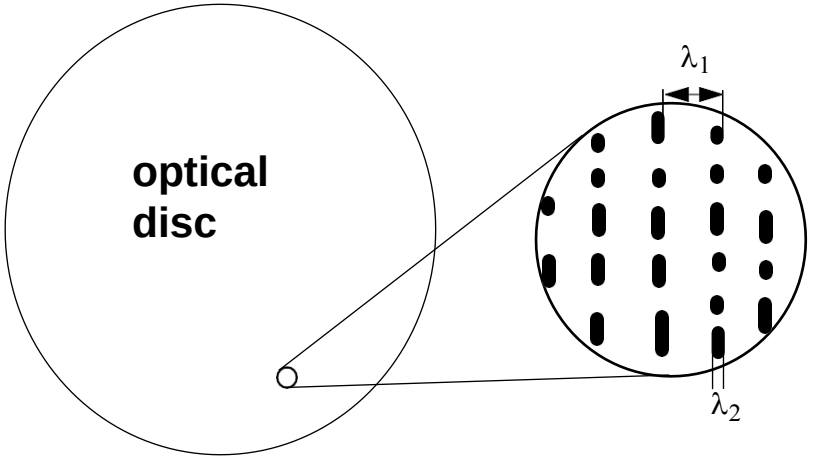
Fig. :Data on a CD as an example of an optical disk (track with "lands' and "pits').

6.2. Fundamentals (cont..)

- Magnetic disks is that on the former 1.66 data bits per μm can be stored. This results in a data density of 1,000,000 bits per mm^2, which implies 16,000 tracks per inch. In comparison, a floppy disk has 96 tracks per inch.

6.2. Fundamentals (cont..)

Pits and Lands



e.g. CD:
λ_1=1.6μm
λ_2=0.6μm

Information is stored in a spiral-shaped track:

- Series of pits and lands in substrate layer
- Transition from pit to land and from land to pit: ‘1’
- Between transitions: sequence of ‘0’ s
- 16000 turns/inch (tpi)

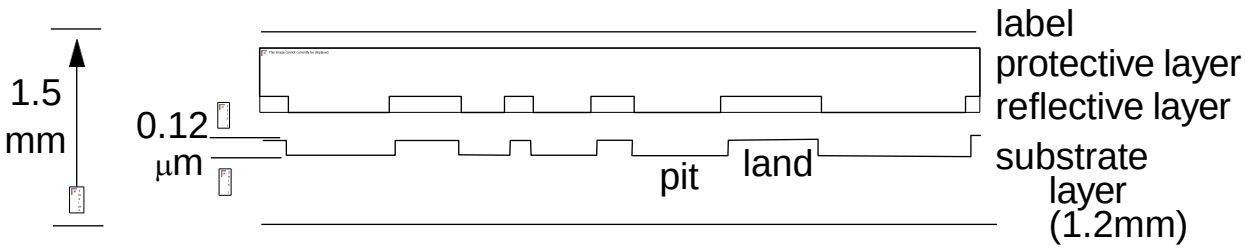
Laser focused onto reflective layer

- Lands - almost totally reflecting
- Pits - scattering

6.2. Fundamentals (cont..)

Fundamentals: Physical Structure

Cross-section through disc in direction of spiral track:

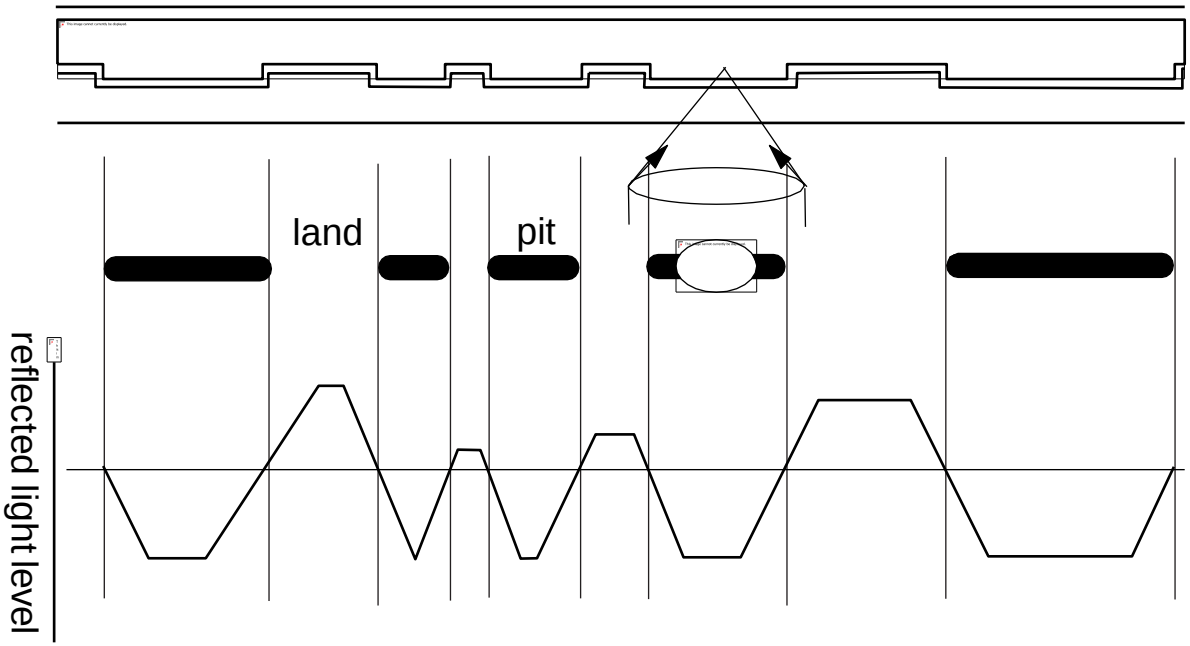


3 layers:

- Transparent substrate layer
- Reflective layer
- Protective layer

6.2. Fundamentals (cont..)

Fundamentals: Read Data



Laser focused onto reflective layer:

- Lands - almost totally reflecting
- Pits - scattering

Advantages of Optical Storage Media

High data density:

- 1.66 data bits / µm of track
- 16000 tpi ⇔ floppy disk: 96 tpi

Long term storage:

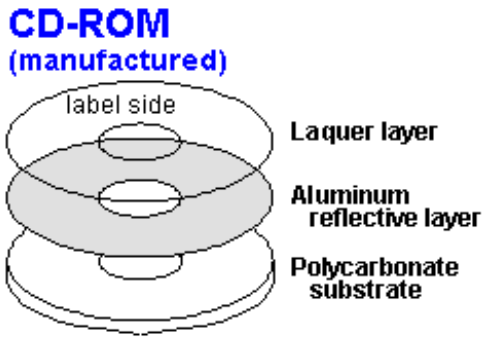
- Protection of data
- Surface out of focus ⊥ insensitivity to dust, scratches

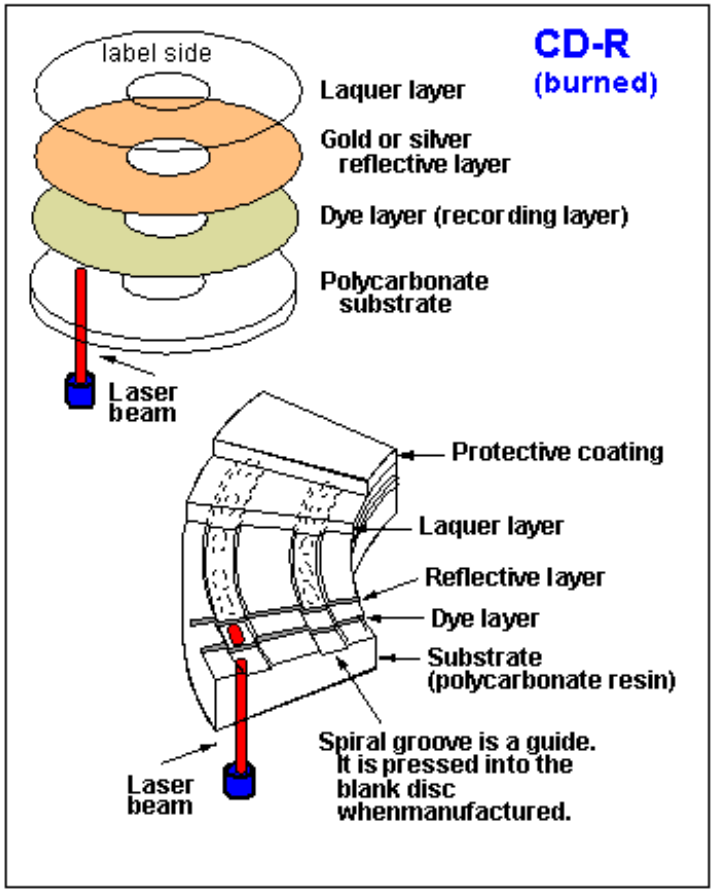
Low probability of head crashes:

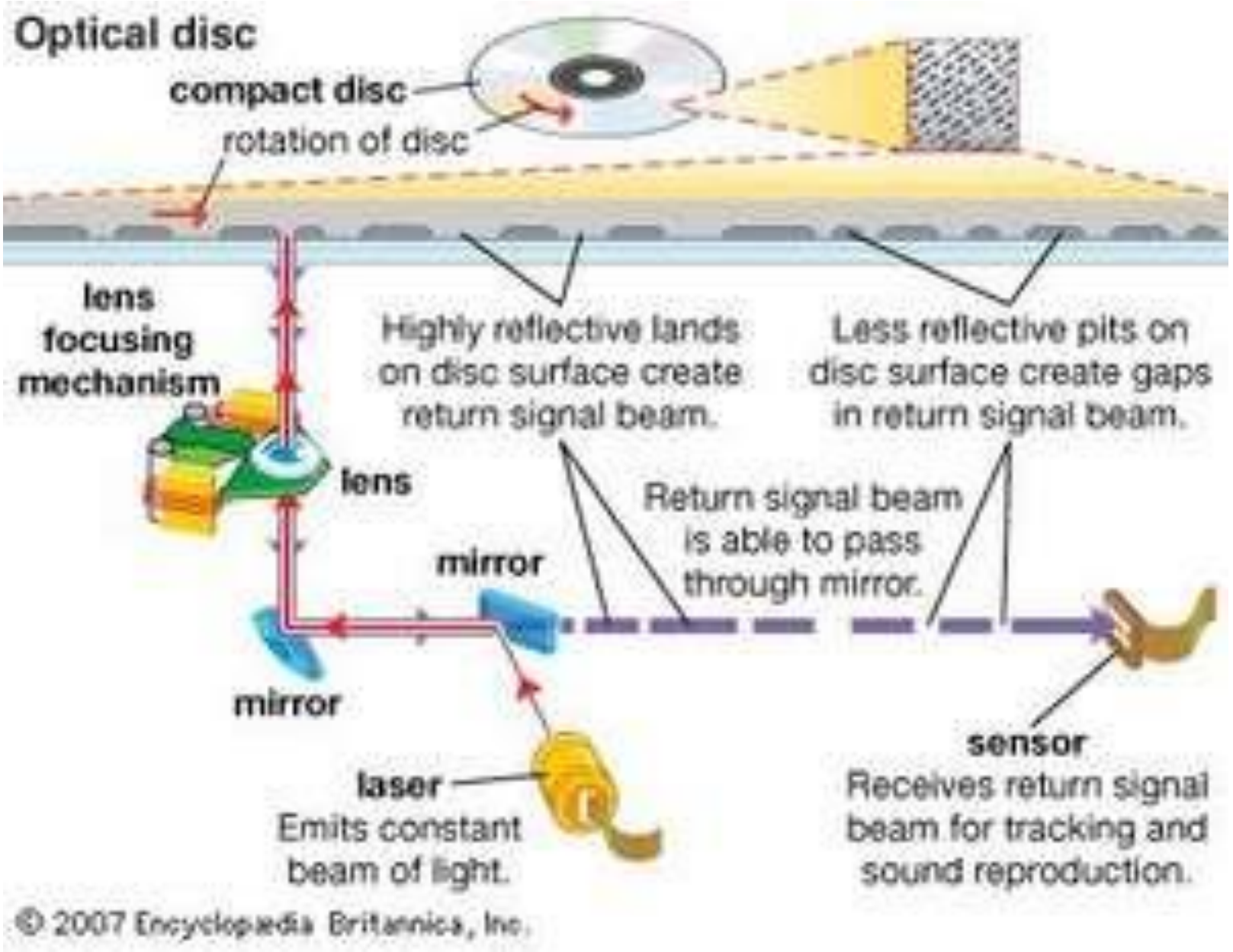
- Distance between head and substrate surface > 1mm

Adequate error correction

Each digital disc is equivalent to the master


CD-ROM
(manufactured)
label side
Laquer layer
Aluminum reflective layer
Polycarbonate substrate


label side
CD-R
(burned)
Laquer layer
Gold or silver reflective layer
Dye layer (recording layer)
Polycarbonate substrate
Laser beam
Protective coating
Laquer layer
Reflective layer
Dye layer
Substrate (polycarbonate resin)
Spiral groove is a guide. It is pressed into the blank disc whenmanufactured.
Laser beam


Optical disc
compact disc
rotation of disc
lens focusing mechanism
lens
Highly reflective lands on disc surface create return signal beam.
Less reflective pits on disc surface create gaps in return signal beam.
Return signal beam is able to pass through mirror.
mirror
mirror
laser
Emits constant beam of light.
sensor
Receives return signal beam for tracking and sound reproduction.
© 2007 Encyclopædia Britannica, Inc.

Laser Vision

Characteristics:

- Storage of video and audio
- Analogue encoding
- High quality of reproduced data
- Diameter: ~ 30 cm
- Storage capacity: ~ 2.6 GByte

History:

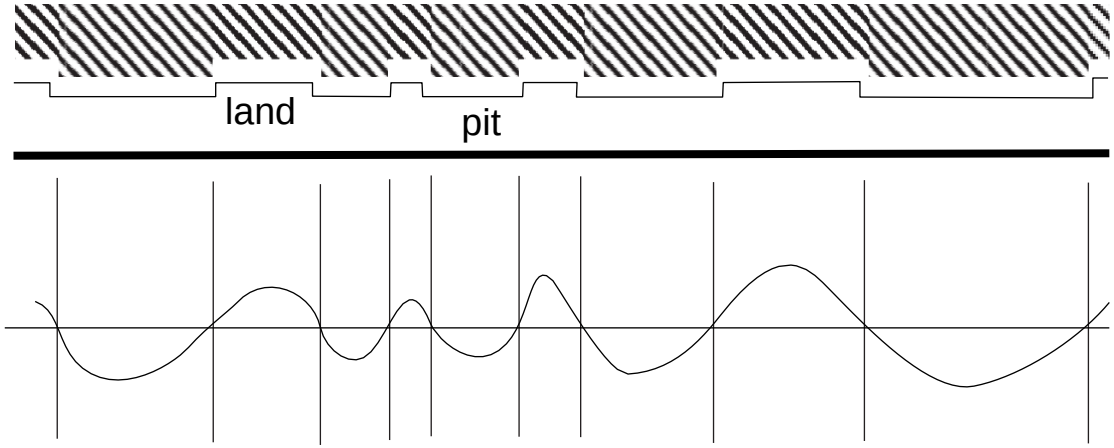
- Originally Video Long Play (VLP)
- 1973 first description in Philips Technical Review

Laser Vision: Fundamentals

Principles:

- Mix of audio and video
- Frequency modulation
- No quantization of pit length

Cross section through a Laser Vision disc:



6.3. Compact Disc Digital Audio (CD-DA)

- An Audio CD is a music CD like that you buy in a music store.
- It can be played on any standard CD player (such as a CD deck, or your car CD player, or a portable CD player).
- Music is stored on Audio CDs as uncompressed digital data, no data is lost and quality is very high, exactly as in WAV(Waveform Audio File Format, WAVE) digitally encoded files.
- When you put an Audio CD into your personal computer CD player and play it, audio is extracted on the fly and played by your PC sound hardware.
- **Compact Disc Digital Audio**(**CDDA** or **CD-DA**) is the standard format for audio compact discs.

6.3. Compact Disc Digital Audio (CD-DA)

Storage of audio data

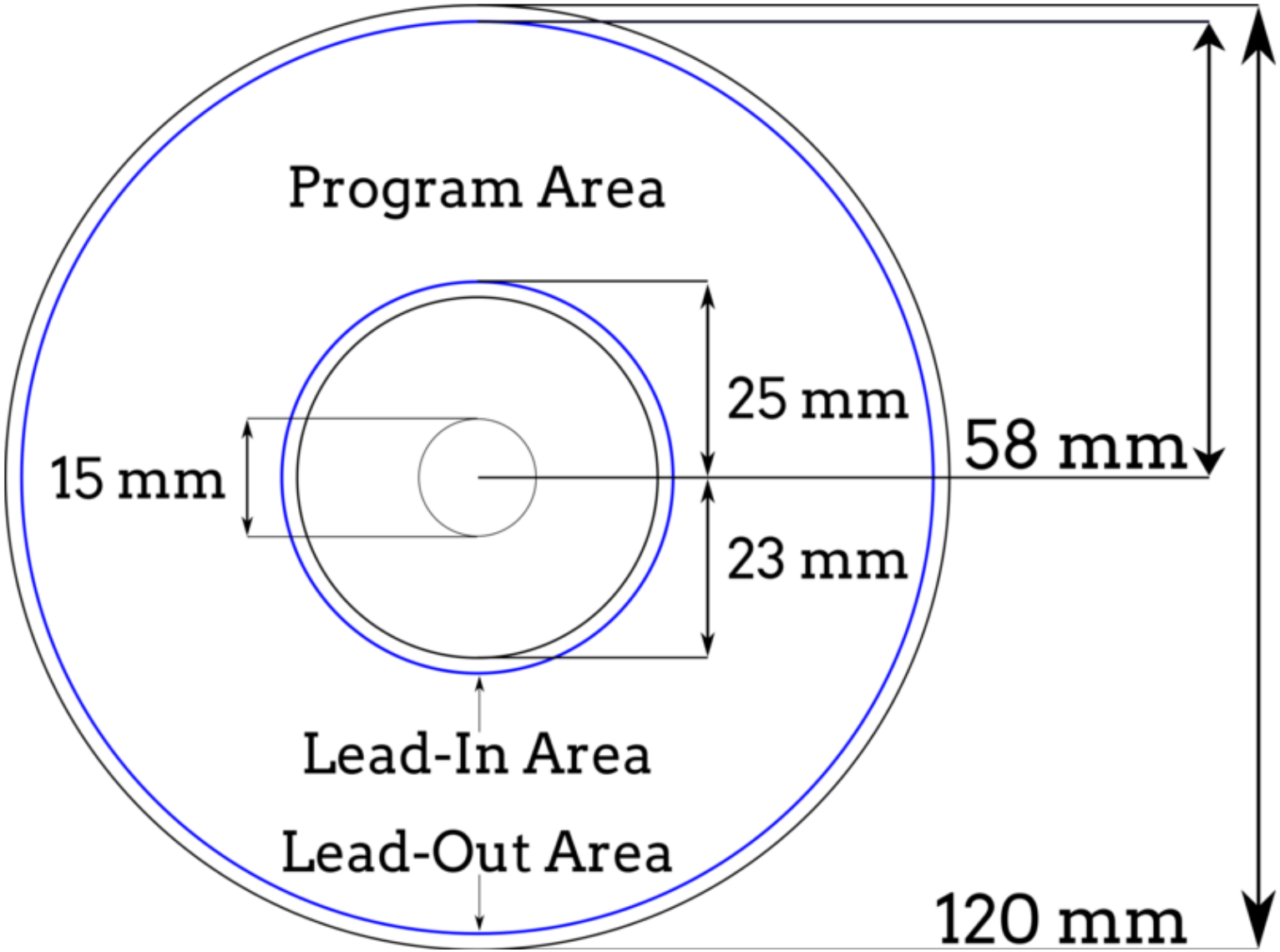
History:

- Development of basic technology by N. V. Philips
- Cooperation of N. V. Philips and Sony Corporation
- 1983 CD-DA available

Physical characteristics:

- Diameter: 120 mm
- Constant linear velocity (CLV),
  i.e. number of rotations/s depends on position of head relative to disc center
- Track shape:
  One spiral with appr. 20000 turns (LP: 850 turns)

Physical characteristics:



Data structure

- The audio data stream in an audio CD is continuous, but has three parts.
- The main portion, which is further divided into playable audio tracks, is the *program area*. This section is preceded by a *lead-in*track and followed by a *lead-out*track.
- The lead-in and lead-out tracks encode only silent audio, but all three sections contain subcodedata streams.
- The lead-in's subcode contains repeated copies of the disc's Table Of Contents (TOC), which provides an index of the start positions of the tracks in the program area and lead-out.

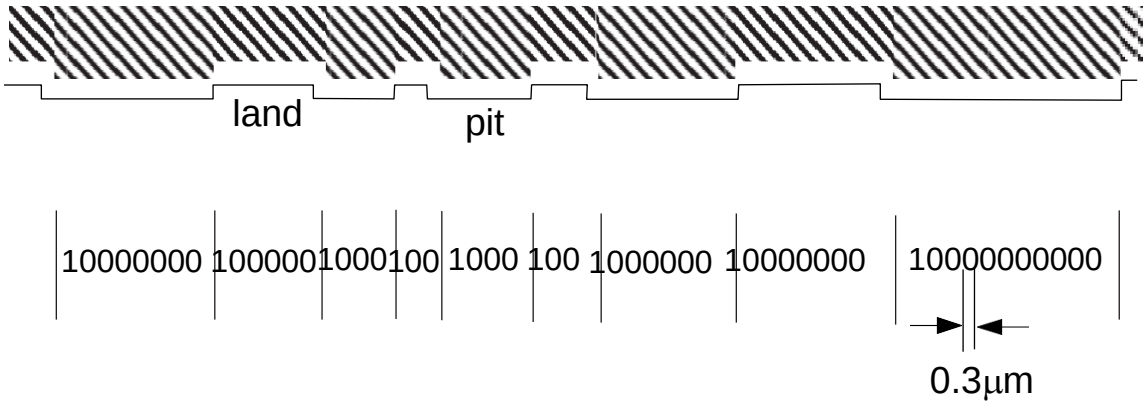
Data structure(cont..)

- The track positions are referenced by absolute time code, relative to the start of the program area, in MSF format: minutes, seconds, and fractional seconds called *frames*. Each time code frame is one seventy-fifth of a second, and corresponds to a block of 98 channel-data frames—ultimately, a block of 588 pairs of left and right audio samples.
- Time code contained in the sub channel data allows the reading device to locate the region of the disc that corresponds to the time code in the TOC. The TOC on discs is analogous to the partition table on hard drives. Nonstandard or corrupted TOC records are abused as a form of CD/DVD copy protection, in e.g. the key2Audio scheme.

CD-DA: Characteristics

- Audio data rate:
  - Sampling frequency: 44100Hz
  - 16 bit quantization (Each audio sample is a signed 16-bit two's complement integer, with sample values ranging from −32768 to +32767.)
  - Pulse code modulation (PCM)
  - Audio data rate = 1411200 bit/s = 176,4 Kbyte/s
- Quality:
  - Signal to noise ratio (S/N):
  - ~ 6dB/bit, 16 bit quantization ⇾ S/N exactly 98 dB
  - LP, tape: S/N 50-60 dB
- Capacity: (without error correction data)
  - Playback time: maximal 74 min
  - Capacity =74 min ∗ 1411200 bit/s = 6265728000 bit ~ 747 MByte

CD-DA: Pits and Lands



Length of pits: multiples of 0.3μm

Coding:

- Transition from pit to land / from land to pit: ‘1’
- Between transitions: sequence of ‘0’s

CD-DA: Eight-to-Fourteen Modulation

- Eight-to-Fourteen Modulation, or EFM as it is abbreviated, is an encoding technique used by CDs and provides a way of countering errors by encoding a byte into 2 bytes.
- Using EFM the data is broken into 8-bit blocks (bytes). Each 8-bit block is translated into a corresponding 14-bit codeword using a predefined lookup **table**.
- The 14-bit codeword are chosen so that binary ones are always separated by a minimum of two and a maximum of ten binary zeroes.
- EFM maximizes the number of transitions possible with an arbitrary pit and land length which is determined by the wavelength of the laser light used to read the data.

CD-DA: Eight-to-Fourteen Modulation

Restricted laser resolution:

- Minimal distance between transitions (pit to land, land to pit)
- At least two “0” between two “1”

Generation of clock signal:

- Maximal distance between transitions (pit to land, land to pit)
- Not more than 10 consecutive “0”

✦ **Eight-to-Fourteen Modulation:**

- 8 bit value is encoded using 14 bits
- 267 combinations possible
- 256 are used
  (criterion: efficient implementation with small number of gates)

CD-DA: Eight-to-Fourteen Modulation

Example for a code conversion table:

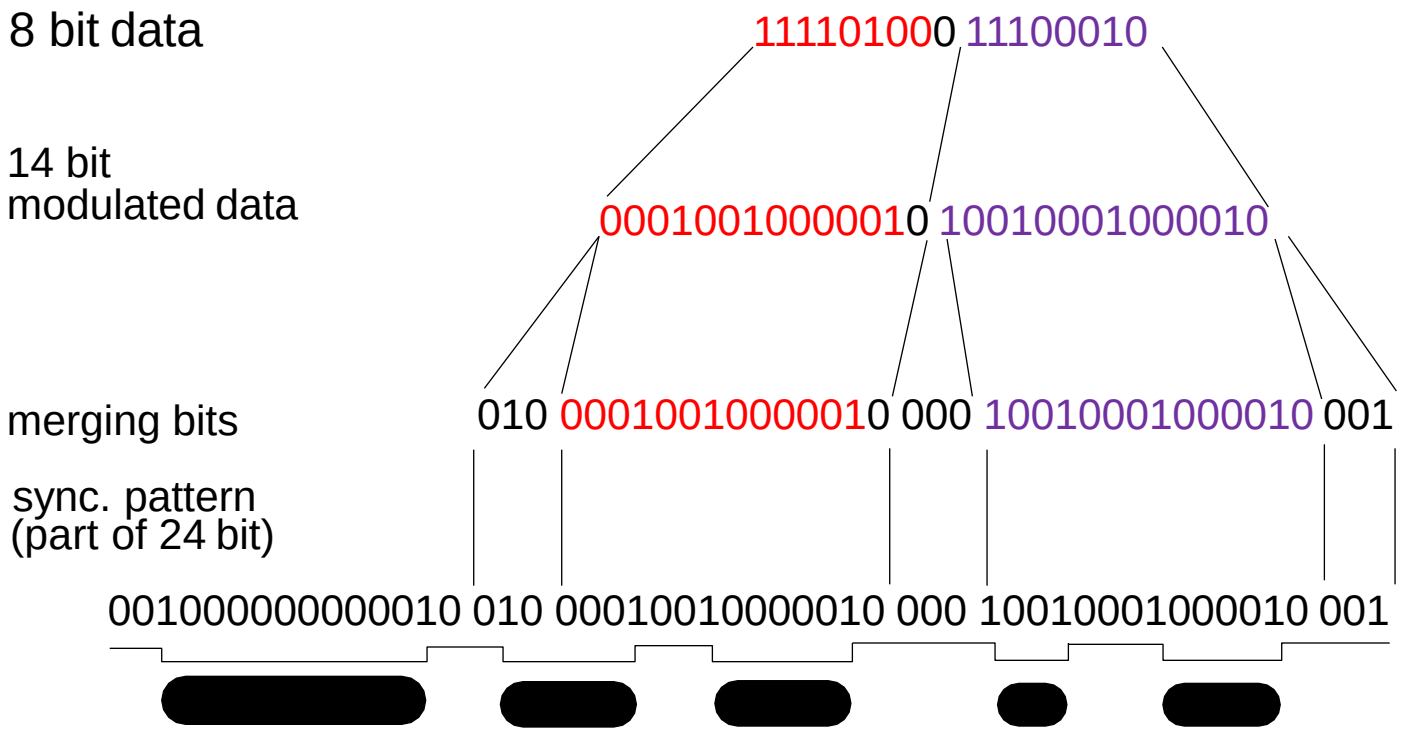
data bits	channel bits
00000000	01001000100000
00000001	10000100000000
...	...

Concatenation of independent 14 bit values
Í potential violation of:

- Min. distance of 2 bits
- Max. distance of 10 bits

⌖ Three additional *merging bits*

CD-DA: Eight-to-Fourteen Modulation Example



CD-DA: Error Handling

Typical Errors:

- Scratches, dust, fingerprints
- "Burst errors"
- To be detected and corrected

Two-level Reed-Solomon Code with frame interleaving:

- First level: byte level, EDC and ECC
  - two groups: each with 4 correction bytes for 24 data bytes
  - first group: correction of single byte errors
  - second group: correction of double byte errors, detection of further errors
- Second level: Frame interleaving
  - frame: 588 channel bits = 24 audio data bytes
  - distribution of consecutive data bytes and corresponding ECC bytes over adjacent frames

CD-DA: CIRC

Cross Interleaved Reed Solomon Code

Error rate: 10^{-8} (~ 1bit/100 millions of bits) Exact correction of 4000 data bits possible:

- 4000 data bits * 0.3 μm/channel bit
- ~ 2.5 mm
- Hence: burst errors within 2.5 mm can be corrected

Interpolation:

- Up to 12,300 data bits (~ 7 mm)
- Hence: error within 7mm can be repaired

CD-DA: Frames

***Frame* consists of:**

- Data:
  - 2 groups of 12 audio data bytes each (actual data)
- Error detection and correction code:
  - 2 groups of 4 parity bytes
  - According to Reed-Solomon
- Control & display byte:
  - Together with c&d bytes of other frames it forms subchannel stream
  - E.g., subchannel byte for track start identification
- Synchronization pattern:
  - Start of a frame
  - 12 x “1” + 12 x “0” + 3 merging bits = 27 bits

CD-DA: Data Streams

Audio bit stream ~ 1.41 x 10^6 bit/s:

- 44,1 kHz sampling frequency~ 1411200 bit/s
- 16-bit stereo PCM
- Uniform quantization

Data bit stream ~ 1.94 x 10^6 bit/s:

- Audio bit stream
  + parity bytes
  + control & display byte

Channel bit stream ~ 4.32 x 10^6 bit/s:

- Data bit stream
  + EFM
  + merging bits
  + synchronization pattern

CD-DA: Areas

Areas:

- Lead-in area:
  - List of contents
  - Indication to start of each track
- Program area:
  - Up to 99 tracks of different lengths
  - Typically one track relates to one song
- Lead-out area

Random Access:

- Tracks
- Index points:
  - IP_0: start of track
  - IP_1: start of audio data
  - Track pregap: part between IP_0 and IP_1

CD-DA: Summary

Provides:

- Suitable means for typical errors caused by damage, dust in audio data
- CD-DA specification is base for family of optical storage media

But:

- Not conceived for:
  - video (different ECC, EDC scheme required)
  - discrete data (error rate too high)
- Desired: simultaneous play back of various media

6.4. Compact Disc Read Only Memory (CD-ROM) and Extended Architecture

- A **CD-ROM** is a pre-pressed optical compact disc which contains data.
- Computers can read CD-ROMs, but cannot write to CD-ROMs, which are not writable or erasable.

6.4. Compact Disc Read Only Memory (CD-ROM) and Extended Architecture

Storage of:

- Data, audio, compressed audio and video

Yellow Book CD-ROM Standard:

- CD-ROM mode 1: for any data
- CD-ROM mode 2: for compressed audio and video data
- But can not be combined on single track

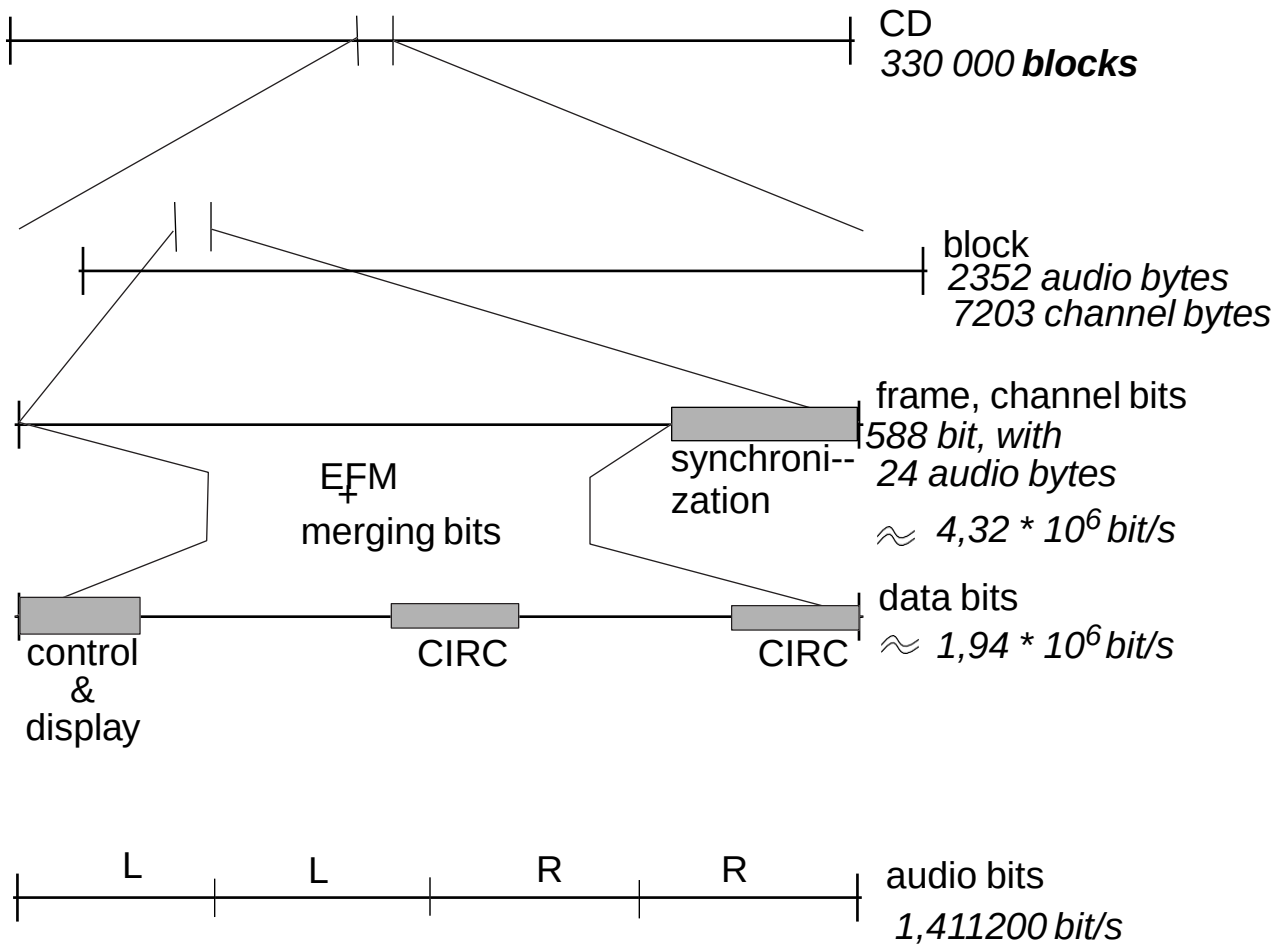
Within single track:

- Only CD-DA audio or only CD-ROM specific data

Mixed Mode Disc:

- Data tracks at the beginning
- Subsequent tracks for audio data

CD-ROM: Structure



CD-ROM: Structure

Fine granularity for random access:

- Tracks, IP not sufficient
- Structure with a higher resolution: block
- Blocks with fixed number of frames

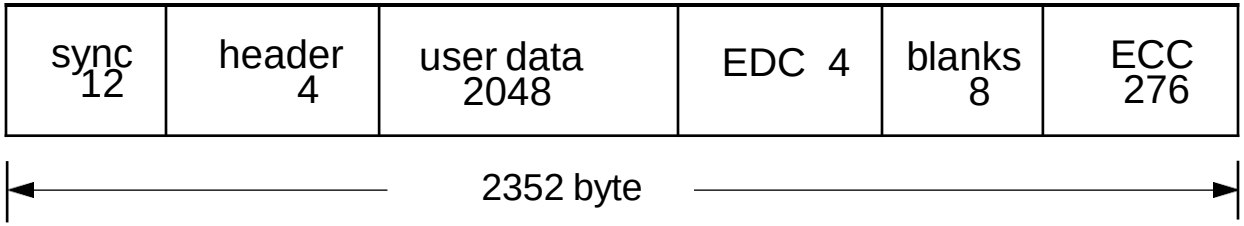
Some numbers:

- 1 block = 32 frames
- 75 blocks/s (for single-speed CD-ROM)
- 1411200 bit/s / 75 blocks/s / 8bit/byte = 2352 byte/block

Allows for:

- Random access
- Better EDC, ECC

CD-ROM Mode 1



- 4 bytes for the header, which carries an unambiguous (definite) specification of the block.
  - The first byte stores minutes, the second byte stores seconds and the third byte contains the block number. The fourth byte includes the mode specification.
- 2,048 bytes for the user data.
- 4 bytes for error detection.
- 8 unused bytes.
- 276 bytes for error correction. Hence, an error rate of 10^{-12} can be achieved

CD-ROM Mode 1 (cont..)

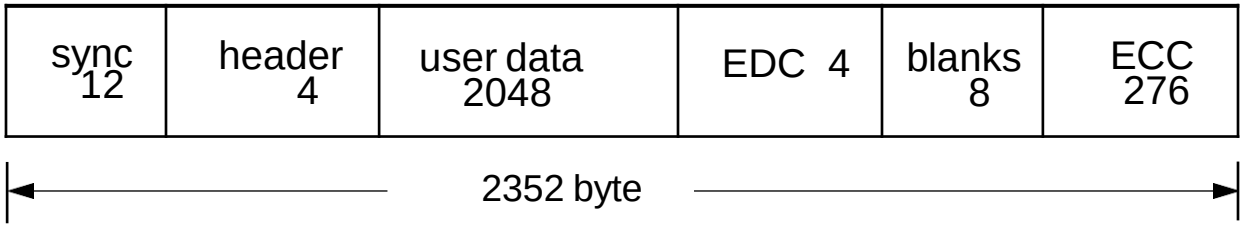
- A CD-ROM contains 333,000 blocks to be played in 74 minutes. The capacity of a CD-ROM with all blocks in mode 1 can be computed as follows

$$
\begin{aligned}
Capacity_{CD-ROM_{mode1}} &= \\
&= 333,000 blocks \times 2048 \frac{bytes}{block} = 681,984,000 bytes \\
&= 681,984,000 \times \frac{1}{1024 \frac{bytes}{Kbyte}} \times \frac{1}{1024 \frac{Kbytes}{Mbyte}} \approx 660 Mbytes
\end{aligned}
$$

The *data rate* in mode 1 is:

$$
\begin{aligned}
Rate_{CD-ROM_{mode1}} &= \\
&= 2,048 \frac{bytes}{Block} \times 75 \frac{Blocks}{s} = 153.6 \frac{Kbytes}{s} \equiv 150 \frac{Kbytes}{s}
\end{aligned}
$$

CD-ROM Mode 1



1 block = 2352 byte:

- Header bytes include minutes, seconds, block number, mode
- Error rate = 10^{-12}

Capacity:

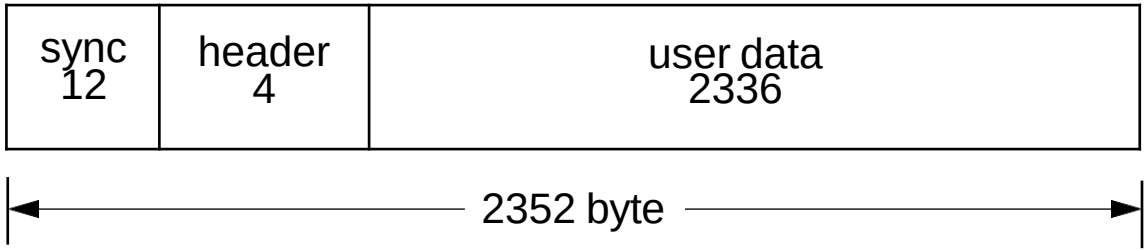
- Max. 74 min x 60 s/min x 75 block/s = 333000 blocks
- 333000 blocks/CD ~ 650 MByte (user data)

Data rate:

- 2048 byte/block x 75 block/ s ~150 KByte/s (single-speed)

Used by most CD-ROM applications

CD-ROM Mode 2



Capacity:

- 333000 blocks x 2336 byte/block
  = 777888000 byte ~ 741.85 MByte

Data rate:

- 2336 byte/block x 75 block/s = 171 KByte/s (single-speed)

Problem: concatenation of mode 1 and mode 2 blocks

CD-ROM Mode 2 (cont..)

1. Additional error correction does not exist. The capacity and data rate of a CD-ROM with all blocks in mode 2 can be computed as follows:

$$Capacity_{CD-ROM_{mode2}} = 333,000\ blocks \times 2336 \frac{bytes}{block} \approx 777,888,000\ bytes$$

$$Rate_{CD-ROM_{mode2}} = 2336 \frac{bytes}{block} \times 75\ blocks/s \approx 175.2\ Kbytes/s$$

CD-ROM: Average Access Time

Time to position a block/sector:

- Synchronization time:
  - Adapt internal clock to disc signal
  - Range of milliseconds
- Seek time:
  - Adaptation of laser to radius: max. 1s
- Rotation delay (for constant velocity time):
  - Find sector within 1 rotation
  - Adapt disk speed
  - ~ 300 ms

✦ **Maximum access time > 1s**

✦ **Average access time > 300ms (with data caching)**

- Simultaneous reading of audio and other data in CD-ROM mode 1 not possible

CD-ROM: File System

CD-ROM:

- No logical file format
- No directory specification

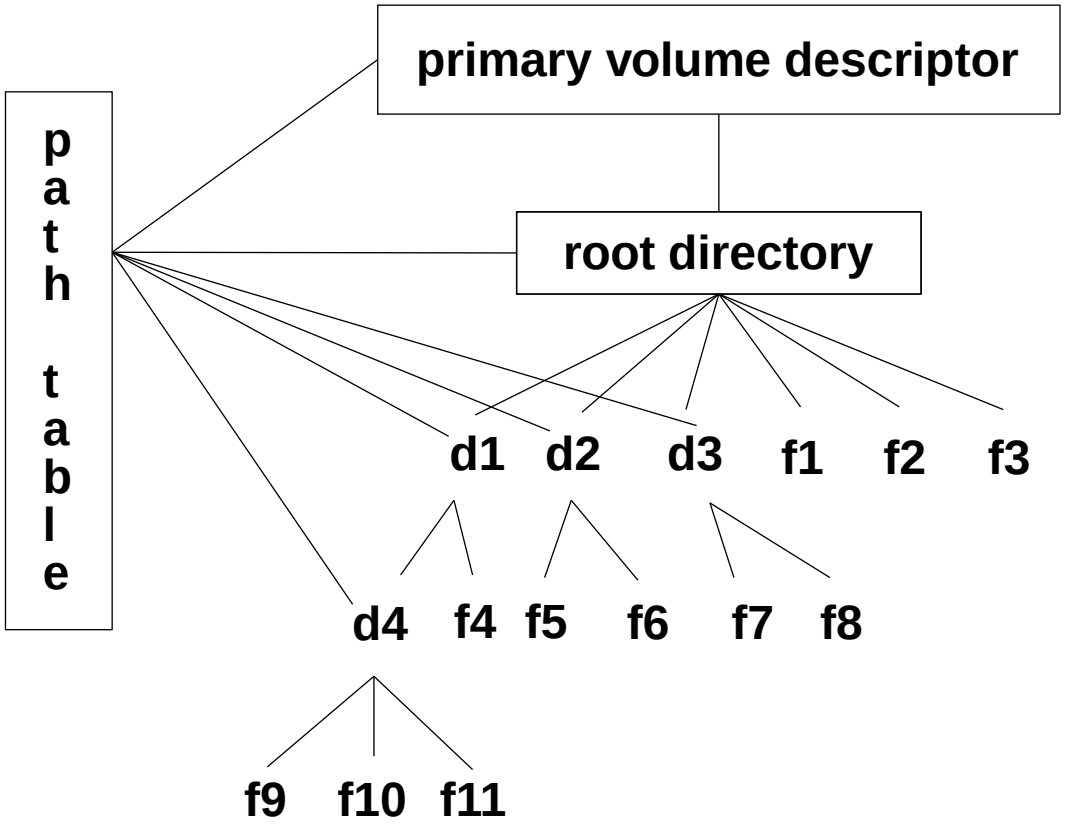
High Sierra Proposal:

- Developed by group of industry representatives
- Initial file system leading to ISO 9660

ISO 9660 file standard:

- Directory tree: information about files
- Path table:
  - List of all directories
  - Direct access to files of any level
- File interleaving

CD-ROM: File System - Path Table



ISO 9660 File System

First track:

- 16 blocks (sectors 0 to 15): system area
- Volume descriptors in subsequent blocks:
  - Primary descriptor:
    - Length of file system
    - Length and address of path table
  - Supplementary descriptors
- Volume descriptor terminator

Logical block size:

- Between 512 byte and 2048 byte (in steps of 2^i)
- Blocks of 512 byte, 1024 byte, and 2048 byte are used
- Files begin at logical block start

CD-ROM Extended Architecture (CD-ROM / XA)

History:

- N.V. Philips, Sony and Microsoft (announcement in 1988)

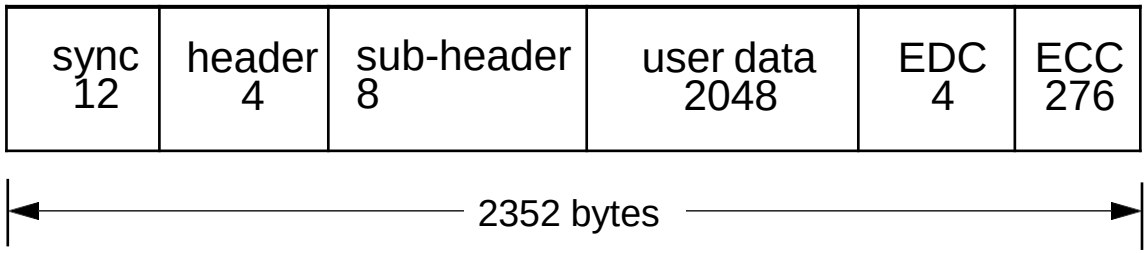
Goal:

- Simultaneous transfer of various media data

Characteristics:

- Based on CD-ROM mode 2, ISO 9660, CD-I
- Extension of Yellow Book standard
- Interleaving of blocks of different media within the same track
- Definition of a new type of track used for:
  - compressed audio (ADPCM) and video data
  - images
  - text, programs
- Distinction between two block formats: „Form 1“, „Form 2“

CD-ROM / XA (Mode 2) Form 1



Subheader:

- Specification of CD-ROM Mode 2 XA-Format type
- 8 bytes

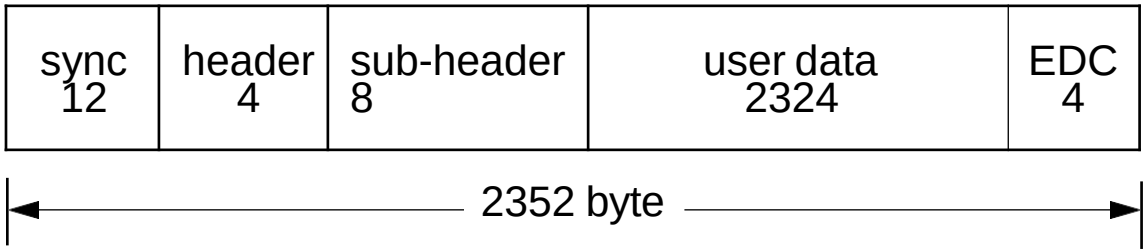
Improved error handling for:

- Text
- Program data

By:

- 4 byte for error detection
- 276 byte for error correction

CD-ROM / XA (Mode 2) Form 2



- Storage of compressed data (incl. audio, video)
- Only 4 bytes for error detection
- 13% more data bytes

CD-ROM / XA: Audio

	CD audio	level B stereo	level B mono	level C stereo	level C mono
compr. ratio	1	4:1	8:1	8:1	16:1
coding techn.	PCM	ADPCM	ADPCM	ADPCM	ADPCM
sampling freq.	44100 Hz	37800 Hz	37800 Hz	18900 Hz	18900 Hz
capacity	74 min	4 h 48 min	9 h 36 min	9 h 36 min	19 h 12 min
data rate	176 kByte/s	43 Kbyte/s	22 Kbyte/s	22 Kbyte/s	11 Kbyte/s

CD-ROM / XA: Drawbacks

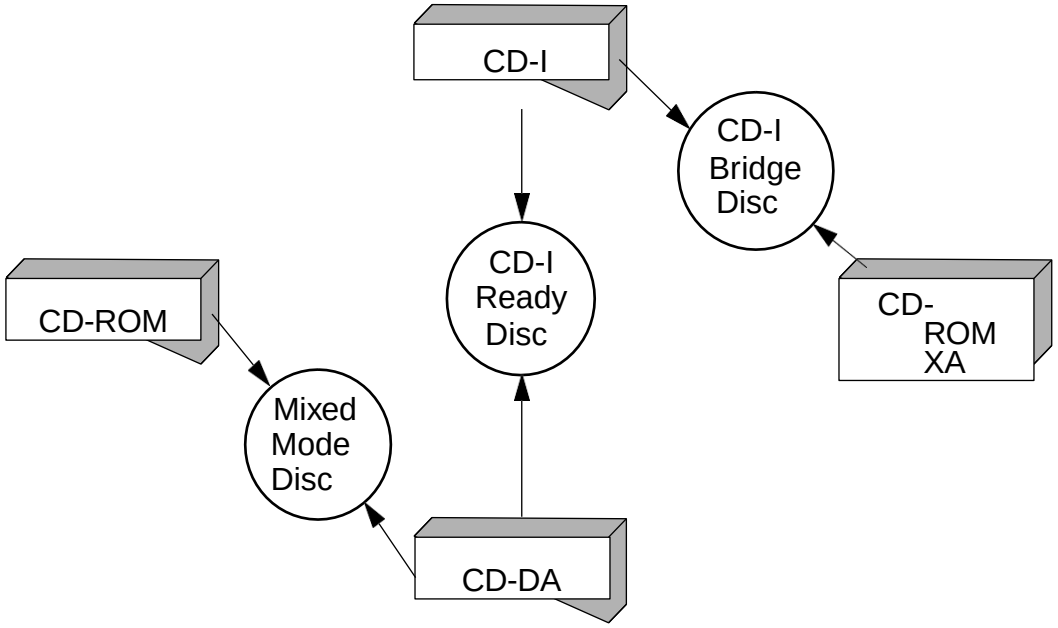
Compatibility to audio and video compression

- For some media only reference to standard
  - coding / decoding not part of CD technology
- MPEG audio not compatible (MPEG does not use ADPCM)

Interleaved storage of data of different types in the same track:

- Requires special disc layout
- Requires effective interleaving with choice of suitable audio level
- Complex application development

Further CD-ROM Based Developments



CD-Interactive (CD-I)

History:

- Developed by Philips and Sony
- 1986 CD-I announcement
- 1988 Green Book: CD-I extension based on Red and Yellow Book
- Originally for consumer market

CD-I system:

- CD-ROM based format with interleaving of different media
- Compression algorithms
- Software (operating system)
- Hardware (decoder)

Different quality levels Low

data rates

CD-I: Software and Hardware

CD-I Software with CD-RTOS operating system:

- CD-RTOS operating system is an extension of OS/9
- Real-time capabilities

CD-I Hardware (decoder):

- System board:
  - 680xx processor
  - Video-, audio -chips
- CD player with CD-DA components
- Mouse or joystick interface
- CD controller
- Connection to RGB monitor or TV
- Replacement of CD-DA
- Size of a video recorder

CD-I: Audio

	CD digital audio	**CD-I 'A' hi-fi music**	**CD-I 'B' mid-fi music**	**CD-I 'C' speech**
sampling rate	44.1 kHz	37.8 kHz	37.8 kHz	18.9 kHz
freq. range	20 kHz	17 kHz	17 kHz	8.5 kHz
encod.	16 bit PCM	8 bit ADPCM	4 bit ADPCM	4 bit ADPCM
s/n ratio	98 dB	90 dB	60 dB	60 dB
max. playing time	74 min stereo	2.4 h stereo 4.8 h mono	4.8 h stereo 9.6 h mono	9.6 h stereo 19.2 h mono
appr. fidelity equival.	CD	mono LP	mono FM	mono AM

CD-I: Video

Coding of still images at different qualities and resolutions:

- Different amount of data
- Different data rates

YUV mode:

- Reproduction of natural images with many colors
- Encoding of changes of luminance and chominance values
- 360 x 240 pixel, 18 bit/pixel
- 262144 colors
- 360 * 240 * 18 bit/image = 194400 byte/image

Animations with few colors:

- Run-length encoding, about 10000 to 20000 Byte/image

MPEG for video encoding

CD-I: Video

Color Look-Up Table (CLUT):

- 4 bit/pixel (3.7 or 8 bit/pixel)
- For simple graphics fast data read-out
- Predefined color table
- 720 x 240 pixel, 16 colors
- 720 * 240 * 4 bit = 86400 Byte/image

RGB mode:

- For very good graphics
- 5 bit/pixel for each component
- 15 bit/pixel + 1 additional bit/pixel = 16 bit/pixel
- 360 x 240 pixel/image, 65538 colors
- 360 * 240 pixel/image * 16 bit/pixel = 172800 Byte/image

CD-I Ready Format

CD that can be played in CD-DA and CD-I players:

- Track pregap:
  - Contains CD-I specific information
  - Increased from 2-3 s to at least 182 s
- Audio players ignore the track pregap information and play only audio data part

Three different modes of play:

- Standard audio playback:
  - Track pregap information is ignored and only audio data played
- Reading, display and interpretation of the pregap data:
  - Audio data part is ignored
- Displaying pregap data as audio is played:
  - First step: loading CD-I information into player's RAM memory
  - Second step: start playing audio and information display

6.5. Principle of CD-Write and CD-Magneto optical

CD-Write Once

- So far, all of the CD technologies considered do not allow the user to write to the disk. Thus, the application scope is limited.
- This has led research laboratories to develop, besides the Read Only Storage Media, compact disks that can be recorded once or several times.
- The compact Disk write once (CD-WO), like WORM (write once Read Many),allows the user to write once to a CD and afterwards to read it many times.

Principle of the CD-WO

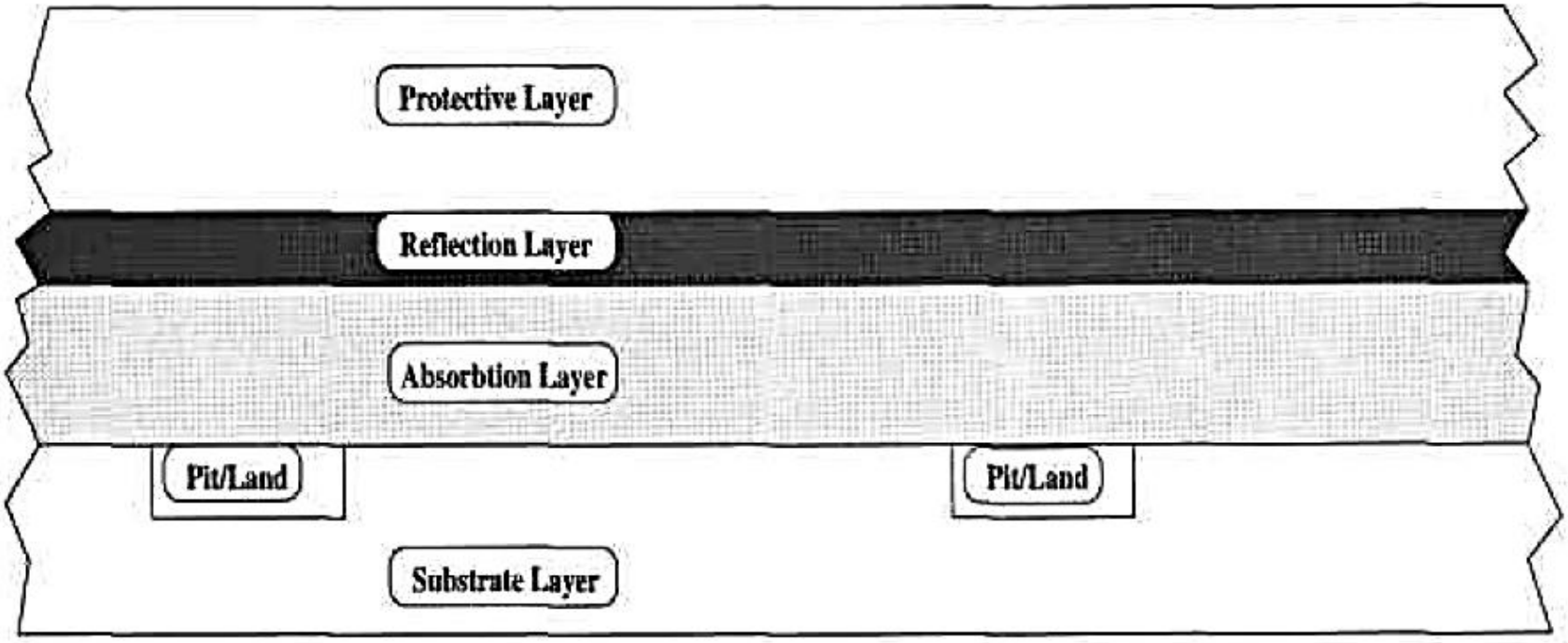


Figure 7.12: *Cross-section of a CD-WO disk.*

Principle of the CD-WO (cont..)

- Figure shows a cross-section of a CD-WO, vertical to the disk surface and data track.
- In the case of read-only CDs, the substrate (a polycarbonate) lies directly next to the reflection layer.
- In the case of a CD-WO, an absorption layer exists between the substrate and the reflection layer. This layer can be irreversibly (permanently) modified through strong thermal influence, which changes the reflection properties of the laser beams.

Principle of the CD-WO (cont..)

- In its original state, a CD-WO player recognizes a track consisting of lands.
- The **absorption layer** in the pre-grooved track is heated to above 250^0 C with a laser three to four times the intensity of a reading player. Hence, the absorption layer changes such that the reflection of the laser light now corresponds to a **pit**.
- This method determines the most remarkable property of the CD-WO: its data can be played by any devices which are meant only for read-only CDs.

6.5. Principle of CD-Write and CD-Magneto optical

Compact Disk Magneto Optical

- The Compact Disk Magneto Optical (CD-MO)has a high storage capacity and allows one to write multiple times to the CD.

Principle of the Magnetic-Optical Method

- The magnetic-optical method is based on the polarization of the magnetic field where the polarization is caused by a heat.
- To be written, the block (sector) is heated to above 150^0C. Simultaneously, a magnetic field approximately 10 times the strength of the earth's magnetic field is created.
- The individual dipoles in the material are then polarized according to this magnetic field.
- Hereby, a pit corresponds to a low value of the magnetic field. A land is coded through a high value of the magnetic field.

Principle of the Magnetic-Optical Method (cont..)

- After the CD is irradiated (illuminated) with a laser beam, the polarization of the light changes corresponding to the existing magnetization. Using this process, the read operation is executed.
- For a delete activity, a constant magnetic field is created in the area of a block and the sector is simultaneously heated.

Areas of the CD-MO

- A CD-MO consists of an optional *read-only* area and a *write-many* (recordable) area.
- The read-only area (the premastered area) includes data which were written in a specified format onto the disk.
- CD-MO read-only area can be read by available playback devices.

6.6. Other Storage Media; DVD, Flash Drive, HD Cards, USB

DVD

Also known as: “Digital Versatile Disk”

Goal:

- **Create a new optical media to store an entire high-quality digital movie on a single side of a disk**

Technical overview of DVD:

- CD-like optical storage media
  - same size as CD ⇒ allows for backward compatibility of reading devices
- Capacity considerably higher than CD
  - shorter pit/lands
  - tighter tracks
- EFM PLUS error correction scheme: more robust than CD scheme

Formats:

- single-sided single-layer
- single-sided double-layer: laser must switch focus to read both layers
- double-sided: disk must be flipped over to read both sides

DVD

- The 12 cm type is a standard DVD, and the 8 cm variety is known as a MiniDVD.
- These are the same sizes as a standard CD and a mini-CD, respectively.
- The capacity by surface area (MiB/cm^2) varies from 6.92 MiB/cm^2 in the DVD-1 to 18.0 MB/cm^2 in the DVD-18.

DVD

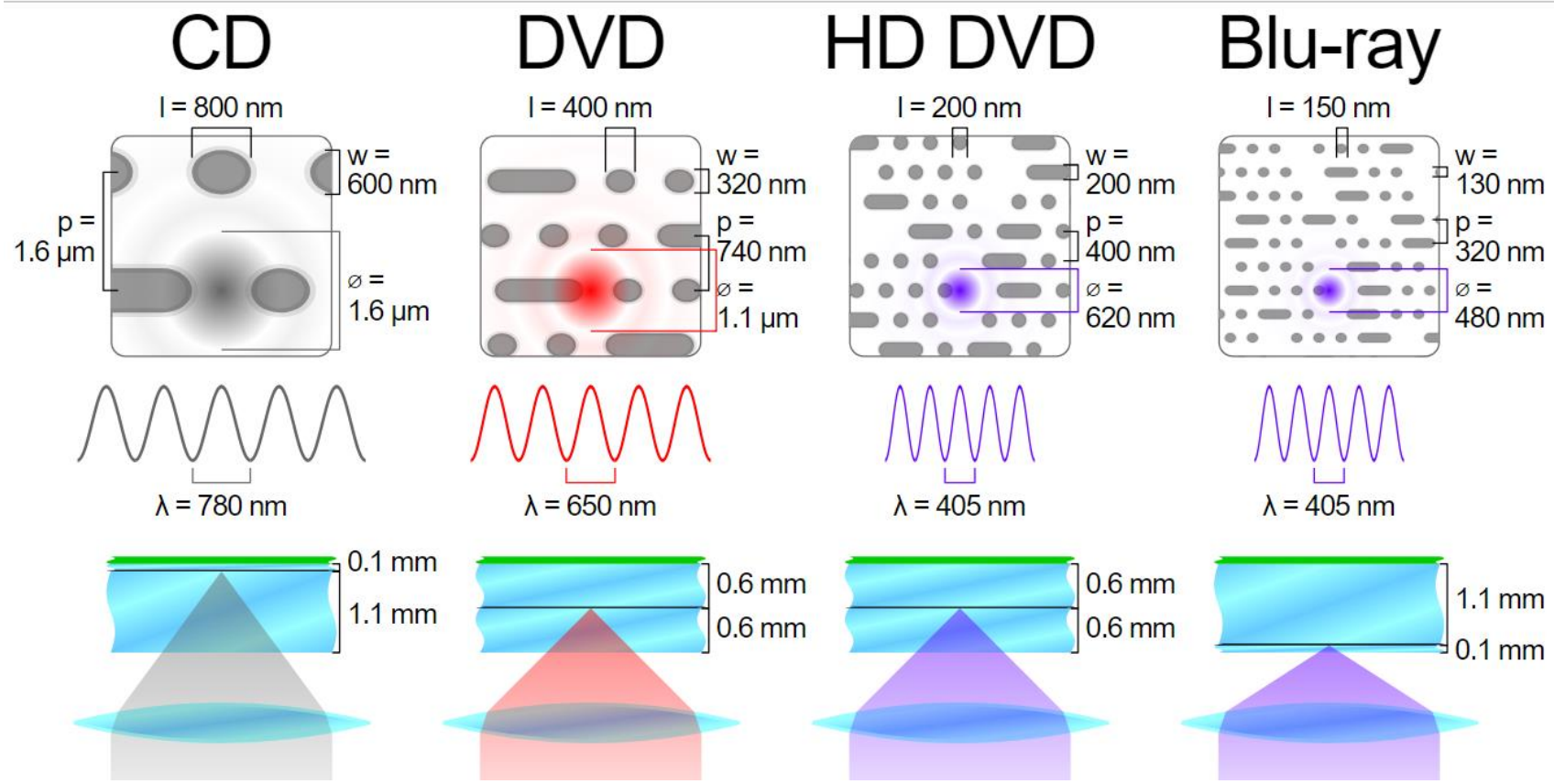
- Each DVD sector contains 2,418 bytes of data, 2,048 bytes of which are user data.
- There is a small difference in storage space between + and -(hyphen) formats:

- Scan of a DVD-R; the "a" portion has been recorded on while the "b" portion has not

DVD

- A dual-layer disc differs from its single layered counterpart by employing a second physical layer within the disc itself.
- The drive with dual-layer capability accesses the second layer by shining the laser through the first semitransparent layer.
- In some DVD players, the layer change can exhibit a noticeable pause, up to several seconds.
- This caused some viewers to worry that their dual-layer discs were damaged or defective, with the end result that studios began listing a standard message explaining the dual-layer pausing effect on all dual-layer disc packaging.

DVD


CD
l = 800 nm
w = 600 nm
p = 1.6 µm
⌀ = 1.6 µm
λ = 780 nm
0.1 mm
1.1 mm
DVD
l = 400 nm
w = 320 nm
p = 740 nm
⌀ = 1.1 µm
λ = 650 nm
0.6 mm
0.6 mm
HD DVD
l = 200 nm
w = 200 nm
p = 400 nm
⌀ = 620 nm
λ = 405 nm
0.6 mm
0.6 mm
Blu-ray
l = 150 nm
w = 130 nm
p = 320 nm
⌀ = 480 nm
λ = 405 nm
1.1 mm
0.1 mm

CD versus DVD

	CD	DVD
Disc diameter	120 mm	120 mm
Disc thickness	1.2 mm	1.2 mm
Laser wavelength	780 nm (infrared)	650 and 635 mm (red)
Track pitch	1.6 μm	0.74 μm
Min. pit/land length	0.83 μm	0.4 μm
Data layers	1	1 or 2
Sides	1	1 or 2
Data capacity	~ 650 MB	Single-Layer: 4.7 GB Dual-Layer: 8.5 GB Double-Sided: 9.4 GB

USB Flash Drive

- A **USB flash drive**, also variously known as a **thumb drive**, **pen drive**, **gig stick**, **flash stick**, **jump drive**, **disk key**, **disk on key** (after the original M-Systems DiskOnKey drive from 2000), **flash-drive**, **memory stick** (not to be confused with the Sony Memory Stick), **USB stick** or **USB memory**, is a data storage device that includes flash memory with an integrated USB interface.
- Most weigh less than 30 g (1 ounce).
- flash drives with anywhere from 8 to 256 GB are frequently sold; less frequent are 512 GB and 1 TB units.
- USB flash drives are often used for the same purposes for which floppy disks or CDs were once used; i.e. for storage, data back-up and transfer of computer files.

USB Flash Drive

- They are smaller, faster, have thousands of times more capacity, and are more durable and reliable because they have no moving parts.
- USB flash drives use the USB mass storage device class standard, supported natively by modern operating systems such as Windows, Linux, macOS and other Unix-like systems, as well as many BIOS boot ROMs.

Memory card

- A **memory card**, **flash card** or **memory cartridge** is an electronic flash memory data storage device used for storing digital information.
- These are commonly used in portable electronic devices, such as digital cameras, mobile phones, laptop computers, tablets, etc