After a lifespan of ten years, during which time the capacity of hard disks increased a hundred-fold, the CD-ROM finally got the facelift it required to take it into the next century when a standard for DVD, initially called digital video disc but eventually known as digital versatile disc, was finally agreed during 1996.

The movie companies immediately saw a big CD as a way of stimulating the video market, producing better quality sound and pictures on a disc that costs considerably less to produce than a VHS tape. Using MPEG-2 video compression, the same system that will be used for digital TV, satellite and cable transmissions, it is quite possible to fit a full-length movie onto one side of a DVD disc. The picture quality is as good as live TV and the DVD-Video disc can carry multi-channel digital sound.

For computer users, however, DVD means more than just movies, and while DVD-Video has been grabbing the most headlines, DVD-ROM is going to be much bigger for a long time to come. Over the next few years, computer-based DVD drives are likely to outsell home DVD-Video machines by a ratio of at least 5:1. With the enthusiastic backing of the computer industry in general and the CD-ROM drive manufacturers in particular, it is expected that will be more DVD-ROM drives in use than CD-ROM drives early in the this millennium.

Initially, the principal application to make use of DVD's greater capacity will be movies. However, the need for more capacity in the computer world is obvious to anyone who already has multi-CD games and software packages. With modern-day programs fast outgrowing CD, the prospect of a return to the multiple disc sets which had appeared to gone away for ever when CD-ROM took over from floppy disc was looming ever closer. The unprecedented storage capacity provided by DVD lets application vendors fit multiple CD titles (phone databases, map programs, encyclopaedias) on a single disc, making them more convenient to use. Developers of edutainment and reference titles are also free to use video and audio clips more liberally. And game developers can script interactive games with full-motion video and surround-sound audio with less fear of running out of space.

History

When Philips and Sony got together to develop CD, there were just the two companies talking primarily about a replacement for the LP. Decisions about how the system would work were carried out largely by engineers and all went very smoothly. The specification for the CDís successor went entirely the other way, with arguments, confusions, half-truths and Machiavellian intrigue behind the scenes.

It all started badly with Matsushita Electric, Toshiba and the movie-makers Time/Warner in one corner, with their Super Disc (SD) technology, and Sony and Philips in the other, pushing their Multimedia CD (MMCD) technology. The two disc formats were totally incompatible, creating the possibility of a VHS/Betamax-type battle. Under pressure from the computer industry, the major manufacturers formed a DVD Consortium to develop a single standard. The DVD-ROM standard that resulted at the end of 1995 was a compromise between the two technologies but relied heavily on SD. The likes of Microsoft, Intel, Apple and IBM gave both sides a simple ultimatum: produce a single standard, quickly, or doní t expect any support from the computer world. The major developers, 11 in all, created an uneasy alliance under what later became known as the DVD Forum, continuing to bicker over each element of technology being incorporated in the final specification.

The reasons for the continued rearguard actions was simple. For every item of original technology put into DVD, a license fee has to be paid to the owners of the technology. These license fees may only be a few cents per drive but when the market amounts to millions of drives a year, it is well worth arguing over. If this didnít make matters bad enough, in waded the movie industry.

Paranoid about losing all its DVD-Video material to universal pirating, Hollywood first decided it wanted an anti-copying system along the same lines as the SCMS system introduced for DAT tapes. Just as that was being sorted out, Hollywood became aware of the possibility of a computer being used for bit-for-bit file copying from a DVD disc to some other medium. The consequence was an attempt to have the U.S. Congress pass legislation similar to the Audio Home Recording Act (the draft was called 'Digital Video Recording Act') and to insist that the computer industry be covered by the proposed new law.

Whilst their efforts to force legislation failed, the movie studios did succeed in forcing a deeper copy protection requirement into the DVD-Video standard, and the resultant Content Scrambling System (CSS) was finalised toward the end of 1996. Subsequent to this, further copy-protections systems have been developed.

Formats

Not unlike the different flavours of CDs, there are five variations, or books, of DVD:

DVD-ROM is a high-capacity data storage medium

DVD-Video is a digital storage medium for feature-length motion pictures

DVD-Audio is an audio-only storage format similar to CD-Audio

DVD-R offers a write-once, read-many storage format akin to CD-R

DVD-RAM will be a rewritable (erasable) flavour of DVD.

With the same overall size as a standard 120mm diameter, 1.2mm thick CD, DVD discs provide up to 17GB of storage with higher than CD-ROM transfer rates and similar to CD-ROM access times and come in four versions:

DVD-5 is a single-sided single-layered disc boosting capacity seven-fold to 4.7GB

DVD-9 is a single-sided double-layered disc offering 8.5GB

DVD-10 will be a 9.4GB dual-sided single-layered disc

DVD-18 will increase capacity to a huge 17GB on a dual-sided dual-layered disc.

Technology

At first glance, a DVD disc can easily be mistaken for a CD: both are plastic discs 120mm in diameter and 1.2mm thick and both rely on lasers to read data stored in pits in a spiral track. And whilst it can be said that the similarities end there, it's also true that DVD's seven-fold increase in data capacity over the CD has been largely achieved by tightening up the tolerances throughout the predecessor system.

Firstly, the tracks are placed closer together, thereby allowing more tracks per disc. The DVD track pitch (the distance between each) is reduced to 0.74 micron, less than half of CD's 1.6 micron. The pits, in which the data is stored, are also a lot smaller, thus allowing more pits per track. The minimum pit length of a single layer DVD is 0.4 micron as compared to 0.834 micron for a CD. With the number of pits having a direct bearing on capacity levels, DVD's reduced track pitch and pit size alone give DVD-ROM discs four times the storage capacity of CDs.

The packing of as many pits as possible onto a disc is, however, the simple part and DVD's real technological breakthrough was with its laser. Smaller pits mean that the laser has to produce a smaller spot, and DVD achieves this by reducing the laser's wavelength from the 780nm (nanometers) infrared light of a standard CD, to 635nm or 650nm red light.

Secondly, the DVD specification allows information to be scanned from more than one layer of a DVD simply by changing the focus of the read laser. Instead of using an opaque reflective layer, it's possible to use a translucent layer with an opaque reflective layer behind carrying more data. This doesn't quite doubl the capacity because the second layer can't be quite as dense as the single layer, but it does enable a single disc to deliver 8.5GB of data without having to be removed from the drive and turned over. An interesting feature of DVD is that the discs' second data layer can be read from the inside of the disc out, as well as from the outside in. In standard-density CDs, the information is always stored first near the hub of the disc. The same will be true for single- and dual-layer DVD, but the second layer of each disc can contain data recorded 'backwards', or in a reverse spiral track. With this feature, it takes only an instant to refocus a lens fromone reflective layer to another. On the other hand, a single-layer CD that stores all data in a single spiral track takes longer to relocate the optical pickup to another location or file on the same surface.

Thirdly, DVD allows for allows for double-sided discs. To facilitate the focusing of the laser on the smaller pits, manufacturers used a thinner plastic substrate than that used by a CD-ROM, thereby reducing the depth of the layer of plastic the laser has to travel through to reach the pits. This reduction resulted in discs that were 0.6mm thick - half the thickness of a CD-ROM. However, since these thinner discs were too thin to remain flat and withstand handling, manufacturers bonded two discs back-to-back - resulting in discs that are 1.2mm thick. This bonding effectively doubles the potential storage capacity of a disc. Note that single-sided discs still have two substrates, even though one isn't capable of holding data.

Finally, DVD has made the structure of the data put on the disc more efficient. When CD was developed in the late 1970s, it was necessary to build in some heavy-duty and relatively crude error correction systems to guarantee the discs would play. When bits are being used for error detection they are not being used to carry useful data, so DVDís more efficient and effective error correction code (ECC) leaves more room for real data.

UDF

One of the major achievements of DVD is that it has brought all the conceivable uses of CD for data, video, audio, or a mix of all three, within a single physical file structure called UDF, the Universal Disc Format. Promoted by the Optical Storage Technology Association (OSTA), the UDF file structure ensures that any file can be accessed by any drive, computer or consumer video. It also allows sensible interfacing with standard operating systems as it includes CD standard ISO 9660 compatibility. UDF overcomes the incompatibility problems from which CD suffered, when the standard had to be constantly rewritten each time a new application like multimedia, interactivity, or video emerged.

Because UDF wasn't supported by Windows until Microsoft shipped Windows 98, DVD providers were forced to use an interim format called UDF Bridge. UDF Bridge is a hybrid of UDF and ISO 9660. Windows 95 OSR2 supports UDF Bridge, but earlier versions do not. As a result, to be compatible with Windows 95 versions previous to OSR2, DVD vendors had to provide UDF Bridge support along with their hardware.

DVD-ROM

Like DVD discs, there is little to distinguish a DVD-ROM drive from an ordinary CD-ROM drive as the only giveaway is the DVD logo on the front. Even inside the drive there are more similarities than differences: the interface is ATAPI or SCSI for the more upmarket drives, and the transport is much like any other CD-ROM drive. CD-ROM data is recorded near the top surface of a disc. DVD's data layer is right in the middle so that the disc can be double-sided. The laser is different, having a pair of lenses on a swivel: one to focus the beam onto the DVD data layers and the other for reading ordinary CDs.

DVD-ROM drives spin the disk a lot slower than their CD-ROM counterparts. However, since the data is packed much closer together on DVD discs, the throughput is substantially better than a CD-ROM drive at equivalent spin speed. While a 1x CD-ROM drive has a maximum data rate of only 150KBps, a 1x DVD-ROM drive can transfer data at 1,250KBps, which is just over the speed of an 8x CD-ROM drive.

DVD-ROM drives became generally available in early 1997 and these early 1x devices were also capable of reading CD-ROM discs at 12x speed - sufficient for full-screen video playback. As with CD-ROM, higher speed drives appeared as the technology matured. By the beginning of 1998, multispeed DVD-ROM drives had already reached the market, capable of reading DVD media at double-speed, producing a sustained transfer rate of 2,700KBps, and of spinning CDs at 24-speed and by the end of that year DVD read performance had been increased to 5-speed. A year later performance had improved to six-speed (8,100KBps) reading of DVD media and 32-speed reading of CD-ROMs.

DVD-Video

DVD-Video titles use MPEG-2 compression to store video. MPEG-2 offers greater overall compression than MPEG-1 and yields a much sharper, cleaner picture. MPEG-2-encoded video commonly uses 480 horizontal lines per frame (720 x 480 pixels), versus 425 lines for laserdisc and 250 to 270 lines for VHS video.

DVD audio includes the option of PCM (pulse code modulation) digital audio with sampling sizes and rates higher than audio CD. Alternatively, audio for most movies is stored as discrete, multi-channel surround sound using Dolby Digital or Digital Theatre Systems Digital Surround (DTS) audio compression similar to the digital surround sound formats used in theatres. DTS is an audio encoding format similar to Dolby Digital, requiring a decoder, either in the player or in an external receiver. It accommodates channels for a subwoofer plus five speakers - front left, front centre, front right, rear left, and rear right - and some argue that because of its lower compression level DTS sounds better than Dolby Digital. As with video, audio quality depends on how well the processing and encoding was done. In spite of compression, Dolby Digital and DTS can be close to or better than CD quality.

The net result is that a movie played from DVD-Video should look a good bit better than one played from VHS, assuming the picture has been encoded with at least a reasonable degree of skill.

Movie buffs will appreciate DVD-Video's multiple aspect ratios. DVD-Video titles typically let you choose from at least a couple, such as 16:9 letterbox or wide-screen formats and a more conventional 4:3 ratio, which would fill a normal television screen. Furthermore, DVD-Video titles also typically let you choose from up to eight different languages and from 32 different sets of sub-titles.

A single-sided (DVD-5) DVD-Video disc was designed to hold a typical feature-length movie - which averages 133 minutes. With MPEG-2 compression a full-motion image needs about 3,500Kbit/s. Digital surround-sound - centre, left, right left-rear and right-rear directional channels, plus a non-directional subwoofer - requires a further 384Kbit/s. Add additional storage for dialogue tracks in different languages and subtitles and the required capacity increases to 4,692Kbits - or 586.5KB - for every second of a 133-minute movie (a minimum of 4Mbit/s being required for high quality results). The sums work out to a total required storage capacity of 4.68GB.

For a dual layer disc (DVD-9) capacity increases to 240 minutes. A double-sided disc (DVD-10) will hold slightly more at 266 minutes, but the disc needs to be turned over to play the other side. Many DVD movies have taken advantage of double-sided discs by putting a version formatted for a normal TV or monitor with a 4:3 aspect ration on one side and a widescreen version formatted for 16:9 aspect ratio on the other.

There are two ways of writing the DVD data layers: parallel track path (PTP) and opposite track path (OTP). In PTP discs both layers read from the inside of the disc to the outside, whereas in an OTP disc the outer layer reads from the inside to out, and then back in for the inner layer. This allows the drive to read both layers almost continuously, with only a short break to refocus the pickup lens. This is especially useful for DVD movies, where long play time without interruption is needed.

In 1998 the spectre of another VHS vs Beta-type confrontation in the DVD arena was raised when Digital Video Express (DVE) - a partnership a partnership between one of the largest US electronics retailers, Circuit City, and a prominent Los Angeles entertainment law firm - announced an alternative movie format to DVD-Video. Known as Divx, the rival format took a pay-per-view approach to viewing movies and quickly garnered the support of leading studios Disney, Paramount, Universal and MGM.

Divx

Divx is essentially a limited-use, pay-per-view DVD technology. Marketed as a more affordable DVD format - with the financial backing of the Circuit City Stores retail chain - it allows a user to purchase a Divx disc at a minimal cost and view its contents for an unlimited number of times within a 48-hour period. Once the 48 hours are up, the user is charged for each additional use - Divx machines having a built-in modem which it uses to automatically call the central billing server to report player usage roughly twice a month. Users have the option to purchase the right to unlimited viewing - for a sum equivalent to the cost of a DVD-Video disc. Given that a Divx player is basically a DVD-Video player with additional features to enable a pay-per-view mode of operation, it not surprising that it's capable of playing standard DVD-Video discs. Obviously a standard DVD player will not allow viewing of a Divx disc.

In addition to the built-in modem the typical Divx player also contains decrypting circuitry, in order to read the Divx discs which are encoded with a state-of-the-art algorithm [Triple-DES]. Also the player is able to read a unique serial number off the disc which is recorded on an area of the Divx disc known as the Burst Cutting Area (BCA), located in the inner most region of the disc. Annex K of Part 1 of the DVD Specification defines the BCA for a DVD. Essentially, this can be used to record up to 188 bytes of data after the disc has been manufactured. Divx uses this number to keep track of the viewing period.

Despite some consumers balking at the idea of having two different standards for digital discs, and others objecting to the idea that they would have to keep paying for something they had already purchased, Divx appeared to be gaining acceptance amongst consumers - with sales of the enhanced players reportedly matching those of standard DVD units - when its backers pulled the plug on the format in mid-1999, blaming inadequate support from studios and other retailers for the format’s demise. Its fate was effectively sealed once companies - including US retail chain Blockbuster - announced plans to rent DVDs to consumers instead of Divx discs.

It might not have lasted long, but its likely that Divx played a useful role in creating a viable rental market - essential for DVD-Video to become as popular as VHS. Furthermore, one of its features - the use of the BCA - offers some interesting possibilities future distribution of software on DVD-ROM discs. For example, it could mean an end to the rigmarole of consumers having to manually enter a long string of characters, representing a product’s serial number, during software installation. A unique vendor ID, product ID, and serial number can be stored as BCA data, and automatically read back during the software installation process. Storing a product’s serial number as BCA data could also confer important ant-pirating benefits - making it almost impossible to install a software product without possessing an authentic copy of the disc.

Encoding

Variable bit rate (VBR) encoding allows higher image quality at a lower average bit rate by using more data to encode those parts of a video sequence which are more complex and do not compress well. Using constant bit rate (CBR) encoding, the video data rate must be high enough to encode all the video well.

Early DVD-ROM drives used one of two strategies for delivering MPEG-2 video. Some used a technique called analogue overlay, also referred to as video overlay or simply overlay. Others employed the VGA-inlay approach, sometimes referred to as VideoInlay. Both methods display video in a window or at full screen, but they take different approaches. VideoInlay relies on the PC’s graphics adaptor to scale the video and output it to a monitor. Overlay boards, by contrast, provide their own hardware scaling and output the video themselves, overlaying it with graphics output passed through from the VGA card. With these boards, an included cable runs from the VGA connect of the display adaptor to an input on the bracket of the decoder board.

The major drawback of the VGA-inlay approach is the load it places on a system. While pushing 30 frames of video per second might not saturate the PCI bus, it does keep bus utilisation high. When playing scenes encoded at a high bit rate, VGA-inlay boards can overwhelm older, slower display adaptors with too much data, requiring a reduction in horizontal resolution to produce an acceptable picture.

Requiring a bit more work to install and configure than VGA-inlay boards, video-overlay boards demand less of a system and tolerate a wider variety of hardware. While video output may be less sharp than that displayed by VGA-inlay boards, the video-overlay approach has the advantage of being capable of decent performance with just about any video card.

The original audio encoding format specification for European DVD discs was MPEG-2 surround sound, creating a degree of confusion since Dolby Digital AC3 had become established as a mainstream format with the rest of the DVD world. The situation was clarified in January 1998 when the DVD Forum (DVDF) agreed on a dual standard which allowed both encoding formats.

The launch of DVD-Video has been severely impacted by technical issues, and not least those concerning encryption. DVD-Video players finally came to market in Japan in November 1996 and in the USA in March 1997. In Europe, the major launch was delayed until the autumn of 1998.

Encryption

There are currently four forms of copy protection used by DVD:

CGMS: This is a ‘serial’ copy generation management system (SCMS) designed to prevent copies or copies of copies. The CGMS information is embedded in the outgoing video signal. For CGMS to work, the equipment making the copy must recognise and respect the CGMS.

Content Scrambling System (CSS): This is a form of data encryption to discourage reading media files directly from the disc. The system requires that DVD-ROM drives and video decoder hardware or software incorporate a decryption circuit that decodes data before displaying it.

Analogue CPS (Macrovision): The general term is APS (Analogue Protection System). The system is designed to prevent copying onto consumer VCRs. The producer of the disc decides what amount of copy protection to enable and then pays Macrovision royalties accordingly. Just as with videotapes, some DVDs are Macrovision-protected and some aren’t.

Digital Transmission Content Protection (DTCP): A draft proposal (called the 5CP, for ‘five-company proposal’) was made by Intel, Sony, Hitachi, Matsushita, and Toshiba in February1998 which addresses digital connections between components via IEEE 1394. Content is marked with standard CGMS flags of ‘copy never’ or ‘copy once’. Devices that are digitally connected, such as a DVD player and a digital TV, will exchange keys and authentication certificates to establish a channel. Products using DTCP are not expected before mid-1999.

Regional coding

Motion picture studios want to control the home release of movies in different countries because cinema releases aren’t simultaneous (a movie may come out on video in the U.S. when it’s just hitting screens in Europe). Also, studios sell distribution rights to different foreign distributors and would like to guarantee an exclusive market. Therefore they have required that the DVD standard include codes that can be used to prevent playback of certain discs in certain geographical regions. Each player is given a code for the region in which it’s sold. The player will refuse to play discs that are not allowed in that region. This means that discs bought in one country may not play on players bought in another country.

Regional codes are entirely optional for the maker of a disc. Discs without codes will play on any player in any country. It’s not an encryption system, it’s just one byte of information on the disc, which recognises six different DVD worldwide regions, that the player checks:

Region 1	USA, Canada
Region 2	Europe, Middle East, South Africa, Australia, Japan
Region 3	South East Asia, Taiwan
Region 4	Central America, South America, Mexico, New Zealand
Region 5	Russian federation, Africa (part), India, Pakistan
Region 6	China

Region-2 coding standards proved more complicated to finalise than was originally expected, due to huge variations in censorship laws and the number of different languages spoken across the region, and was one of the main reasons for DVD taking so long to become established. It’s impossible to include films coded for every country in Region-2 on a single disc. This led the DVDF to split the region into several sub-regions, and this, in turn, caused delays in the availability of Region-2 discs. By the autumn of 1998 barely a dozen Region-2 discs had been released, compared to the hundreds of titles available in the US. This situation led to many companies selling DVD players that had been reconfigured to play discs from any region.

With hindsight, the attempt at regional segregation was probably doomed to failure from the very start. The games console manufacturers (Nintendo, Sega and Sony) have been trying to stop owners from playing games imported from other countries for several years now. Generally, whenever such regional standards were implemented, it only took someone a few weeks to work out a way around it, whether it be a cartridge adaptor or a modification to the machine itself. In real terms, all regional DVD coding has cost the DVD Forum a lot of money, delayed market up-take and allowed third-party companies to make a great deal of money bypassing it.

Ultimately, DVD will prevail as there's simply far too much heavyweight support behind it. In the US, even the die-hard LaserDisc collectors are being forced to adopt DVD as the movie studios cut down their LaserDisc production and ramp up their DVD output. With the increasing availability of DVD-ROM drives in notebook PCs and the availability of software-based MPEG-2 decoders capable of delivering significantly better results than older hardware-based solutions, it appears likely that DVD will make significant market inroads in the second half of 1998.

DVD Recordable

Similar in concept to CD-R, DVD-R (or, DVD-Recordable) is a write-once medium that can contain any type of information normally stored on mass produced DVD discs - video, audio, images, data files, multimedia programs, and so on. Depending on the type of information recorded, DVD-R discs are usable on virtually any compatible DVD playback device, including DVD-ROM drives and DVD Video players. An early release of DVD-R was important to the development of DVD-ROM titles since software developers needed a simple and relatively cheap way of producing test discs before going into full production.

When it first appeared in the autumn of 1997 DVD-R media had a capacity of 3.95GB. This was later increased to 4.7GB of information on a single-layer, single-sided DVD-R disc. Since the DVD format supports double-sided media, up to 9.4GB can be stored on a single double-sided DVD-R disc. Data can be written to a disc at a DVD "1X" equivalent to 11.08 Mbit/s, which is roughly equivalent to nine times the transfer rate of CD-ROMís "1X" speed. After recording, DVD-R discs can be read at the same rate as mass produced replicated discs, depending on the "X" factor of the DVD-ROM drive used.

DVD-R, like CD-R, uses a constant linear velocity (CLV) rotation technique to maximise the storage density on the disc surface. This results in a variable number of revolutions per minute (RPM) as disc writing/reading progresses from one end to the other. Recording begins at the inner radius and ends at the outer. At "1X" speeds, rotation of the disc varies from 1,623 to 632 RPM on 3.95GB media and 1,475 to 575 RPM on 4.7GB media, depending on the record/playback headís position over the surface. On 3.95GB media, the track pitch, or the distance from the centre of one part of the spiral information "track" to an adjacent part of the track, is 0.8 microns (Δ–), one-half that of CD-R. 4.7GB media uses an even smaller track pitch of 0.74Δ–.

To help achieve a six to seven-fold increase in storage density over CD-R, two key components of the writing hardware needed to be altered: the wavelength of the recording laser and the numerical aperture of the lens that focuses it. With CD-R, an infrared laser with a wavelength of 780nm is employed, while DVD-R uses a red laser with a wavelength of 635nm. At the same time, the numerical aperture of a typical CD-R driveís objective lens is 0.5, while a DVD-R drive uses lenses with a numerical aperture of 0.6. These factors allow DVD-R discs to record marks as small as 0.40Δ– as compared with the minimum 0.834Δ– size with CD-R.

The table below highlights the differences between some basic parameters of both media formats:

Parameter	DVD-R	CD-R
Media Type	Write-once	Write-once
Wavelength (Recording)	635 - 645 nm	775 - 795 nm
Wavelength (Reading)	635 - 650 nm	770 - 830 nm
Recording Power	6-12 mw	4 - 8 mw
Numerical Aperture	0.60	0.50
Numerical Aperture (Reading)	0.60	0.45
Reflectivity	R14H > 0.6	RTOP > 0.65

Recording on DVD-R discs is accomplished through the use of a dye recording layer that is permanently transformed by a highly focused red laser beam. This dye substance is spin-coated onto a clear polycarbonate substrate that forms one side of the "body" of a complete disc. The substrate is injection moulded, and has a microscopic, "pre-grooved" spiral track formed onto its surface. This groove is used by a DVD-R drive to guide the recording laser beam during the writing process, and also contains recorded information after writing is completed. An undulating "wobble" signal is moulded into the pre-groove for synchronising a DVD-R driveís spindle motor during the writing process, and "Land Pre-Pits" (LPP) are also contained in the land areas between grooves for addressing purposes. A thin layer of metal is then sputtered onto the recording layer so that a reading laser can be reflected off the disc during playback. A protective layer is then applied to the metal surface, which prepares the side for the bonding process.

These steps are carried out for each side of a disc that will be used for recording. If only a single recording side is required, then the opposite side can contain a label or some other visible information such as pit art. If both sides are needed for recording, then two recordable sides can be bonded together as depicted in the diagram. In this case each side must be read directly by flipping the disc over, as dual layer technology is not currently supported.

The recording action takes place by momentarily exposing the recording layer to a high power (approximately 8-10 milliwatt) laser beam that is tightly focused onto its surface. As the dye layer is heated, it is permanently altered such that microscopic marks are formed in the pre-groove. These recorded marks differ in length depending on how long the write laser is turned on and off, which is how information is stored on the disc. The light sensitivity of the recording layer has been tuned to an appropriate wavelength of light so that exposure to ambient light or playback lasers will not damage a recording.

Playback occurs by focusing a lower power laser of the same approximate wavelength (635 or 650 nm) onto the surface of the disc. The land areas between marks are reflective, meaning that most of the light is returned to the playerís optical head. Conversely, recorded marks are not very reflective, meaning that very little of the light is returned. This “on-off” pattern is thereby interpreted as the modulated signal, which is then decoded into the original user data by the playback device

All DVD discs, recordable or not, must have three basic areas recorded on them: lead-in, user data and lead-out. The lead-in and lead-out areas are boundaries that indicate to a playback device where the inner and outer limits of a recording are respectively. They contain no user accessible information, but are critical to the proper functioning of a disc. The basic recording process is similar to that employed by CD-R technology.

There are two methods of writing a DVD-R disc, ‘disc-at-once’ and ‘incremental writing’:

Disc-at-once, as its name implies, is the process of writing an entire discís worth of data, up to 4.7GB, at one time. A host computer must consistently provide data at a full 11.08 Mbit/s during any recording to avoid buffer underrun errors, a condition that can be minimised by the use of a arge writing buffer memory. DVD-R disc-at-once writing is performed such that the lead-in, data area and lead-out areas are all written sequentially. This differs from how CD-R discs are typically written, where the data area is written first, followed by the lead-in/table of contents and lead out areas. Disc-at-once recording is likely to be used when authoring video titles due to the large size of these programs. It can also be used for multimedia or other software titles intended for publishing, as these works are normally assembled on hard drives as a finished image file prior to testing them on DVD optical discs.

Incremental writing is also supported by the DVD-R format. This is very similar in concept to the packet writing technology that is used with CD-R. Incremental writing allows a user to add files directly to a DVD-R disc one recording at a time instead of requiring that all files be accumulated on a hard disk prior to writing as with the disc-at-once method. The minimum recording size must be at least 32KB, (even if the file to be recorded is smaller) as this is the minimum error correction code (ECC) block size for DVD. A disc that is being written to incrementally cannot be considered a complete volume until the final information has been stored or the disc capacity has been reached. The lead-in and lead-out boundary areas therefore cannot be written until either of these two events occur. Such an “unfinalised” disc (one without lead-in, lead-out and complete file system data) can only be read by a DVD-R drive until this process can be completed. After finalisation, a destination playback device can then read a disc, but data can no longer be added to it.

By late-1999, the take-up of DVD-R remained slow and the drives were prohibitively expensive - at around 10 times the cost of a DVD-Rewritable drive - having been further impacted by the appearance of DVD-ROM drives capable of reading DVD-RAM discs in mid-1999. It’s large capacity and durability - its media has a typical life expectancy of better than 100 years - make it a good choice for the long-term archival of any information that can be stored digitally. Since DVD discs are dimensionally identical to the CD family of discs, they have the advantage of being compatible with existing CD-based jukebox and changer mechanisms. This allows automated retrieval of recorded DVD-R volumes in networked environments, with a six to seven-fold increase in storage density as compared with CD-R technology.

The DVD-Forum's Version 2 specification - finalised in May 2000 - and consequent increase in capacity to 4.7GB, did serve to increase DVD-R's value as a tool for creating master discs before mass production by software houses and in multimedia post-production operations and as a medium for making back-up copies of movie discs.

However, DVD-RAM's increase in capacity to 4.7GB in mid-2000 - coupled with its promised compatibility with the DVD-RAM based VCRs expected to appear in the first half of 2001 - make it increasingly difficult for DVD-R to succeed as anything more than a niche product, suited to a limited number of specialist applications.

DVD-RAM

Rewritable DVD-ROM drives, or DVD-RAM, employs phase-change technology with some MO features mixed in rather than the pure optical technology of CD and DVD discs and has its roots in the PD optical disc system. A 'land groove' format allows signals to be recorded on both the grooves formed on the disc and in the lands between the grooves. The grooves and pre-embossed sector headers are moulded into the disc during manufacturing. The first generation of DVD-RAM products delivered 2.6GB of reusable data space on either side of a disc. However, these early drives will be incompatible with the higher-capacity standard, which may use a contrast enhancement layer and a thermal buffer layer to achieve higher density. Hitachi reached the 4.7MB capacity by reducing mark size from 0.41/0.43 microns to 0.28/0.30 microns and track pitch from 0.74 microns to 0.59 microns.

The principal difference between DVD-RAM and ROM is one of compatibility. Single-sided DVD-RAM discs come with or without cartridges and will therefore be readable by 'fourth generation' DVD-ROM drives when they become available later in 1999. There are two types of cartridges: Type 1 is sealed, Type 2 allows the disc to be removed. Cartridge dimensions are 124.6mm x 135.5mm x 8.0mm. Discs can only be written while in the cartridge. Double-sided DVD-RAM discs, on the other hand, will be available in Type 2 sealed cartridges only and, as a consequence, cannot be read on current DVD-ROM drives - a situation that will remain the case unless there are caddy-loading DVD-ROM drives sometime in the future.

Panasonic was first to market with its SCSI-based first generation LFD101 DVD-RAM drive launched in the autumn of 1998. This was capable of writing data to DVD-RAM discs at an average 0.5MBps and of reading data at between 2 and 3 times this rate. It was also capable of reading DVD-ROM discs at 2-speed and had upped CD-ROM reading performance to 20-speed. The LFD101 allows DVD-RAM discs to be formatted to either UDF or FAT16 standard and, unsurprisingly given the similarity between the formats, is also capable of handling PD format discs. The main advantage of using UDF is that the full capacity of each side of a DVD-RAM disc can be used, by-passing the 2GB limit imposed by FAT16. One drawback of these early drives is that they won't be able to use the forthcoming double-density DVD-RAM discs.

Hitachi followed, in early 1999, with its GF-1050 DVD-RAM drive. This was also capable of dual-speed DVD-ROM reading but was slower than its Panasonic rival when it came to CD-ROM play back, handling these and CD-R and CD-RW discs at eight-speed in CLV mode.

In mid-2000, Panasonic were again first off the mark with a second generation DVD-RAM drive. This was capable of supporting a full 4.7GB of storage per disk side - reduced to 4.2GB after formatting - the same as a single-layer DVD-ROM. Importantly, this means that DVD-RAM now has sufficient capacity to record a 2-hour high-quality MPEG-2 movie, making it an ideal replacement for videotape. Whilst the quality of a pre-recorded VHS videocassette will start to degrade after being played as little as 20 times, manufacturers claim that DVD-RAM media can be overwritten up to 100,000 times and will maintain data integrity for at least 30 years. In addition to the FAT, FAT32 and UDF1.5 formats, the 4.7GB media can also be formatted to the UDF 2 standard, thereby allowing compatibility with the future generation of DVD-RAM based VCRs - expected to appear in early 2001.

DVD+RW

Consistent with the bickering that had dogged DVD since its inception, the DVD-RAM specification was a compromise between two different proposals by the principal protagonists - the Hitachi, Matsushita Electric and Toshiba grouping and the Sony/Philips alliance - but with primary reliance on that put forward by the former.

The degree to which Sony and Philips were unhappy about this became clear in the summer of 1997 when, together with Hewlett-Packard, they broke away from the agreed format to develop Phase-Change Rewritable, referred to as DVD+RW. This is a competitor rewritable format, based on DVD and CD-RW technology, and incompatible with the DVD-RAM standard which had been agreed only three months previously. While they have not chosen to drop out of the DVD Forum, the DVD+RW camp have submitted a modified form of their original specification to the European Computer Manufacturers' Association (ECMA) for adoption as a standard.

DVD+RW drives - which will be capable of reading DVD-ROMs and CDs - use phase-change technology with wobbled groove and either CLV format for sequential video access or CAV format for random access. Its supporters claim the drives will have a sustained data transfer rate of 1.7Mbytes per second and offer a better access time than DVD-RAM. In addition, the DVD+RW drives will offer a user experience similar to using current CD-RW drives. For example, users will be able to record a bare disc or use a protective caddy or cartridge for the media. This is in contrast to DVD-RAM drives which require cartridge-based media. Furthermore, second-generation DVD+RW drives will write CD-Rs and CD-RWs - claimed by its supporters as another important advantage the format will have over DVD-RAM.

It is DVD-RAM's reliance on a caddy, making it look like a large floppy disc, that has generated key criticisms from DVD+RW's supporters; they say that the DVD-RAM approach would force future DVD-ROM to have to be modified to take caddies and discs. A single-sided DVD-RAM can be removed from its caddy to play in any DVD-ROM drive, but disc manufacturers say that the DVD-RAM disc cannot be reliably replaced for further recording.

The DVD+RW consortium further claim that the cartridge requirement of DVD-RAM could lead to larger carriage mechanisms, thus limiting the technology's use in laptops or small enclosures. The companies sticking with the DVD Forum (Matsushita, Hitachi and Toshiba), on the other hand, claim the DVD-RAM cartridge improves reliability, especially for double-sided media and believe that the costs and difficulties of making DVD-ROM drives physically compatible with DVD-RAM are overstated.

There are data structure differences between the two formats. DVD+RW is like CD-RW with the data written into pre-cut grooves in the blank disc, and the file system is split into data blocks. DVD-RAM uses both the grooves and the 'land' either side of the grooves to hold data, and has a PD-type data structure relying on embossed markers. At the data level, the formats are incompatible and the discs from one format cannot be used with the writers of other.

The rift between the rival camps is such that it appears inevitable that, by the end of 1998, there will be at least two rewritable DVD formats available to the PC market. Both groups insist they will not support the opposition's rewritable format in their DVD-ROM drives. This affects every buyer of DVD-ROM, with, for example, a Sony drive able to read DVD+RW discs but rejecting DVD-RAMs, and Pioneer drives doing exactly the opposite.

Despite the posturings on both sides, it would seem that the PC industry may put commercial pressure on manufacturers on all sides to support both formats, at least in their DVD-ROM drives. Although a strong selling point for upmarket PCs, the DVD-ROM drive remains one small part of the complete PC system. PC manufacturers want to avoid a situation where one OEM'ed part of their PC is responsible for a rush of service support calls from puzzled and annoyed customers who find that their branded PC will read some ëDVDí rewritables and not others. There is pressure for drives that will handle both formats, no matter how unpalatable that is to the manufacturer concerned.

Hewlett-Packard was first to announce a DVD+RW drive - promising its 3.0GB DVD Writer 3100i drive would reach the US market by the autumn of 1999. However, at about the time the device was expected to reach the market HP announced that it was instead will focusing on a 4.7GB version for release in 12 to 18 months, claiming there would be little sense in releasing sooner because the current crop of DVD-ROM drives are unable to read either 4.7GB media or 3.0GB DVD+RW discs. A fix for this has apparently been developed and DVD-ROM drives capable of reading DVD+RW media are expected to begin shipping in early 2000.

Amidst all the rivalry and disagreement over DVD standards, there is, fortunately, at least one organisation that has the consumer's interests in mind - the Optical Storage Technology Association (OSTA) - and the intention of it's MultiRead specification is to ensure backward read compatibility among all types of drives, including CD and DVD.

DVD-RW

Formerly known as DVD-R/W - and also briefly as DVD-ER - DVD-RW is Pioneer’s evolutionary development of existing CD-RW/DVD-R technology that became available at the end of 1999. Using a similar track pitch, mark length, and rotation control as DVD-R, DVD-RW provides a capacity of 4.7GB. Its phase-change technology means that discs have a higher reflectivity than DVD-RAM or DVD+RW media, and can be generally be read in existing DVD-ROM drives. The format has been accepted by the DVD Forum for evaluation as a possible member of the DVD family.

OSTA

The Optical Storage Technology Association is an association-not a standards body-and its members account for more than 80 percent of all worldwide writable optical product shipments. Its specifications represent a consensus of its members, not the proclamation of a committee.

The MultiRead specification defines the requirements that must be met in order for a drive to play or read all four principal types of CD disks: CD-Digital Audio (CD-DA), CD-ROM, CD-Recordable (CD-R), and CD-Rewritable (CD-RW). The specification was conceived, drafted and proposed to OSTA by member companies Hewlett-Packard and Philips. OSTA took over, providing an open forum for interested members to complete the specification. During this process, several significant enhancements were made, including one to ensure readability of CD-R discs on DVD-ROM drives. After the specification was approved by vote of the technical subcommittee to which it was assigned, it was ratified by the OSTA Board of Directors.

Compliance with the MultiRead specification is voluntary. To encourage compliance, a logo program has been established that will be administered by Hewlett-Packard. Companies wanting to display the MultiRead logo on their drives will be required to self test their drives using a test plan published on the OSTA web site. To receive a license permitting use of the logo, they must submit a test report to Hewlett-Packard along with a nominal license fee.

How does this specification affect the current rewritable DVD standards battle? It protects consumers by providing them with the knowledge that whichever type of drive they buy (assuming the two different standards go forward), they will be able to read all earlier types of media, as long as they see the MultiRead logo on the drive. The only incompatibility will be between DVD-RAM and DVD+RW drives. Thus, consumers need not worry about their existing inventory of media or about media produced on today’s drives. All will be compatible with future drives bearing the MultiRead logo.

Compatibility Issues

The DVD format has been dogged by compatibility problems from the very beginning. Some of these have now been addressed but others, in particular those concerning the rewritable and video variants, persist and look as though they might escalate to become the same scale of issue as the VHS vs Beta format war was for several years in the VCR industry.

Incompatibility with some CD-R and CD-RW discs was an early problem. The dies used in certain of these discs will not reflect the light from DVD-ROM drives properly, rendering them unreadable. For CD-RW media, this problem was easily solved by the MultiRead standard and fitting DVD-ROM drives with dual-wavelength laser assemblies. However, getting DVD-ROM drives to read all CD-R media reliably presented a much bigger problem. The DVD laser has great difficulty reading the CD-R dye because the change in reflectivity of the data at 650nm is quite low, where at 780nm it’s nearly the same as CD-ROM media. Also the modulation at 650nm is very low. Designing electronics to address this type of change in reflectivity is extremely hard and can be expensive. By contrast, with CD-RW the signal at 780nm or 650nm is about one quarter that of CD-ROM. This difference can be addressed simply by increasing the gain by about 4x. This is why CD-RW was originally proposed by many companies as the best bridge for written media to DVD from CD technology.

DVD-R Video discs can be played on a DVD video player, as well as a computer that is equipped with a DVD-ROM drive, a DVD-compliant MPEG decoder card (or decoder software) and application software that emulates a video playerís control functions. A recorded DVD-ROM disc can be read by a computer equipped with a DVD-ROM drive, as well as a computer equipped for DVD video playback as described above. DVD Video components are not necessary, however, if DVD Video material is not accessed or is not present on a disc.

By the autumn of 1998, DVD-ROM drives were still incapable of reading rewritable DVD discs. This incompatibility was slated to be fixed in so-called 'third-generation' drives which will include LSI modifications to allow them to read the different physical data layout of DVD-RAM or to respond to the additional headers in the DVD+RW data stream. The first DVD-ROM drives capable of reading DVD-RAM discs began to appear around mid-1999.

Speed was another issue for early DVD-ROM drives. By mid-1997 the best CD-ROM drives were using full CAV to produce higher transfer rates and lower vibration. However, early DVD-ROM drives remained strictly CLV. This was not a problem for DVD discs as their high density allows slower rotational speeds. However, because CLV was also used for reading CD-ROM discs the speed at which a CLV-only DVD-ROM drive could read these was effectively capped at eight-speed.

These issues resulted in a rather slow roll-out of DVD-ROM drives during 1997, there being a six-month gap between the first and second drives to come to market. However, by early 1998 second-generation drives were on the market that were capable of reading CD-R and CD-RW discs and with DVD performance rated at double-speed and CD-ROM performance equivalent to that of a 20-speed CD-ROM drive.

With the early problems solved, the initial trickle of both discs and drives was expected to become a flood since the manufacture of DVD discs is relatively straightforward and titles from games and other image-intensive applications are expected to appear with increasing regularity. However, in 1998 progress was again hampered by the appearance of the rival Divx format. Fortunately this disappeared from the scene in mid-1999, fuelling hopes that a general switch-over to DVD-based software would occur towards the end of that year, as DVD-ROM drives reached entry-level pricing and appeared likely to begin to outsell CD-ROM drives.

DVD-Audio

It's interesting to note that the first optical storage medium made available to the public was the now-familiar audio CD. Since then, the fields of digital audio and digital data have been intertwined in a symbiotic relationship, with one industry making use of the other's technology to their mutual benefit. It took several years for the computer industry to realise that the CD was the perfect medium for storing and distributing large amounts of digital data, and it was not until well into the 1990s that CD-ROMs became standard pieces of PC equipment.

With the latest PC industry-driven developments in optical storage, the record industry is now looking to borrow from the technology to find another way to make the public buy their album collections all over again. The quest for higher fidelity CDs has produced a number of standards which are battling with DVD-Audio to become the next accepted standard. Amongst these are SACD (Super Audio CD) and DAD (digital Audio Disc). When one of these finally wins out it could produce discs with 24-bit resolution at a 96kHz sampling rate, as opposed to the current 16-bit/44.1kHz format. The SACD format is backward compatible with existing players - a fact which may help it in the battle for consumer acceptance.

When DVD was released in 1996 there it did not include a DVD-Audio format. Following efforts by the DVD Forum to collaborate with key players from the music industry a draft standard was released in early 1998. The DVD-Audio 1.0 specification (minus copy protection) was subsequently released in spring of 1999. This offers a range of new features including even higher quality, surround sound, longer playing times plus additional features which are not available on CDs. DVD-Audio discs will be capable of carrying video, like DVD-Video titles, as well as high quality audio files and include limited interactivity.Capacity of a dual layer DVD-Audio will be up to at least 2 hours for full surround sound audio and 4 hours for stereo audio. Single layer capacity will be around half these times.

The first DVD-Audio products are expected to appear in mid-2000. The delay is in part caused by the slow process of selecting copy protection features (encryption and watermarking), complications having arisen as a result of the Secure Digital Music Initiative (SDMI). In late 1999 a decision was made as to which copy protection technology would be used by SDMI, but a later version of the DVD-Audio specification incorporating this is not expected until mid-2000.

Whilst DVD-Audio discs can be designed to work in DVD-Video players, it's also possible to make a DVD-Audio disc that won't play at all in a DVD-Video player. This is because the DVD-Audio specification includes new formats and features that DVD-Video can't handle. The sensible way forward is 'universal players' that can play both DVD-Video and DVD-Audio discs - but these aren't expected for some time.