deluxe® global media services ltd
southwater business park ▪ worthing road ▪ southwater
west sussex ▪ RH13 9YT ▪ united kingdom
p: (+44) (0)1403 739600 ▪ f: (+44) (0)1403 739601

CD and DVD Disc Manufacturing

July 2003

by Graham Sharpless

The information contained in this document is intended to provide an overview and is not a comprehensive description of the technology or processes involved for CD or DVD. Deluxe cannot be held liable for any consequence of using this information. For more complete information the reader is advised to see the appropriate CD or DVD specifications.

Contents

1. Introduction

Both CD and DVD discs are 12 cm in diameter and 1.2mm thick. Most of the processes needed to replicate are similar but DVD requires some new processes plus tighter tolerances.

- **CDs** comprise a single clear polycarbonate substrate covered by an aluminium layer, which is protected by a lacquer on which a label is usually printed.
- **DVDs** comprise two substrates each of which is covered by a metallic layer (not always aluminium) and bonded together. DVDs can be single or double sided and one or two layers per side. Pit sizes and track pitch are both smaller for DVDs than CDs.

These differences are illustrated in Figure 1.

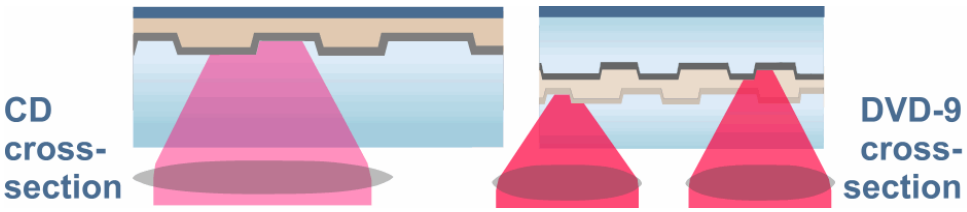


Figure 1 Cross-section of CD and DVD-9 Discs

The main CD and DVD formats are listed in Table 1 with their capacity[1] and description.

Table 1 CD & DVD Disc Formats

Format	Capacity	Description
CD	0.7 GB	Single layer, single side; read from one side only.
DVD-5	4.7 GB	Single layer, single side; read from one side only.
DVD-10	9.4 GB	Single layer, double side; read from both sides.
DVD-9	8.5 GB	Dual layer, single side; read from one side only.

CD and DVD disc production involves the following processes:

- **Premastering** and/or authoring, which creates the data to be contained on each replica CD or DVD or modifies the data ready for glass mastering.
- **Glass Mastering**, which is needed to create stampers that are used to mould the individual discs.
- **Replication** of individual discs by moulding using stampers followed by metallising and lacquering (for CDs) or bonding (for DVDs)
- **Printing** of disc labels on each disc. CD and DVD have different print specifications.
- **Packaging** of discs in suitable cases, usually different for CD and DVD.
- **Quality assurance** to ensure discs meet the necessary specifications.

These stages are detailed in the sections below for both CD and DVD.

[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 x 1024 x 1024 bytes. Therefore the capacity of a DVD-5 disc is 4.337 GB using the latter definition.

1.1 DVD vs CD Replication

DVD discs are more difficult to manufacture than CDs, requiring new, purpose designed equipment rather than upgraded equipment. DVD discs are different from CDs in the following ways:

- Pit sizes are half that of CD pits (0.4 microns instead of 0.8 microns for the smallest pits)
- Track pitch is half that for CDs, with tighter tolerances (0.74 microns instead of 1.6 microns)
- Higher mastering speeds, both in angular and linear velocity and data rate.
- New data formatting requirements, particularly for dual layer discs.
- Two disc substrates to mould per final disc, each half the thickness of a CD.
- Tighter tolerances on tilt and jitter in particular.
- A semi-reflective layer for dual layer discs, where the reflectivity must be within tight tolerances.
- Additional bonding stage, which for dual layer discs must be optically transparent and have the correct thickness.
- A range of disc formats including dual layer and double sided discs.
- New or modified inspection criteria and QA measurements.

These differences require new or modified mastering equipment, moulding machines, metallisers and inspection equipment plus a new bonding stage, which present new challenges for equipment manufacturers and replicators.

DVD replication has now reached a stage when well over 1 billion discs have been replicated for commercial purposes. As a result it has become a more mature format than a few years ago. Cycle times are faster and yields are higher. Replication capacity has also increased dramatically over the last few years.

1.2 Format and Logo Licensing

Manufacturing of all CD and DVD formats is carried out under a license from Philips or the DVD Format and Logo Licensing Corp. In all cases the appropriate license is needed by the replicator who is obliged to comply with the format specification. Any logo used on the disc or paper parts must be the correct one, used in the correct way.

Content owners do not need to be licensed to have discs replicated nor to use the logos either on the discs or associated paper parts.

1.3 Copy Protection

In recent years, copy protection has become available for most formats. This usually requires encryption of the content and the addition of encoded data containing the encryption key to the data on the disc. Copy protection is carried out using a combination of premastering, glass mastering and QA, all of which need new or modified equipment and processes.

Clients who need copy protection should in most cases contact the copy protection provider and sign a license agreement before copy protection can be implemented.

2. Premastering

Before replication can begin the data content of the disc (whether CD or DVD) must be premastered. This involves taking the source data (as computer files for CD-ROM and DVD discs) and creating a disc image on a suitable tape or disc format.

2.1 CD Audio

CD Audio is the only format where the data (ie audio in this case) is not stored on the disc as data files. The audio data will normally be provided with the correct sampling frequency (ie 44.1 kHz) and quantisation (16 bits per channel). Audio premastering therefore usually starts with digital audio (eg on U-matic, DAT or CD-R) and includes the following operations:

- PQ encoding (adding Table of Contents data with track start times). This is normally only required for audio supplied on U-matic tape, which is now an almost obsolete media.
- Editing and Compilation, which is made easy with modern PC based editors. Audio can be input from various sources including CD, DAT or U-matic, stored on hard disk, edited and written to Exabyte or CD-R. Editing includes compilations, sample rate conversion, cross fades, equalisation, dynamic range compression, normalisation etc.
- Sample rate conversion, eg from 48kHz (eg on some DATs) to the 44.1kHz needed for CD.

2.2 CD-ROM

CD-ROM titles can include games, multimedia titles, computer software and computer databases and these will need to be created using specific software tools and will include software development and authoring processes. The end result will usually be a CD-R containing the complete application (or multiple CD-Rs if the application will not fit on one disc), which is used for glass mastering, without any further premastering operations. In some cases a separate premastering process may be needed and this depends on the final format. Examples of premastering processes are:

- Formatting to ISO 9660, HFS or hybrid formats to play on both Windows and Mac platforms from individual files on tape, CD or hard disk. With the widespread use of CD-Recorders this is becoming increasingly rare as a separate premastering process.
- Video CD formatting, which is normally part of the authoring process. As Video CD is now used almost exclusively in the Far East, this process is rare in Europe and the USA.
- Enhanced CD (CD EXTRA) formatting using the Blue Book multisession format with mode 2 sectors and, optionally, with hybrid format for PC/ Macintosh. This may involve combining the audio and data sessions ready for glass mastering.
- CD Graphics and CD TEXT formatting including R to W subcode data.
- Copy protection for CD-ROM includes a premastering stage, which will normally include encrypting the content and creating the coded data to be stored on the disc during glass mastering as a ‘signature’ containing the encryption key. This stage can be carried out by the content owner, technology provider or the replicator.

2.3 DVD-Video

DVD-Video Premastering is usually a complex process, which comprises video and audio compression, graphics editing, authoring and testing. The finished application data must be formatted according to the appropriate DVD specification and transferred, usually, to DLT (digital linear tape) for glass mastering.

DVD-5 discs can alternatively be mastered from a DVD-R disc unless the application needs copy protection. DVD-10 discs can also be mastered from two DVD-R discs in the same way. DVD-9 discs can be mastered only from DLT.

Where copy protection is required certain steps need to be taken during premastering. For CSS the appropriate flags must be set and each Video Title Set (VTS) to be protected must be marked. This is normally easy to carry out using the premastering tools available.

2.4 DVD-Audio

DVD-Audio premastering is similar to DVD-Video, using similar authoring and premastering tools. The audio must be prepared as PCM data at the appropriate sampling frequency (eg 96kHz) and quantisation (eg 24 bits) in up to 5 channels (for surround sound). This audio is then converted to MLP, together with a stereo down-mix if required. Authoring will add optional still images, menus, subpictures and video.

DVD-Audio titles can use CPPM copy protection and the premastering tool must add two dummy files (DVDAUDIO.MKB and DVDAUDIO.BUP) which will, after glass mastering, contain the Media Key Block (MKB) data for that disc.

The result of premastering will normally be an image file plus DDP file and control data stored on a DLT tape. But DVD-R (both authoring and general use) may be used for a DVD-5 if there is no copy protection or region coding required.

2.5 DVD-ROM

DVD-ROM premastering is similar to CD-ROM premastering with the following differences:

- DVD-ROM discs are much larger so the data needs to be written to DVD-R or DLT for mastering.
- DVD-ROMs that require a DVD-9 (dual layer disc) must be premastered and the data written to two DLTs, one for each layer. Two DVD-Rs are not suitable because the two layers must be a single volume with one file system instead of two. The final disc will be formatted as a parallel track path disc (unlike DVD-Videos which are usually opposite track path) with the file system data on layer 0.

3. Input Media

Both premastering and mastering require the source data to be be formatted appropriately and written to any suitable media.

3.1 Suitable Input Media

Table 2 summarises the input media that may be used for CD and DVD mastering and premastering.

Table 2 Input Media

Media	Format	Mastering	Premastering
DLT	Any DVD	One DLT per layer/side	Depends on content
U-matic	CD Audio	Yes if PQ'ed	Yes
DVD-R (G & A)	DVD-5 & -10	Yes, if no copy protection	Yes
DVD-RAM/-RW	DVD	No	Yes
CD & CD-R	CD Audio & CD-ROM	Yes	Yes
8mm Exabyte	CD Audio & CD-ROM	Yes with DDP	Yes
DAT	CD Audio	Not recommended	Yes

Tape formats used for glass mastering CD or DVD will need to contain the appropriate DDP files.

DLT (Digital Linear Tape)

DLT is currently used for transferring DVD data for glass mastering. Drives in use include the DLT4000, DLT7000 and DLT8000, each of which writes to tapes using a slightly different data format. Tapes can be Type 3 or Type 4.

A lower cost version, the DLT1, has also been launched and is not compatible with the other DLT drives. This means that a tape written using a DLT1 must be read by a DLT1 drive.

U-matic tape

This is the oldest format but is still in use as a digital audio media for mastering. When directly mastering from U-matic tape, the audio should be recorded at 44.1kHz (to avoid sample rate conversion) to the Sony 1610/1630 format and the PQ code recorded on Channel-1 so that the title can be mastered directly from the U-matic tape.

Alternatively, audio can be premastered by inserting the PQ codes directly onto the tape. Mastering from U-matic can only be done at single speed. Therefore it is usual to transfer the audio data to a server for high speed mastering.

Digital U-matic tape is being replaced by Exabyte tape or CD-R as media for glass mastering.

CD and CD-R discs

These discs contain the necessary TOC and, unless they include any faults which need correcting, they can be used as the direct input for CD audio and CD-ROM mastering.

Damage to CD-Rs, such as writing on the label with the incorrect pens/ markers, can prevent successful reading of the data. But if normal precautions are taken, CD-R can be a perfectly satisfactory media for glass mastering audio CDs and CD-ROMs. For some CD-ROM formats, such as Enhanced CD discs, it is the most suitable format.

DVD-R discs

DVD-R discs can also be used to test DVD applications, just as CD-Rs are currently used for CD and CD-ROM. DVD-R may be used also to transfer the finished data for glass mastering for DVD-5 discs or DVD-10, but two DVD-Rs are needed one for each side. There are two versions of DVD-R: DVD-R for Authoring and DVD-R for General. Either version can be used as source media for glass mastering.

DVD-9s or discs with copy protection cannot be mastered from DVD-R.

DVD-RAM & DVD-RW discs

DVD-RAM discs are not suitable as input media for mastering, as the files may not be contiguous on the disc. The same applies to DVD-RW and any other recordable disc format.

However, data files can be copied from a DVD-RAM or DVD-RW and premastered to DLT or DVD-R.

8mm Exabyte tape

This is physically identical to 8mm videotape and uses the same helical scan mechanism for reading and writing. Exabyte tapes can store from 5 GB to 40 GB depending on length of tape. Compression can be used to increase the capacity but Disctronics do not use this feature. Table 3 lists a number of different types of Exabyte tape and drive.

Table 3 Exabyte Tape Formats

Drive	Capacity	Data rate	Availability
EXB-8500	5GB	500kBps	No longer manufactured
EXB-8700	14GB	1MBps	Read/write 8500 format tapes
Eliant 820	14GB	2MBps	Read/write 8500 format tapes
Mammoth	40GB	6MBps	Reads 8500 tape format

Transfer rates of 500kB/s allows mastering directly from Exabyte tape at up to 2.8 times normal speed for both audio CD and CD-ROM discs. The faster 8mm formats can allow even faster mastering speeds.

It is now becoming a more popular format for audio as more customers use digital editing equipment that makes use of this tape format to store the edited digital audio.

Tapes will normally contain the three DDP files and the disc image.

DAT tape

The DAT was developed as a consumer audio recording technology based on 3.81 mm (0.15 inch) wide tape used in a helical scan recorder but has become a professional rather than a consumer format. The DAT can be used to master from if the audio is recorded at 44.1kHz sample rate with continuous SMPTE or ABS timecode. The time code should start at the beginning of the DAT, and at least one minute of digital silence should precede any programme. Each individual track should be indexed. DATs are not to be recommended as formats for transferring digital audio as they tend to be the least reliable format.

3.2 Data Description Protocol

The Data Description Protocol (DDP) was defined by DCA in Oklahoma, USA in conjunction with other organisations in the industry.

DDP-1

DDP-1 was developed for CD and CD-ROM formats and defines three or four DDP (streams) files, which accompany and describe premastered audio and CD-ROM data, either on the same media (if Exabyte) or on a separate floppy disk (see Table 4).

Table 4 DDP-1 Files

File	Description
DDPID	DDP level identifier, Master ID (catalogue number) and UPC/EAN number. It also serves to locate the DDPMS Map Stream for direct access input media.
DDPMS	Information to locate and process each file of Text, Subcode or Main Channel input data.
TS (Text)	Optional file contains either Volume/Track/Index titling text or Commentary text or Customer information text
PQ_DESC	Optional file contains a PQ description or fully processed P to W channels of subcode data

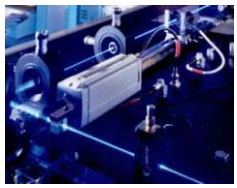
DDP-2

DDP-2 was developed by DCA for DVD and comprises one DDP-2 file, which is included on a DLT together with the control data (for the lead-in) and the image file. The DDP file defines the type of DVD including number of layers/sides, copy protection etc. The source data for DVD comprises the data files listed in Table 5.

Table 5 DDP-2 Files

File	Description
DDP	Information about the type of disc, whether copy protection is required etc
CONTROL.DAT	Control data to be stored in the lead-in area of the final disc
IMAGE.DAT	Disc image, which is divided into sectors of 2054 or 2064 bytes and includes the UDF Bridge file system

4. Glass Mastering



Both CD and DVD glass mastering (see Figure 2) involves several stages to convert the premastered data into a stamper ready for replication. The stages include laser beam recording, developing & metallising, electroforming and stamper finishing.

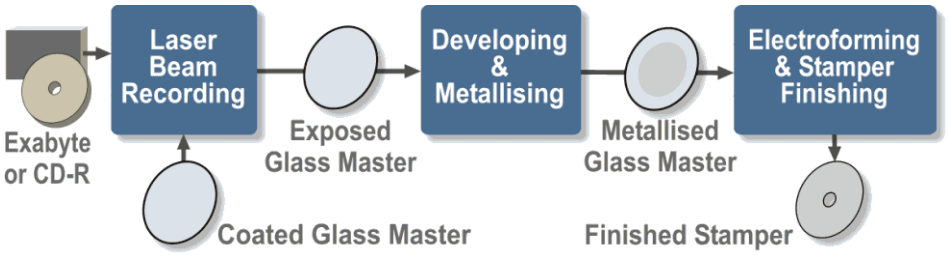


Figure 2 Glass Mastering

4.1 DVD vs CD Glass Mastering

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 (see Figure 3).

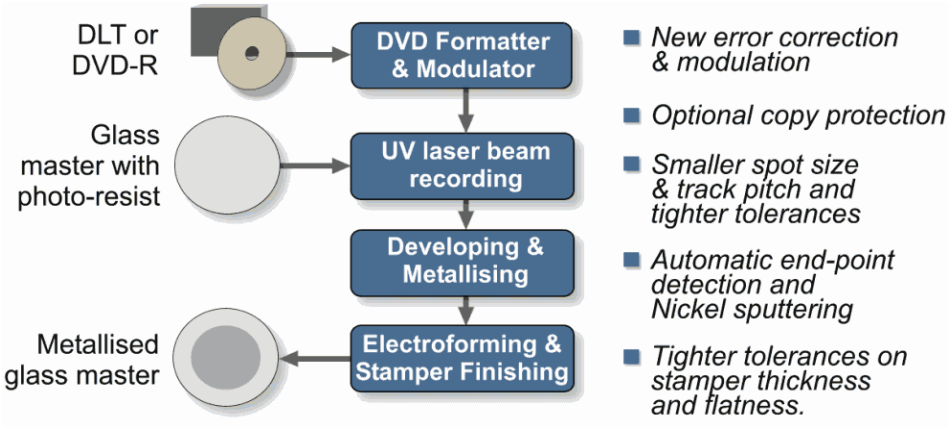


Figure 3 DVD vs CD Glass Mastering

- The photo-resist layer should be thinner than for CD. Also any defects or variations in thickness of this layer must be kept very small.
- Laser beam recording requires a smaller spot size, higher numerical aperture and tighter tolerances than for CDs. Many LBRs designed for DVD mastering use a UV laser (instead of the blue or violet laser used for CDs). To handle CD and DVD mastering, it is necessary to increase the numerical aperture from 0.6 for CD to about 0.9 for DVD mastering.
- DVD data is formatted differently from CDs and requires new formatting hardware/software to handle the RSPC error correction, 8 to 16 modulation and the higher channel data rate.
- DVD-9 (dual layer) discs require the upper layer (layer 1) to be mastered with the turntable rotating in the reverse direction. Also, the direction of writing will be either from the inside to outside (parallel track) or outside to inside (opposite track), depending on the application requirements.
- CSS (Content Scrambling System) copy protection is carried out at the mastering stage. The data on DLT is combined with the encrypted keys

and the audio and video data scrambled using these keys, which are hidden on the DVD disc.

- Stamper finishing requires more care than for CDs, since tilt (variations in flatness of the final disc) and thickness are critical for DVD.

4.2 Glass Master Preparation

The glass master is first cleaned using de-ionised water and the surface coated with a photo-resist layer about 120 microns thick (see Figure 4). The photo-resists must be very uniform in thickness without any defects or impurities.

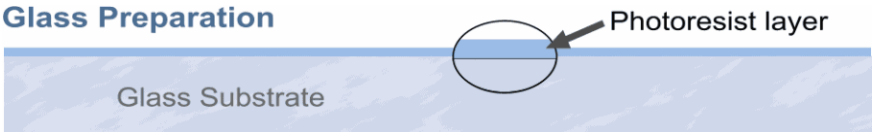


Figure 4 Glass Master Preparation

4.3 Laser Beam Recording

The CD or DVD data is normally read from the appropriate source media (see above) and copied to a server for checking prior to laser beam recording.

- **CD** source media include CD-R, Exabyte and U-matic (CD Audio only).
- **DVD** source media will include DLT (digital linear tape) and DVD-R. Both DVD-R for Authoring and DVD-R for General types are suitable for DVD-5 or DVD-10 glass mastering where no copy protection is required. For DVD-9 discs and where copy protection is required only DLT will suffice. DVD-9 and DVD-10 discs require two DLTs to create two stampers.

The glass master with photo-resist coating is placed on the turntable of the laser beam recorder (LBR), where a gas laser is used to expose the photo-resist, where the pits are to be moulded in the final discs. This is illustrated in Figure 5.

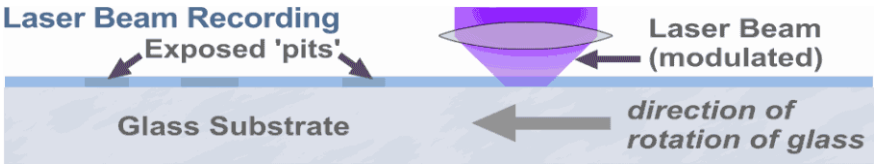


Figure 5 Laser Beam Recording

The laser can be blue, violet or (for DVD mastering) ultra violet. The laser beam is modulated to expose the photo-resist where pits should be, while the glass master spins at exactly the correct linear velocity and is moved gradually and smoothly to maintain the correct track pitch and linear velocity.

Laser beam recording for DVD requires a smaller spot size, higher numerical aperture and tighter tolerances than for CDs. The use of an ultra violet laser is crucial to ensure good pits in the final disc, instead of the blue or violet lasers normally used for CD mastering. Also the turntable and associated mechanics must ensure constant linear velocity and track pitch as the pits are recorded.

DVD-9 (dual layer) discs require the upper layer (layer 1) to be mastered with the laser beam recorder turntable rotating in the reverse direction. Also, the direction of writing will be either from the inside to outside (parallel track) or outside to inside (opposite track), depending on the application requirements.

Copy protection

Copy protection is added during laser beam recording.

- **CD audio** copy protection is implemented at the glass mastering stage. Since the audio cannot be encrypted, copy protection works by preventing the reading and transfer of CD audio data via the CD-ROM drive of a PC. To allow the audio to be played on a PC, compressed audio files are usually added to a second (CD-ROM) session. This is also carried out during the glass mastering stage, which requires dedicated hardware and/or software.
- **CD-ROM** copy protection uses encryption and scrambling technology and needs a premastering process to be carried out prior to laser beam recording. This creates a digital 'signature', which is stored on the disc in a way that makes it difficult to copy. Different systems require different hardware and/or software to implement the encoding process.
- For **DVD-Video** both CSS (Content Scrambling System) digital copy protection and Macrovision analogue copy protection are carried out at the mastering stage by the data formatting system. For CSS the content and copy control information (CCI) are scrambled using the Title key, which is stored on the disc encrypted by the Disc Key, which in turn is stored on the disc in a secure way (see Figure 6).

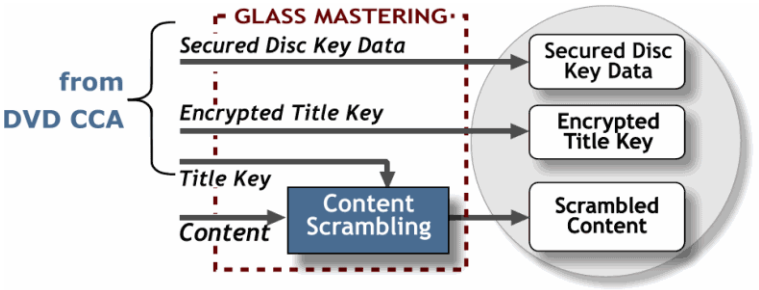


Figure 6 CSS Encoding during Glass Mastering

The CSS keys are provided by the DVD CCA (DVD Copy Protection Association). For DVD-9, where a contiguous video spans both layers, the same set of CSS keys must be used for both layers. Apart from this requirement the keys are generally only used once, for security reasons.

- For **DVD-Audio** discs, CPPM (Content Protection for Pre-recorded Media) is used. A media key block (MKB) is used for each disc side mastered and is stored on the disc within the dummy files (DVDAUDIO.MKB and DVDAUDIO.BUP) that were created during premastering. The formatter must obtain the media key from the MKB and its unique device key before encrypting the audio data (see Figure 7). MKBs are obtained from the DVD CCA and used only once.

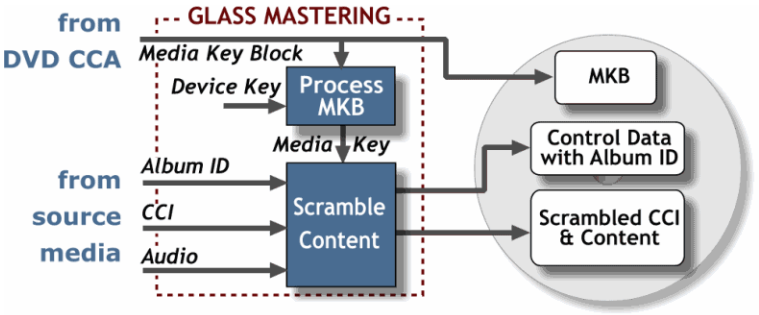


Figure 7 CPPM Encoding during Glass Mastering

4.4 Development & Metallisation

After laser beam recording the photo-resist is developed to create pits in the surface and metallised by sputtering a Nickel layer as shown in Figure 8. The exposed photoresist surface is developed to remove the photoresist exposed by the laser, creating pits in the surface. These pits should extend right through the photoresist to the glass underneath to achieve good pit geometries. The glass itself is unaffected by this process and acts merely as a carrier for the photoresist.

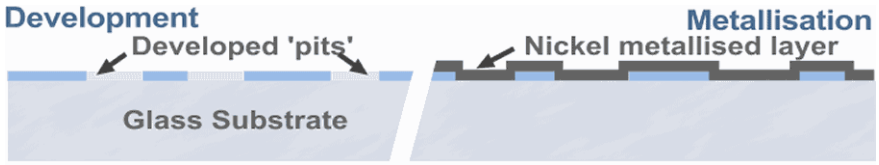


Figure 8 Development & Metallisation

4.5 Electroforming

The electroforming stage involves creating stampers from the glass master as shown in Figure 9.

Figure 9 Electroforming Father from Glass Master

The metallised glass master is electroplated with nickel in a class 1000 clean room environment to produce a father. This can be used as the stamper for pressing the finished discs but, more usually, two more nickel-plating stages are used to produce a mother from which the individual stampers are created (see Figure 10).

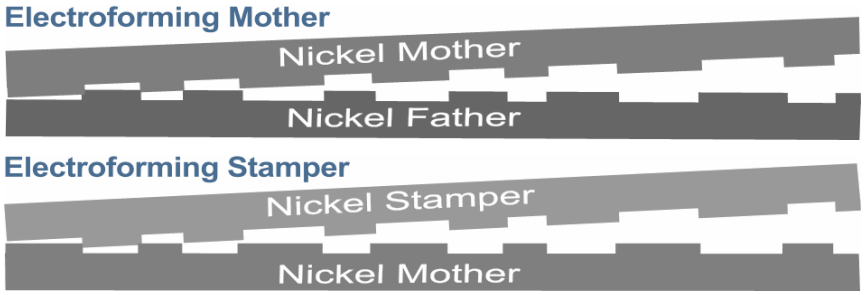


Figure 10 Electroforming Mother & Stamper

Note that at each stage, the surface of the nickel is oxidised before electroforming the next layer so that the two layers can be separated.

Each stamper is checked visually, the back polished, a hole accurately cut in the centre and finally it is checked on a stamper player before being fitted to the press.

5. Replication

The finished stamper is fitted to the moulding machine ready to start moulding the CDs or DVD substrates. One stamper is needed for CDs but two for DVDs, as described below. CD and DVD discs are made by first moulding and then metallising and lacquering (CD) or bonding (DVD). The steps are:

- Injection moulding of the clear polycarbonate discs
- Metallising to create an aluminium reflective surface
- Lacquering to protect the reflective surface of CDs ready for printing
- Bonding of 2 substrates to produce a DVD disc
- Printing of the disc label on top of the lacquer.

5.1 CD and DVD Replication Processes

CD and DVD discs require different equipment for replication. There is also the possibility of a hybrid format that combines a CD layer with a DVD or SACD.

CD replication

CD replication comprises moulding, metallising (to create a reflective coating) and lacquering followed by inspection and printing. These are illustrated in Figure 11.

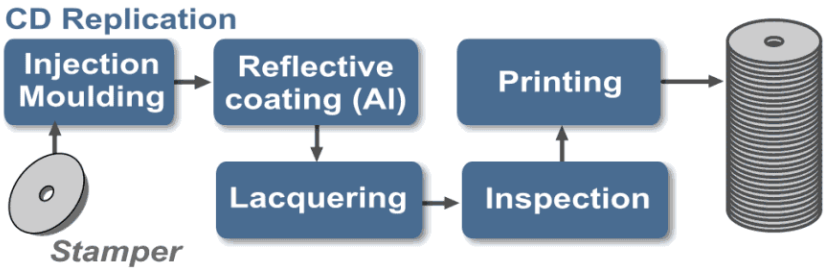


Figure 11 CD Replication Processes

DVD Replication

DVD Replication requires the moulding of two substrates, which are bonded together. The replication process varies somewhat for the different formats, DVD-5, DVD-10 and DVD-9.

- For **DVD-5** discs, the active substrate is metallised and then bonded with the blank, non-metallised substrate.

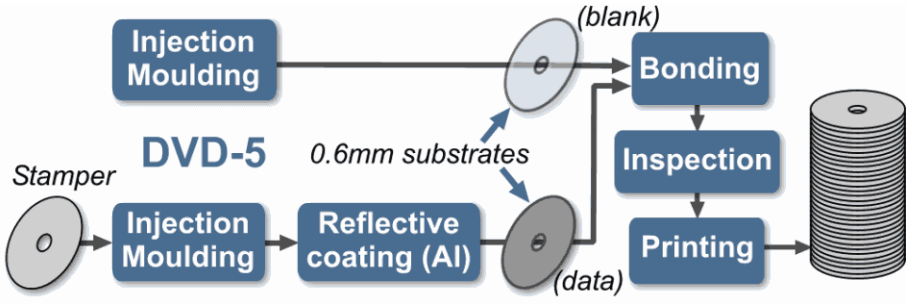


Figure 12 DVD-5 Replication

- For **DVD-10**, both substrates are metallised.

- For **DVD-9** discs two metallisation layers are required, one being semi-reflective, using gold or silicon (see Figure 13). Parameters such as tilt, bonding layer transparency etc are more severe for DVD-9. Also the layer 1 aluminium layer must be uniform in thickness to avoid jitter.

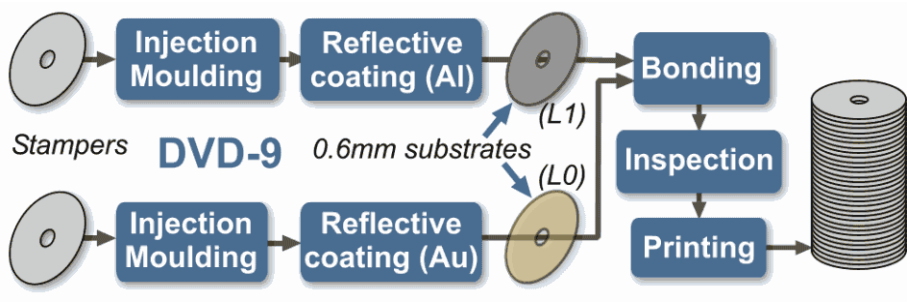


Figure 13 DVD-9 Replication

Hybrid DVD/SACD replication

Hybrid DVD/SACD discs comprise one CD substrate bonded to a DVD/SACD substrate such that a CD player or CD-ROM drive will read the CD layer through the semi-reflective DVD/SACD layer. Replication requires a modified DVD-9 line to be used with the following minimum changes:

- An extra station to flip the layer 1 substrate, which contains the CD layer.
- New material, which does not absorb water as much as polycarbonate, for the DVD/SACD substrate in order to reduce the tilt resulting from sputtered layers on the upper side of both substrates instead of opposite sides.
- Surface treatment of this substrate prior to metallising to ensure adhesion of the semi-reflective layer.
- A new or modified metalliser for the semi-reflective layer, which is likely to be non-metallic so needs reactive sputtering.
- Lacquer coating stage, which is used for CDs but is not needed for normal DVDs.
- Modified inspection equipment.

These stages are illustrated in Figure 14.

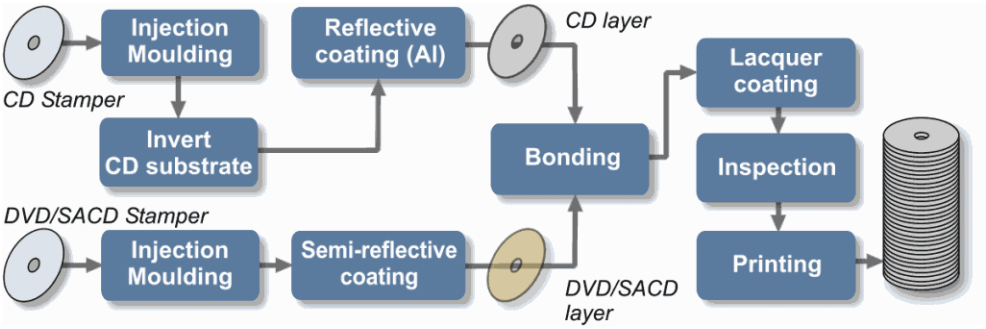
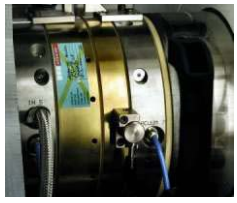


Figure 14 Hybrid DVD/SACD Replication

5.2 Injection Moulding



Optical grade polycarbonate is first 'baked' to remove any moisture and is injection moulded in a high pressure moulding machine (press) using the stamper mounted in the mould fixed to the press. This mould is in two parts and provides a cavity, which ensures that perfectly moulded discs

are produced with the correct dimensions every time. One half of the mould contains the stamper (to form the pits) while the other half contains the mirror block to ensure a smooth surface.

The hydraulic press applies a force to the two halves of the mould, which are closed. Molten polycarbonate is then injected into the cavity and held in place by the applied pressure while the disc cools and solidifies. During cooling the centre hole is punched. After cooling, the press opens and the pressed disc is transferred by robot arms to a conveyor to allow the disc to cool before the next stage. The centre hole with sprue (formed by the injected polycarbonate) is discarded or re-cycled.

Successful moulding of CDs, which meet the CD specification, requires stable processes with the machines set up correctly. Moulding parameters that can affect the resultant CD include stamper geometry, mould temperature, polycarbonate temperature, compression force and cycle time.

Cycle times for injection moulding of CDs have decreased substantially and are now around 3 seconds for the latest presses and moulds.

DVD moulding is similar to CD moulding but with some important differences.

- Two pressings are needed for each final DVD disc
- Each half disc (substrate) is 0.6mm thick instead of 1.2mm
- The thinner disc also requires different moulding parameters, such as a shorter injection time and higher mould temperature.
- Redesigned or new moulding machines are needed with injection compression where the mould is kept slightly apart until most of the polycarbonate has been injected.
- Cycle times tend to be longer than for CDs.
- The quality of the final disc, including tilt and jitter, is critically dependent on the moulding process.

5.3 Metallising

The polycarbonate discs after moulding are transparent, so need to be covered by a mirror surface to reflect the laser light, to allow the pits to be read.

The active surface of each disc is coated with aluminium by sputtering. Sputtering requires the transparent polycarbonate discs to be transferred to the sputtering chamber, which is then quickly evacuated of any remaining air and filled with argon gas. The argon ions are attracted to the aluminium target by the use of a high voltage. As the ions strike the target, particles of aluminium are ejected and are deposited onto the CD surface.

Modern metallisers for CD offer cycle times of less than 2 seconds allowing them to be used in lines where one metalliser can handle the output from two moulding machines. The fastest metallisers can achieve cycle times of about 1.5 seconds.

The two DVD substrates are each metallised in the same way, but layer 0 of a DVD-9 is metallised with gold, silver alloy or silicon, instead of aluminium, to achieve a semi-reflective layer. DVD-5s, DVD-10s and layer 1 of DVD-9s are usually metallised using aluminium.

Hybrid DVD discs need reactive sputtering so a different design of sputtering chamber is needed with increased cycle times.

5.4 Lacquering

The aluminium layer on each CD is then protected by a lacquer, which is spread as a liquid evenly across the surface of the disc by spin coating. The centrifugal force created by spinning the disc ensures that the lacquer covers the whole disc in an even layer.

It is important that the lacquer overlaps the aluminium therefore sealing it from the elements. If left exposed, aluminium will start to oxidise within a few days.

The lacquer is cured by ultra-violet (UV) light producing a hard protective surface. The discs are then ready for printing.

Lacquering involves two steps in the spin-coating process, lacquer deposition and spin-off (see Figure 15). Cycle times of less than 2 seconds are normally achieved by either splitting the two steps into two stations or using two spin coating stations.

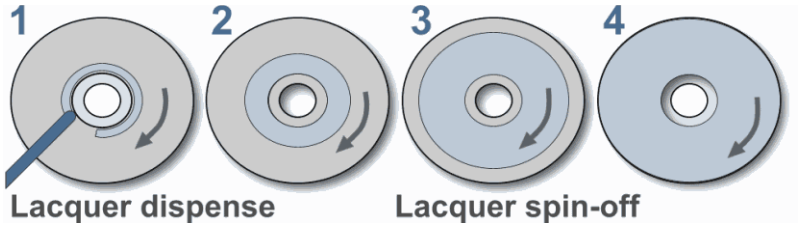


Figure 15 Lacquering

DVD discs do not need to be lacquered as the reflective layers are protected by the two substrates, which are bonded together to make a DVD.

5.5 DVD Bonding

Bonding is necessary for DVD as these discs comprise two substrates. It is one of the most difficult parts of the DVD replication process. A number of possible solutions have been developed.

- Hot melt bonding is the method used for Laserdiscs where the two substrates just need to be glued together. It is also suitable for single layer (single or double sided) DVDs. The process is simple and relatively inexpensive, but tends now to be replaced by UV bonding.
- Radical UV Cured bonding is suitable for dual layer discs because it is transparent. It involves coating one or both of the substrates with a UV cured resin similar to normal lacquer, but with suitable optical and mechanical characteristics.
- Cationic UV Bonding involves screen printing the resin over both substrates, curing each with UV light and then pushing the discs together. This method is not suitable for dual layer discs as the resin used is opaque.

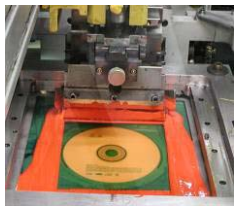
Radical UV Cured bonding is the most widely used, as it is compatible with all DVD formats. DVD-9 bonding is particularly difficult as the bonding layer must

- be of uniform thickness within close tolerances
- be optically transparent with no defects such as bubbles
- not introduce tilt outside the DVD specification

6. Disc Finishing

Printing and finishing options for CDs and DVDs differ, but all discs can be printed using the same technologies. It is also possible to add serialisation or other information to a DVD disc using the Burst Cutting Area.

6.1 Label Printing



The upper surface of a finished disc is usually printed with up to six colours by a flat silkscreen process or offset printer. Each colour requires a different screen created from label films produced as colour separations from the artwork. A squeegee is used to push the ink through the mesh of the screen on to the disc surface. The inks are then cured using UV light to produce a durable surface.

For picture discs five colours are needed. These are white for the base, plus cyan, magenta, yellow and black (CMYK). Very high quality printing can be achieved using modern printing machines, which are capable of speeds of 70 discs per minute or faster. A sixth, spot colour can be used where required.

Automatic checks are carried out during this stage to ensure that all discs being printed carry the correct catalogue number, which is placed on the disc hub during mastering. In addition cameras can be used to monitor print quality and stop the printing machine if print quality is not maintained.

CD Label Printing

CDs can be printed on the upper surface of the disc as shown in Figure 16). The two options are for standard (where the stacking ring area is not printed) and fully metallised discs.

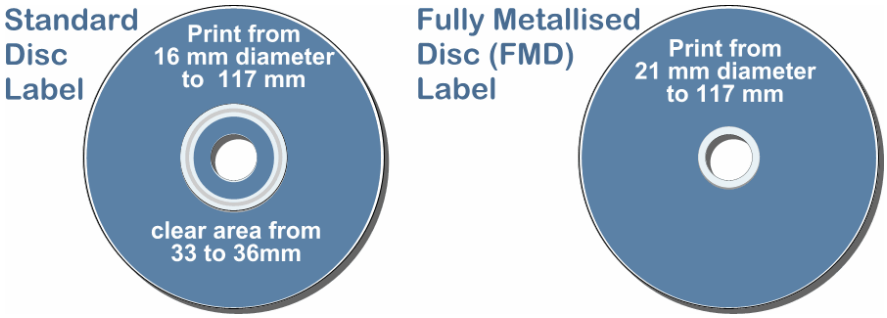


Figure 16 CD Label Printing

DVD Label Printing

Printing options for DVD discs depend on the format as shown in the table below:

Table 6 DVD Printing Options

Printing options	DVD-5	DVD-9	DVD-10
Normal printing on upper surface of disc	Yes	Yes	No
Printing on inside surface of blank substrate to give smooth 'glossy' effect	Yes	No	No
Pit Art where a holograph like image is moulded into the blank substrate	Yes	No	No
Printing on both sides but only within hub area	-	-	Yes

In Figure 17, the printable areas for DVD-5, DVD-10 and DVD- 9 discs are shown in blue. The print area for a DVD-5 or DVD-9 is normally from 38 mm diameter to 117 mm diameter, but in special cases can extend from 21 mm to 117 mm. For a DVD-10 the inner and outer diameters are 38 mm and 43.8 mm.

Figure 17 DVD Label Printing

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. 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 data stored in the BCA can be from 12 bytes to 188 bytes in steps of 16 bytes.

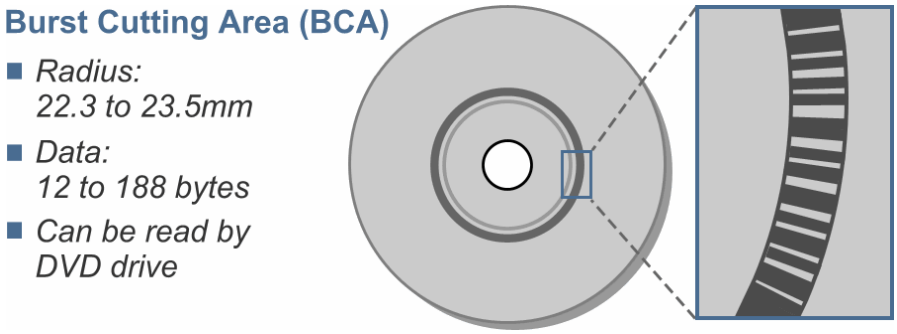


Figure 18 Burst Cutting Area on DVD Discs

6.2 Packaging

CDs and DVDs can be machine packed in a number of different packages together with booklets and other printed parts. Some examples are listed below:

- **Jewel case** (the most common) comprises a transparent plastic case with hinged lid, a plastic tray, inlay card and booklet.
- **Slimline case**, a slimmer version with no tray, but with an inlay card (J-card), mainly used for audio singles.
- **Amaray case**, introduced for DVD-Video discs to differentiate them from CDs in jewel cases, but now used for CD-ROM games and other formats.
- **Super Jewel Box Plus**, chosen for DVD-Audio discs.
- **Super Jewel Box King**, and alternative case for DVD-Video discs.
- **Card wallets, sleeves** and many other options are available. For card sleeves the card itself is printed.

A range of outer packaging is used particularly for CD-ROM discs eg to hold a printed manual.

Automated machines are used to pack discs in jewel cases, slimline cases, Amaray cases, sleeves, wallets and some other packaging. The packed cases can then be over-wrapped and packed into boxes as required.

- The machine automatically takes each case and opens it ready for the disc to be inserted.
- A robot arm transfers the printed discs from spindles and places them in the opened cases.
- Booklets are fed to the machine by another robot arm and placed in the jewel cases. Some machines are capable of handling two booklets per CD.
- The packaged CD can have stickers automatically added and, optionally, can be over-wrapped.

Machines operate at speeds up to 100 discs per minute or more. For smooth operation at these speeds it is essential that cases and paper parts adhere to the specified dimensions and other physical properties.

7. Quality Assurance

Quality Assurance is an essential part of manufacturing CDs to ensure that they meet specifications and to monitor the processes involved.

- **QA in Mastering** ensures only the highest quality stampers are used
- **Disc Inspection** of all replicas is used to identify defects
- **QA measurements** of sample CD and DVD replicas ensures that the moulding and downstream processes are within specification.
- **Environmental testing** ensures that discs stay within specification during their lifetime and under differing environmental conditions
- **ISO 9001 Accreditation** ensures that procedures and processes are designed for quality at every stage

7.1 QA in Mastering

The purpose of mastering is to produce perfect stampers with good pit geometry so that replicated discs meet industry standards. To ensure high quality levels:

- Stampers are played on a disc stamper player.
- The first disc to be pressed is verified against the source to ensure that it has been mastered without errors.
- The pit geometry on a metallised glass master can be inspected using a suitable high power microscope.
- Each maiden stamper production run for a CD Audio has a PQ test carried out to check start and finish times of all tracks.

Errors that can occur during mastering include variations in track pitch and linear velocity and pit geometry, which can produce high jitter in the moulded discs. In addition poor stamper finishing can result in discs with eccentricity and/or unbalance out of specification.

7.2 CD Quality Assurance

CD quality is assured using both automatic inspection of every disc and measurements of samples.

Disc inspection

All discs replicated are subject to automatic inspection before and after printing including:

- Evaluation of any visual defect such as pinholes, cold marks, bubbles and dimples.
- Automatic checks during printing to ensure that all discs being printed carry the correct catalogue number and that print quality is maintained.

CD QA measurements

To ensure that discs meet the necessary standards, sample CDs are tested at the start of all production runs. Measurements include the following signals measured while the disc is playing.

Electrical and Optical Measurements include:

- **Reflectivity**, which relates to the depth of the pits and the ability to read the disc easily.
- **Asymmetry** checks, which are needed to find out how central the I3 signal is in relation to the rest of the signal.
- **I3**, which is the signal coming from the shortest pits.
- **I11**, which is the signal coming from the longest pits.
- **Push Pull**, which is called the radial tracking signal which allows the laser to seek to a random position on the disc quickly.
- **Cross Talk**, which measures the difference between the reflectivity from the pits being scanned and the unwanted signal from the adjacent rows of pits.
- **BLER**, which is the Block Error Rate before any error correction takes place.
- **E22**, which measures uncorrected errors correctable by error concealment.
- **E32**, which is a measure of uncorrectable errors and should be zero.
- **Birefringence** within the polycarbonate, which is a measure of the optical properties of the disc substrate.

Mechanical Tests and measurements include:

- **Radial Noise** to determine the lateral tracking drift from the centre of the pits being scanned.
- **Eccentricity**, which calculates the accuracy of the centre hole.
- **Track Pitch**, which should be between 1.5 and 1.7 microns.
- **Scan Velocity**, which should be between 1.2 and 1.4 m/s.
- **BLI** (begin of lead-in) should be at a maximum radius of 23 mm.
- **BPL** (begin of program area) should be at radius 24.8mm to 25mm.
- **BLO** (begin of lead-out) must not exceed radius 58.

Special industry test equipment is used to make these measurements and results are printed out and used to assess the performance of the replication equipment.

7.3 DVD Quality Assurance

DVD inspection and testing requires the use of some different techniques, new parameters to be tested and new readers. DVD discs must meet certain stringent quality parameters, the most important of which are:

- Discs must be flat to ensure they are playable so tilt is an important measurement to ensure that the mastering and replication processes are within specification.
- Jitter must be low, requiring accurate mastering and moulding.
- Signals must be within certain constraints, which implies care at the mastering, moulding and metallising stages

In addition, mastering and replication is often the only way to ensure that a DVD title has been premastered correctly. Therefore it is important to verify the replicated discs using DVD players to ensure correct functionality. This is particularly true for DVD-9 discs for which a pressed disc is the only solution. Now that 4.7GB DVD-R discs are available, it is possible to test DVD-5 and

DVD-10 applications before committing to mastering and pressing. However, CSS and APS copy protection can be tested only with a pressed disc.

Disc inspection

DVD inspection is similar to CD inspection but includes tilt and bonding layer thickness. Discs must be inspected after bonding as this stage can introduce tilt and other defects. DVD-10 and DVD-9 discs need inspection of both top and bottom of each disc. DVD-9 discs need inspection of the semi-reflective layer and the bonding gap.

Test measurements

Electrical and optical measurements include:

- **Reflectivity**, which relates to the pit geometry, thickness of the reflective layer and the ability to read the disc easily.
- **Asymmetry** checks, which are needed to find out how central the I3 signal is in relation to the rest of the signal.
- **I3**, which is the signal coming from the shortest pits.
- **I14**, which is the signal coming from the longest pits.
- **Push Pull**, which is called the radial tracking signal which allows the laser to seek to a random position on the disc quickly.
- **Cross Talk**, which measures the difference between the reflectivity from the pits being scanned and the unwanted signal from the adjacent rows of pits.
- **Jitter** must be within 0.8 per cent, which is tighter than for CD.
- **Birefringence** within the polycarbonate, which is a measure of the optical properties of the disc substrate.

Mechanical measurements include:

- **Radial Noise** to determine the lateral tracking drift from the centre of the pits being scanned.
- **Eccentricity**, which calculates the accuracy of the centre hole.
- **Track Pitch**, which should be between 0.74 microns.
- **Scan Velocity**, which should be between 3.49 m/s for a single layer disc and 3.84 m/s for a dual layer disc.
- **BLI** (begin of lead-in) should be at a maximum radius of 23 mm.
- **BPL** (begin of program area), should be at radius 24mm.
- **BLO** (begin of lead-out) must not exceed radius 58.
- **Radial and tangential tilt** must be within quite tight tolerances to ensure discs play.

Environmental testing

The parameters measured can change with time and environmental conditions, particularly DVDs where tilt in particular can become worse. It is therefore very important to carry out age or environmental testing, which involves placing sample discs in an oven at a specified temperature and humidity for 48 hours and then testing again after 96 hours.

Since this is a time-consuming procedure it is normally used to ensure that the process can produce good discs that will stay good and to determine if a tighter tolerance needs to be used when measuring discs before age testing.