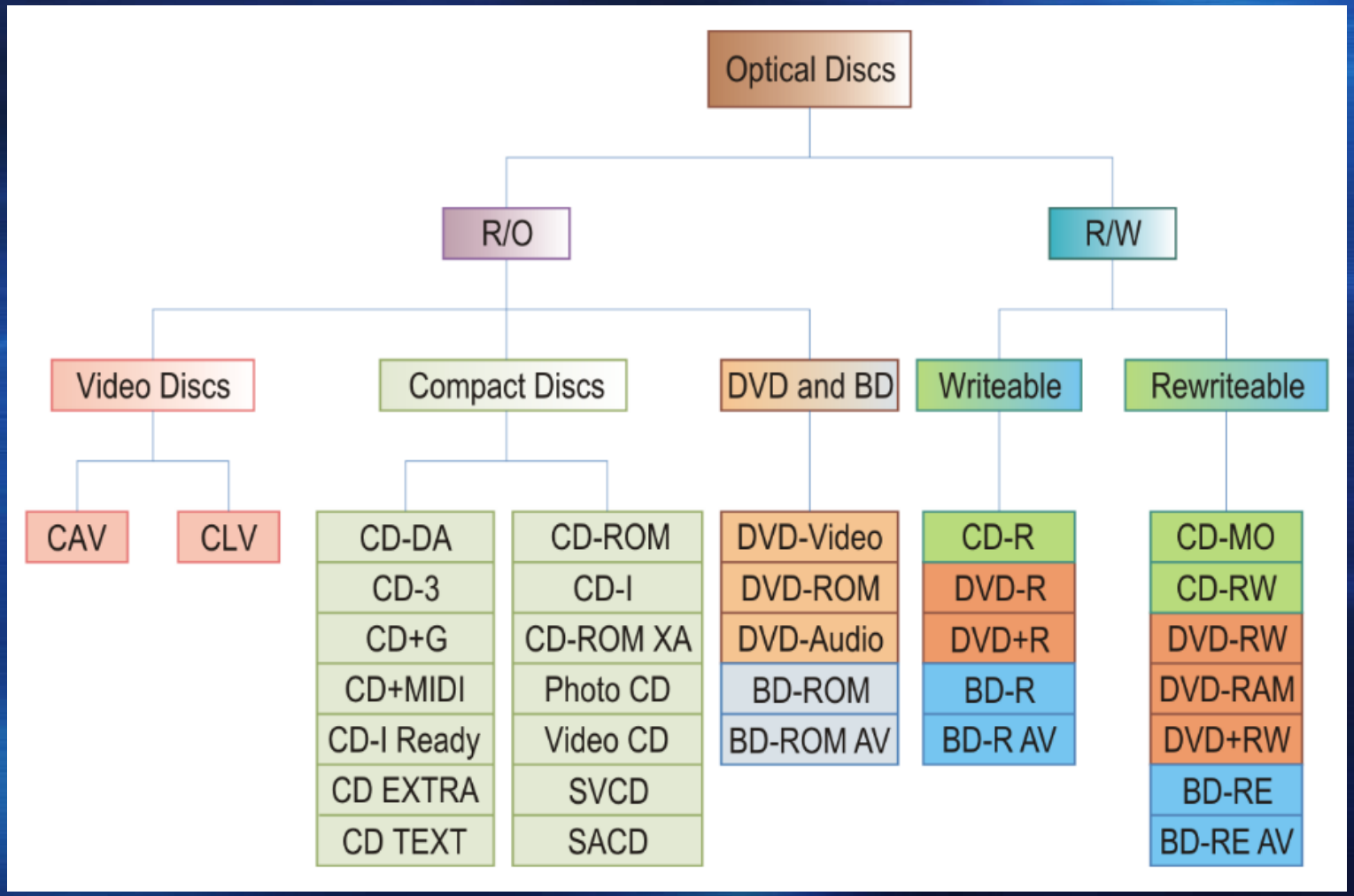
Contents of the Lecture

7. Optical Discs

- Classification of Optical Discs
- Compact Discs
- DVDs
- Blu-ray Discs

Classification of Optical Discs (1)



Classification of Optical Discs (2)

- Optical discs:
  - R/O (*Read/Only*): recorded by manufacturer
  - R/W (*Read/Write*): recorded by the user
- Video discs:
  - CAV (*Constant Angular Velocity*)
  - CLV (*Constant Linear Velocity*)
- Compact discs:
  - CD-DA (*Compact Disc-Digital Audio*)
  - CD-3

Classification of Optical Discs (3)

- CD+G (CD+*Graphics*)
- CD+MIDI (CD+*Musical Instruments Digital Interface*)
- CD-I Ready (CD-*Interactive Ready*)
- CD EXTRA: multi-session mixed disc; it contains an audio part and a data part
- CD TEXT: extension of the CD-DA format for recording the texts of songs
- CD-I (CD-*Interactive*): it may contain video images, graphics, animation, sound, text, data

Classification of Optical Discs (4)

- CD-ROM XA (CD-ROM *Extended Architecture*): extension of the CD-ROM format with characteristics defined for the CD-I format
- Photo CD: implementation of the CD-ROM/XA format for storing photographs
- Video CD: format for recording compressed video and audio data
- SVCD (*Super Video* CD): improved video and audio quality compared to Video CD format
- SACD (*Super Audio* CD)

Classification of Optical Discs (5)

- DVD (*Digital Versatile Disc*)
- BD (*Blu-ray Disc*)
  - BD-ROM AV (BD-ROM *Audio Visual*)
- Writeable discs:
  - CD-R (CD-*Recordable*)
  - DVD-R (DVD-*Recordable*)
  - DVD+R (DVD+*Recordable*)
  - BD-R (BD-*Recordable*)
  - BD-R AV (BD-*Recordable Audio Visual*)

Classification of Optical Discs (6)

- Rewriteable discs:
  - CD-MO (CD-*Magneto Optical*)
  - CD-RW (CD-*Read/Write*)
  - DVD-RW (DVD-*Read/Write*)
  - DVD+RW (DVD+*Read/Write*)
  - DVD-RAM
  - BD-RE (BD-*Rewritable*)
  - BD-RE AV (BD-*Rewritable Audio Visual*)

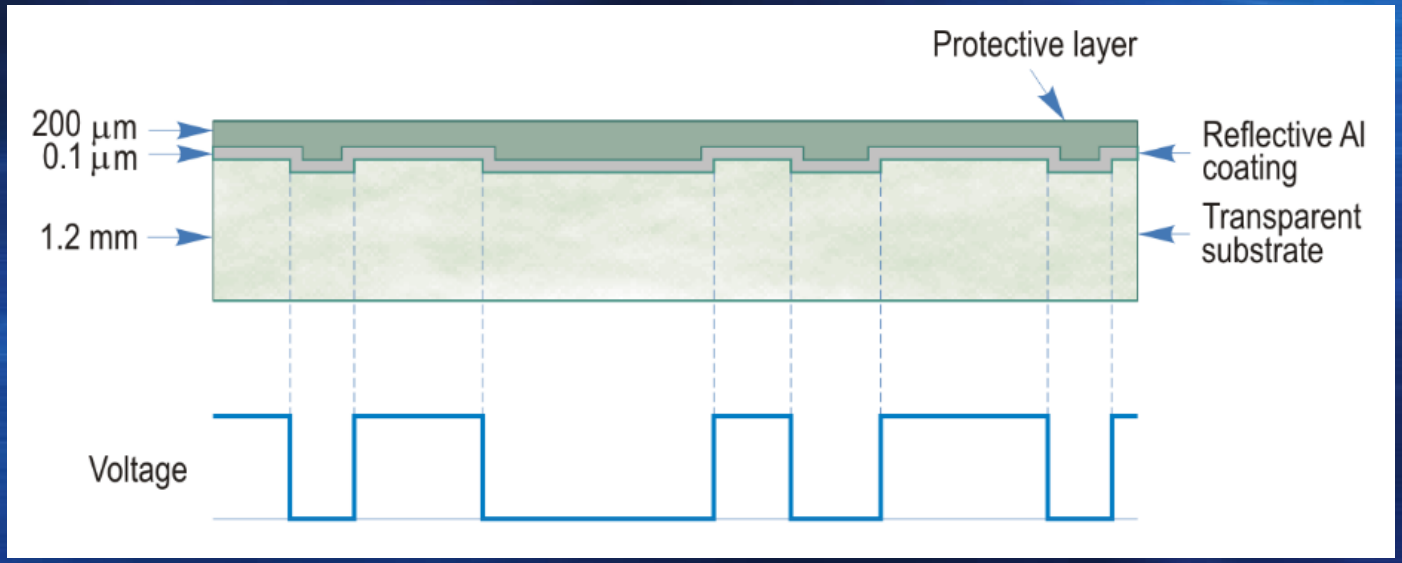
7. Optical Discs

- Classification of Optical Discs
- Compact Discs
- DVDs
- Blu-ray Discs

Compact Discs

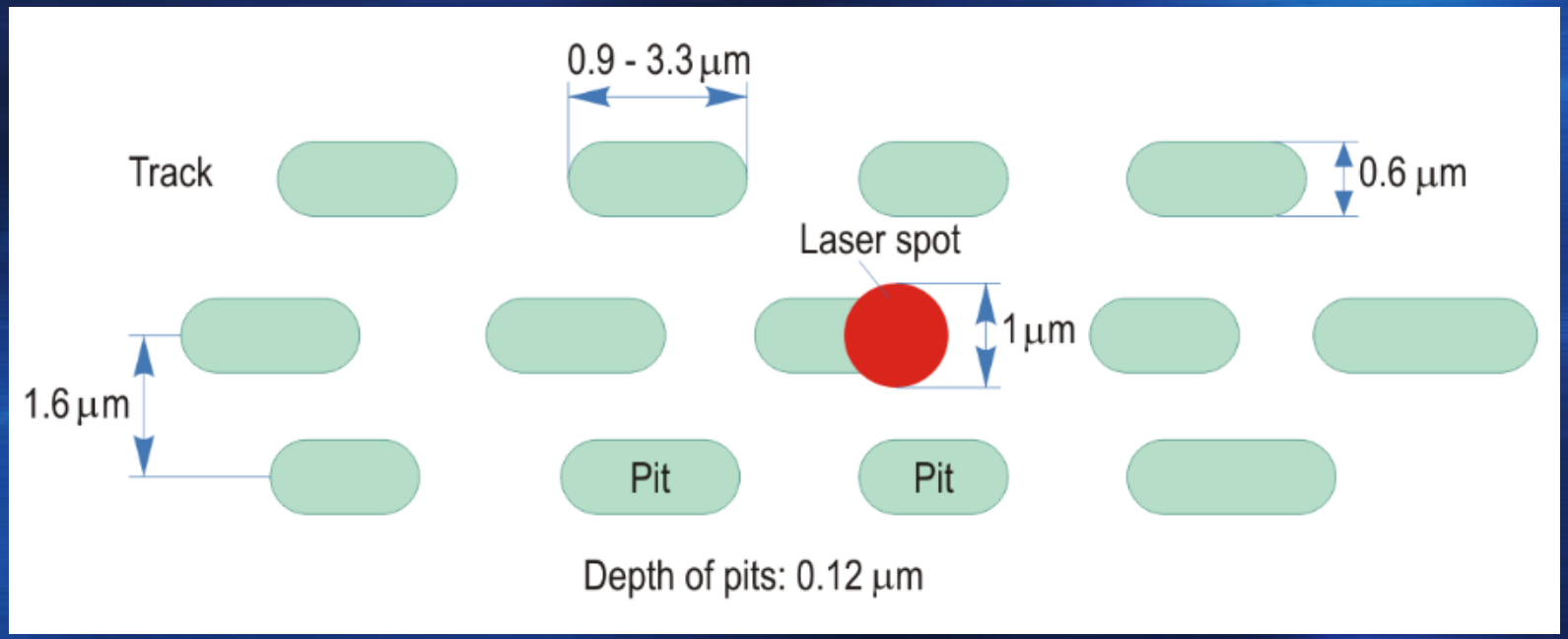
- Compact Discs
  - Compact Disc Physical Medium
  - Data Organization and Encoding
  - Optical Read Assembly
  - CD-R
  - CD-RW

Compact Disc Physical Medium (1)



- Diameter: 12 cm; thickness: ~1.2 mm
- Data are recorded as cavities called pits placed between surfaces called lands
- Different reflection degree for pits and lands

Compact Disc Physical Medium (2)



- Data are recorded on a single spiral
- Distance between two consecutive tracks: 1.6 µm
- Wavelength of the laser beam: 780 nm

Compact Discs

- Compact Discs
  - Compact Disc Physical Medium
  - Data Organization and Encoding
  - Optical Read Assembly
  - CD-R
  - CD-RW

Data Organization and Encoding (1)

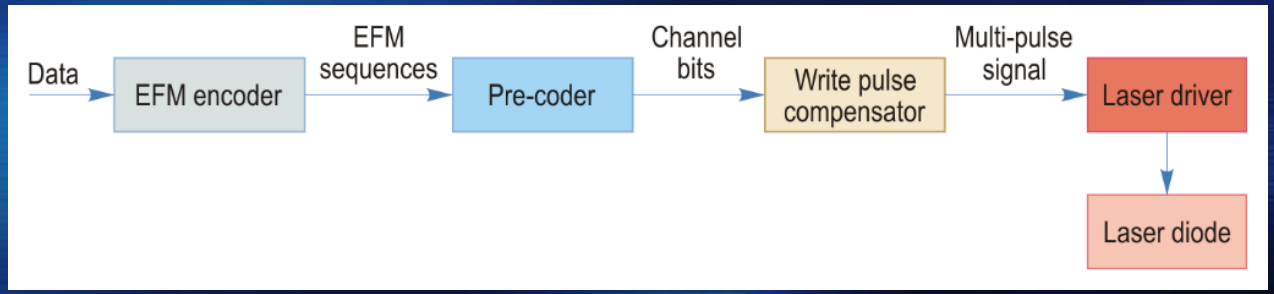
- At the lowest level, data are recorded as pits and lands
  - Data are encoded $\rightarrow$ high recording density; reliable error recovery
- At the next level, data are organized into sectors and tracks
- The High Sierra specifications (ISO 9660 standard) define a file system
  - Extensions: Rock Ridge, HFS, Joliet

Data Organization and Encoding (2)

- Bits are recorded on the medium using the NRZI (*Non-Return to Zero Inverted*) coding
  - Bit of 1: pit $\leftrightarrow$ land transition
  - Bit of 0: no transition
- Before recording, data bits are modulated
  - Avoiding very short and very long runs of successive zeros or ones
- Modulation method: EFM (*Eight-to-Fourteen Modulation*)
  - A data byte is represented through 14 bits
  - Three merging bits are added

Data Organization and Encoding (3)

- The EFM codes satisfy the constraints of a RLL (*Run-Length Limited*) code
  - An RLL code is specified as: (*d*, *k*) RLL
  - *d*, *k*: minimum and maximum number of 0 bits between two consecutive 1 bits
  - RLL code used: (2, 10) RLL
- Recording system for compact discs



Data Organization and Encoding (4)

- Data are broken up into blocks → frames
- Frame structure:
  - Synchronization header
  - Control byte
  - 2 × 12 data bytes
  - 2 × 4 bytes for error detection and correction (CIRC - *Cross Interleaved Reed-Solomon Code*)

Synchronization	Control	Data (L)	CIRC	Data (R)	CIRC
27 bits	1 byte	12 bytes	4 bytes	12 bytes	4 bytes

Data Organization and Encoding (5)

- The error detection and correction system used within the frames: CIRC (*Cross Interleaved Reed-Solomon Code*)
  - Integrated at hardware level into the disc drives
- Two components:
  - The "*Cross interleave*" component breaks up the long errors into several short errors
  - The "*Reed-Solomon*" component provides the error correction

Data Organization and Encoding (6)

- Sector: 98 frames
  - 98 control bytes
  - 24 × 98 = 2352 data bytes
  - 8 × 98 = 784 error detection and correction bytes
- Format similar to that of audio discs
- For direct access to each sector, synchronization bytes and a header containing the sector address are used

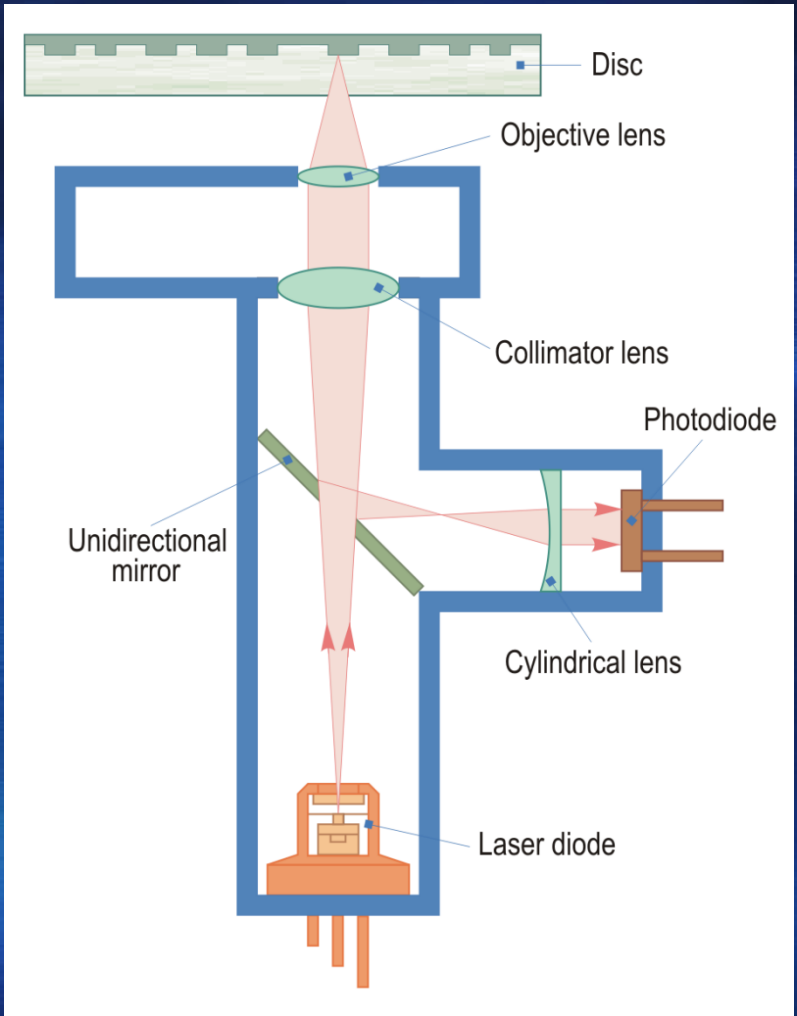
Data Organization and Encoding (7)

- The error rate for the CIRC method: $10^{-9} \rightarrow$ insufficient for data discs
- For data discs a second level of error detection and correction is provided
  - 4 bytes for error detection (EDC)
  - 276 bytes for error correction (ECC)
- L-EC (*Layered Error Correction*), rate of 10^{-12}
- The error detection code: Cyclic Redundancy Check (CRC)
- The error correction code: Reed-Solomon

Compact Discs

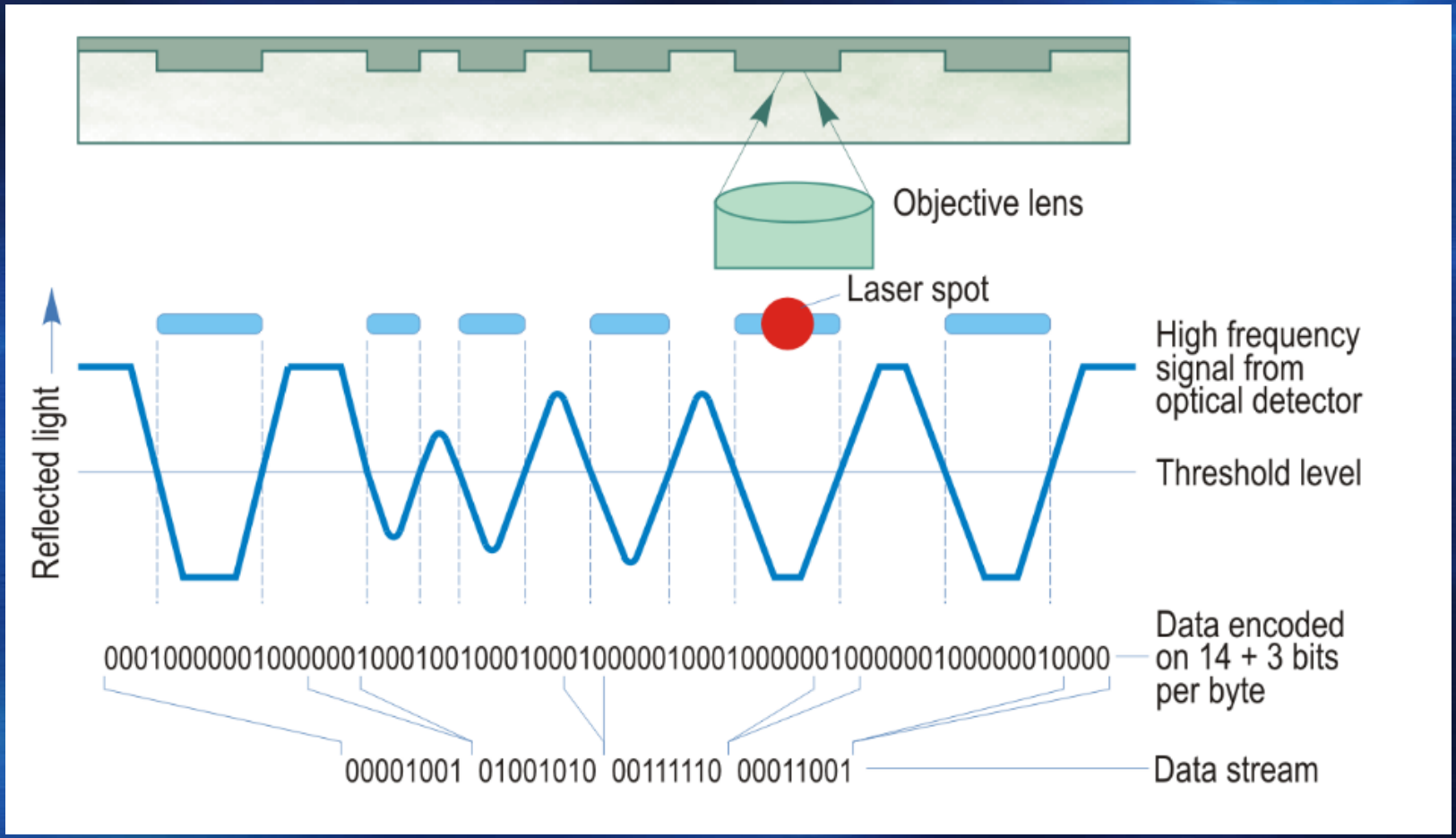
- Compact Discs
  - Compact Disc Physical Medium
  - Data Organization and Encoding
  - Optical Read Assembly
  - CD-R
  - CD-RW

Optical Read Assembly (1)



- The laser diode emits a laser beam
- The beam is focused on the disc surface
- The beam is positioned with a servomechanism
- Part of the beam is reflected back and directed to a photodiode $\longrightarrow$ electric signal

Optical Read Assembly (2)



Optical Read Assembly (3)

- Positioning mechanism
  - Moves the mirror and the lens system
  - The optical assembly moves on a set of rails
  - The precise positioning onto a track is achieved with a microcontroller and an electronic servo system
  - The servo system measures the signal level and adjusts the position of the read assembly

Optical Read Assembly (4)

- Common systems use three beams:
  - The beam generated by the laser diode is split into three beams with a polarized prism
  - The intensity of the side beams is measured → signal for correcting the beam position
- Compensating the vertical movement:
  - The photodiode is split into four quadrants
  - On the disc's deviation, the spot becomes elliptical → the signals generated by the quadrants will differ
  - The objective lens is moved accordingly

Optical Read Assembly (5)

- Rated speed ("X" speed)
  - Refers to the spin speed of the disc
  - Indicator of the maximum theoretical transfer rate
  - A single-speed (1X) drive has the same spin speed as a standard CD audio drive
    - Audio drive: 75 sectors/s $\rightarrow$ 75 × 2336 = 175,200 B/s = 171.09 KB/s
    - 1X CD-ROM drive: 75 × 2048 = 153,600 B/s = 150 KB/s

Optical Read Assembly (6)

- CLV (*Constant Linear Velocity*)
  - The spin speed is variable: higher towards the disc centre
  - The transfer rate is constant
  - Method used for CD audio drives and early generations of CD-ROM drives (1X .. 12X)
    - The first CD audio drives were designed to transfer the same amount of data in each second

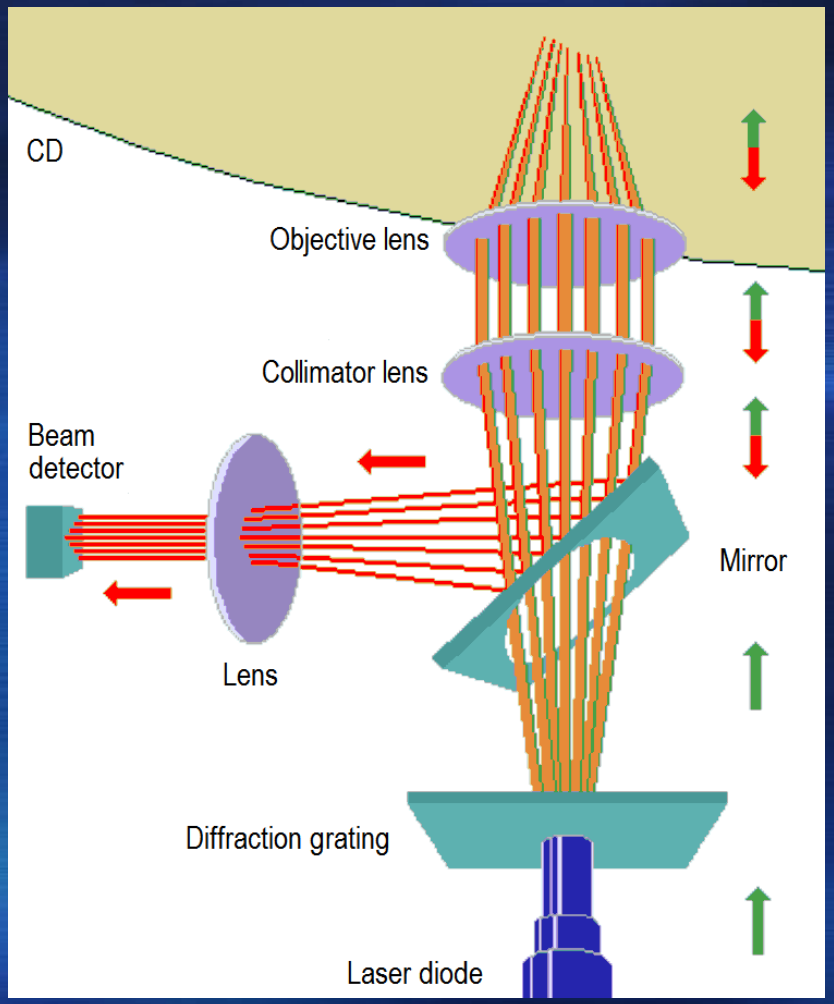
Optical Read Assembly (7)

- CAV (*Constant Angular Velocity*)
  - The spin speed is constant
  - The transfer rate is variable
  - Advantage: there is no need to change the spin speed
  - Disadvantage: the transfer rate is reduced towards the center of the disc
  - Method used for CD-ROM drives with a spin speed of over 12X

Optical Read Assembly (8)

- TrueX technology
  - Allows to increase the performance of optical disc drives
  - Several laser beams are used to scan simultaneously multiple tracks
  - Integrated circuit that contains: signal processor, servo controller, decoder, error correction system, ATAPI interface
  - Optionally: SCSI or USB interface

Optical Read Assembly (9)



- The laser beam is split with a diffraction grating
- The beams pass through the unidirectional mirror
- Focusing: attained with the central beam
- Higher transfer rates at lower revolution speeds → reducing vibrations

Compact Discs

- Compact Discs
  - Compact Disc Physical Medium
  - Data Organization and Encoding
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  - CD-R
  - CD-RW

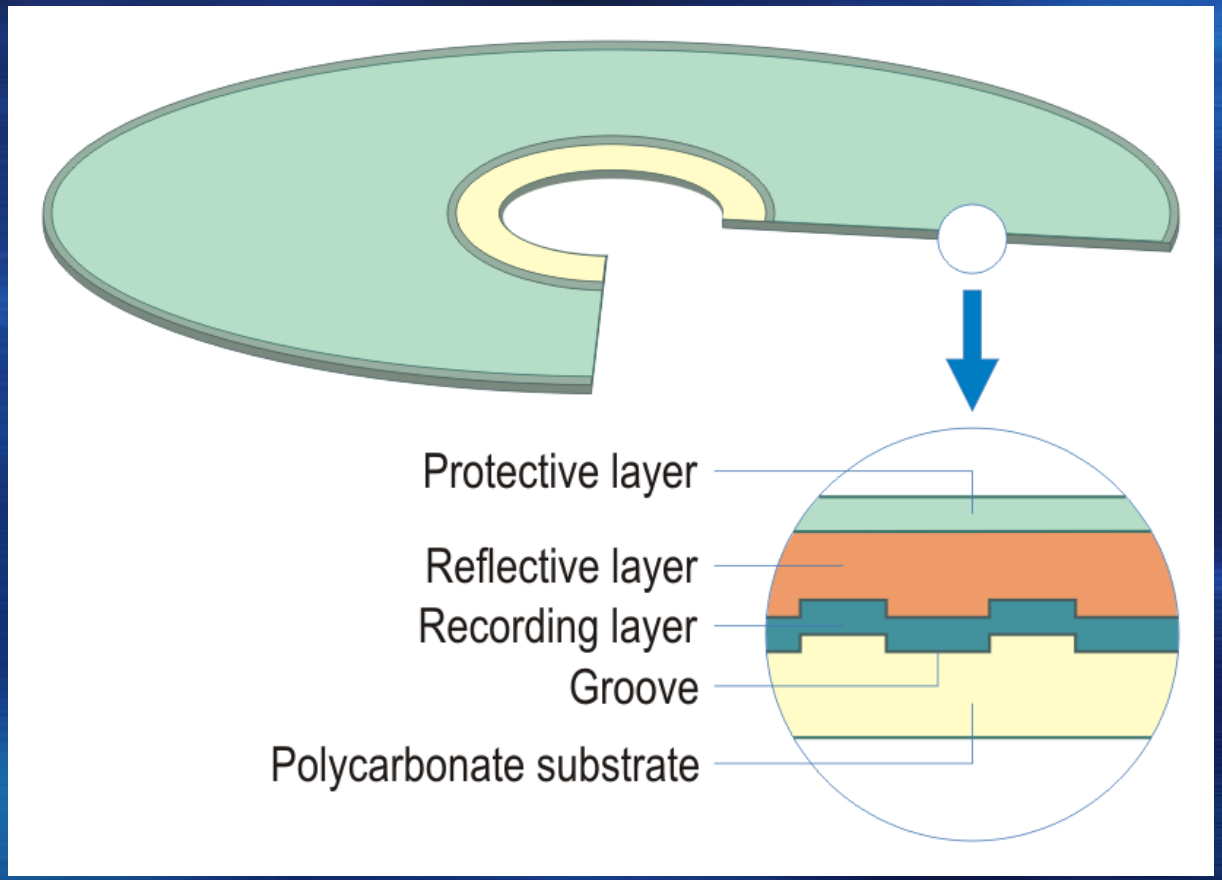
CD-R (1)

- CD-R (CD *Recordable*)
  - CD-WORM (CD *Write Once, Read Many*)
  - CD-WO (CD *Write Once*)
- Specifications defined in the "*Orange Book*" document, Part II
- CD-ROM discs are based on the CD audio standard, changing the interpretation of data
- CD-R discs define new physical media and recording methods, using the standard formats

CD-R (2)

- Writing method: changing the reflectivity of an organic dye
- Photosensitive organic dyes:
  - Cyanine (blue cyan)
  - Phthalocyanine (greenish blue)
  - Azo (dark blue)
- To protect against oxidation, a metal layer (silver alloy or gold) is coated over the dye

CD-R (3)


Protective layer
Reflective layer
Recording layer
Groove
Polycarbonate substrate

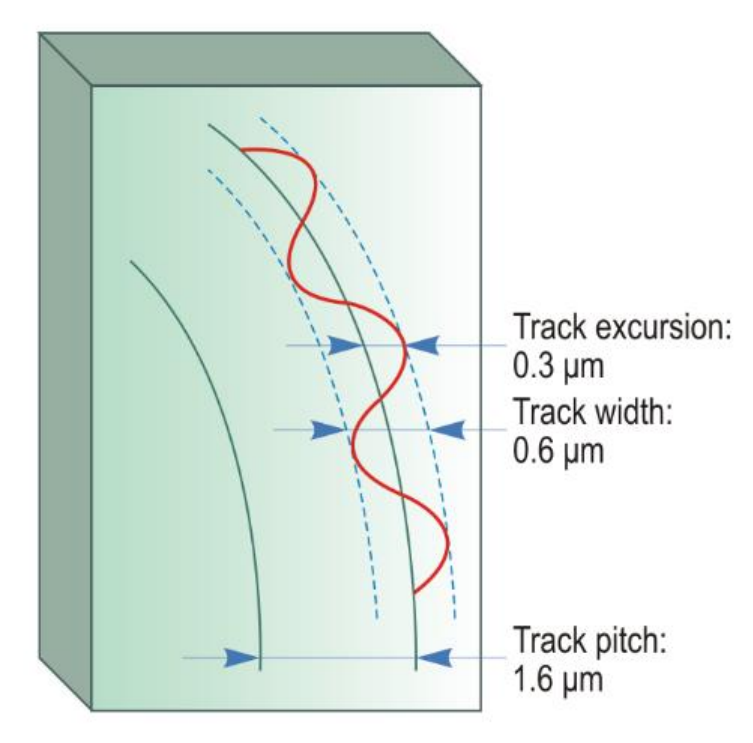
CD-R (4)

- Writing: with a laser beam that heats up selectively certain areas
  - In the heated areas, the organic dye changes its chemical composition
  - “Burned” areas reflect light to a lesser degree → correspond to pits
  - “Non-burned” areas reflect light to a higher degree → correspond to lands
- The disc can be read by regular drives

CD-R (5)

- The disc is stamped with a spiral pre-groove
  - It is similar to the spiral on a regular CD
- The microscopic groove is used by the CD-R drive during recording to follow the data path on the disc
  - If the disc were completely unformatted, writing the spiral tracks would be complex
- The groove has a sinusoidal excursion (deviation) of 0.3 µm at a frequency of 22.05 KHz → wobbles

CD-R (6)



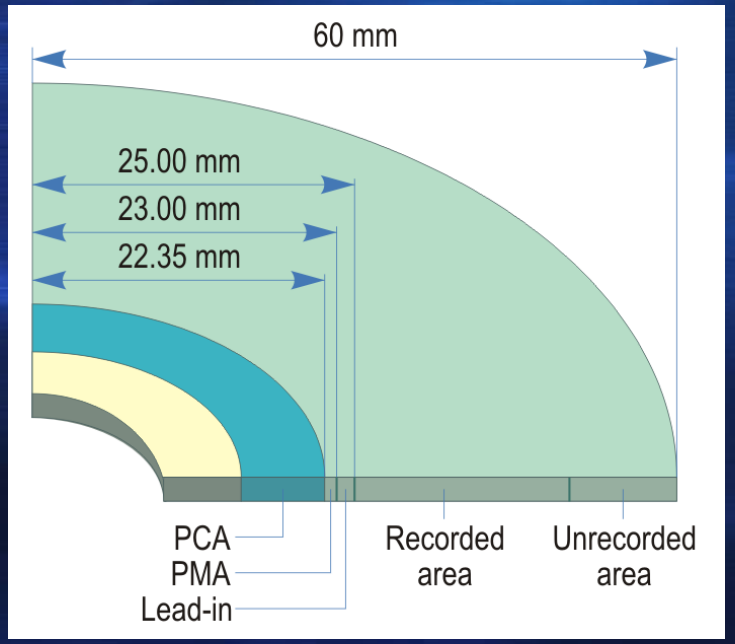
- Recordable discs have to store the block addresses
- Addresses are stored using the ATIP (*Absolute Time In Pre-groove*) method
  - The sinusoid is modulated with a 1-KHz signal
  - Information stored: addresses in MSF form; manufacturer; writing speeds; laser power

CD-R (7)

- CD-R discs have two additional data areas located in the beginning area of the disc
- Are used to store data specific to the recording process
- Program Memory Area (PMA)
  - Contains the track numbers of the recorded titles as well as their start and stop addresses

CD-R (8)

- Power Calibration Area (PCA)
  - Used to calibrate the laser power → trial recording
  - The optimal power setting depends on: recording speed, ambient temperature, humidity, disc type



Compact Discs

- Compact Discs
  - Compact Disc Physical Medium
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  - Optical Read Assembly
  - CD-R
  - CD-RW

CD-RW (1)

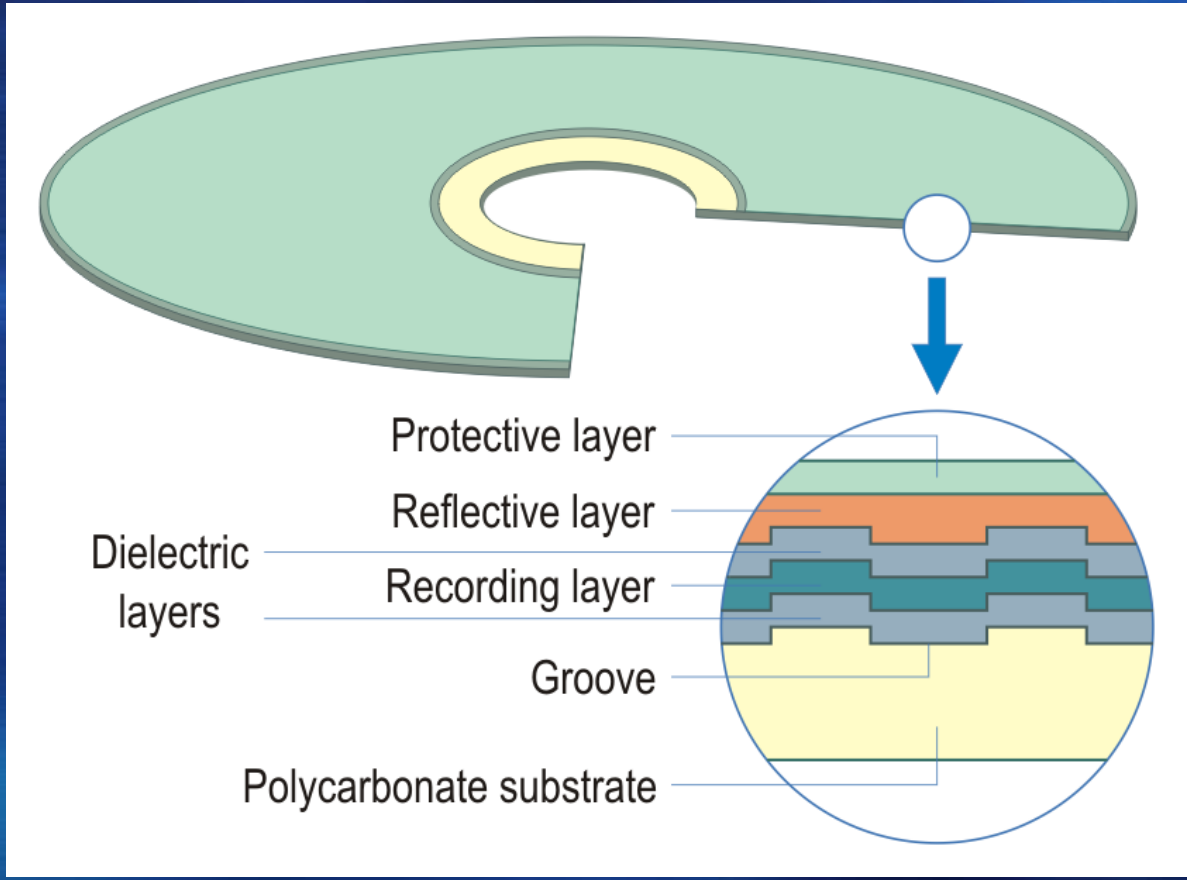
- CD-RW (CD *ReWritable*)
  - CD-E (CD *Erasable*)
- Specifications defined in the "*Orange Book*" document, Part III
- The dye layer is replaced with a special phase-change recording layer
  - Can change state when a certain energy is applied to it and can return to the initial state

CD-RW (2)

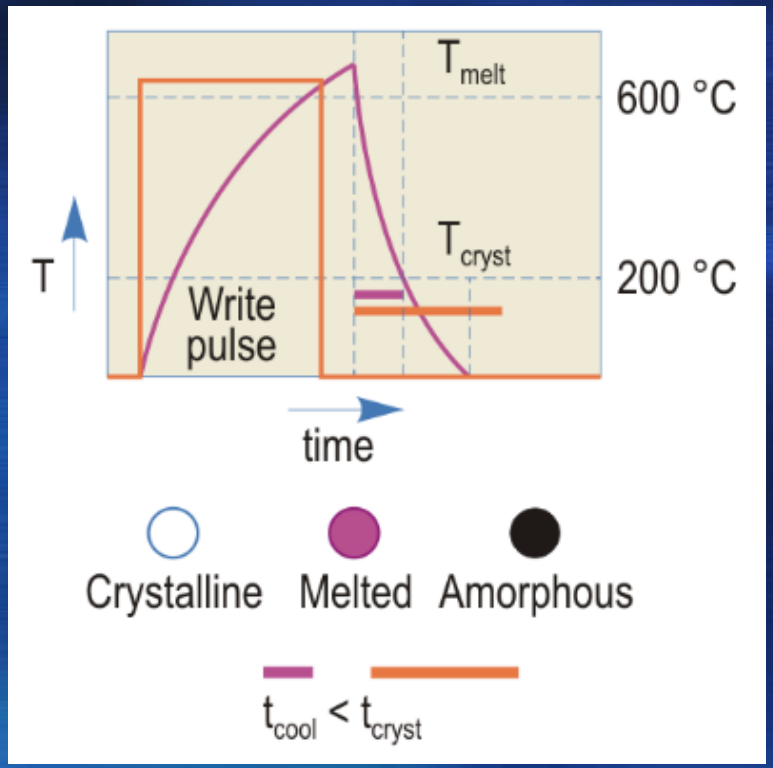
- When the material is heated to a certain temperature and then is cooled, a crystalline structure is formed → land
- When the material is heated to a higher temperature, an amorphous structure is formed → pit

- Recording layer: alloy of silver, indium, antimony, and tellurium
  - Placed between two dielectric layers that eliminate excess heat during writing

CD-RW (3)


Protective layer
Reflective layer
Dielectric layers
Recording layer
Groove
Polycarbonate substrate

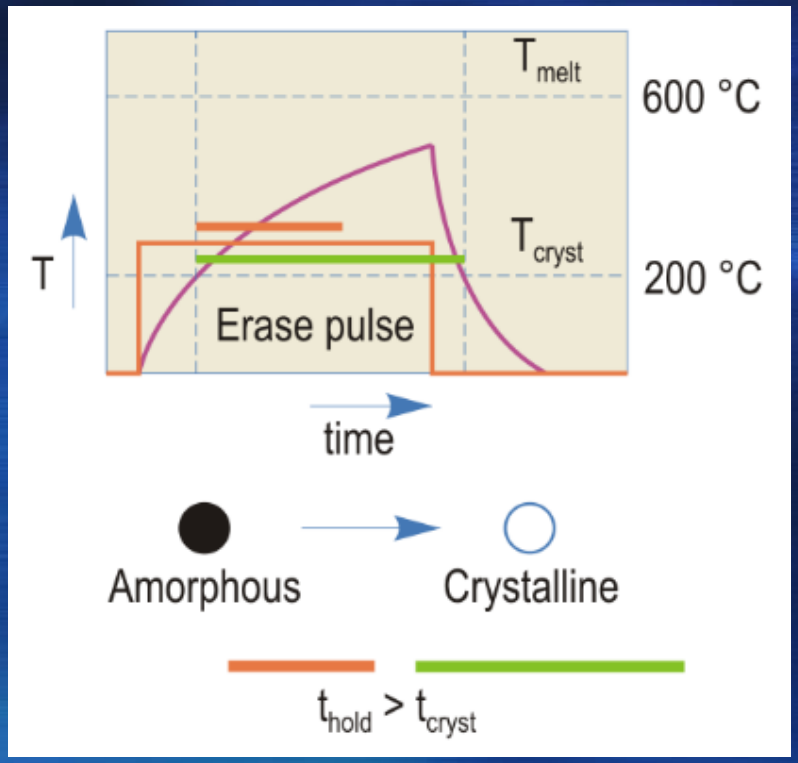
CD-RW (4)



Writing

- The recording layer is heated to a temperature above the melting point
- The crystals get to an amorphous state
- If the cooling is fast, the amorphous state is maintained

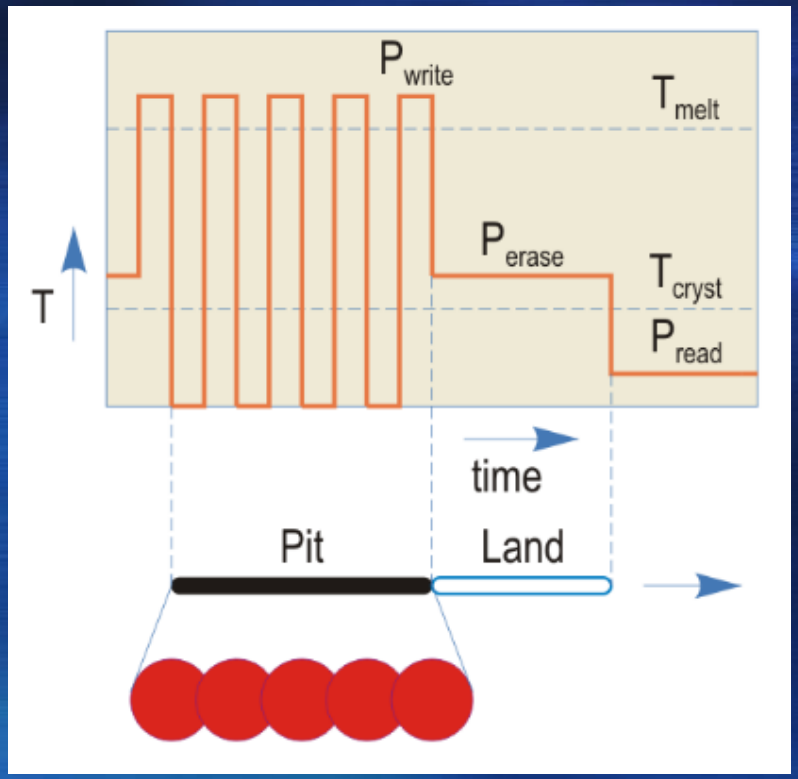
CD-RW (5)



Erasing

- The recording layer is heated below the melting point, but above the crystallization point
- The temperature is maintained for a time longer than the min. crystallization time

CD-RW (6)



Overwriting

- New pits are created using the laser beam for writing
- A constant laser beam is used to create new crystalline lands
- The process can be repeated about 1000 times

CD-RW (7)

- The reflectivity of CD-RW discs is lower than that of regular CDs
  - Regular CDs: min. 70% for lands, max. 28% for pits
  - CD-RW discs: 15 .. 25% for lands
  - Dual-function drives
  - The MultiRead specifications of OSTA (*Optical Storage Technology Association*) have been developed to solve the compatibility issues

7. Optical Discs

- Classification of Optical Discs
- Compact Discs
- DVDs
- Blu-ray Discs

DVDs

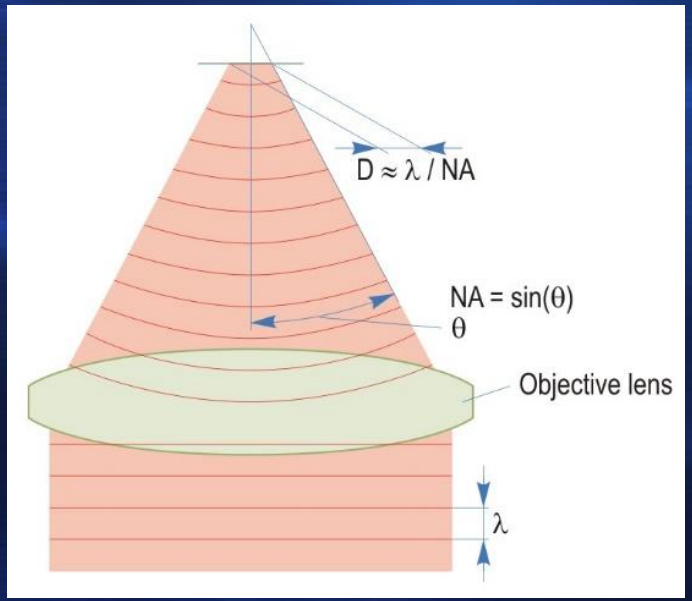
- DVDs
  - Overview
  - DVD-ROM
  - DVD-R
  - DVD+R
  - DVD-RW
  - DVD+RW
  - M-DISC Technology

Overview (1)

- DVD – *Digital Video Disc*, *Digital Versatile Disc*
- Developed by the *DVD Consortium* → changed into *DVD Forum*)
- Characteristics:
  - Up to four layers
  - Higher capacity: 4.38 GB (one layer), 15.9 GB (four layers)
  - Pit size is smaller
  - Distance between tracks is lower
  - Wavelength of the laser beam: 650 nm

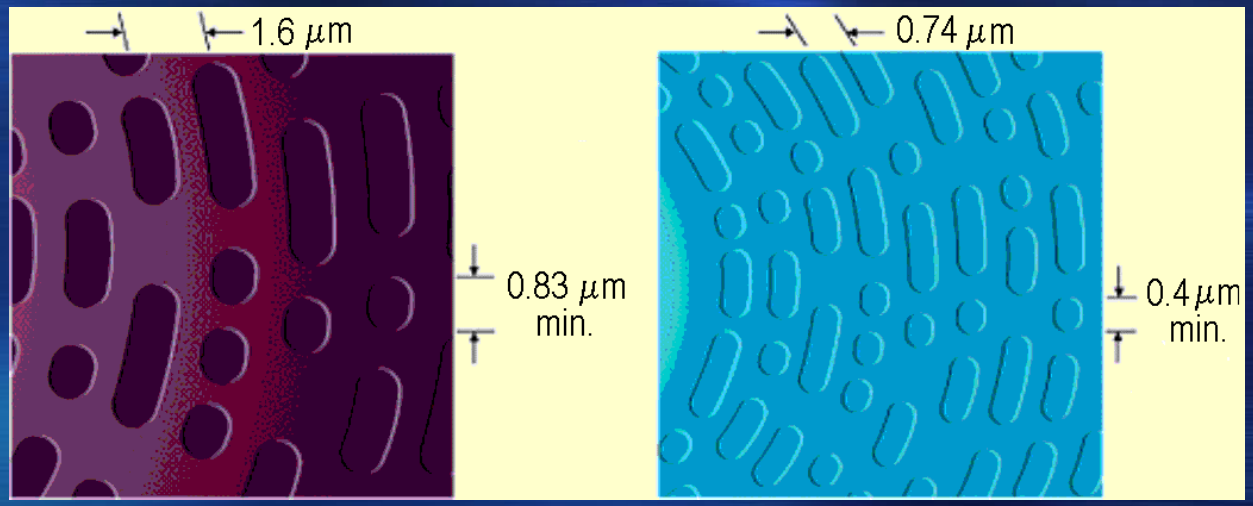
Overview (2)

- Capacity is inversely proportional to the square of laser spot diameter
  - Inversely proportional to the square of wavelength (λ^2)
  - Proportional to the square of numerical aperture (NA^2)
  - $NA = \sin(\theta)$
    - Indicates the convergence performance of objective lens
  - NA has been increased to 0.60 (from 0.45 for CDs)



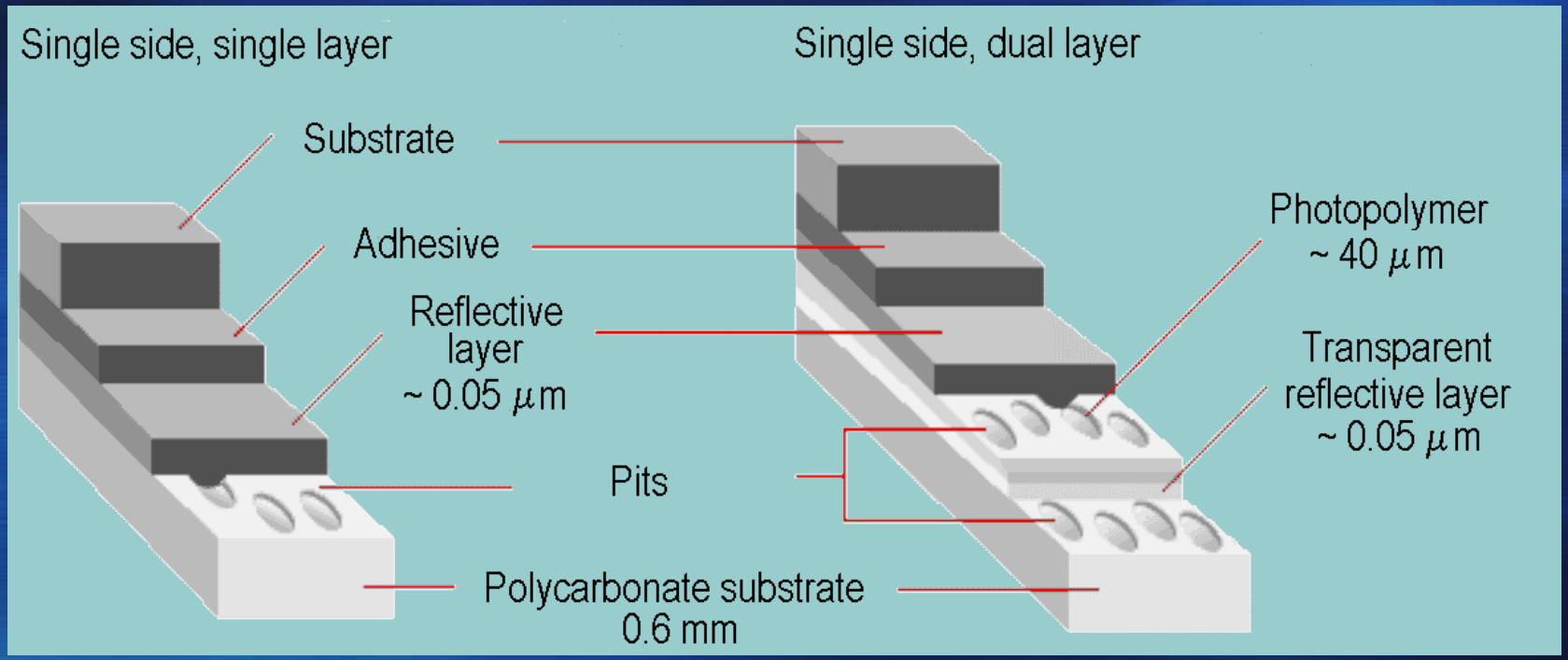
Overview (3)

- Modulation method: EFMPlus
  - A data byte is represented through 16 bits
  - No merging bits are required
  - Constraint satisfied by EFMPlus codes: (2, 10) RLL

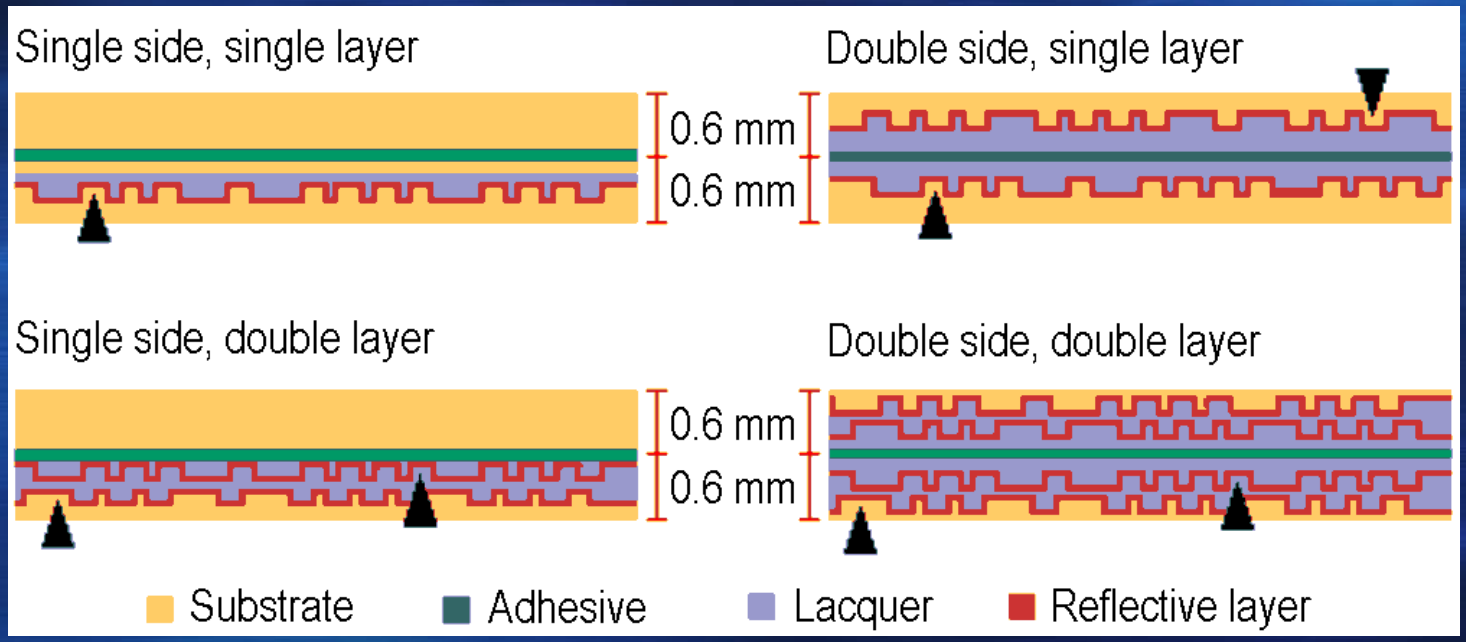


CD DVD

Overview (4)


Single side, single layer
Single side, dual layer
Substrate
Adhesive
Reflective layer ~ 0.05 μm
Pits
Polycarbonate substrate 0.6 mm
Photopolymer ~ 40 μm
Transparent reflective layer ~ 0.05 μm

Overview (5)



Single-Sided and Double-Sided DVD Discs

DVDs

- DVDs
  - Overview
  - DVD-ROM
  - DVD-R
  - DVD+R
  - DVD-RW
  - DVD+RW
  - M-DISC Technology

DVD-ROM (1)

- Sector size: 2064 B (2048 – data)
- The sector is divided into 12 lines x 172 B
  - First line: contains the sector header (12 B)
    - Sector identifier (ID) (4 B)
    - Error correction code for the ID (2 B)
    - Reserved area (6 B)
  - The next 160 B of the first line contain data
  - The last line contains 4 B for error detection and correction of the data area

DVD-ROM (2)

- A number of 16 sectors make a block
  - Sectors are placed dispersed on the disc
  - 10 bytes are added to the lines of each sector for the error correction code (ECC)
  - A block contains 16 additional lines for the ECC
  - This results in a block of 37,856 B
- For recording, both the CLV method and the CAV method are allowed

DVD-ROM (3)

- DVD discs can use the UDF (*Universal Disk Format*) file system
  - Defined by OSTA (*Optical Storage Technology Association*)
  - Based on ISO 13346/ECMA-167 standard
  - Intended for DVD and CD-R/RW discs as replacement of the ISO 9660 system
  - OS independent
  - UDF defines the data structures, character sets, read/write methods

Summary (1)

- On optical discs, data are recorded as pits and lands
  - Pits and lands have different reflectivity
  - Data are encoded to provide high density and reliable data recovery
- For compacts discs, two levels of error correction can be used
  - At frame level: used for all compact disc formats
  - At sector level: used for data discs

Summary (2)

- Optical read assemblies use a laser beam positioned with a servomechanism
  - The beam is reflected back, and electrical pulses are generated with a photodiode
- Writing of CD-R discs is based on changing the reflectivity of a photosensitive dye
- CD-RW discs use a phase-change recording layer
  - Crystalline and amorphous areas can be formed in a reversible manner

Summary (3)

- DVDs have higher capacities compared to compact discs
  - Providing multiple layers
  - Reducing the pit size and track pitch
  - Reducing the wavelength of the laser beam
  - Increasing the objective lens' numerical aperture
- Data on DVD-ROM discs are organized into lines, sectors, and blocks
  - Each block contains additional lines for the ECC
  - Both the CLV and CAV recording can be used

Concepts, Knowledge (1)

- Compact disc data organization
- Compact disc data encoding
- Levels of error correction
- Optical read assembly structure and operation
- Recording methods: constant linear velocity (CLV); constant angular velocity (CAV)
- TrueX technology
- CD-R disc writing
- Spiral pre-groove of CD-R discs

Concepts, Knowledge (2)

- Program memory area and power calibration area of CD-R discs
- CD-RW disc writing
- CD-RW disc erasing
- CD-RW disc overwriting
- Characteristics of DVDs
- Techniques used for increasing the capacity of DVDs compared to compact discs
- DVD-ROM organization: lines, sectors, blocks