Pioneer

DVD White Paper

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An Introduction to DVD Recordable (DVD-R)

What is DVD Recordable?

Overview

DVD Recordable (DVD-R) technology allows anyone to create DVD discs at the desktop. Similar in concept to Compact Disc Recordable (CD-R), DVD-R 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 standard DVD playback devices, including most DVD-ROM drives and DVD Video players. Compatibility with existing players and ROM drives is a key attribute of the format.

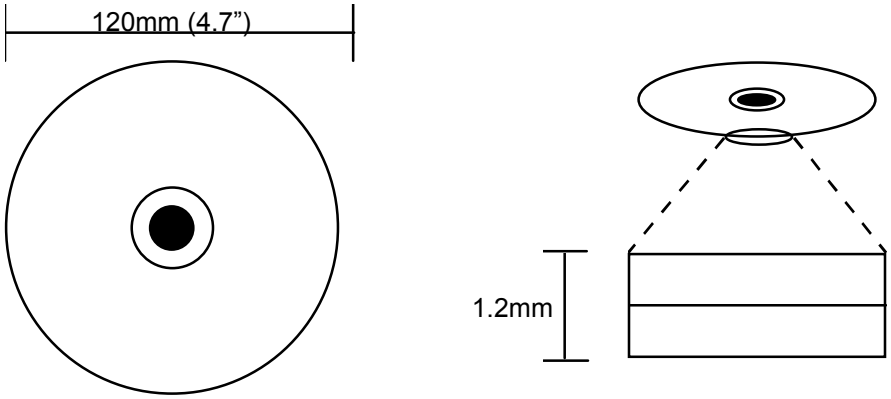
A DVD-R disc is able to contain a maximum of either 4.7 or 3.95 billion bytes of information on each side, depending on the type of blank media used. Since the DVD format supports double-sided media, up to 9.4 Gbytes can be stored on a single double-sided DVD-R disc. Note that the term "Gbyte" refers to one billion bytes in DVD Forum specifications.

Depending on the drive being used, data can be written to a disc at either a DVD "1X" equivalent of 11.08 megabits per second (Mbps) or "2X" equivalent of 22.16 Mbps. A "1X" transfer rate for DVD is roughly equivalent to nine times the transfer rate of CD-ROM's "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. These transfer rates, coupled with DVD-R's capacity, compatibility and conformance to worldwide DVD standards, makes it an extremely viable and cost effective storage medium.

DVD-R Technology

DVD-R is a write-once format, meaning that data can be written to a disc and stored without fear of accidental erasure. The fundamental technology employed is similar to that used by CD-R, except that data is written at a higher rate and density.

DVD-R, like CD-R, uses a constant linear velocity rotation technique to maximize 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 3.95 Gbyte media and 1,475 to 575 RPM on 4.7 Gbyte media, depending on the record/playback head's position over the surface. On 3.95 Gbyte media, the track pitch, or the distance from the center of one part of the spiral information "track" to an adjacent part of the track, is 0.8 microns, one-half that of CD-R. 4.7 Gbyte media uses an even smaller track pitch of 0.74 microns.



DVD-Recordable Disc Dimensions

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 (n.a.) of the lens that focuses it. With CD-R, an infrared laser with a wavelength of 780 nanometers (nm) is employed, while DVD-R uses a red laser with a wavelength of either 635 nm or 650 nm. At the same time, the numerical aperture of a typical CD-R drive's objective lens is 0.5, while a DVD-R drive uses lenses with an n.a. of 0.6. These factors allow DVD-R discs to record marks as small as 0.40 µm as compared with the minimum 0.834µm size with CD-R.

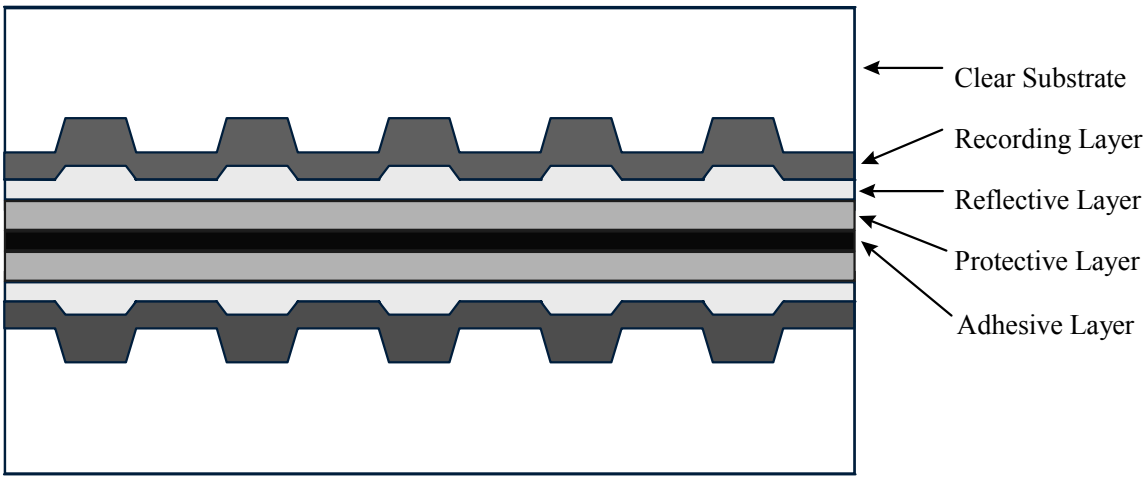
The table below highlights the differences between some basic parameters of both media formats as compared with CD-R. Note the reference to "Authoring" and "General" media types for DVD-R; the differences between these two types are covered in a separate section.

Parameter	DVD-R (Authoring)	DVD-R (General)	CD-R
Media Type	Write-once	Write-once	Write-once
Wavelength (Recording)	635 nm	650 nm	780 nm
Wavelength (Reading)	650 nm	650 nm	770 - 830 nm
Recording Power	6-12 mw	6-12 mw	4 - 8 mw
Numerical Aperture (Recording)	0.60	0.60	0.50
Numerical Aperture (Reading)	0.60	0.60	0.45
Reflectivity	$R_{14H} > 0.6$	$R_{14H} > 0.6$	$R_{TOP} > 0.65$

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 molded, 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 molded into the pre-groove for synchronizing a DVD-R drive's 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 done 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 below. In this case each side must be read directly by flipping the disc over, as the DVD-R format does not currently support dual layer technology.



Double-Sided Disc Example
(Not to Scale)

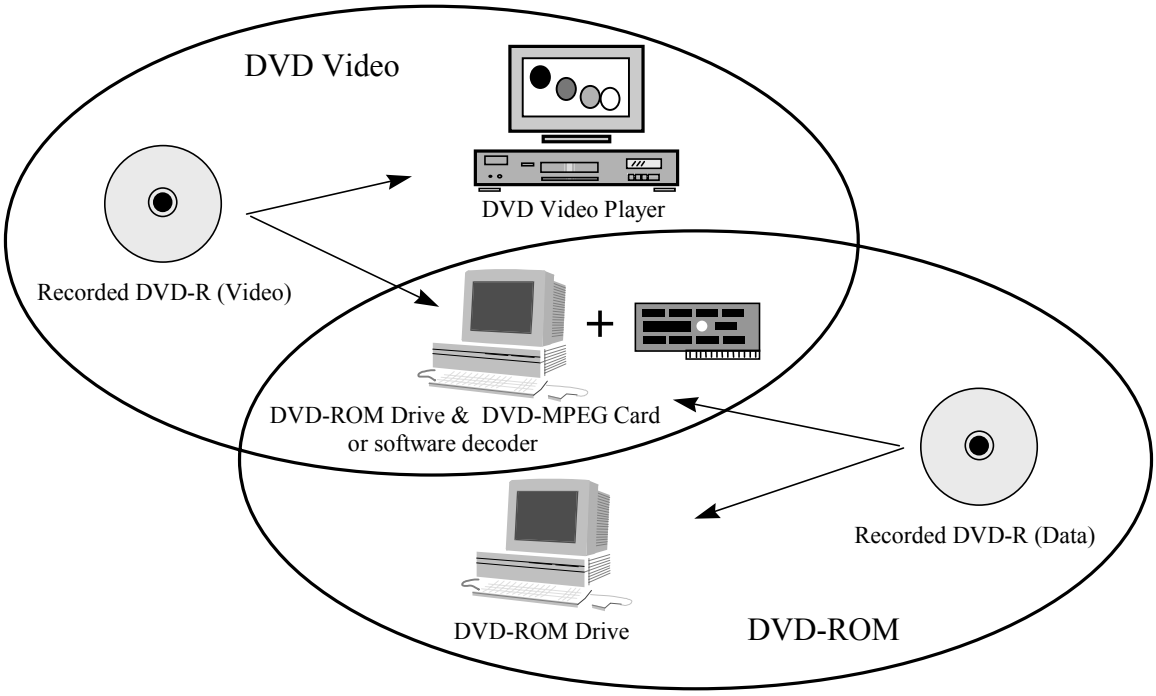
The recording action takes place by momentarily exposing the recording layer to a high power (approximately 8-10 milliwatt) laser beam that is tightly focused onto its surface. As the dye layer is heated, it is permanently altered such that microscopic marks are formed in the pre-groove. These recorded 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 areas between marks are reflective, meaning that most of the light is returned to the player's 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.

Expected Life of DVD-R Media

Life expectancy is a key issue when considering the use of DVD-R for applications such as video, document imaging and other archival applications. Although each disc media manufacturer has its own life expectancy rating, Pioneer DVD-R media is currently rated at better than 100 years.

Compatibility

Properly recorded DVD-R discs should be playable on any destination device that can both physically recognize DVD-R media and properly make use of whatever data or application layer is written. The diagram below illustrates this:



DVD-R Compatibility

Recorded DVD Video discs can be played on a standard 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 player's control functions. A recorded DVD data 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.

Recorded DVD-R discs support a file system called "UDF Bridge". This is a hybrid approach that provides both the UDF (Universal Disc Format) system as well as the older ISO-9660 system used by the CD-ROM format. This allows DVD discs to be used with computer operating systems that do not have any provision for UDF support.

Recording a Disc

The basic recording process for DVD-R discs should be familiar to any user of CD-R technology. Like CD-R, blank DVD-R discs are recorded in a DVD-R drive that is controlled by a host computer. The recording process is orchestrated by application software that allows a user to specify which files will be transferred to the disc as well as conducting the actual recording itself.

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.

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 disc's worth of data, up to 4.7 Gbytes, at one time. A host computer must consistently provide data at a full 11.08 or 22.16 megabits per second during any recording to avoid buffer underrun errors. Buffer underruns can be minimized by the use of a large writing buffer memory in a DVD-R drive; Pioneer's second generation drive in fact provides a 6.75 megabyte buffer that can absorb bit stream interruptions of more than four seconds in duration. Pioneer's third generation drive utilizes a lossless linking scheme to seamlessly resume the recording process in case a buffer underrun occurs; for this reason, a writing buffer size of only 2 MB is required.

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 track-at-once 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 typically used when authoring and recording video titles due to the structure and 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.

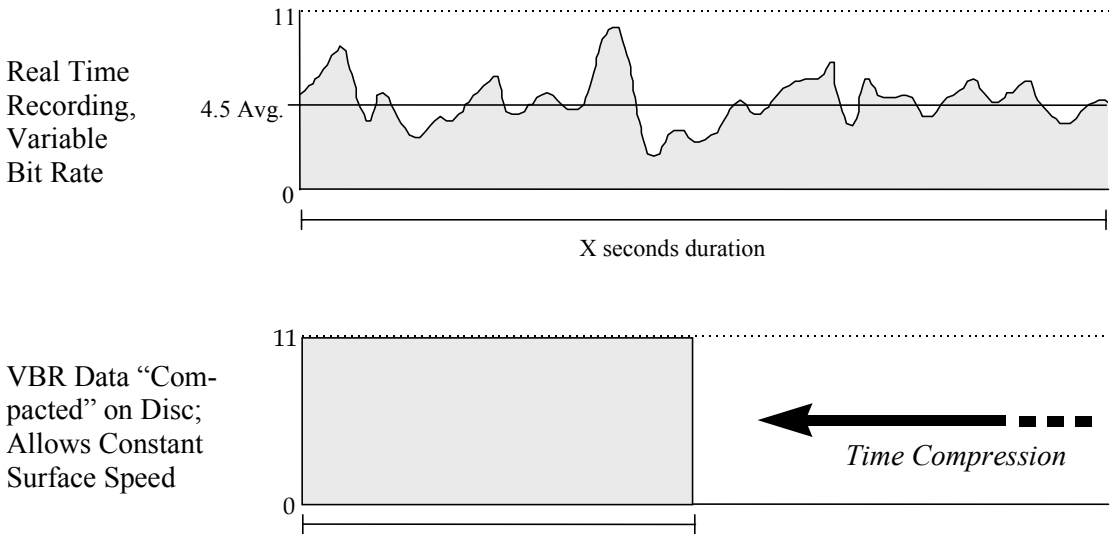
Incremental writing is also supported by the DVD-R format. This is very similar in concept to the packet writing technology that is used with CD-R. Incremental writing allows a user to add files directly to a DVD-R disc one recording at a time instead of requiring that all files be accumulated on a hard disk prior to writing as with the disc-at-once method. The minimum recording size must be at least 32 kilobytes, (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 "unfinalized" 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 finalization, a destination playback device can then read a disc, but data can no longer be added to it.

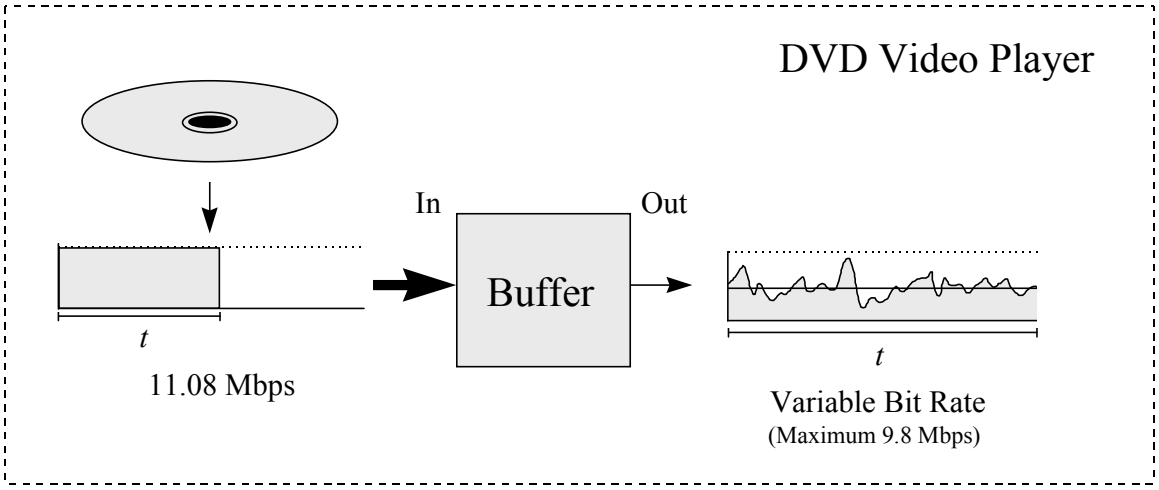
Time to Record One Disc Side

At "1X" recording speed, a complete 3.95 Gbyte side is written in approximately 50 minutes, regardless of the data that will be contained. A 4.7 Gbyte disc can be fully written in approximately one hour. At "2X" recording speed, a complete 4.7 Gbyte disc can be fully written in about 30 minutes.

Even variable bit rate MPEG video data is recorded at the full 11.08 megabits per second rate, as illustrated below:



Upon playback, a video player accomplishes the necessary bit rate variation with a buffering technique as illustrated below:



As these illustrations show, all information, video or otherwise, is written at the full 11.08 Mbps data rate (or faster depending on the drive specifications), with playback equipment providing any necessary time base adjustments.

General vs. Authoring Media

To support consumer applications for DVD-R, the DVD Forum determined that an additional type of DVD-R media was necessary. The newest member of the DVD-R family uses a recording wavelength of 650nm, and discs are recorded on different drives than the original 635nm format. This new type of media is called "DVD-R for General", because it is aimed at a broad base of applications. Meanwhile, the existing 635nm media type has been renamed "DVD-R for Authoring" to reflect its use in professional applications.

The key reason for the introduction of DVD-R for General media is that it contains content protection measures that make it physically impossible to make bit-for-bit copies of CSS encrypted entertainment titles.

Meanwhile, the 4.7 GB Authoring media specification has introduced a new feature that is of potential value to professional users: the Cutting Master Format (CMF). CMF allows 4.7 GB Authoring media to be used as a direct replacement for DLT master tapes when submitting a title for replication, thus saving time in the final authoring stage. This is accomplished by using a portion of the DVD-R disc's lead-in area to store the DDP (Disc Description Protocol) header information normally used on DLT master tapes. The CMF capability is one reason why Pioneer anticipates that Authoring drives and media will continue to be utilized in the professional DVD environment; General media does not accommodate this feature.

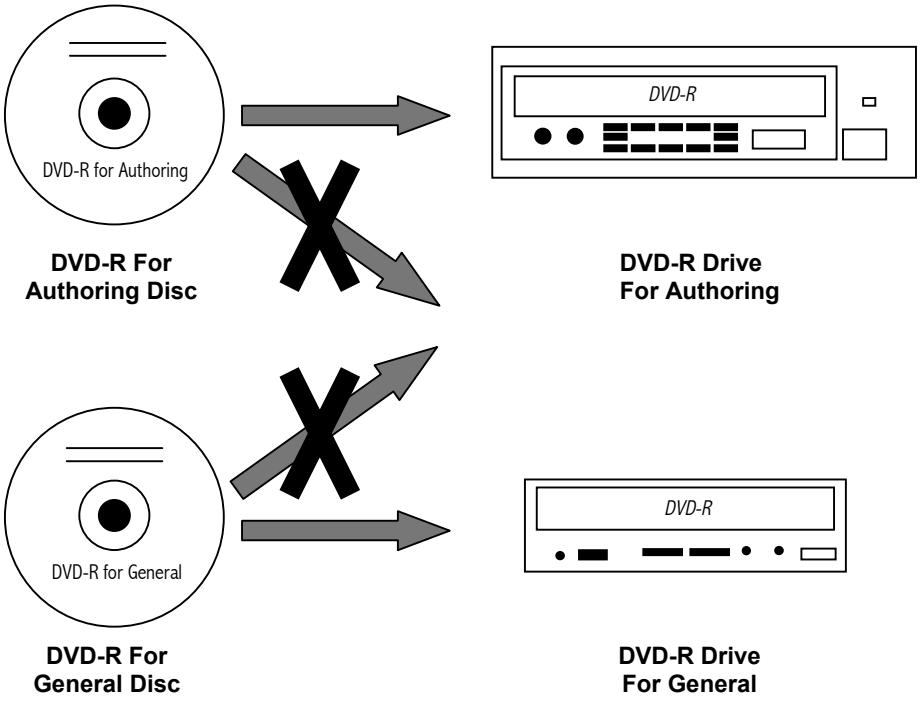
Either type of DVD-R media can be used for DVD video authoring, which is the process of preparing video content for use in DVD video players. It should be noted, however, that CSS encryption cannot be used with either type of DVD-R media.

General/Authoring Recording Compatibility

The two types of DVD-R media use different recording laser wavelengths, which means that the proper type of media must be recorded in the corresponding type of DVD-R drive. Authoring media must be recorded in either a Pioneer DVR-S101 (3.95 GB only) or DVR-S201 (both capacities) drive, and General media must be recorded in a General drive such as the Pioneer DVR-A03 or DVR-2000 video set top recorder. Pioneer expects that future drives, including those from other manufacturers, will most likely be General type drives.

The recording process is the only time when the user must be aware of the different media types and to use them accordingly. The playback process does not discern between Authoring or General media.

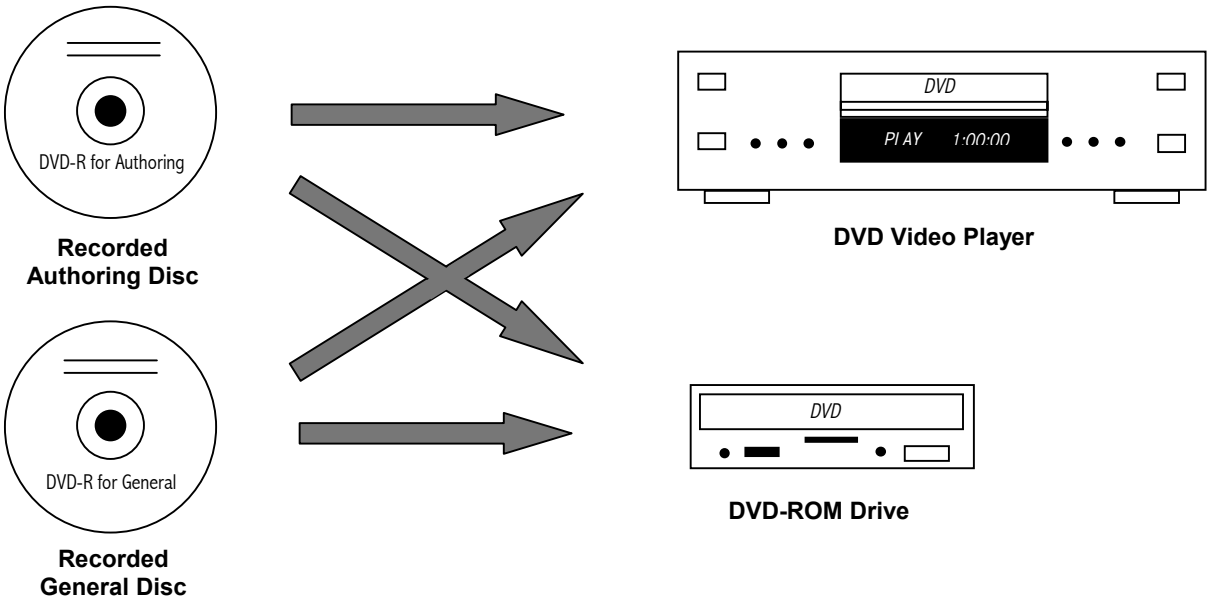
The illustration below illustrates the recording compatibility between the two media types and recording hardware.



Authoring vs. General Recording Compatibility

Playback Compatibility

For playback, there is no compatibility consideration between the two media types. Both Authoring and General DVD-R media can be played back equally well in any DVD video player or DVD-ROM drive that supports DVD-R (most existing models).



Authoring vs. General Playback Compatibility

DVD-R Applications

DVD-R's relatively low cost per megabyte, physical storage efficiency and easy portability of its recording equipment makes the medium applicable to a large variety of uses in virtually all industries.

There are several key applications for DVD-R:

- Home video editing and archiving
- Testing and development
- Program distribution
- Data storage and archival

Home Video Editing and Archiving

A key application for consumer use of DVD-R is the transfer of home movie content to a more robust digital medium. This solves two problems faced by anyone who stores their own video material on videotape: the removal of unwanted content as well as stopping the degradation of recorded signal quality due to the gradual physical deterioration of magnetic tape. Many computer-based tools are now available that can help content owners digitize, edit and add entertainment value to their video material, as well as convert the finished work into a DVD video image file that can be transferred to DVD-R.

DVD-R's compatibility means that the finished home video DVD can then be viewed on standard DVD video players rather than on a computer. The disc can also be shared with others who also own DVD video players.

Testing and Development

Many commercial DVD applications utilize replicated read-only discs that are mass-produced and distributed to a large number of users. Preparation of the content that will be published can be a complex and time consuming process that must be completed accurately to avoid qualitative or functional defects. Compared to the cost of the mastering and set-up efforts required to replicate only one disc, DVD-R provides a far more cost effective method of testing content prior to mass production. A single low cost disc can be quickly written and tested in a representative destination device (video player or ROM drive). In fact, multiple test discs may be required throughout the development process, as published titles are often the collaborative effort of many people.

By providing a means for testing published programs prior to mass replications, DVD-R media can also make a significant contribution to reducing environmental waste products caused by the disposal of unwanted media and packaging.

Program Distribution

The key attributes of low cost and playback compatibility allows DVD-R to be used for small-scale distribution of DVD content. As described in the testing example above, mastering and replication expenses can be prohibitive when only a single disc or very small quantity is required. DVD-R allows discs to be recorded at the desktop level, which can result in very quick turnaround and significantly lower cost.

Some users may not be comfortable with sending sensitive data files or other work in progress to an outside facility for replication, so the ability to maintain continuous in-house control of this information can be crucial. This is particularly true with classified data maintained by government agencies. Confidentiality can be accomplished through the use of DVD-R because it can be maintained as a completely in-house process.

Storage and Archival

DVD-R media provides an archival life expectancy that is equal to or better than CD-R; Pioneer media is rated at greater than 100 years. For this reason, the format is suitable for long-term archival of any information that can be stored digitally. This includes image data, film and video archives, or any other media that need to be easily retrieved by users. DVD-R's much larger capacity is also suitable for very large image files that do not fit onto a single CD-R volume, thus creating new storage opportunities for these assets.

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.

As an example of how DVD-R can reduce overall archival system costs, a 100-disc DVD-ROM jukebox can contain a total of 470 Gbytes, or nearly a half-terabyte of data. If 50 kilobyte image files are written on every disc, a total of 10 million images can be stored and retrieved in an single, compact device. Using CD-R, seven of the same jukebox mechanisms would be required to maintain the same disc-to-drive ratio, which significantly adds to the system cost.

Conclusion

Write-once DVD Recordable provides users with a powerful tool that has exciting applications in both industrial and consumer environments. Pioneer believes that DVD-R is the next logical step forward from the very successful CD-R format in applications that benefit from playback interchangeability and write-once security but inevitably require more capacity. DVD-R is proving to be an indispensable recording medium that can be counted upon to store and deliver digital information reliably and inexpensively.