DVDs

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

DVD-R (1)

- Developed by Pioneer
- The format is approved by the *DVD Forum*
- Uses a technology similar to that of the CD-R discs
  - The organic dyes are different
- Two variants: DVD-R(A) and DVD-R(G)
- DVD-R(A) (*Authoring*)
  - Intended for applications such as archiving, disc production
  - Wavelength of the laser beam: 635 nm

DVD-R (2)

- DVD-R(G) (*General purpose*)
  - Intended for consumer applications
  - Wavelength of the laser beam: 650 nm
  - The cost of drives and media is lower compared to that of DVD-R(A)
- Capacity: 4.38 GB (single layer – SL); 7.95 GB (double layer – DL)
- Discs are engraved with a spiral groove
  - Contains addressing information for blocks
  - Method used: LPP (*Land Pre-Pit*)
    - Pits engraved in the area between grooves

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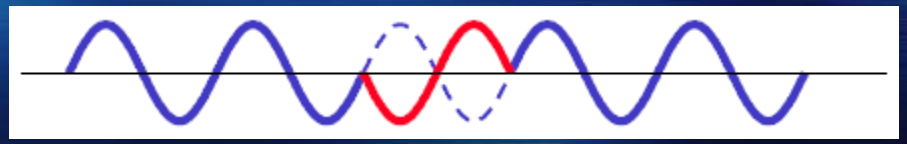
DVD+R (1)

- Developed by *DVD+RW Alliance*
- The format is not approved by the *DVD Forum*
- Discs can be recorded only once
- Capacity: 4.37 GB (SL); 7.92 GB (DL)
- DVD+R drives are not compatible with DVD-R drives
  - Usually, the drives are hybrid: DVD±R

DVD+R (2)

- The disc is engraved with a spiral groove that has a sinusoidal deviation
  - Frequency of the sinusoid: 817 KHz (at 1x)
  - Allows a correct positioning of the spot and control of the rotational speed
  - Method used to store block addresses: ADIP (*ADdress In Pre-groove*)
  - Addressing information is stored by phase modulation of the sinusoid



DVD+R (3)

- Improvements of the DVD-R technology
  - The spot tracking control system and ADIP addressing is less susceptible to interference and errors
    - Higher reliability at higher speeds
  - The error management system is more robust
    - More accurate writing independent of the quality of the media
  - More accurate linking of multiple sessions

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DVD-RW (1)

- Developed by Pioneer
- The format is approved by the *DVD Forum*
- Originates from the DVD-R(A) format
- For the physical medium, the phase-change technology is used
  - The reflectivity is lower (18 .. 30% compared to 45 .. 80% for DVD-ROM)
  - Early DVD drives confused the DVD-RW discs with two-layer DVD-ROM discs

DVD-RW (2)

- Blank discs contain:
  - Address information between the grooves
  - A *lead-in* track → copy protection
- Advantages:
  - The ability for erasing and rewriting
  - If there are writing errors, the disc can be used by erasing the faulty data
  - DVD-RW discs can be read by most DVD drives
- Number of rewrites: ~1000

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  - DVD-RW
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DVD+RW (1)

- Developed by the *DVD+RW Alliance*
- The format is not approved by the *DVD Forum*
- Designed as a random-access medium
- The intention was to ensure compatibility with regular DVD drives
  - However, DVD+RW drives are not compatible with DVD-RW drives
  - Usually, the drives are hybrid: DVD±RW
- The same phase-change technology is used as with CD-RW and DVD-RW discs

DVD+RW (2)

- For recording, the CAV method can also be used (besides the CLV method)
  - Increased performance for random access
  - The power consumption decreases
- The same type of spiral groove is used as with DVD+R discs
  - Encodes the addresses of 32 KB blocks
  - Each 2 KB cluster can be accurately located
    → clusters can be rewritten independently

DVD+RW (3)

- The high-frequency sinusoidal deviation of the groove allows for lossless linking
  - With other rewriteable discs, part of the blocks are allocated as link blocks → start and end of writing
  - For DVD+RW discs, link blocks are not needed → resuming writing after an area previously written with a precision of 1 µm
- An automatic defect management system is used → defective areas are masked

DVDs

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  - DVD-RW
  - DVD+RW
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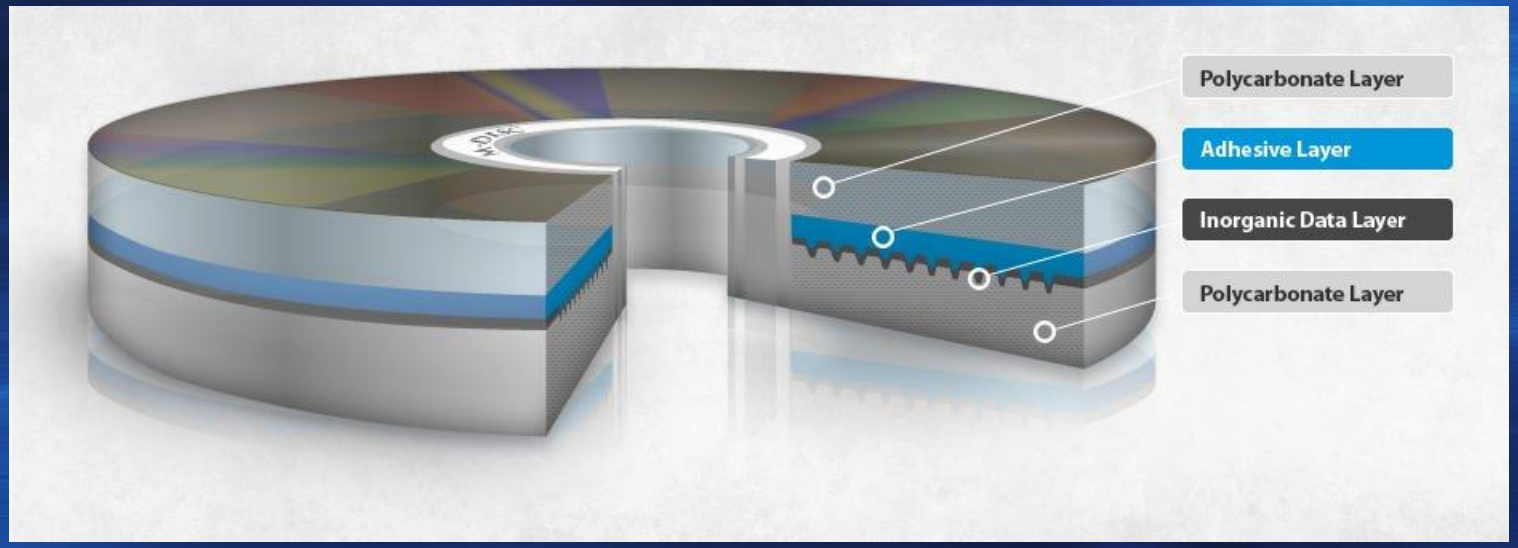
M-DISC Technology (1)

- M-DISC (*Millennial Disc*)
  - Developed by Milleniata, Inc. for DVDs and Blu-ray discs
  - Designed for long-term archiving
  - Uses an inorganic recording layer
    - Glass-like (glassy) carbon material
    - Combines the properties of glass and graphite: thermal stability, conductivity, hardness
  - Durability of up to 1,000 years
  - Formats: DVD+R, BD-R, BD-R DL, BDXL-R TL

M-DISC Technology (2)



- Durability tests
  - Discs passed the tests of ISO/IEC and Ecma International
  - Accelerated aging tests conducted by the US Department of Defense (DoD)

M-DISC Technology (3)

- Drive compatibility
  - M-discs can be read in conventional DVD and Blu-ray drives
  - DVD drives: require special firmware for writing
  - Blu-ray drives: are able to write M-discs
- Alternative technologies for archiving
  - Optical: recordable Blu-ray discs with inorganic materials rated for 100-150 years
  - Magnetic: susceptible to mechanical failure
  - Solid state: limited number of write cycles

7. Optical Discs

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

Blu-ray Discs

- Blu-ray Discs
  - Overview
  - BD-R/RE Discs
  - BDXL Discs
  - BD-R/RE AV Format
  - BD-ROM Discs
  - Ultra HD Blu-ray Discs
  - BD-ROM AV Format

Overview (1)

- BD – *Blu-ray Disc*
- Developed by the *Blu-ray Disc Association* (BDA)
- Diameter of 12 cm or 8 cm
- Higher capacity compared to DVD discs:
  - Single-Layer (SL): 23.3 GB (25 GB in decimal)
  - Dual-Layer (DL): 46.5 GB (50 GB in decimal)
  - Triple-Layer (TL): 93.1 GB (100 GB in decimal)
  - Quadruple-Layer (QL): 119.2 GB (128 GB in decimal)

Overview (2)

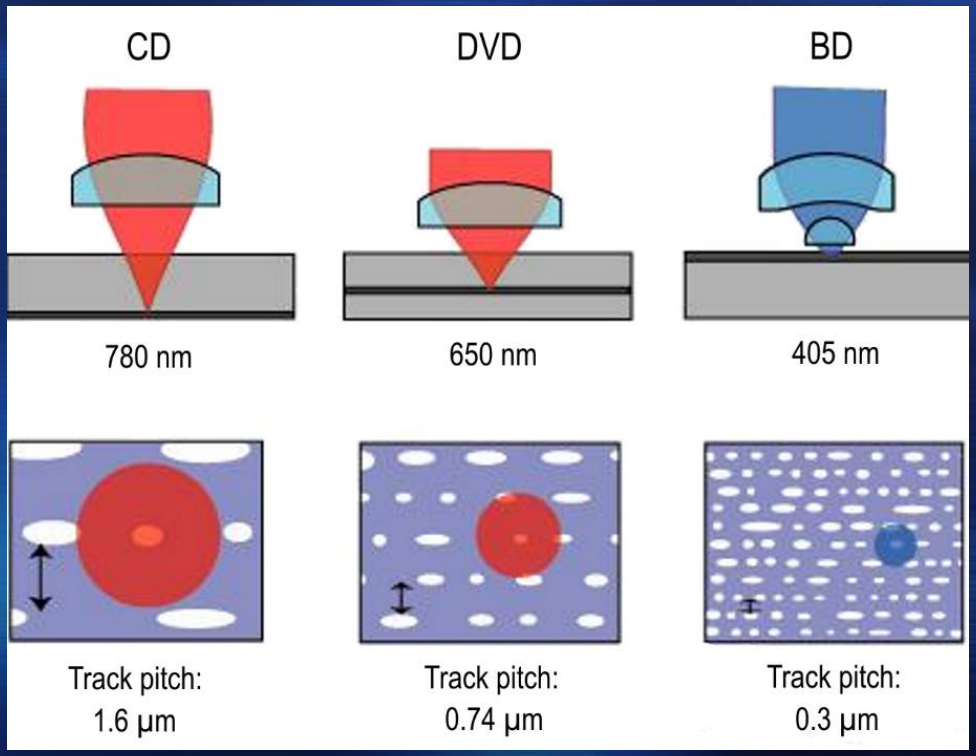
- The wavelength (λ) of the laser beam is 405 nm (blue-violet)
- The pit size is smaller
  - Minimum length: 0.15 µm (0.4 µm for DVDs)
- The track pitch is reduced
  - 0.32 µm (0.74 µm for DVDs)
- The Numerical Aperture (NA) of the objective lens is increased
  - 0.85 (0.6 for DVDs)

Overview (3)

- The effects of optical aberrations increase by reducing λ and increasing NA
  - Defocusing: caused by the focusing servomechanism; proportional to NA^2
  - Refraction angle error: occurs when the optical axis of the objective lens is not perpendicular to the disc; proportional to NA^3
  - Spherical aberration: caused by irregularity of the cover layer thickness; proportional to NA^4
- The refraction angle error is proportional to the thickness of the cover layer

Overview (4)

- Compensating the refraction angle error: reducing the cover layer thickness
  - A thickness of 100 µm has been chosen



Overview (5)

- Data encoding is more efficient
- Modulation: 17PP (1,7 *Parity-Preserve*) code
  - Satisfies the constraints of a (1, 7) RLL (*Run-Length Limited*) code
  - Preserves the parity of the source bit-stream
  - One additional bit (1 or 0) is inserted in the source bit-stream at regular intervals
  - The 17PP code prohibits the occurrence of repeated minimum run-lengths $\rightarrow$ would lead to low signal levels

Overview (6)

- Early discs required a protective cartridge
- Today's discs are covered with a protective hard coating layer → the cartridge is not needed
  - Silicon dioxide resin
  - Transparent and thin layer (2 .. 5 µm)
  - Protects against damage from accidental impact
  - Repels dust and fingerprints → conductive material

Overview (7)

- Blu-ray disc types
  - BD-RE (BD-*Rewritable*)
  - BD-R (BD-*Recordable*)
  - BD-ROM
  - Each type also has an AV (*Audio Visual*) format
- Write and read speeds
  - Transfer rate at 1x speed: 36 Mbits/s
  - Higher speeds: 2x, 4x, …, 12x

Overview (8)

- Disc rotational methods
  - Constant Linear Velocity (CLV): approx. 4.9 m/s at a speed of 1x
  - Constant Angular Velocity (CAV): the rotational speed is constant
  - Zoned Constant Linear Velocity (ZCLV): the disc is divided into zones; progressively faster CLV speeds are used in each zone
  - Partial Constant Angular Velocity (PCAV): CAV (near the center) + CLV

Blu-ray Discs

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  - BDXL Discs
  - BD-R/RE AV Format
  - BD-ROM Discs
  - Ultra HD Blu-ray Discs
  - BD-ROM AV Format

BD-R/RE Discs (1)

- BD-R Discs
  - Use either an organic dye or inorganic material as recording layer
  - Inorganic material: Cu alloy + Si $\rightarrow$ CuSi alloy
- BD-RE Discs
  - Use the same phase-change technology as CD-RW and DVD±RW discs
- Both types of discs contain a spiral groove
  - Used to perform tracking control and to generate a writing clock signal

BD-R/RE Discs (2)

- The groove is modulated by wobbling
  - Amplitude of the wobbles: ± 10 nm
- The wobbles are further modulated to add addressing and auxiliary information
  - Contain the addresses of 64-KB blocks
- The modulation is robust against the distortions inherent to optical discs
  - Wobble shift
  - Wobble crosstalk of adjacent tracks
  - Disc defects

BD-R/RE Discs (3)

- A combination of two wobble modulation systems is used
  - Minimum-Shift Keying (MSK)
    - Based on the cosine function
    - A bit of 1 is distinguished from a bit of 0 by the phase inversion of certain wobbles
  - Saw-Tooth Wobble (STW)
    - Based on a combination of the cosine and sine functions
    - Different orientation of the “saw teeth” for 0 and 1 bits

BD-R/RE Discs (4)

- Addressing method: ADIP (*ADdress In Pre-Groove*)
  - Different than the ADIP method used for DVD+R and DVD+RW discs
  - ADIP unit: a single bit of the address
    - Length of 56 wobbles (56 x 5 µm = 280 µm)
    - Three MSK wobbles: synchronization
    - Monotone wobbles: 11 (bit of 0) or 9 (bit of 1)
    - 37 STW wobbles: different for a bit of 0 or 1
  - ADIP word: 83 ADIP units
    - 24-bit address; 12-bit auxiliary data; ECC

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BDXL Discs (1)

- High-Capacity BD specifications 

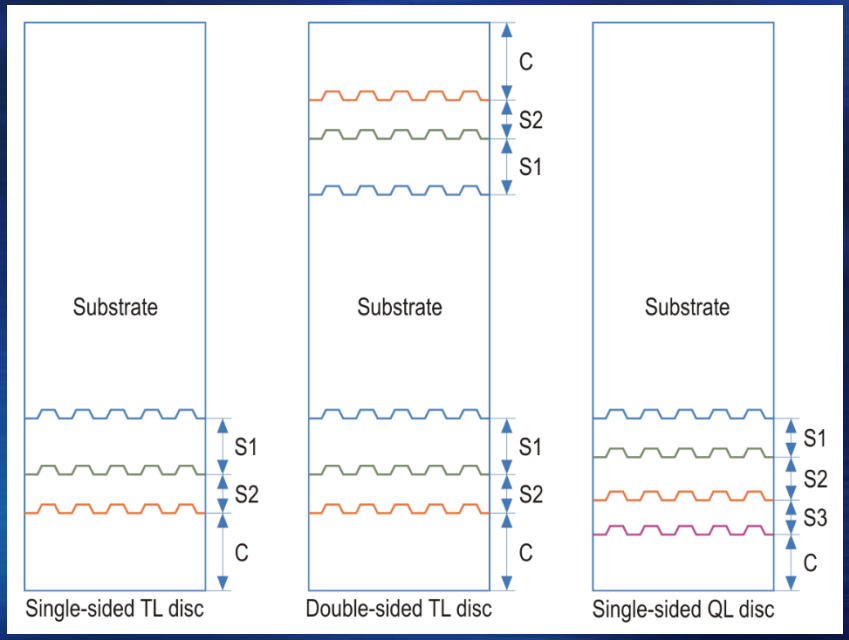
  - Developed by the Blu-ray Disc Association
  - Define the formats for triple-layer (TL) and quadruple-layer (QL) BD-RE and BD-R discs
  - Use the same basic parameters as SL and DL discs: wavelength, NA, track pitch, etc.
  - The changes to achieve high capacity are minimized
    - Thickness and linear density for each layer
  - Physical parameters for BDXL-RE and BDXL-R discs are optimized: reflectivity, laser power

BDXL Discs (2)

- BDXL-RE Discs
  - Only TL discs are specified
  - Capacity per layer: 33.3 GB (total: 100 GB)
  - Write speed: 2x (72 Mbits/s)
- BDXL-R Discs
  - TL discs: single-sided or double-sided
    - Capacity per layer: 33.3 GB
    - Single-sided TL discs: capacity of 100 GB
    - Double-sided TL discs: capacity of 200 GB; enclosed in a non-removable case; used for professional devices

BDXL Discs (3)

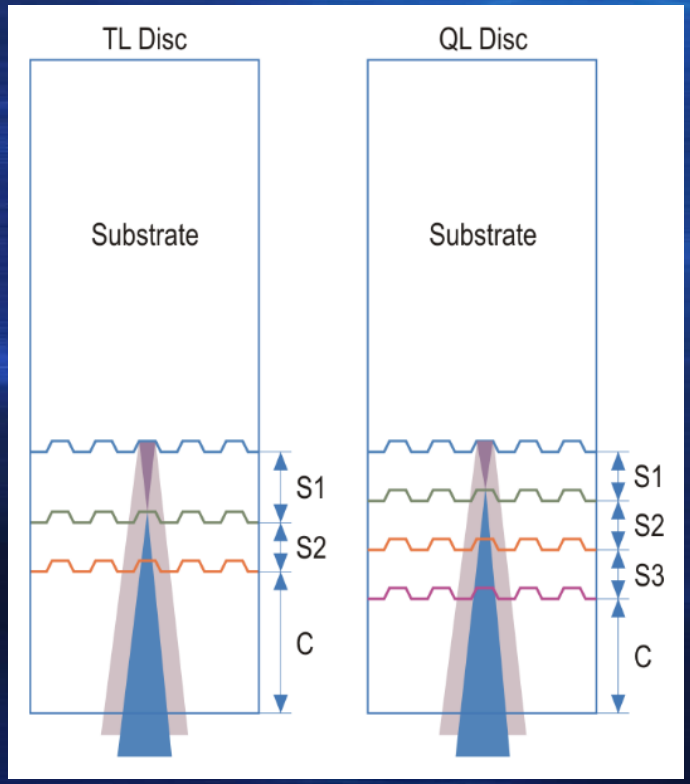
- QL discs: single-sided
  - Capacity per layer: 32 GB (total: 128 GB)
- Write speed: 2x (72 Mbits/s), 4x (144 Mbits/s)



Original image © Blu-ray Disc Association

BDXL Discs (4)

- Two types of optical interferences
  - Optical crosstalk from adjacent layers
    - Caused by signals that pass from one layer to another
    - Thickness of the spacer layer must be more than 10 µm



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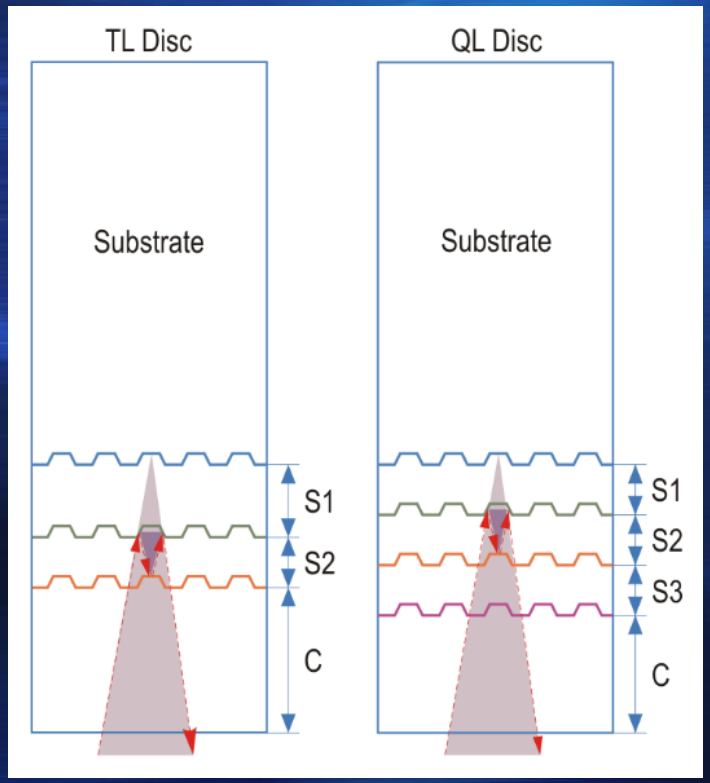
BDXL Discs (5)

- Optical inter-layer interference
  - Caused by the signals that are reflected by the recording layers
  - The reflected signals interfere with the main signal
  - The difference in thickness between the cover layer and spacer layers must be > 1 µm



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  - BD-R/RE AV Format
  - BD-ROM Discs
  - Ultra HD Blu-ray Discs
  - BD-ROM AV Format

BD-R/RE AV Format (1)

- Designed to record and play back digital TV broadcasts on BD-R and BD-RE discs
  - Approx. 2 hours of HD material or 12 hours of SD material on a SL disc
- For video and audio multiplexing, the MPEG-2 Transport Stream format is used
  - Packets of 188 B
  - Multiple channels (TV, audio) and electronic program guide (EPG) information are multiplexed

BD-R/RE AV Format (2)

- BD-R/RE AV discs also accept data from an HD video camcorder
  - Streams in MPEG-2 format
- Two layers of organizational structure for managing AV data
  - Clip layer: contains the partial transport streams and clip information files
  - Playlist layer: allows the user to view, edit, and group clips through playlist files

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BD-ROM Discs (1)

- Targeted for HD movie distribution
- Format specifications: BD-ROM v. 1.41 (2013)
- Single-layer (SL) and dual-layer (DL) discs
- SL discs (25 GB in decimal)
  - MPEG-2: HD (135 min.); SD bonus (2 hr.)
  - MPEG-4 AVC: HD (4 hr.); SD bonus (105 min.)
- DL discs (50 GB in decimal)
  - MPEG-2: HD (3 hr.), SD bonus (9 hr.)
  - MPEG-4 AVC: HD (8 hr.), HD bonus (3.5 hr.)

BD-ROM Discs (2)

- Disc parameters
  - Length of a data bit: 111.7 nm
  - Nominal velocity (1x): 4.9 m/s
- The BD player uses a buffer
  - User data: disc → buffer
  - Transport Stream (TS): buffer → decoder
  - Minimum user-data transfer rates:
    - 54 Mbits/s (2D at 1.5x), 72 Mbits/s (3D at 2x)
  - Maximum TS transfer rates:
    - 48 Mbits/s (2D), 64 Mbits/s (3D)

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Ultra HD Blu-ray Discs (1)

- Targeted for UHD 4K movie distribution
- Format specifications: BD-ROM v. 2.0 (2015)
- Dual-layer (DL) and triple-layer (TL) discs
- DL discs (50 GB)
  - Same structure as DL BD-ROM discs
  - Cannot be played back by players designed for the BD-ROM format v. 1.x
- DL discs (66.7 GB)
  - Capacity of 33.3 GB per layer
  - Reduced length of a data bit: 83.8 nm
  - Reduced nominal velocity (1x): 3.6 m/s

Ultra HD Blu-ray Discs (2)

- TL discs (100 GB)
  - Same parameters per layer as DL discs with capacity of 66.7 GB
- The transfer rates required are higher than for HD movies
  - Higher rotation speeds may be required
  - The specifications limit the maximum disc rotation speed to 5000 rev./min
  - Options for the transfer rate (TR): Default TR; Low TR; High TR

Ultra HD Blu-ray Discs (3)

- With the High TR option, the disc rotation speed would exceed 5000 rev./min at the inner part of the data zone
  - Two zones: LTR zone (inner part), HTR zone
  - LTR zone: Default TR; HTR zone: maximum TR

Disc Capacity	TR Option	Min. User-Data TR (Mbits/s)	Max. TS TR (Mbits/s)
50 GB	Low TR	72	64
	Default TR	92	81.7
66/100 GB	Low TR	92	81.7
	Default TR	123	109
	High TR	144	127.9

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BD-ROM AV Format (1)

- Designed for HD and UHD movies
- High-Definition Movie (HDMV) mode
  - Extended DVD-Video features: support for HD or UHD video; more sophisticated navigation and visual possibilities
- BD Java (BD-J) mode
  - Application development environment
  - Enables interactivity and optional Internet and network connection

BD-ROM AV Format (2)

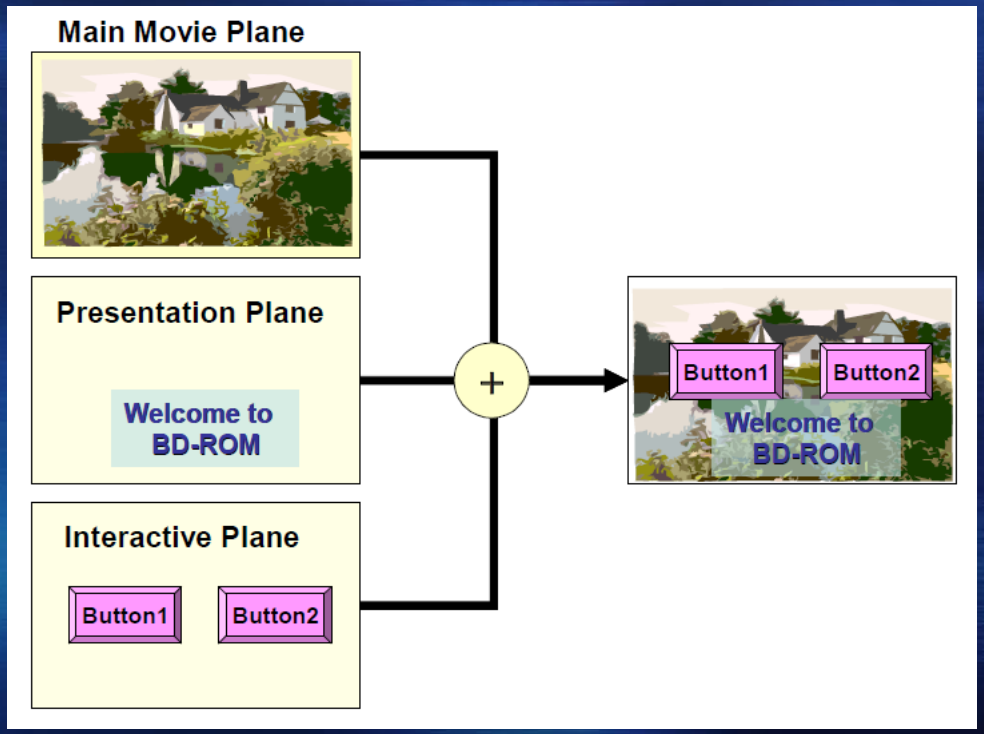
- Uses the MPEG-2 Transport Stream format
  - The transport stream is formed by encoding and multiplexing each component
- BD-ROM v. 1.x discs with 2D video content: played back at 1.5x CLV speed (54 Mbits/s)
- BD-ROM v. 1.x discs with 3D video content: played back at 2x CLV speed (72 Mbits/s)
- Ultra HD Blu-ray discs: according to the TR option (2x – Low TR, 4x – High TR)

BD-ROM AV Format (3)

- HDMV Mode
  - The multiplexed stream can be extended with individual streams stored separately → are decoded at the same time
  - Features: subtitles, menus, button sounds
  - Playback image: formed by overlaying five independent image planes
  - BD-J background plane
  - Two video planes (primary, secondary): enable picture-in-picture (PiP) playback

BD-ROM AV Format (4)

- Presentation graphics plane: subtitles
- Interactive graphics plane: graphic menus (information, buttons for navigation)



BD-ROM AV Format (5)

- Video encoding methods (BD-ROM v. 1.x):
  - MPEG-2
  - MPEG-4 AVC (H.264)
  - VC-1 (*Microsoft Windows Media*)
- Video encoding methods (Ultra HD Blu-ray):
  - MPEG-4 AVC: resolution of 1920 x 1080; 24p
  - HEVC (*High Efficiency Video Coding*, H.265)
    - Successor to the MPEG-4 AVC method
    - Resolution of 1920 x 1080 or 3840 x 2160; 24p, 25p, 50p, 60p

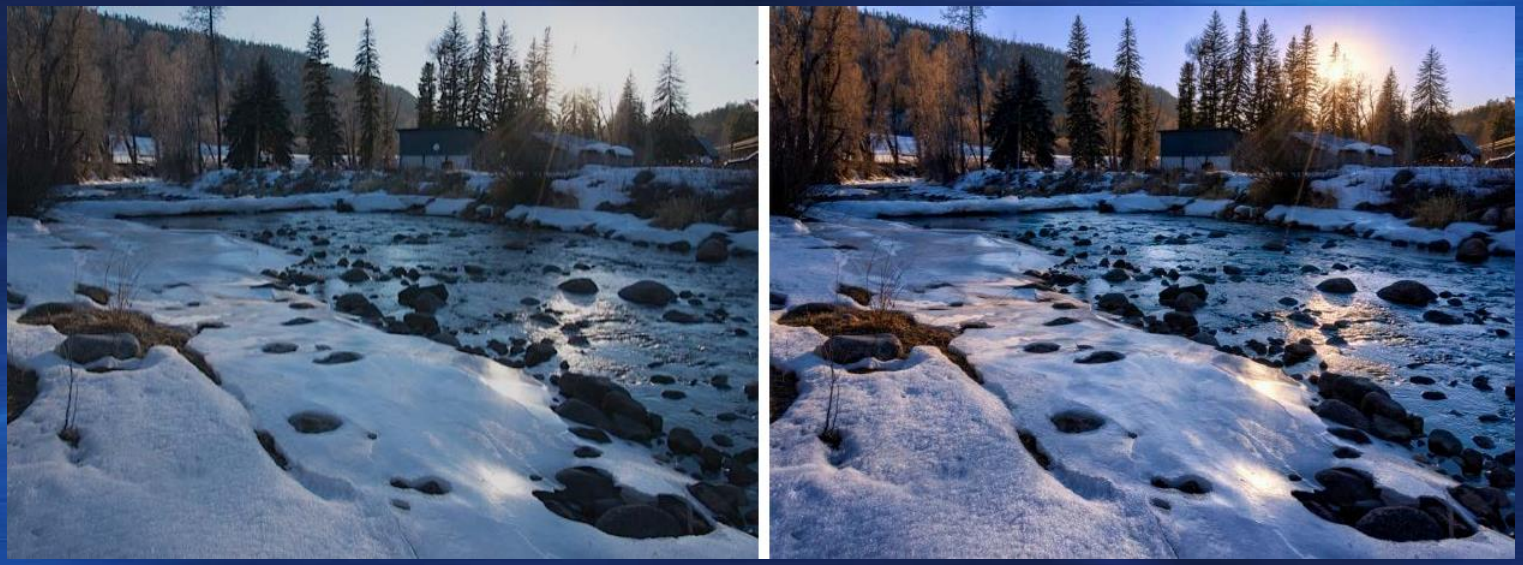
BD-ROM AV Format (6)

- Up to 32 audio streams with up to 8 channels each (24 bits, 192 KHz)
- Mandatory audio encoding methods:
  - LPCM (*Linear* PCM)
  - Dolby Digital (AC-3)
  - DTS (*Digital Theater System*)
- Optional audio encoding methods:
  - Dolby Digital Plus
  - Lossless encoding: Dolby TrueHD, DTS-HD Master Audio

BD-ROM AV Format (7)

- Features specific to Ultra HD Blu-ray discs
  - BT.2020 color space
    - 4K resolution; 10 bits per color component
    - Covers 75.8% of the CIE chromaticity diagram
  - HDR (*High Dynamic Range*) video format
    - The video signal contains brightness and color information across a wider range than for the SDR (*Standard Dynamic Range*) video format
    - The TV set or monitor can display images with a wider gamut of colors and brightness

BD-ROM AV Format (8)



- Three types of HDR video formats
  - BDMV HDR: HEVC video stream; 30-bit color
  - Dolby Vision: BDMV HDR video stream + Dolby Vision video stream; 36-bit color
  - Philips HDR: BDMV HDR video stream + Philips HDR messages (metadata)

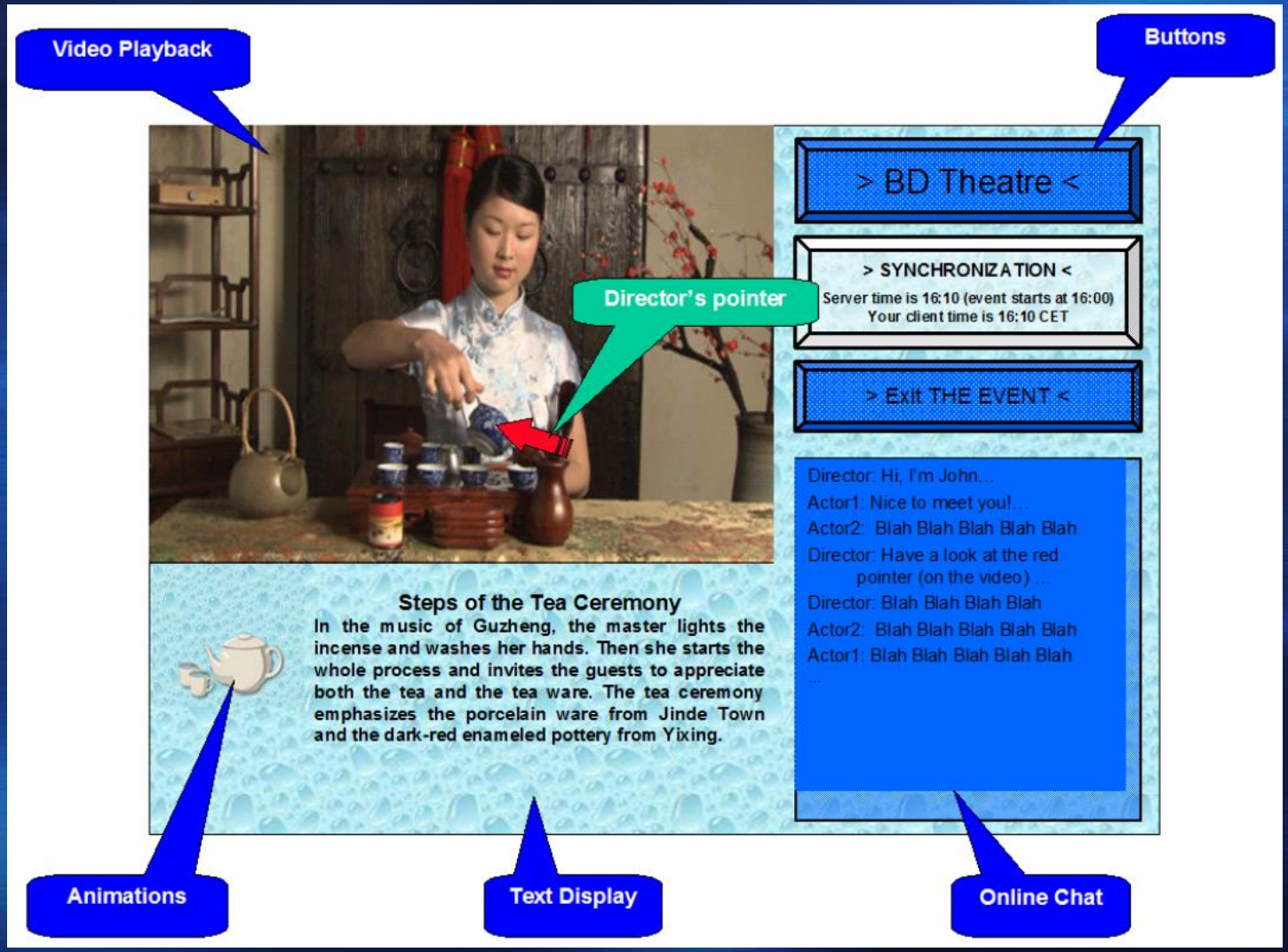
BD-ROM AV Format (9)

- BD-J Mode
  - Extends the HDMV mode's features
  - Frame accurate animation
  - Interactive audio
  - Internet and network connection
  - Control of local storage devices
  - Content extension: games, access to online material, extra languages or commentaries
  - Compliant with Java 2 Micro Edition (J2ME)

BD-ROM AV Format (10)

- Example application: Playback control
  - Playing an introduction of the movie
  - Language and chapter selection
  - Displaying background information
- Example application: Subtitle updates
  - Obtaining subtitles in a language not included
  - Subtitles retrieved from the publisher's website or a dedicated website
- Example application: Playing games
  - Set of games stored in a title on the disc
  - Games downloaded from the publisher

BD-ROM AV Format (11)



Summary (1)

- DVD±R discs use the same technology as CD-R discs, but the organic dyes are different
  - DVD+R discs ensure higher reliability, more accurate writing and linking of multiple sessions
- DVD±RW discs use the same phase-change technology as CD-RW discs
  - DVD+RW discs do not need link blocks between areas written in consecutive sessions
- M-DISC technology uses an inorganic glass-like carbon material for long-term archiving

Summary (2)

- High capacities of Blu-ray discs are achieved by: smaller pit size; reduced track pitch; reduced wavelength; increased NA; thinner cover layer
- BD-RE and BD-R discs contain a spiral groove with two wobble modulation systems
  - The wobbles encode ADIP addressing information
- The BDXL specifications define BD-RE and BD-R discs with three and four layers
- The BD-R/RE AV format enables to record and play back TV broadcasts in HD resolution

Summary (3)

- The BD-ROM AV format is used for distributing commercial HD and UHD movies
  - HDMV mode: provides extended DVD-Video features at HD or UHD resolutions
  - BD-J mode: extends the HDMV mode with applications for interactivity and Internet connection
- Ultra HD Blu-ray discs may have specific features: 4K video resolution; more efficient HEVC (H.265) video encoding; BT.2020 color space; HDR video format

Concepts, Knowledge (1)

- DVD-R disc variants: DVD-R(A), DVD-R(G)
- Spiral groove of DVD+R discs
- Improvements introduced by DVD+R discs
- Spiral groove of DVD+RW discs
- Advantages of DVD+RW discs
- Features of M-DISC technology
- General features of Blu-ray discs
- Methods used to increase the capacity of Blu-ray discs compared to DVDs

Concepts, Knowledge (2)

- Blu-ray disc rotational methods
- Spiral groove of BD-R and BD-RE discs
- Addressing method of BD-R and BD-RE discs
- Optical interferences of BDXL discs
- BD-R/RE AV format
- HDMV mode of BD-ROM AV format
- BD-J mode of BD-ROM AV format
- Specific features of Ultra HD Blu-ray discs