Multimedia-Systems:
(Optical) Storage Media

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httc - Hessian Telemedia Technology Competence-Center e.V.
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9. CD-WO: Compact Disc Write Once
10. CD-MO: Compact Disc Magneto Optical
11. DVD: Digital Video Disk
12. Future
1. Overview

Compact Disc and in addition Digital Versatile/Video Disk

- CD-MO
- CD-WO
  - ISO 9660
  - CD-ROM/XA
  - CD-ROM
  - CD-DA
  - R/W
    - magneto optical basis
  - RO
  - WO
    - optical basis
## 2. History

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

Pits and Lands

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

\[ \lambda_1 = 1.6 \mu m \]
\[ \lambda_2 = 0.6 \mu m \]

\( e.g. \) CD:
Fundamentals: Read Data

- **Scope**
- **Contents**

- [http://www.kom.e-technik.tu-darmstadt.de](http://www.kom.e-technik.tu-darmstadt.de)
- [http://www.tk.informatik.tu-darmstadt.de](http://www.tk.informatik.tu-darmstadt.de)

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**Label**

- 1,2 mm
- 0,12 mm

**Pit Land substrate layer**

- Protective layer (Schutzschicht)
- Reflective layer (Reflexionsschicht)
- Substrate layer (Substratschicht)

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**Intensität des reflektierten Laserstrahls**

- **Pit**
- **Land**

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11appendixB-mem.fm 7 20.June.01
Advantages of Optical Storage Media

High data density:
- 1.66 data bits / \( \mu \text{m} \) of track
- 16000 tpi \( \Leftrightarrow \) floppy disk: 96 tpi

Long term storage:
- Protection of data
- Insensitivity to dust, scratches

Low probability of head crashes:
- Distance between head and substrate surface > 1mm

Adequate error correction:
- allows handling of certain defects

(Perception) Quality:
- e.g. each digital music disc is equivalent to the master
4. 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

Principles:
- Mix of audio and video
- Frequency modulation
- No quantization of pit length
5. CD-DA: Compact Disc Digital Audio

Goal:
- 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)
CD-DA: Characteristics

Audio data rate:
- Sampling frequency: 44100Hz
- 16 bit quantization
- 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 / lands: multiples of 0.3\(\mu\)m

Coding:
- Transition from pit to land / from land to pit: ‘1’
- Between transitions: sequence of ‘0’s
CD-DA: Eight-to-Fourteen Modulation

Restricted laser resolution requires:
- Minimal distance between transitions (pit to land, land to pit)
- At least two “0” between two “1”

Generation of clock signal is driven by transitions:
- 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:

<table>
<thead>
<tr>
<th>data bits</th>
<th>channel bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>00000000</td>
<td>01001000100000</td>
</tr>
<tr>
<td>00000001</td>
<td>10000100000000</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Concatenation of independent 14 bit values
⇒ potential violation of:
- **Min. distance of 2 bits**
- **Max. distance of 10 bits**
- ⇒ Three additional *merging bits*

### CD-DA: Eight-to-Fourteen Modulation Example

<table>
<thead>
<tr>
<th>Audio Bits</th>
<th>0 0 0 0 0 0 0 0 0 0 0 0 0 0 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulation Bits</td>
<td>0 1 0 0 1 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Filling Bits</td>
<td>0 1 0</td>
</tr>
<tr>
<td>Channel Bits</td>
<td>0 1 0 0 1 0 0 0 1 0 0 0 1 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0</td>
</tr>
</tbody>
</table>
CD-DA: Error Handling

Typical Errors:
- Scratches, dust, fingerprints
- „Burst errors“
- To be detected and corrected

Two-level Reed-Solomon Code with frame interleaving
Cross Interleaved Reed Solomon Code
- First level: byte level, EDC and ECC
  - two groups: each with 4 correction bytes for 24 data bytes
    - 1st group: correction of single byte errors
    - 2nd 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
- Error rate: $10^{-8}$ (~ 1bit/100 millions of bits)
  - Exact correction of 4000 data bits possible:
    - 4000 data bits * 0.3 μm/channel bit
    - Hence: burst errors within 2.5 mm can be corrected
- Interpolation: Up to 12,300 data bits (~ 7 mm)
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
  - \(12 \times 1 + 12 \times 0 + 3\) merging bits = 27 bits
CD-DA: Data Streams

Audio bit stream $\sim 1.41 \times 10^6$ bit/s:
- $44.1$ kHz sampling frequency $\sim 1411200$ bit/s
- 16-bit stereo PCM
- Uniform quantization

Data bit stream $\sim 1.94 \times 10^6$ bit/s:
- Audio bit stream
  + parity bytes
  + control & display byte

Channel bit stream $\sim 4.32 \times 10^6$ 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 supported via:
- **Tracks**
- **Index points:**
  - IP₀: start of track
  - IP₁: start of audio data
  - Track pregap: part between IP₀ and IP₁
6. CD-ROM: Compact Disc - Read Only Memory

CD-DA provides:
- Suitable means for handling of typical errors caused by damage or dust
- 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)
- simultaneous play back of various media

Need for 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: 330,000 blocks
- Block: 2,352 audio bytes, 7,203 channel bytes
- Frame, channel bits: 588 bit, with 24 audio bytes
  - Data bits: \(\approx 4.32 \times 10^6\) bit/s
- Audio bits: \(\approx 1.94 \times 10^6\) bit/s
- EFM + merging bits
- Synchronization
- Control & display
- Data bits: \(1.4112\times 10^6\) bit/s
- Audio bits: \(1.4112\times 10^6\) bit/s

[Diagram showing CD-ROM structure with data bits, audio bits, and channel bytes.]
CD-ROM: Structure

Fine granularity for random access:
- Tracks and Index Points not sufficient
- Structure with a higher resolution: block
- Blocks with fixed number of frames

Some figures:
- 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

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, but
• Simultaneous reading of audio and other data in CD-ROM mode 1 not possible
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: 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, meanwhile about 100 ms
- **Rotation delay (for constant linear velocity):**
  - Find sector within 1 rotation
  - Adapt disk speed
  - for 40x CD devices (with 9000 rotations per minute) ~ 6.3 ms

Access times (also) depends on
- actual and desired position of the head
- cache strategies of the device

⇒ Average access time may be about 100 ms (with data caching)
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 at any level
- File interleaving

First track:
- 16 blocks (sectors 0 to 15): system area
- Volume descriptors in subsequent blocks with e.g. length of file system

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
7. CD-ROM / XA: CD-ROM Extended Architecture

History:
- N.V. Philips, Sony and Microsoft (announcement in 1988)
- Extension of Yellow Book standard

Goal: Simultaneous transfer of various media data
- Based on CD-ROM mode 2, ISO 9660, CD-I
- 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“

Drawbacks
- Compatibility to audio and video compression
  - For some media only reference to standard
  - 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
**CD-ROM / XA (Mode 2) Form 1**

<table>
<thead>
<tr>
<th>sync 12</th>
<th>header 4</th>
<th>sub-header 8</th>
<th>user data 2048</th>
<th>EDC 4</th>
<th>ECC 276</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2352 byte

**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

<table>
<thead>
<tr>
<th>sync 12</th>
<th>header 4</th>
<th>sub-header 8</th>
<th>user data 2324</th>
<th>EDC 4</th>
</tr>
</thead>
</table>

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

- 2352 byte
8. Further CD-ROM Based Developments

- CD-I Bridge Disc
  - e.g. Photo CD

- Mixed Mode Disc

- CD-ROM/XA:
  - mixed-media tracks

- CD-I: complete system

- CD-ROM:
  - data

- Mixed Mode Disc

- Mode 1:
  - any data

- Mode 2:
  - audio/video

- CD-DA:
  - audio

- Mixed Mode Disc
  - is based on

- CD-I Ready Format
  - can be played on

- CD-I Bridge Disc
Overview of further developments

Further standards:
- directly based on CD-ROM mode 2 standard
- CD-ROM/XA
  - allows for mode 1 and mode 2 blocks in the same track
- CD-I
  - complete multimedia system

Compatibility formats:
- Can be played on multiple players
- CD-I Bridge Disc: CD-ROM/XA and CD-I players
- Mixed Mode Disc: CD-ROM and CD-DA players
- CD-I Ready Format: CD-I and CD-DA players
Photo Compact Disc: Example of a CD-Bridge Disc

Storage of photos of high quality

History:
• Eastman Kodak and N.V. Philips Company
• 1990 announcement of Kodak Photo CD system

Characteristics:
• Based on CD Write Once (CD-WO)
• Readable with:
  • Photo CD players
  • CD-I players
  • CD-ROM / XA players
• Written by:
  • Special Photo CD writers and CD-WO writers

Capabilities:
• New professional and private application areas
• Simultaneous display of several images
• Image editing
• Integration in documents
Photo Compact Disc: ImagePac

Production:
- Photos are taken with conventional cameras
- Digitized with 8 bit for luminance component and 8 bit for each chrominance component
- Written on CD

Image resolution of a Photo CD:

<table>
<thead>
<tr>
<th>type of image</th>
<th>compr./uncompr.</th>
<th>number of lines</th>
<th>number of columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>base/16</td>
<td>uncompressed</td>
<td>128</td>
<td>192</td>
</tr>
<tr>
<td>base/14</td>
<td>uncompressed</td>
<td>256</td>
<td>384</td>
</tr>
<tr>
<td>base</td>
<td>uncompressed</td>
<td>512</td>
<td>768</td>
</tr>
<tr>
<td>4base</td>
<td>compressed</td>
<td>1024</td>
<td>1536</td>
</tr>
<tr>
<td>16base</td>
<td>compressed</td>
<td>2048</td>
<td>3072</td>
</tr>
<tr>
<td>64-Base</td>
<td>compressed</td>
<td>4.096</td>
<td>6.144</td>
</tr>
</tbody>
</table>

Per photo:
- ImagePac at five different resolutions: hierarchical coding
- About 3 to 6 MByte storage per ImagePac
9. CD-WO: Compact Disc Write Once

Defined in Orange Book Standard Part II

- “raw” CD-WO has:
  - pre-grooven track
  - absorption layer between substrate and reflective layer

- **Recording - Irreversible change of the reflection characteristics by:**
  - Heating up the absorption layer

- CD-WO can be played in CD-DA players
CD-WO: Sessions

Disc layout with several sessions:

Sessions:
- Several sessions each with:
  - Lead-in part
  - Data part
  - Lead-out part
- New sessions can be added
- Maximum of 99 sessions

Note
- CD players before 1992 can only read first session
- Regular CD-WO: only one session
- Hybrid CD-WO: several sessions
10. CD-MO: Compact Disc Magneto Optical

- CD-MO: Rewritable, premastered
- CD-WO: Regular, hybrid
- ISO 9660
- CD-ROM/XA
- CD-ROM
- CD-DA
- R/W: Magneto optical basis
- RO: Optical basis
- WO: Regular hybrid
CD-MO: Features and Principles

Definition in Orange Book Standard Part I:
- High capacity (double-sided): about 650 MByte
- Data transfer rate: about 1.2 Mbit/s

Features:
- write data
- read data
- erase data
- rewrite data

Principles of magneto optical technique:
- **Write:**
  - Heating up of blocks
  - Apply about 10 x earth magnetic field
  - Polarization of single elements
- **Discard:**
  - Use constant magnetic field
  - Simultaneous heating up of block
- **Read:**
  - Polarization of light is influenced by magnetic characteristics
11. DVD: Digital Video Disk

Also known as: „Digital Versatile Disk“

Goal:
  • to create a new optical media to store an entire high-quality digital movie on a disk

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

Under discussion: smaller DVDs
  • Diameter of 8 cm (instead of 12 cm)
DVD - Technical Overview

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
• maps 8 to 16 bits, no need for 3 merging bits
# CD vs. DVD

<table>
<thead>
<tr>
<th></th>
<th>CD</th>
<th>DVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mediendurchmesser</td>
<td>ca. 120 mm</td>
<td>120 mm</td>
</tr>
<tr>
<td>Medienstärke</td>
<td>ca. 1,2 mm</td>
<td>1,2 mm</td>
</tr>
<tr>
<td>Laser-Wellenlänge</td>
<td>780 nm (infrarot)</td>
<td>650 und 635 nm (rot)</td>
</tr>
<tr>
<td>Track-Abstand</td>
<td>1,6 µm</td>
<td>0,74 µm</td>
</tr>
<tr>
<td>Min. Pit/Land-Länge</td>
<td>0,83 µm</td>
<td>0,4 µm</td>
</tr>
<tr>
<td>Daten-Layer</td>
<td>1</td>
<td>1 oder 2</td>
</tr>
<tr>
<td>Seiten</td>
<td>1</td>
<td>1 oder 2</td>
</tr>
<tr>
<td>Kapazität</td>
<td>ca. 650 MB</td>
<td>ca. 4,38 GB (SLSS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ca. 7,95 GB (DLSS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ca. 8,75 GB (SLDS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ca. 15,9 GB (DLDS)</td>
</tr>
<tr>
<td>Videodatenrate</td>
<td>ca. 1,5 Mbit/s</td>
<td>1-10 Mbit/s (var.)</td>
</tr>
<tr>
<td>Video-Kompressionsstandard</td>
<td>MPEG-1</td>
<td>MPEG-2</td>
</tr>
<tr>
<td>Videokapazität</td>
<td>ca. 1 Stunde</td>
<td>je nach Format zwischen 2 und 8 Stunden</td>
</tr>
<tr>
<td>Sound-Tracks</td>
<td>2-Kanal MPEG</td>
<td>2-Kanal PCM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5,1-Kanal AC-3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>optional: bis zu 8 Datenströme</td>
</tr>
<tr>
<td>Untertitel</td>
<td>-</td>
<td>bis zu 32 Sprachen</td>
</tr>
</tbody>
</table>
**DVD: Variants**

**DVD Read Only Spezifikation** (DVD-ROM, Buch A):
- Speichermedium hoher Kapazität, Nachfolger der CD-ROM

**DVD Video Spezifikation** (DVD-Video, Buch B):
- Spezielle Applikation der DVD zur Verbreitung „linearer“ Videodatenströme

**DVD Audio Spezifikation** (DVD-Audio, Buch C):
- Spezielle Anwendung der DVD zur Verbreitung reiner Audiodaten, ähnlich der CD-DA

**DVD Recordable Spezifikation** (DVD-R, Buch D):
- Variation der DVD, die es erlaubt, Daten einmalig zur späteren Verwendung aufzuzeichnen

**DVD Rewriteable Spezifikation** (DVD-RW, Buch E):
- DVD-Art, die ähnlich der CD-RW mehrfach beschreibbar und löschar ist.
- Wird auch als DVD-RAM (Random Access Memory) bezeichnet
## DVD: Physical Disk Configurations

<table>
<thead>
<tr>
<th>Bezeichnung</th>
<th>Durchmesser (cm)</th>
<th>Seiten</th>
<th>Schichten pro Seite</th>
<th>Kapazität (GB)</th>
<th>Anmerkungen</th>
</tr>
</thead>
<tbody>
<tr>
<td>DVD-5</td>
<td>12</td>
<td>SS</td>
<td>SL</td>
<td>4,38</td>
<td>&gt;2 Std. Video</td>
</tr>
<tr>
<td>DVD-9</td>
<td>12</td>
<td>SS</td>
<td>DL</td>
<td>7,95</td>
<td>ca. 4 Std. Video</td>
</tr>
<tr>
<td>DVD-10</td>
<td>12</td>
<td>DS</td>
<td>SL</td>
<td>8,75</td>
<td>ca. 4,5 Std. Video</td>
</tr>
<tr>
<td>DVD-18</td>
<td>12</td>
<td>DS</td>
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<td>15,9</td>
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12. Future

Technology
- smaller in size
- new medium?

Performance
- enhanced storage capacity
- larger data retrieval rate