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An Introduction to DVD Formats

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1. Introduction

DVD, the Digital Versatile Disc, is a high capacity CD-size disc for video, multimedia, games and audio applications. Capacities for the read-only disc range from 4.7GB to 17.1GB. The high quality of video and audio has helped DVD-Video to compete very effectively with VHS for pre-recorded video titles, statistics showing that DVD is growing faster than any other consumer electronics format in the USA and Europe. PCs with DVD capability are also selling, but multimedia and games applications of DVD have been slow to start. The advent of new games consoles using DVD is also helping to stimulate further sales.

1.1 DVD Applications

Despite the success of the compact disc there has been a clear need for a higher capacity format to meet additional application requirements.

- **DVD-Video**, which was launched in 1997 in the USA, has become the most successful of all the DVD formats, as it has proved to be an ideal vehicle for distributing video content from the movie industry. It can store a full-length movie in high quality video with surround sound audio on a disc the same size as a CD. DVD now accounts for the majority of video sales in the USA and Europe.
- **DVD-ROM** is beginning to replace the CD-ROM and provide a new high capacity disc format for the computer industry. New PCs are now provided with DVD drives instead of CD drives. The entertainment industry has developed new games consoles (eg Sony's PS2 and Microsoft's X-Box) which incorporate DVD-ROM drives for more sophisticated and realistic games applications.
- **DVD-Audio**, which was launched in 2000, is slowly gathering momentum to become the format for very high quality, surround sound music, offering the music industry new revenue opportunities.
- Recordable formats such as **DVD-RAM**, **DVD-RW** and **DVD-R** are now being extensively used in PCs for computer backup and short runs of DVDs and in standalone products such as video recorders and camcorders.

DVD-Video and DVD-ROM hardware and software have been available since 1997. DVD-Audio was launched in 2000. DVD writers and DVD video recorders are now available at affordable prices.

1.2 DVD Features

DVD started as the Digital Video Disc but now means Digital Versatile Disc or just DVD. It is a multi-application family of optical disc formats for read-only, recordable and re-writable applications. The main features of the DVD formats are:

- Backwards compatibility with current CD media. All DVD hardware will play audio CDs and CD-ROMs and most will play CD-Rs and CD-RWs.
- Physical dimensions are identical to the compact disc but each disc comprises two 0.6 mm thick substrates, bonded together.
- Single-layer/dual-layer and single/double sided options are available.
- Up to 4.7 GB read-only capacity per layer, 8.5 GB per side maximum.
- Designed from the outset for video, audio and multimedia, not just audio.
- All formats use a common file system (UDF).

- Digital and analogue copy protection for DVD-Video and DVD-Audio built into the standard.
- Recordable and re-writable versions are part of the family.

1.3 DVD History

DVD started in 1994 as two competing formats, Super Disc (SD) and Multimedia CD (MMCD). DVD now is the result of an agreement by both camps on a single standard to meet the requirements of all the various industries involved. The major milestones are listed in Table 1.

Table 1 DVD Milestones

1994	Hollywood ad hoc committee defined features for movies on 'CD'.
1995	Agreement on a single standard format called DVD.
1996	DVD-ROM and DVD-Video specifications version 1.0 published Digital copy protection scheme (CSS) agreed First DVD-Video players sold in Tokyo (November)
1997	Launch of DVD in USA (August) DVD Consortium becomes DVD Forum, expands membership and holds first General DVD Forum Meeting with 120 members
1998	DVD-Video version 1.1 and DVD-ROM version 1.01 specifications issued. DVD Forum adopts DVD-RW as another re-writable format 7 new members of DVD Forum Steering Committee making 17 in all DVD Forum publishes DVD-Audio specification version 0.9 Full launch of DVD in Europe. 1m DVD-Video players sold in USA 4.7 GB DVD-R and DVD-RAM version 1.9 specifications released
1999	DVD-Audio (1.0), DVD-Video Recording (0.9 & 1.0), DVD-RW (0.9) and DVD-RAM (2.0) specifications published.
2000	CPPM copy protection for DVD-Audio agreed DVD-Audio players launched in USA (July) First DVD-Audio discs in USA (November) DVD-RW Part 2 (1.0), DVD-R for Authoring (2.0), DVD-R for General (2.0) and DVD Stream Recording (0.9) specifications published.
2001	DVD-Audio players & discs available in Europe and elsewhere DVD Video Recorders launched in Europe etc Guidelines for IEEE 1394 transmission for DVD-Video/Audio issued. DVD Video Recorders launched in Europe etc DVD-Multi (1.0), DVD Stream Recording (1.0), DVD-Audio (1.2) and DVD-Video Recording (1.1) specifications published.
2002	WG-11 created to study future blue laser format DVD-Audio recording specification ver 0.9 issued Hybrid DVD-Audio format approved by DVD Forum
2003	DVD Forum rejects hybrid DVD-Audio format DVD Forum selects 0.6mm HD DVD, shelves 0.1mm DVD Forum releases iDVD specifications

2. DVD Specifications

The DVD technical specifications are contained in five books A to E published by the DVD Forum and listed in Table 2.

Table 2 DVD Book Specifications

Book	Name	Part 1 Physical	Part 2 File System	Part 3 Application	Version
A	DVD-ROM	Read-only	ISO9660/UDF	undefined	1.01
B	DVD-Video	Read-only	UDF	MPEG-2 video	1.1
C	DVD-Audio	Read-only	UDF	MLP & PCM audio	1.2
D	DVD-R	Write once	UDF	not defined	2.0
E	DVD-RAM/RW	Rewritable	UDF	not defined	2.0

Note that SACD, DVD+R and DVD+RW, although based on the DVD format, are not approved by the DVD Forum.

2.1 DVD Disc Parameters

Table 3 provides a comparison between the main physical parameters of DVD and CD discs. Note the smaller geometries and two layers/sides.

Table 3 DVD Disc Parameters

Parameter	CD	DVD	Comments
Sides	1	1 or 2	See 2.2
Layers	1	1 or 2	
Capacity (GB)	0.68	4.7 - 17	1 GB = 10 ⁹ bytes (not 1024 ³)
Track pitch (μ)	1.6	0.74	
Minimum pit length (μ)	0.83	0.4	For I3 pit
Wavelength (nm)	780	650	of laser diode pickup
Numerical aperture	0.45	0.6	Defines angle of beam
Linear velocity (m/s)	1.3	3.49	Nominal 1x speed
Modulation	EFM	8 to 16	EFM is 8 to 14 plus 3 padding bits
Error protection	ECC	RSPC	RSPC is block protection scheme
3rd layer ECC	Yes	No	Not needed for DVD after RSPC
Subcode	Yes	No	No subcode needed
Tracks	Yes	No	DVD uses files not tracks

2.2 DVD Physical Disc Formats

Although identical in appearance, DVDs and CDs differ in a number of key physical parameters. To meet the requirements for 133 minutes of high quality video on one side of a single disc requires the use of a thinner (0.6 mm) substrate, two of which are bonded together (see Figure 1) to form a disc that is thick enough for general use.

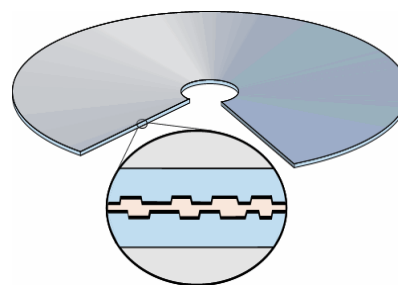


Figure 1 DVD Construction

The use of a sandwich of two substrates allows a range of formats from one layer to four and one or two sides, giving capacities from 4.7 GB to as much as 17.1 GB. These are listed in Table 4 and illustrated below.

Table 4 DVD Physical Disc Formats

	DVD-5	DVD-9	DVD-10	DVD-18	DVD-R	DVD-RW	DVD-RAM
Capacity (GB¹)	4.7	8.54	9.4	17.08	4.7	4.7	4.7 or 9.4
Layers/side	1	2	1	2	1	1	1
Sides	1	1	2	2	1	1	1 or 2

DVD-5 discs comprise a sandwich of two 0.6mm substrates, one metallised and with data, the other blank, bonded together. The data is read from one side only so that labels can be printed on the top surface of the disc as for CDs.

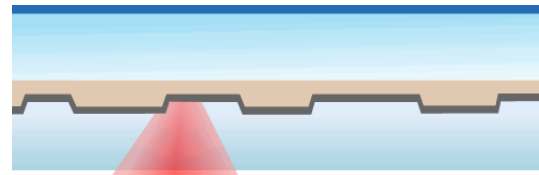


Figure 2 DVD-5 Disc

DVD-9 discs comprise one semi-reflective substrate (layer 0) and one fully metallised substrate (layer 1) above it giving a capacity of 4.25 GB per layer. The reduced capacity is intended to ease the manufacturing tolerances for such discs.

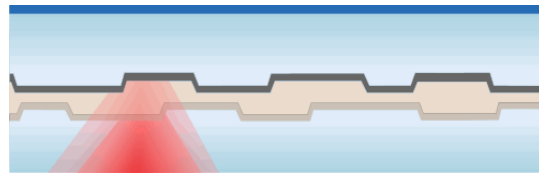


Figure 3 DVD-9 Disc

Labels can be printed on the discs as for DVD-5 discs and CDs.

DVD-10 discs comprise two metallised substrates bonded together and read from both sides. The disc label is restricted to a small annular area within the disc hub, on both sides of the disc.

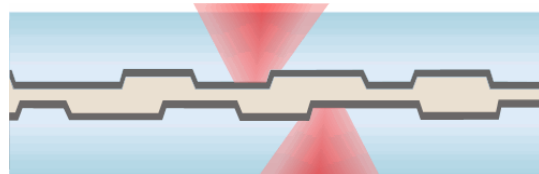


Figure 4 DVD-10 Disc

These discs have been superseded by DVD-9 discs, which are read from one side.

DVD-18 discs, which have limited availability, comprise two dual-layer substrates bonded together and read from both sides. The disc label is restricted as for DVD-10 to small annular areas on both sides.

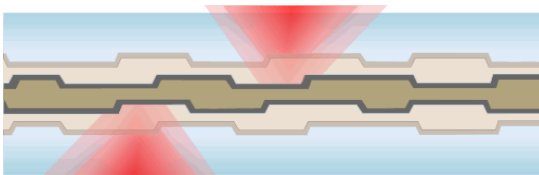


Figure 5 DVD-18 Disc

These are not yet widely used due to manufacturing difficulties and the perceived extra value of two DVD-9 discs instead of one DVD-18.

¹ Note that for capacity purposes one GB (gigabyte) is actually a billion bytes or 10^9 bytes. This contrasts with normal computer storage capacities whereby a GB is $1024 \times 1024 \times 1024$ bytes. Therefore the capacity of a DVD-5 disc is 4.337 GB using the latter definition.

Recordable and Re-writable DVD Formats

The recordable and re-writable formats include two DVD-R types plus DVD-RW and DVD-RAM. In addition DVD+R and DVD+RW are alternative formats that are not supported by the DVD Forum.

- **DVD-R for Authoring** is intended for professional use and requires a 635 nm laser for writing. The lead-in area can contain information needed for glass mastering so that DVD-Video titles can be mastered from this type of media instead of DLT tape.
- **DVD-R for General** use is intended for consumer applications and requires a 650 nm laser for writing. It is not possible to write to the lead-in area of such discs.
- **DVD-RAM** discs are re-writable discs with a capacity of 4.7GB per side for computer data storage and archive applications, although this format is also used in some DVD video recorders.
- **DVD-RW** discs are re-writable discs with a capacity of 4.7GB per side for consumer applications such as video recording.
- **DVD+RW and DVD+R** discs are not officially part of the DVD family, but are similar to the corresponding DVD-RW and DVD-R for General formats.

Note that CSS protected content cannot be written to any of these discs.

Hybrid and combination disc formats

A number of formats that combine different formats on different layers have been developed.

Combination disc formats, for example combining DVD-ROM on one side with DVD-RAM on the other, have been approved by the DVD Forum. Such discs are double sided discs and are read from both sides.

Hybrid SACD is a format developed by Philips and Sony and combines a SACD (ie physically a DVD layer) with a CD layer. Both layers are read from the same side, which means that the SACD layer must be reflective for the red laser but will transmit the infra red CD laser. Such discs can then be played on both a CD player (which will read the CD layer) and a SACD player.

Hybrid DVD is a similar format being studied by the DVD Forum. The first application is likely to be for a DVD-Audio/CD audio combination which is almost identical to the hybrid SACD format.

DVD Plus refers to a disc comprising a CD bonded to a DVD substrate. The resulting disc allows both DVD and CD data to be read from one disc, like a hybrid DVD, but the disc is read from both sides. Early versions of this format were 1.8 mm thick, but this has been reduced to 1.5 mm. At the time of writing this format is not approved by the DVD Forum.

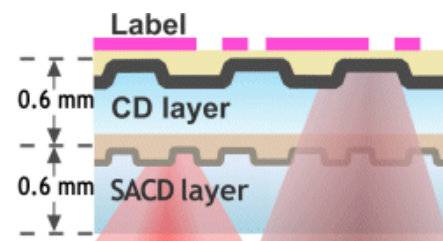


Figure 6 Hybrid SACD

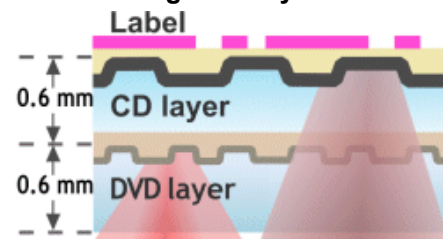


Figure 7 Hybrid DVD

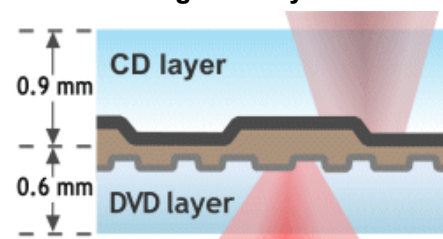


Figure 8 DVD Plus

Single and dual layer disc layout

Each layer of a DVD disc contains Lead In, Data Area and Lead Out like a CD. A single layer disc comprises a Lead In, Data Area and Lead Out. For dual layer discs there are two options depending on the application (see Figure 9).

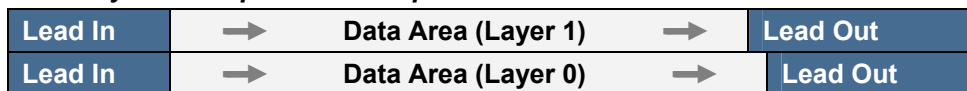
- **Parallel track path**, where the two layers are independent and both start at the inside diameter (ID) and end at the OD with the Lead Out. Dual layer DVD-ROM discs use this layout for access to files on either layer.
- **Opposite track path**, where layer 0 starts at the ID and layer 1 starts where layer 0 ends at the Middle Area. For such discs there is one Lead In (on layer 0), one Lead Out (on layer 1) and two Middle Areas. DVD-Video discs will use opposite track path so that a movie can be placed across both layers and played almost seamlessly from layer 0 to layer 1.

Note that the file system data (see below) will be contained in layer 0.

Single layer disc



Dual layer disc – parallel track path



Dual layer disc – opposite track path



Figure 9 Single and Dual layer DVD disc layouts

2.3 Burst Cutting Area

The Burst Cutting Area (BCA) is an annular area within the disc hub where a bar code can be written for additional information such as serial numbers (see Figure 10). The data stored in the BCA can be from 12 bytes to 188 bytes in steps of 16 bytes.

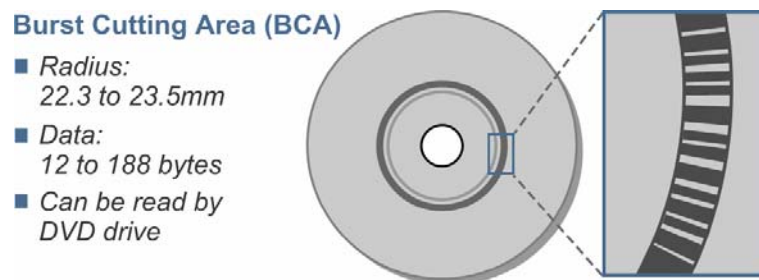


Figure 10 Burst Cutting Area

The BCA can be written during mastering and will be common for all discs from that master or, more usually, will be written using a YAG laser to 'cut' the barcode into the aluminium reflective layer of the finished disc. The ill-fated Divx format used BCA to uniquely identify every disc. New uses of this or similar technologies are being developed to use the BCA as a unique, tamper-proof means of identifying individual discs.

2.4 DVD Sector Structure

The data on a DVD disc are organised as sectors of 2048 bytes plus 12 bytes of header data (see Figure 11). Blocks of 16 sectors are error protected using RSPC (Reed Solomon Product Code), which is block oriented and is more

suitable for re-writable discs (with packet writing) than CIRC, which does not use a block format. The PI and PO data are parity bytes calculated horizontally and vertically over the data bytes.

In addition DVD uses an 8 to 16 modulation scheme giving pit lengths of 3 to 14 (minimum to maximum length) compared with CD's 3 to 11 with EFM modulation. This is only a small difference but does make the jitter specification slightly tighter.

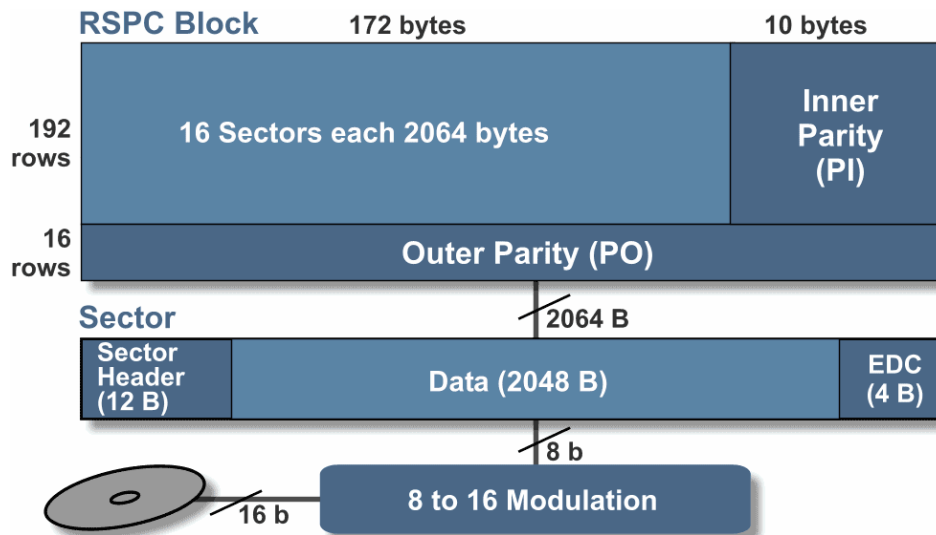


Figure 11 DVD Sector Structure

2.5 DVD File System

All types of DVD disc (DVD-Video, DVD-ROM and DVD-Audio) contain data in files. These files are accessed using a file system common to all DVD discs. For compatibility with recordable and re-writable versions the UDF Bridge Format has been chosen. This comprises a combination of UDF plus ISO 9660 for compatibility with CD-ROM. The main characteristics of UDF are:

- Robust file exchange
- System & vendor independent
- Writable & read-only media
- Based on ISO 13346 (ECMA 167)

UDF has been extended to provide the necessary features for both write-once and re-writable discs. The file system specifications for different writable formats are different in some respects.

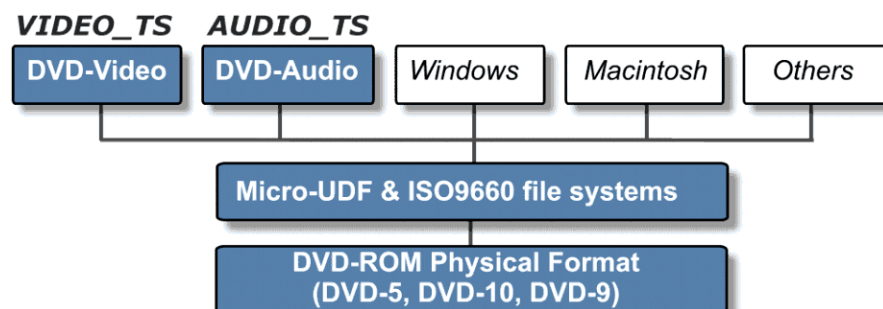


Figure 12 DVD Disc File Structure

A combination of UDF and ISO 9660 (known as UDF Bridge) is used on some DVD discs to provide compatibility with existing operating systems, including

Windows9x and later. Applications can access the data files using either ISO 9660 or UDF file structures, but use of UDF is recommended.

All pre-recorded discs are DVD-ROM discs, but contain any or all of the application data shown in Figure 12. Only DVD-Video and DVD-Audio data must be contained within specific directories VIDEO_TS and AUDIO_TS.

DVD-Video discs use only UDF (not ISO 9660) with all required data specified by UDF and ISO 13346 to allow playing in computer systems. The DVD-Video files must be no larger than 1 GB in size and be recorded as a single extent (ie in one continuous sequence). The first directory on the disc must be the VIDEO_TS directory containing all the files. All filenames are in the 8.3 format. All other files not included in the DVD-Video specification are ignored by DVD-Video players. DVD-Audio discs also only use UDF and files are contained in the AUDIO_TS directory.

2.6 The DVD-Forum

The DVD specifications were originally written by the DVD Consortium, which comprised 10 companies: Hitachi, Matsushita, Mitsubishi, Philips, Pioneer, Sony, Thomson, Time Warner, Toshiba and JVC. In late 1997 the name was changed to the DVD Forum and membership opened up to other companies in the DVD industry. The original 10 members have become the Forum's Steering Committee and increased its numbers to 17 with the addition of the following companies: IBM, Industry Technology Research Institute of Taiwan, Intel, LG Electronics, NEC, Samsung and Sharp.

The DVD Forum has a total membership of over 220 and continues to produce and maintain the DVD specifications by means of nine working groups:

- WG1** DVD-Video, video recording and stream recording specifications.
- WG2** DVD physical specification.
- WG3** File systems for pre-recorded and recordable DVD formats
- WG4** DVD-Audio and audio recording specifications
- WG5** DVD-RAM specifications
- WG6** DVD-R and DVD-RW specifications
- WG9** Copy protection review
- WG10** Industrial/professional applications of DVD
- WG11** New Blue laser disc formats for HDTV

In addition, the DVD Forum has established committees for verification of DVD discs, players etc and promotion of the DVD Format.

DVD Format/Logo Licensing

In 2000 the DVD Format/Logo Licensing Corp (DVD FLLC) was established to handle issuing of the DVD specifications, granting licenses to manufacturers and policing the use of the DVD logos.

All manufacturers of hardware, discs and related DVD products must be licensed and first products verified to ensure that all players will play all discs. The correct logos must be used for licensed DVD products in the appropriate way as shown.

The DVD FLLC is taking firm action against companies that are manufacturing or selling non-licensed products or are using the incorrect logos.



3. DVD Application Formats

Two DVD application formats have been developed: DVD-Video, and DVD-Audio. DVD-ROM is the basis of the other two and can be used for a wide variety of other applications.

3.1 DVD-Video

DVD-Video discs are intended for full-length movies and offer a range of features including the following:

- **Playing time:** a nominal 133 minutes playing time for DVD-5 or each side of a DVD-10 and 240 minutes for DVD-9 using opposite track path format.
- **Video encoding:** MPEG-2 (for better than Laserdisc quality) or MPEG-1.
- **Audio Quality and Languages:** Dolby Digital, DTS, MPEG-2 or Linear PCM audio for up to 5.1 channel surround sound.
- **Subtitling:** Subpictures allow subtitling for up to 32 languages
- **Range of Video Formats:** Pan & scan, letterbox and widescreen formats.
- **Interactivity:** a range of interactive features is available including seamless transitions, menus, camera angles and different routes or endings

Longer movies can make use of dual layer DVDs (DVD-9) for continuous play and the two sides of a DVD-10 disc can be used for two different versions of a movie. Some video titles contain data that can be played only on a PC. Access to websites can be achieved in this way.

DVD Players and Titles

All DVD-Video players should be capable of playing all types of DVD-Video discs (within the region specified), CD audio discs and Video CDs, but most will play additional formats as well. DVD-Video players will output video to both wide-screen and conventional TVs. The user can choose between wide-screen, letterbox and pan & scan outputs where available. Players in the USA will generally only play NTSC video, whilst those in Europe usually play NTSC as well as PAL, but only if the monitor/TV is capable of both systems.

DVD-Video titles can also be played on PCs with DVD-ROM drives and MPEG-2 hardware or software decoders.

Region coding

Many DVD-Video discs are region coded to restrict playing to specific regions as shown below.

- Region 1:** USA, Canada
- Region 2:** Europe, Middle East, South Africa, Japan
- Region 3:** Southeast Asia, Taiwan
- Region 4:** Central & S America, Mexico, Australia, New Zealand
- Region 5:** Russian Federation, Africa (part), India, Pakistan
- Region 6:** China

DVD titles do not have to be region coded, but players generally are coded for only one region. Non-region coded discs will play on any player.

3.2 DVD-ROM

DVD-ROM is essentially the pre-recorded DVD physical and logical format used for DVD-Video, DVD-Audio and a range of other applications, particularly general computer and multimedia applications, for which it can provide at least 7 times the capacity of a CD-ROM. Applications can include MPEG-2 video, as

used on DVD-Video discs, to give added realism to games and richer content for multimedia applications.

DVD-ROM drives will also play CD-ROM and CD audio discs and are forecast to replace CD-ROM drives within the next few years. They are already available as add-on drives and built into new PCs. Early drives were 2x speed, but much faster drives are now available.

3.3 DVD-Audio

The DVD-Audio specification was released in 1999, copy protection methods agreed in 2000 and players and discs are now available. DVD-Audio discs use scalable multi-channel linear PCM coding with optional lossless compression. Additional content can comprise video, text and still pictures. DVD-Video like navigation is also included in the specification.

DVD-Audio discs will require DVD-Audio players or universal DVD-Video/DVD-Audio players. DVD-Audio discs can optionally include DVD-Video content for compatibility with DVD-Video players. Most discs released so far include DVD-Video content so that they will play on DVD-Video players, although the audio quality is not as good as DVD-Audio can provide.

Philips and Sony have developed Super Audio CD (SACD), an alternative to DVD-Audio, which uses DSD (direct stream digital) encoding and offers a hybrid disc version containing CD and DVD audio on different layers so that the one disc will play on both SACD and CD audio players (although with a difference in quality). Future DVD-Audio discs may also offer a hybrid option.

3.4 Copy Protection

Copy protection for DVD is only for video and audio content and comprises both digital and analogue methods for preventing users from making perfect copies of the source material.

Digital copy protection involves scrambling the raw data using certain keys, which are stored on the disc in encrypted form. In the decoder, the original keys are obtained by inverting the encryption process and the data is then de-scrambled using the decrypted keys.

- DVD-Video titles can use **CSS** (Content Scrambling System)
- DVD-Audio titles can use **CPPM** (Content Protection for Pre-recorded Media)
- Recordable discs can use **CPRM** (Content Protection for Recordable Media).

For DVD-ROM there is no copy protection, but techniques currently used for CD-ROM are being extended to DVD.

Analogue copy protection (APS) makes use of a technique developed by Macrovision, which distorts the analogue output waveform so that the picture quality is unaffected but it cannot be successfully played back from VHS tape.

Watermarking systems have been developed for both audio and video content and are undergoing tests. These systems allow the source and ownership of the audio or video to be verified.

4. DVD Production

DVD discs are produced by first premastering and then manufacturing.

4.1 DVD Premastering

Premastering of DVD applications is relatively straightforward for DVD-ROM but can be very complex for DVD-Video and DVD-Audio.

DVD-Video premastering

DVD-Video premastering comprises the following processes.

- **Video encoding to MPEG-2** using variable or constant bit rate encoding
- **Audio encoding** to Dolby Digital, MPEG or PCM
- **Subtitles** created as subpictures
- **Authoring** to add interactivity and create menus and navigation data
- **Emulation/title testing**

DVD-Audio premastering

DVD-Audio premastering is similar to DVD-Video and can include:

- **Audio encoding** and lossless packing
- **Still image encoding** for slideshows (optional)
- **Text preparation** for audio related text
- **Authoring** for optional interactivity, menus and navigation data.
- **Emulation/title testing**

DVD-ROM premastering

DVD-ROMs can be premastered in a similar way to CD-ROM. Premastering tools must format the data according to the DVD specifications including the UDF file system. For Windows 95, the ISO 9660 file system with Joliet extensions must be included as well. A single disc can comprise any or all of DVD-Video, DVD-Audio and DVD-ROM content each complying with the appropriate specifications. Combination discs are likely to play differently on a DVD-Video player, DVD-Audio player and DVD PC.

4.2 Manufacturing DVD Discs

Manufacturing CD and DVD discs both require similar processes. The data are stored as minute pits (which are much smaller for DVD) in the surface of the plastic disc. A stamper is created by a glass mastering process and used to mould the DVD pits in the surface of the polycarbonate disc substrate. An additional stage, bonding, is required only for DVD discs to bond two thin substrates together to produce the finished disc.

Glass mastering

Both CD and DVD discs glass mastering is needed to create stampers used to mould pits in the surface of the disc. The differences between DVD and CD means that much of the mastering process for DVD needs new equipment including improved glass master preparation, laser beam recording and developing.

Replication

Replication comprises injection moulding, using the stamper created during mastering, of two disc substrates, metallisation of one or both substrates and bonding.

Disc Finishing

Printing of single sided DVD discs can be the same as CDs, eg using screen-printing of up to six colours. Double-sided discs can only be printed within the hub area but on both sides.

New Packaging has been developed for DVD to differentiate it from CDs and, in most cases, to allow the disc to be removed from the packaging while protecting them from any force that might delaminate the substrates.

Quality Assurance

DVD discs must meet certain stringent quality parameters, the most important of which are disc flatness, low jitter and signals within specifications. Mastering and replication equipment must be set up to ensure these specifications are met and measurement equipment is needed to check the actual parameters.

In addition, mastering and replication is the only way to ensure that a DVD title has been pre-mastered correctly. Therefore it is important to verify the replicated discs using DVD players to ensure correct functionality.