White paper
Blu-ray Disc Format

General

August 2004

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1.1 The Objective of Blu-ray

The standards for 12-cm optical discs, CDs, DVDs, and Blu-ray rewritable discs (BD-RE Standard) were established in 1982, 1996, and 2002, respectively. The recording capacity required by applications was the important issue when these standards were decided (See Fig.1.1.1). The requirement for CDs was 74 minutes of recording 2-channel audio signals and a capacity of about 800 MB. For DVDs, the requirement as a video disc was the recording of a movie with a length of two hours and fifteen minutes using the SD (Standard Definition) with MPEG-2 compression. The capacity was determined to be 4.7 GB considering the balance with image quality. In the case of the Blu-ray *1) Disc, abbreviated as BD hereafter, a recording of an HDTV digital broadcast greater than two hours is needed since the BS digital broadcast started in 2000 and terrestrial digital broadcast has begun in 2003. It was a big motivation for us to realize the recorder using the optical disc. In a DVD recorder, received and decoded video signals are compressed by an MPEG encoder and then recorded on the disc. To record in the same fashion for an HDTV broadcast, an HDTV MPEG-2 encoder is required. However, such a device for home use has not yet been produced. In the case of BS digital broadcasts, signals are sent as a program stream at a fixed rate, which is 24 Mbps for one HDTV program. In the program stream of BS digital broadcast there is a case that the additional data stream is multiplexed, and it is desirable to record and read the data as is. Fig.1.1.2 shows the recording capacity with the data transfer rate and recording time parameters. Two hours of recording requires a recording capacity of 22 GB or more. This capacity is about 5 times that of DVDs, which cannot achieve this capacity by merely increasing their recording density.

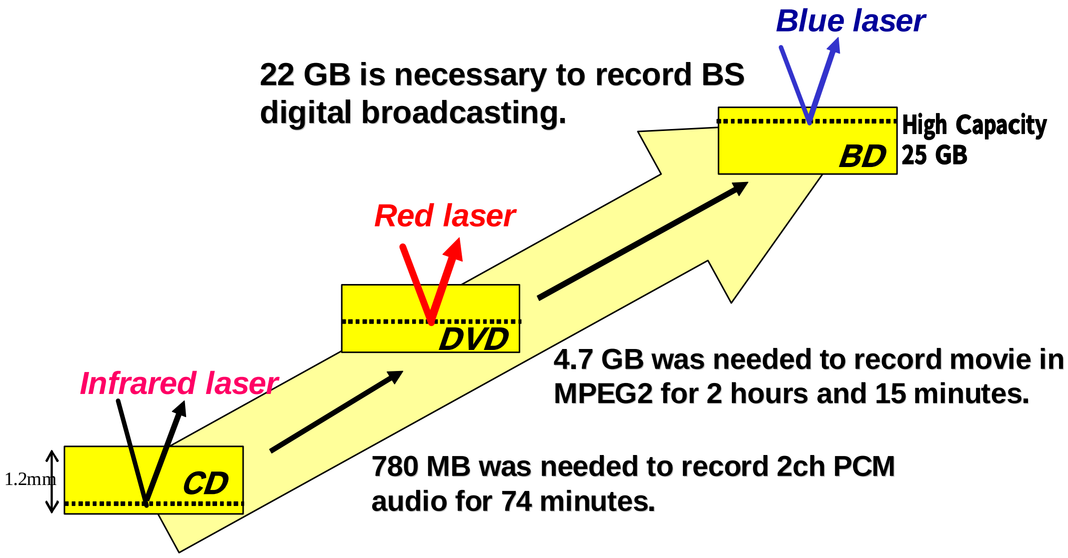


Fig.1.1.1 Evolution of consumer optical discs

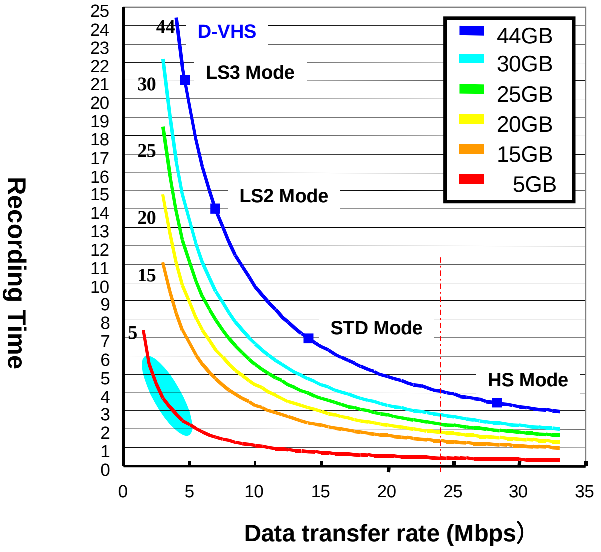


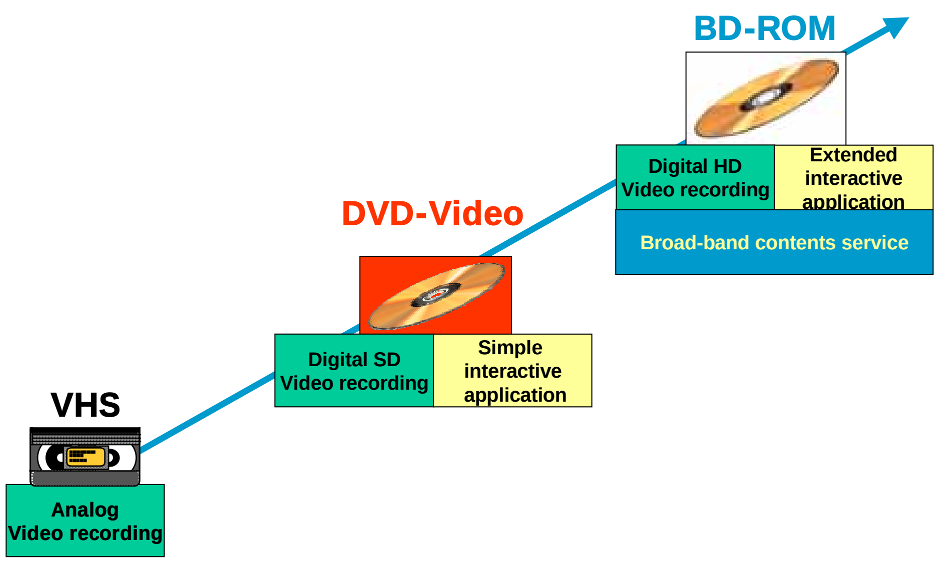
Fig.1.1.2 Relation of Data transfer rate, Recording time and Required capacity

To obtain this capacity we have developed a number of techniques such as: employing a blue-violet laser, increasing the numerical aperture of objective lens, making the optical beam passing substrate thin, 0.1 mm, and evenly thick, using an aberration compensation method of pickup adapted to the substrate thickness and dual layer discs, improving the modulation method, enhancing the ability of the error correction circuit without sacrificing the efficiency, employing the Viterbi decoding method for reading signals and improving the S/N ratio and the inter symbol interference, using the on-groove recording and highly reliable wobbling address system, developing high speed recording phase change media, etc. In addition, the convenient functions of a recording device have also been realized in the application formats.

These techniques are described in this paper. Furthermore, the key concepts of the Blu-ray standard such as the reason for employing 0.1 mm thick transparent layer and a dual layer recording disc will be described in each dedicated chapter. Following the rewritable system, the planning of a read-only system and write-once system has already started.

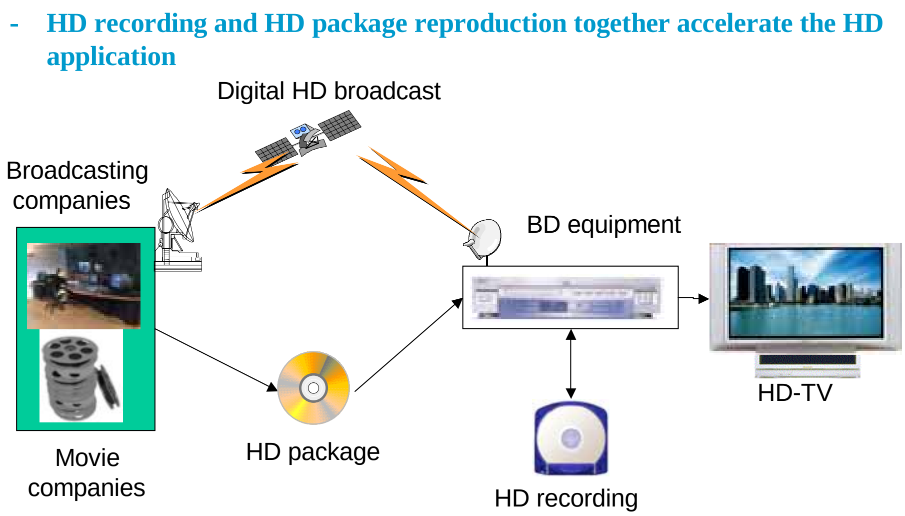
In addition to high picture quality, the introduction of core and new functions is indispensable for the spread of the next generation package media. For example, during the switch from VHS to DVD, digital recording and interactive functions were newly introduced. Consequently, it is anticipated that the specifications of BD-ROM will provide a high performance interactiveness and a connection to broadband services, reflecting the demands of the movie industry (Fig.1.1.3).

Fig.1.1.3 Evolution of the package media for movie application



Recently, the digital HD broadcast started, and PDP and liquid crystal displays with large and high picture quality screens are spreading for home use. The recording of HD digital broadcasts and HD packages with BD-ROM are considered to accelerate this tendency and expected to be the trigger factors for the rapid spread of HD (Fig.1.1.4).

Fig.1.1.4 The driving force to promote HD



* 1) The spelling of "Blu-ray" is not a mistake. The character "e" is intentionally omitted because a daily-used term cannot be registered as a trademark.

1.2 Optimization of the Cover layer Thickness

Roots of a 1.2 mm substrate existed in the video disc.

One of advantages of laser discs has been that they are hardly affected by dirt or dust on the disc surface since information is recorded and read through a cover layer. The first commercial optical disc, which was the videodisc called VLP or Laser Disc, used a 1.2 mm thick transparent substrate, through which information was read. This thickness was determined from conditions such as:

- Deterioration of the S/N ratio due to surface contamination was suppressed to a minimum since it used analog recording,
- A disc of 30 cm in diameter can be molded,
- The disc has sufficient mechanical strength,
- The disc is as thin as possible while satisfying the flatness and optical uniformity.

The last condition is because the thinner the cover layer, the more easily the performance of the objective lens to converge the laser beam can be improved. This convergence performance of the objective lens is expressed by what we call NA (Numerical Aperture), and the diameter of a converging light is inversely proportional to NA (Fig. 1.2.1). Thus NA is required to be as large as possible. However, when the optical axis of the objective lens shift from the perpendicular to the disc surface, a deterioration of the convergence performance (aberration) occurs and its amount grows proportionally to the cube of NA. Since we cannot avoid discs from tilting to some extent from the optical axis of the objective lens due to the bending of discs or inclination of the mounting, and it has prevented the value of NA from increasing.

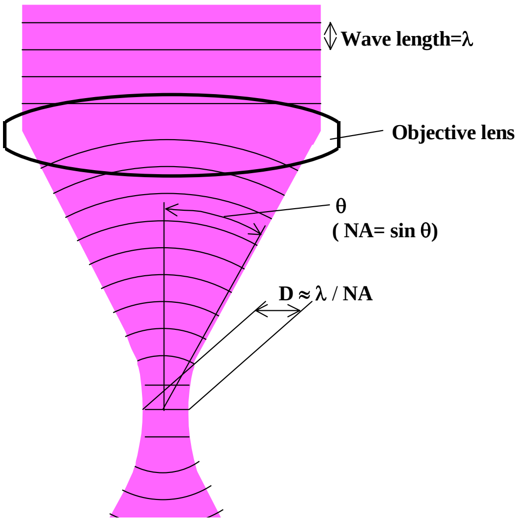


Fig. 1.2.1 NA (Numerical Aperture) is defined as sin(θ). Where θ is half angle of converging light converged by an objective lens. Around 80% of light energy is converged in an area with diameter of λ / NA

On the other hand, an aberration caused by a disc inclination is proportional to the thickness of the cover layer. This aberration was originate in a of the refraction angle error at the cover layer interface resulting from the disc inclination. Further, the amount of blur in the beam spot due to the refraction angle error is proportional to the distance between the disc surface and the focal point (Fig. 1.2.2).

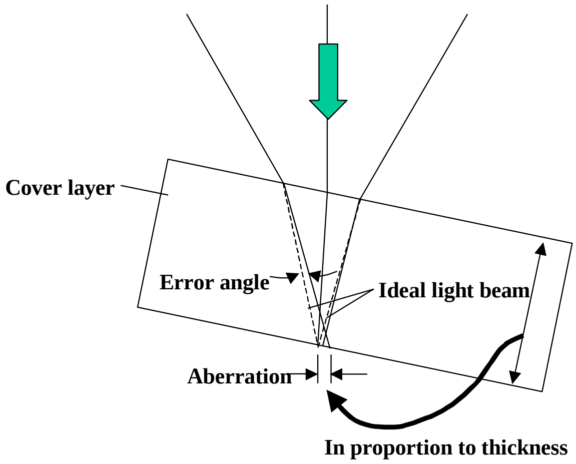


Fig. 1.2.2 When the disc tilts refraction angle error, which is deviation from ideal angle to form an ideal light spot, occurs at the disc surface. This refraction angle error causes aberration at the focal point. Then the aberration is in proportion to the distance between disc surface and the focal point, i.e., the aberration is in proportion to thickness of cover layer.

The Objective Lens is Designed in Accordance with the Cover layer Thickness.

Although the first two conditions, which stated that the cover layer was to be a 1.2 mm thick substrate, are not applicable to CD discs, the same thickness was eventually applied to CD discs. This was because of the great importance placed on the interchangeability of objective lens. Without raising the NA value of the objective lens, discs with a diameter as small as 12 cm could have sufficient capacity for digital audio use.

The interchangeability of the objective lens is generally lost when the thickness of the cover layer changes. This requires more explanation.

An objective lens must converge a laser beam in nearly ideal conditions. Such a laser beam has a spherical wave front in the cover layer and a wave front distorted from a spherical surface in the atmosphere before entering the layer. It is acceptable that the distortion of the spherical wave surface in the atmosphere is made equal to that of light that is spread from a point source placed at the spot where light converges. When a point light source is directed at the information surface of a laser disc, a spherical wave is formed and spread in the cover layer. The wave will be distorted when it enters the atmosphere. This is because the length of optical path from the virtual light source to the interface of the cover layer differs between a beam perpendicular to the interface and ambient beams. Since the difference in optical paths is proportional to the thickness of the cover layer, the thicker the layer is, the greater the amount of distortion from the spherical surface wave in the atmosphere (Fig. 1.2.3).

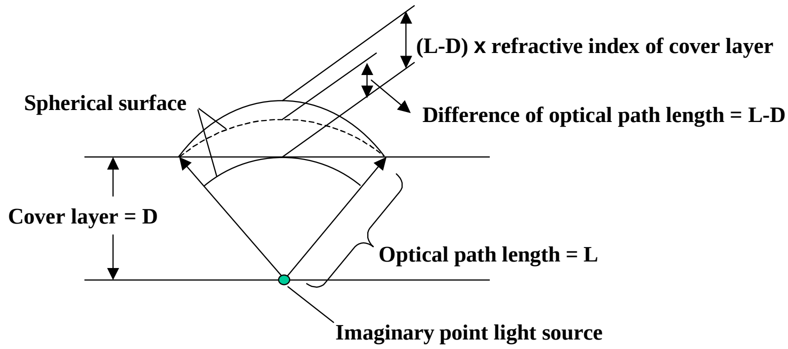


Fig. 1.2.3 A wave front of light diverging from an imaginary light source on the information layer is spherical in the cover layer. But it becomes deformed from spherical surface after getting out of cover layer. When light having this deformed wave front come into the cover layer, it is converged into an ideal light spot.

An objective lens is designed to emit light with this distorted wave front. Because the ideal distortion amount differs with the thickness of cover layer, the design of objective lens also depends on the layer thickness. This is why the conventional thickness of the cover layer tends to be followed even if the format is changed.

Thickness Reduction of the Cover layer

Although a 1.2 mm thickness of the cover layer was adopted when the CD standard was defined, another approach was adopted for DVDs and BDs. This is because the necessary capacity could not be achieved if that particular thickness of the cover layer was used. Therefore, the optimization of the cover layer thickness was examined again in order to gain more capacity.

During digital recording, there's no need for anxiety about the deterioration of the S/N ratio of readout signals, compared with analog recording, as long as the signals can be read without error. In addition, the manufacturing process of 12 cm diameter discs is quite different from that of 30 cm discs. Consequently, there were attempts to reduce the thickness of cover layer as much as possible and increase the NA value of the objective lens as much as possible.

It has been regarded that one of principal advantages of optical discs is that the influence of dust on the disc surface is limited because the beams are defocused for dust on the surface of the cover layer when information is recorded and read. When the cover layer thickness is reduced, the NA value of objective lens can easily be increased, while this defocus effect is sacrificed. Since the cover layer thickness required for the defocus effect is different for digital and analog recordings, a reexamination is needed.

The defocusing effect when light passes through the transmission layer means that by increasing the cross section of incoming laser beam on the surface layer, the influence of small dust is diluted within the large section area of the beam. In other words, although the area influenced by dust is enlarged to entire section of light beam, the signal deterioration is reduced and reading errors are prevented. On the other hand, what we call error correction is generally used as a means to remove reading errors. During this operation, some redundancy data calculated from a large block of data is attached to the block as error check data. After the block is read, the check data is inversely calculated to correct partial errors. This can be compared to an image modification process where a partial defect of a photograph is corrected through estimations using adjacent image data. Through this method, errors are prevented by diluting the influence of partial signal defects in a large-scale data block. It can be said that this error correction method is the electronic version of defocusing by the cover layer. This further suggests that defocusing by the cover layer partially can be replaced by error correction (Fig. 1.2.4). However, there is a problem if the thickness of the cover layer is made nearly zero by raising the error correction capability. This is because the smallest unit of the error correction calculation is one byte, and a very small error such as one bit is practically magnified to a one-byte error. Therefore, defocusing is still desired to prevent small dust from causing bit errors. The thickness of the cover layer for that purpose is about several tens of micrometers.

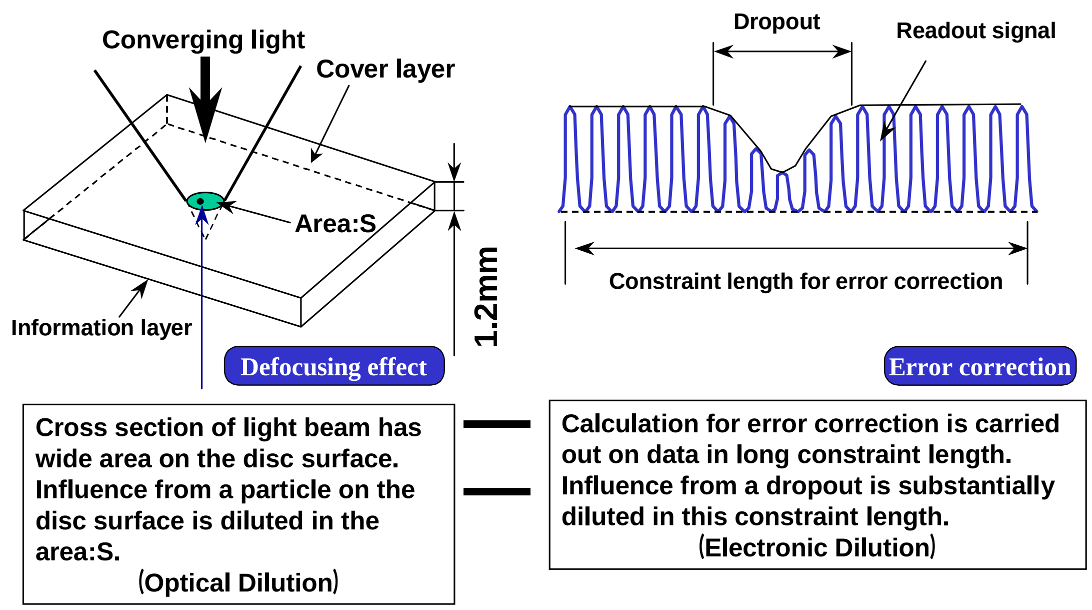


Fig. 1.2.4 Cover layer has a function of optically diluting influence from a particle on the disc surface. Error correction has a function of electronically diluting influence from a dropout. Both of these functions are similar to each other.

In the DVD standard, it was decided that the thickness of cover layer could be as small as 0.6 mm. This thickness could be made by the disc production facilities of those days, because the same mechanical strength as a CD could be obtained by sticking two pieces together.

For the purpose of BDs, this thickness was reconsidered with the essential condition to realize a 23 GB capacity, which is necessary to record a bit stream of Japanese BS digital HD broadcast for two hours.

At first, it was natural to consider using the same production facilities as DVDs, that is, to employ a thickness of 0.6 mm. However, the capacity could only reach around 12 GB by changing the wavelength from red (650 nm) to the blue (405 nm). As a further disadvantage, when there's an incline in the disc, the magnitude of aberrations increases in inverse proportion to the wavelength. To suppress this aberration, the NA value of the objective lens must be reduced. In the mass-produced record type DVD, NA is 0.65 at most, even if a tilt servo controlling the tilt angle of the optical pickup to the disc is used. As described before, the aberration when a disc is inclined is proportional to the cube of NA. To cancel the increase in aberrations due to shortening of the wavelength, NA should be reduced to around 0.55. In this case, the recording capacity is lowered to around 10 GB, far smaller than the 23 GB allowed by one of the newest reading technologies such as PRML. Although the narrowing of the track pitch was considered while suppressing crosstalk by recording in and between the guide grooves, the influence of heat conduction became relatively large when the track pitch was reduced. Further, the problem where heat conduction erased the next track's information could not be overcome.

Thus, we tried to solve this problem by using dual layer recording. However, since the area of the beam spot for an NA value of 0.6 is almost double that for a value of 0.85, the power density of the spot decreases by half, and it has been revealed that the output power of blue laser requires more than 100 mW for dual layer recording. To achieve dual layer recording with a readily available blue laser, it is necessary to increase the NA value by further reducing the thickness of the cover layer.

To determine the thickness of the cover layer for BD, we had to either solve all of above-mentioned problems for a 0.6 mm thickness, or reduce the thickness. After all, there was no other choice than the latter because we could not find solutions for the above-mentioned problems.

As describe before, the required thickness of the cover layer is several 10 μm or more. Considering the balance of the ease of production and the possibility of reducing costs in the future, a thickness of 100 μm was adopted as a base value for the cover layer. By making the thickness of cover layer 100 μm, the NA value of the objective lens could be raised to 0.85. For a capacity of 25 GB, the tilt margin was confirmed as equal to that of the DVD.

Compatibility was Obtained Using the Difference of Wavelengths

As described above, the thickness of the cover layer has been inevitably changed each time to achieve the required capacity. Therefore, the problem has always been how to maintain the compatibility with past standards. The most accepted method is to switch the objective lens. This was actually carried out in the DVD equipments for compatibility with CDs. At the time, many proposals to maintain the compatibility with one objective lens were presented. It is required to have an infrared laser with a 780 nm wavelength for reading CD-Rs, and a difference of wavelength with red laser for DVD (650 nm wavelength) is utilized for the compatibility. Since the NA value of the objective lens for CDs is 0.45, which is smaller than that for DVDs (0.6), an optical device was introduced which lets a 780 nm wavelength beam pass through only the part of the objective lens corresponding to an NA value of 0.45 and which has a high dependency on the wavelength. This allowed the objective lens to perform in optimum conditions for a 1.2 mm thick cover layer. Through this method, a difference of 0.6mm in the cover layer thickness was absorbed within the 0.45 NA range of the objective lens.

A red laser is also required to be installed for BDs in order to guarantee compatibility with DVDs. Gold or silicone is used for the semitransparent film layer as the first layer of a dual layer disc. These materials have a high selectivity of wavelength; the former prevents the reading of a further layer because it absorbs blue light and the latter prevents reading of a nearer layer because it does not reflect blue light.

Installation of red laser with blue laser can be utilized to realize compatibility with DVD with one objective lens like as compatibility between DVD and CD.

To realize compatibility between BD and DVD, a difference of 0.6mm in the cover layer thickness has to be absorbed the 0.6 NA range of the objective lens. Although the conditions for BD/DVD are more severe than for CD/DVD, it is a matter of degree. In fact, at the 2002 CE show, a prototype that achieved compatibility of BD/DVD with one objective lens was demonstrated. If two objective lenses are used and switched, BD/DVD compatibility can be easily achieved.

Although the difference in wavelength has been used to respond to different thicknesses of the cover layer with one objective lens, this is difficult to achieve with the same wavelength. For BD, the standard of rewritable discs (BD-RE Standard) will be established first, and it is very natural that in the upcoming standards for Read-only type and Write-once type discs, a cover layer thickness of 0.1 mm will be adopted (Fig. 1.2.5).

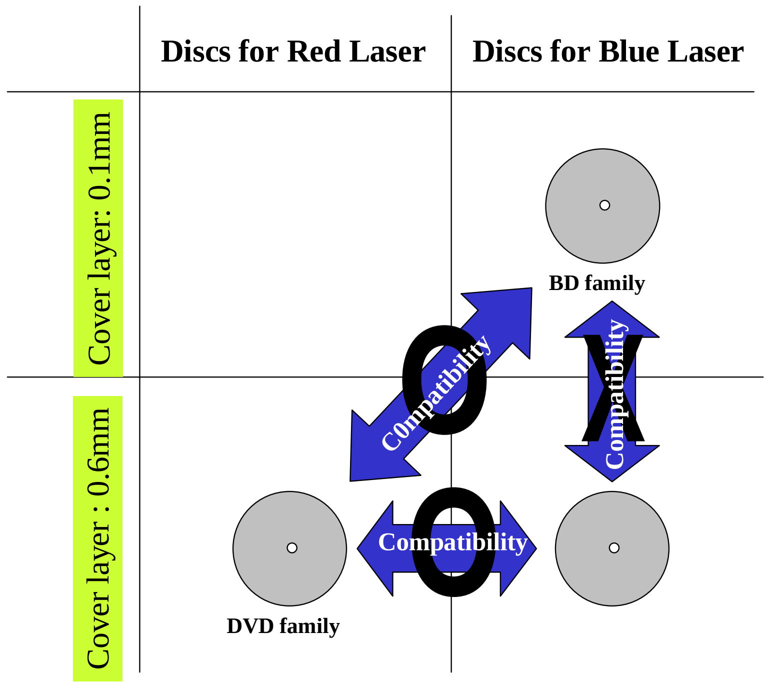


Fig. 1.2.5 0.1mm thick cover layer is selected for BD-RE to satisfy strong demand of sufficient capacity. BD-ROM inevitably select the same thickness for cover layer because changing the thickness of cover layer will be fatal mistake for compatibility.

1.3 Blu-ray Format

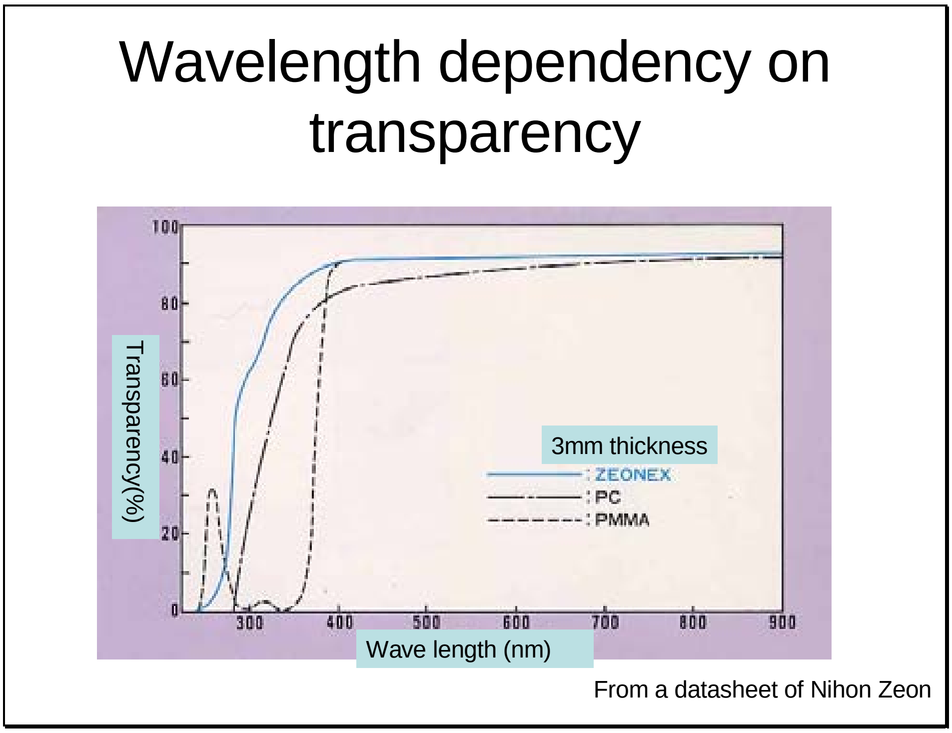
1.3.1 Physical Format

The physical format of the Blu-ray disc system, which follows the 780 nm CD and the 650 nm DVD, will be the last optical disc system using visible light. Based on this information, we decided to use the following basic optical disc parameters, knowing that the development wasn't complete, in order to maintain the expectation of future progress:

the shortest wavelength is 400 nm,
the highest value of NA is 0.85,
the reasonable substrate thickness of 0.1mm,
and the wavelength is 400 nm (blue-violet).

A shorter wavelength was examined, but 400 nm was finally selected because a shorter wavelength causes a durability problem in the plastics of the Substrate Incident.

(Footnote: Durability of plastics for optical discs in a ultra-violet range, from a catalog of Nippon Zeon Co.)
Fig. 1.3.1.1



As shown in the figure many plastics for optical discs or optical devices suddenly show a poor transmission factor when under 400 nm. Furthermore, some are deteriorated by a phenomenon similar to sunburn.

The wavelength fluctuation during production must be considered. The tolerance is set so that the wavelength does not fall below 400 nm. In conventional cases, the wavelength is temperature dependent (for 780 nm the dependency = ca. 0.3 mm/deg.; for 650 nm ca. 0.25 nm/deg.). In particular, when recorded on a film with a pigment series recording sensitivity dependent on wavelength, a number of developments were needed. However, a 400 nm GaN laser seems to have a wavelength with a very small temperature dependency compared with 780 nm and 650 nm lasers.

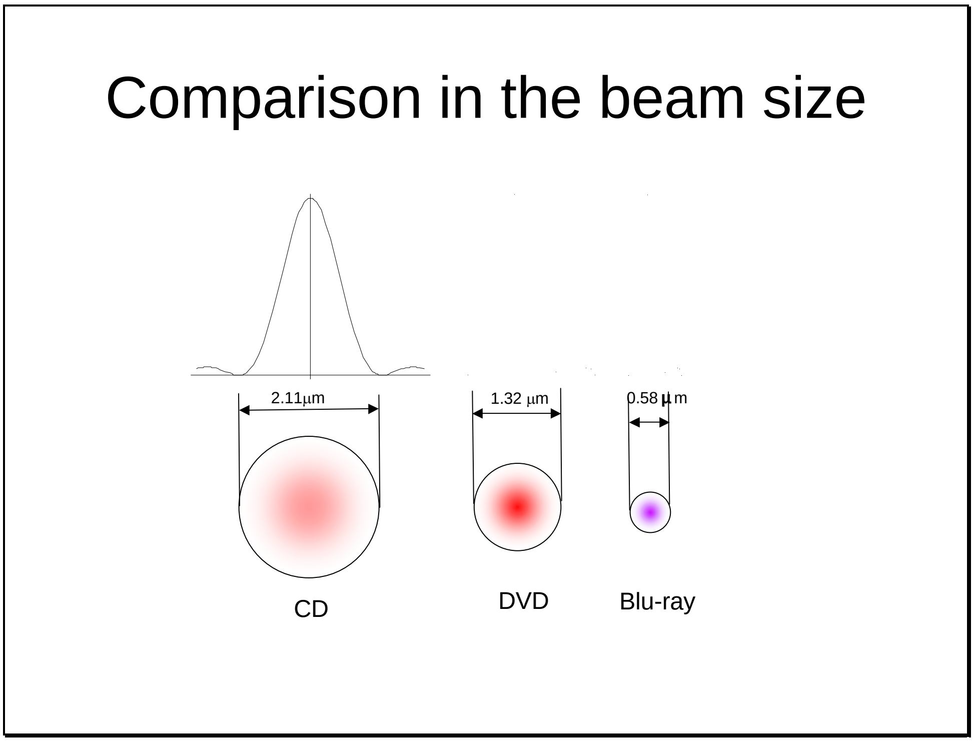
The diameter of the concentrated beam is defined by the NA value of the objective lens and the wavelength, as in the following expression:

Beam Diameter = α * λ/NA
λ = wavelength, α = a constant

As seen in the above expression, the larger NA is, the smaller the beam diameter, although NA does not exceed 1.0 in the atmosphere. The largest NA values of CDs and DVDs obtainable during mass production were 0.45 and 0.6, respectively. For Blu-ray, an objective lens with an NA value of 0.85 was first made by laying two lenses, which can be manufactured with the technique for the 0.6 class NA, one on top of another. The working distance of this lens can be guaranteed at 0.14 mm at most, and it was often said that the lens would hit the disc, unlike CDs or DVDs. However, it was only in the early stages of the CD that using a lens with a diameter as large as 4.5 mm was possible and that the lens never physically hit the disc considering its moving distance. Because of the present compact designs, the lens can sometimes hit the disc both for CDs and DVDs. Therefore, we can't ignore the fact that the smaller the working distance, the higher the probability of a hit. However, some preventive measures can be taken by the hardware to sense danger and activate a protection circuit to prevent a hit, or a damper can be attached in case. In addition, JVC and other manufactures have recently started to design and prototype a stemma lens that can secure a working distance of approximately 0.5 mm. In all practicality, this distance will not cause any problem.

As described later, due to this large value of NA, the margin in the focus direction, which is affected by the square of NA, and the margin in the normal direction of the cover layer, which is affected by NA to the fourth power, must be considered. For optical recording, a large NA value is an advantage. Because of smaller spot size, it can be plainly said that the power necessary for recording by a Blu-ray system with a 400 nm wavelength and 0.85 NA is only 1/4 of a DVD system with a 650 nm wavelength and 0.6 NA.

(Footnote: Fig. 1.3.1.2)



A comparison of diameter and intensity distribution of a concentrated beam on a disc between a CD and a DVD is shown in the figure. The diameter used in the comparison is the first ring diameter when the Rim condition is satisfied at 100%. Since the integral of this waveform is the recording energy on an optical media, the energy is supposed to be input to the objective lens. Assuming the recording on the media begins with the same energy, the smaller the diameter (that is, the higher the density), the less the necessary laser power. This is one of reasons why Blu-ray requires only 5 mW for recording while CDs and DVDs require several tens of mW for a similar recording speed.

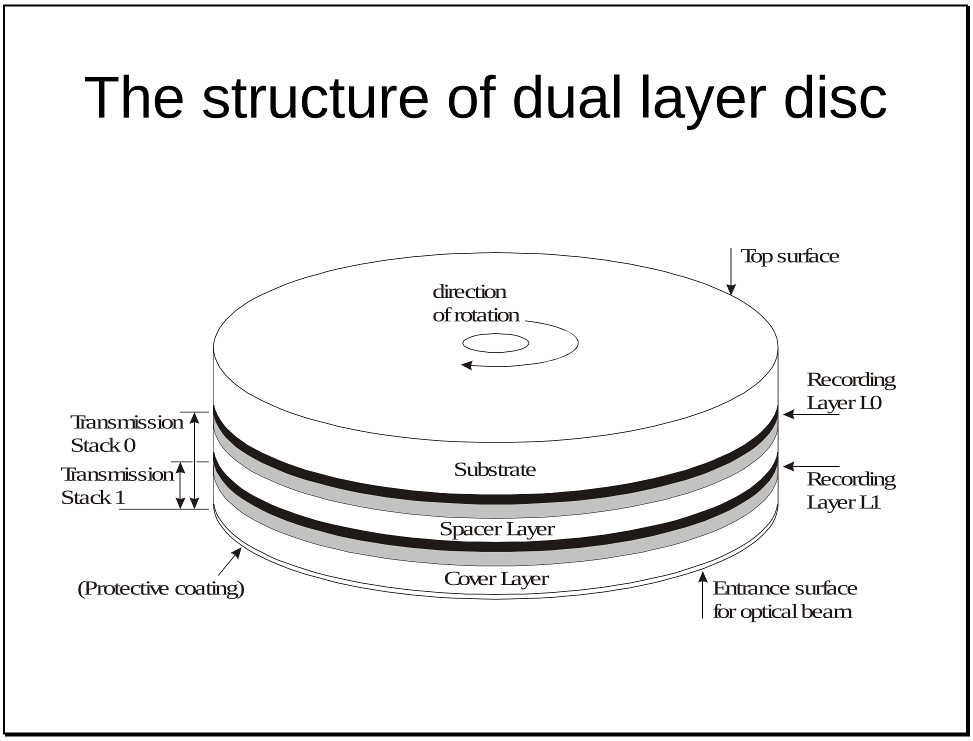
This will make room for recording power when multi-layer recording or high-speed recording is developed in the future.

Thickness of the Cover layer

There is a reason why the cube of NA was not discussed above. With optical discs, the cube of NA is referred to as ""skew"", and it dominates the margin for the shift from 90 degrees of the angle between the disc surface and optical axis of pickup. For Blu-ray discs, this quantity was set to around ±0.75 degrees, the same as for DVDs. This is the reason why the cover layer of Blu-ray is 100 μm thick.

As described before, one of the Blu-ray features is its applicability to multi-layer discs. Blu-ray discs are so designed from the beginning so that the format can be adapted to multi-layer discs.

Fig. 1.3.1.3



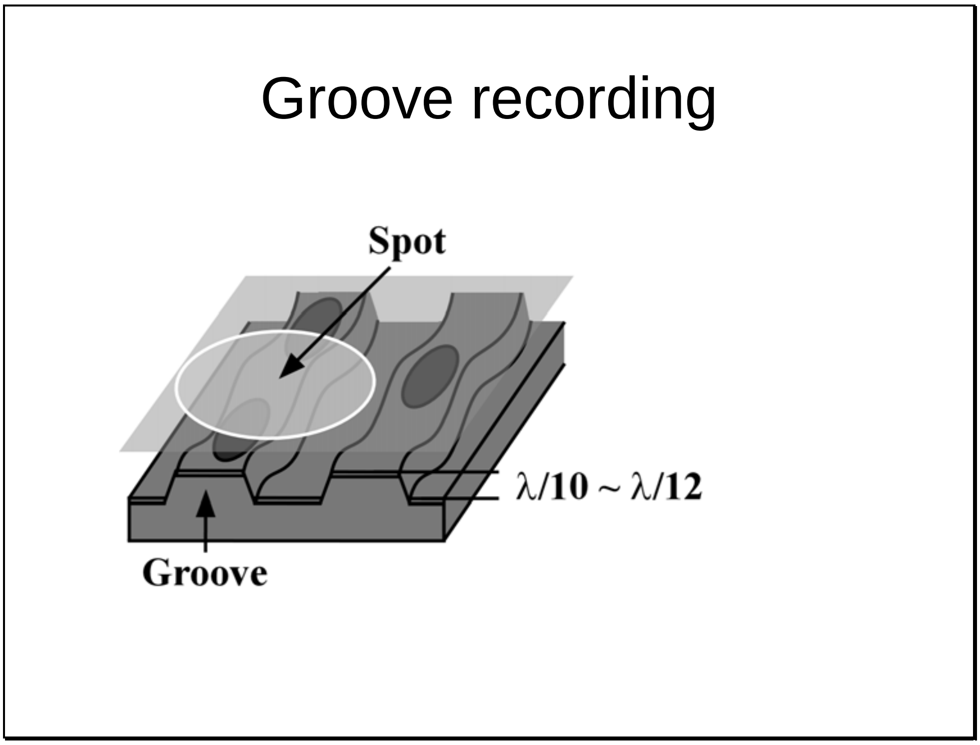
In this case, L1 is defined by the L0 plane sandwiched around a 25 μm thick buffer layer, and the thickness of the cover layer L1 is around 75 μm. This policy is still unchanged today, and the basic thickness of a Blu-ray layer is 100 μm, a thickness that will be kept if multi-layer is adopted.

Since Blu-ray employs different wavelengths, NA values, and cover layer thicknesses from CDs and DVDs, it will be necessary to design and develop a compatible pickup for a system interchangeable with CDs and DVDs for recording and playing back. This is the same problem encountered for reading and writing CDs when a recording/playing back device for DVDs was planned. Some successful studies have already been released.

Groove Format

Physical structure of a Blu-ray disc is a groove recording as shown the following figure.

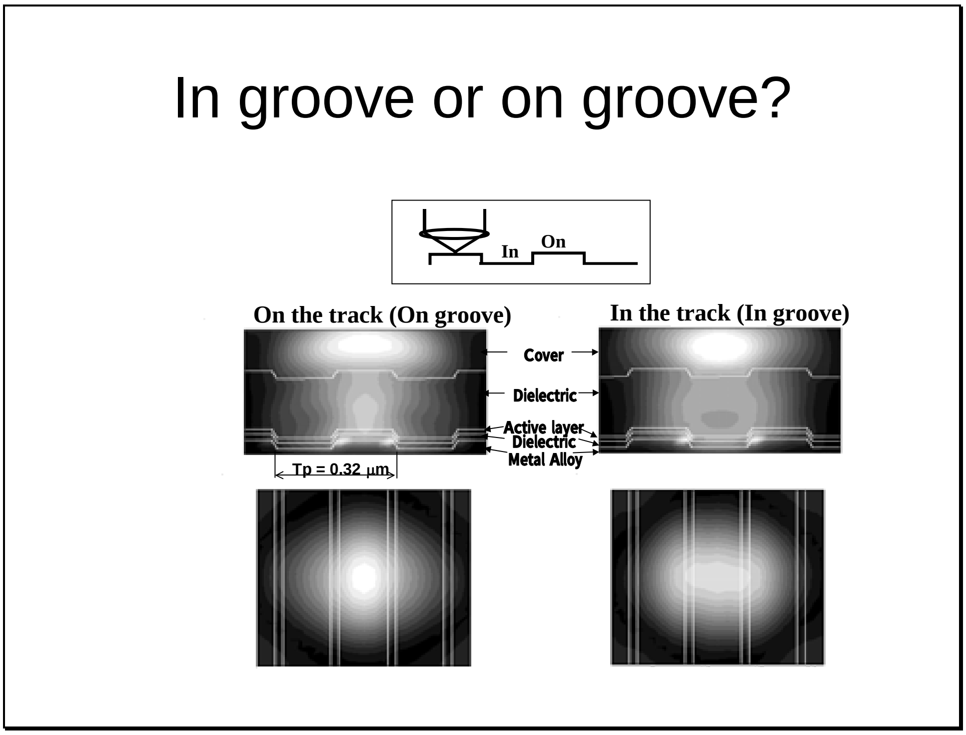
Fig. 1.3.1.4



There were many opinions and study results concerning this, and it would be one of reasons why several recording formats were defined for DVDs. Fortunately, all the of the companies which dealt with the three DVD recording systems have joined the Blu-ray development group; all the studies have been reexamined and one physical format has been established. Furthermore, it was quite helpful that the most comprehensive erasable system was introduced first, unlike the cases for the CD and DVD in which the ROM came first and the other systems had to be adapted to it. It was natural that the master design of blue-ray was made compatible for both home-use devices and computer peripheral devices. Therefore, the structure of the data unit arrangement was made, leaving a gap between blocks as with DVD-RAM. In addition, as in the past, to include ROM and R media into the vision, the groove recording system was employed instead of land/groove recording in order to respond to these three kinds of recording media. This idea had also been adopted for CD-R, RW, DVD-RW, and +RW systems. One of reasons why discs of different track pitch coexist in the family is to prevent losing the freedom of the optical pickup design. At first, the mastering seemed to be extremely difficult for a 0.32 μm track pitch; the groove itself must be formed with about a half the precision of 0.32 μm. Besides, since it would be necessary in the future to make a ROM type disc whose pit must be formed by embossing, intensive developments have been carried out. As a result, mastering by electron beam (EB) was enabled first, and subsequently mastering by deep UV was enabled in the 25 GB class of Blu-ray. Furthermore, the mastering technology for Blu-ray using a beam with a wavelength of 400 nm was even developed, removing all obstacles against groove recording. A stamping technology for this density has already been established.

Furthermore, taking a high NA value such as 0.85 into account, the on-groove method was selected instead of in-groove. Although it is not easy to explain this in a scalar field, on-grove was selected based on simulation results shown in the figure and actual experiments.

Fig. 1.3.1.5



As seen in the in-groove figure for these parameters, the power of the recording beam runs off in a radial direction. A narrow track pitch will make the land/groove recording system, which records both on groove and in groove, difficult.

At first, there were doubts whether or not the R media could respond to an on-groove system. However, as explained in Part 4, an R media that could respond to such a structure has already been developed, and an on-groove system can be applied to derivative formats such as CD and DVD.

Addressing Method

Blank addressing, when groove recording is adopted, is formed only by the wobble method. This concept is close to that employed for +RW. Although addressing with a pit was first examined, an addressing system without a pit was finally chosen considering that the recording density must be increased to make room for the header with the pit and that in a multi-layer disc, the pit address has a great influence on the recording in other layers. The modulation technique wobbling in the radial direction is based on MSK (minimum shift keying) and formatted in blocks of 64 kB. The basic Wobble frequency is around 5 µm, and 0 and 1 are expressed as the position where the sinusoidal wave is modulated by the MSK rule. Although the modulation energy of MSK is large, it is easily influenced by defects because information is localized. For that, a signal called STW (Saw Tooth Wobble) is used in form of multiplying to MSK. The STW adds secondary harmonics to all sinusoidal waves of Wobble, and 0 and 1 of the address data correspond to the polarity of added secondary harmonics. Since the energy of the STW signal is distributed in space unlike that of MSK, and detected by integration, it is robust against partial defects. The detection of an address in the Blu-ray system is robust because of the use of both MSK and STW.

Error Correction Method

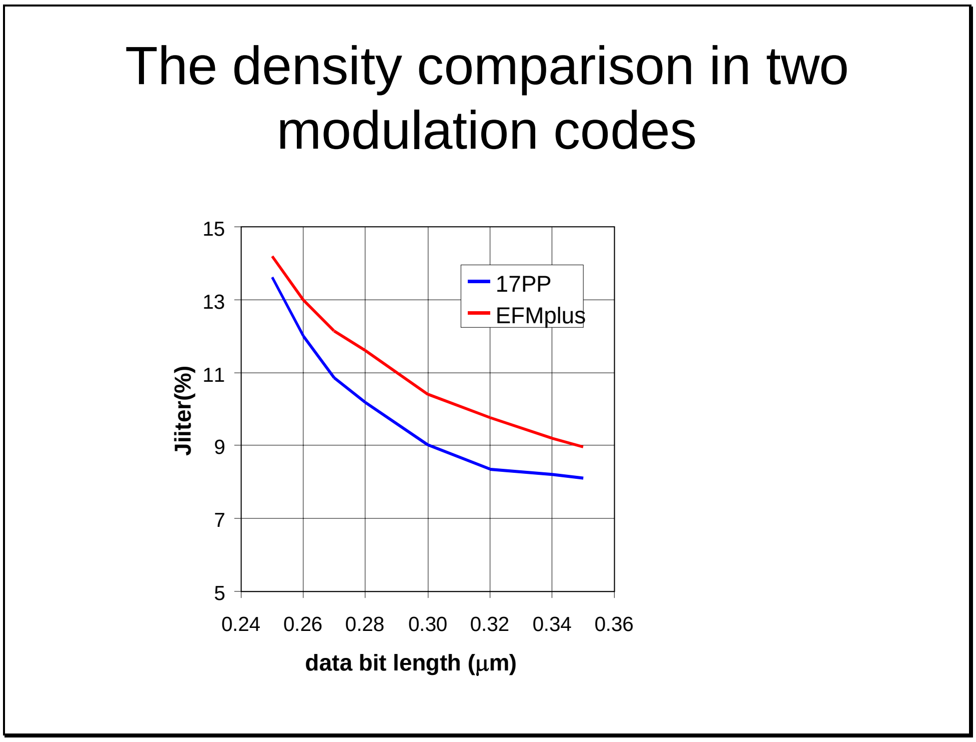
An error correction method must be designed in accordance with the error distribution of a cover layer thickness of 100 µm. This operation started by statistically treating the error distribution when the actual disc structure was subjected to a dust test and played back, and by modeling the distribution. As a result, what came out were short bursting errors by dust or scratches, and so-called picket codes with a structure matching long bursting errors that sometimes occur. This is made by combining a deep interleave to a long distance code, a kind of Reed-Solomon Code with a size of 64 kB, and then adding a burst indicator called

BIS.

Modulation Technique

The modulation technique of the main channel recorded along a track is called 1.7 PP (Parity preserve/Prohibit RMTR). This is the so-called d=1 code. As the examination results show, assuming that a rewritable disc is taken first, the d=1 code was employed this time around because the wide detection window is advantageous as compared with the d=2 code used for CDs and DVDs (see the figure below). Further, a low channel clock can be used when recording at high speed.

Fig. 1.3.1.6



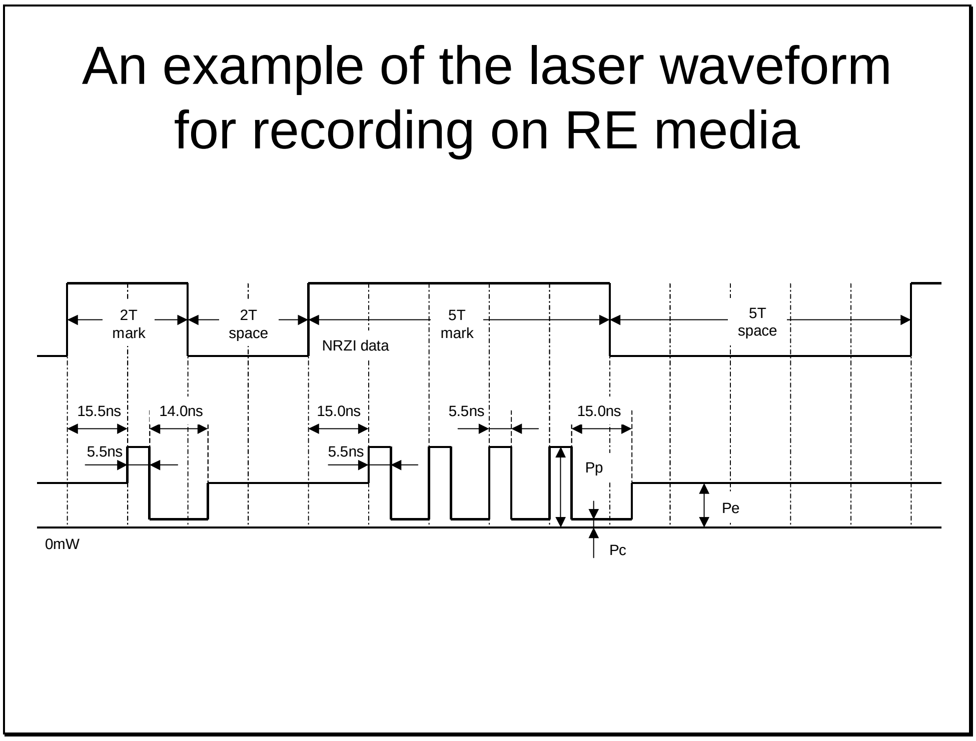
This data was obtained from a past experiment using a wavelength of 650 nm. Although the horizontal axis must be transformed to the density of Blu-ray, this tendency was obtained when recorded and played back on a phase changing film. The use of d =1 means that non-linear equalizer and PRML detection represented by limit equalizer act more effectively, and this type of signal processing is more important in Blu-ray compared with CD and DVD. Although the mastering and embossing ROM pit seemed difficult at first because the minimum pit is shorter than that of d=2, those processes were eventually successful thanks to the progress of the mastering technology when the capacity is around 25 GB. The parity preserve means that DC balance of signals after modulation can be evaluated without looking at the 0-1 series, and it is effective in reducing the hardware load. Prohibit RMTR (Repeated Minimum Transition Runlength) is limited not to run seven or more in 1-7pp by preventing long run of minimum length (what represented by 101 after modulation).

Recording Medium and Writing Strategy

Blu-ray uses phase change film as a recording media. Phase change film is classified into two types: a familiar example is what's called the GST (GeSbTe stoichiometrical composition) type used for DVD-RAM and the other is the eutectic type used for CD-RW, DVD-RW, and +RW. Each type has its advantages in repeat recording characteristics and high-speed recording. For Blu-ray, the recording pattern was devised to allow the application of both types of phase films. Both media were also improved so that a recording pattern of the same type can be used with a predetermined density and a range of almost the same power.

A recorded pattern is shown in the figure. It's a waveform for recording a pit including two pulses of the channel clock, which is the smallest pit length, and a waveform for recording a longer pit including five pulses.

Fig. 1.3.1.7



In BD-RE, the largest recording power at 36 Mbps is 5.2 mW (10.4 mW for dual layers). This was explained previously where a high NA value suppressed the power at this level, even for 36 Mbps.

1.3.2 Outline of the File System Application Format

The BD-RE standard consists of three parts: Part 1 (Physical), Part 2 (File System), and Part 3 (Application). Abstracts are explained here on the application and the file system.

1.3.2.1 Application Format

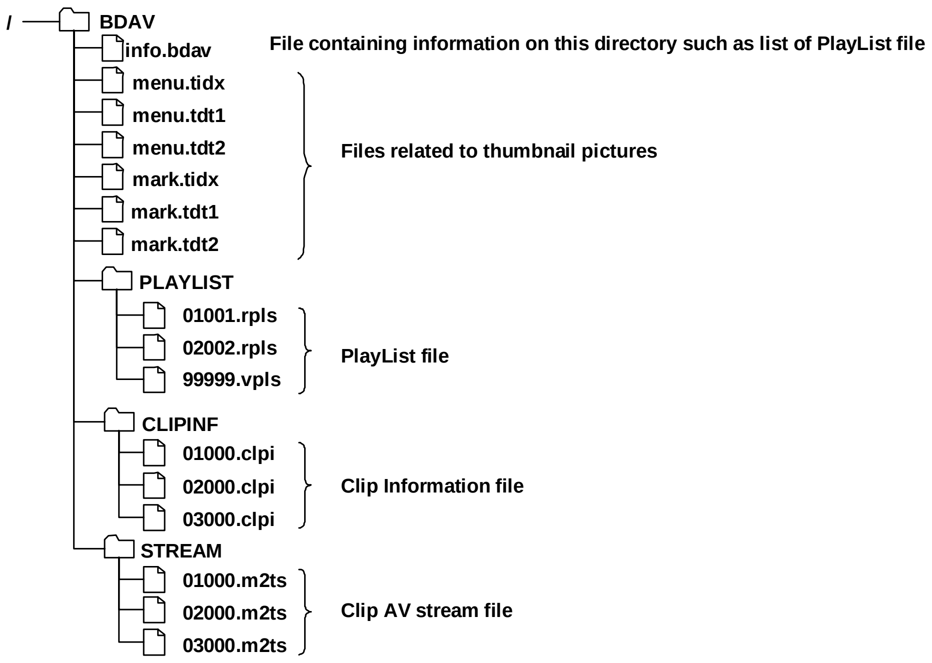
First, the function of the application format is described.

Digital Broadcasting Direct Recording Function

This recording function enables the recording of not only digital broadcast image data without destroying the image quality, but also of data broadcast data and multi-channel sound data altogether. To this end, this format employs the MPEG-2TS (Transport Stream), used by digital broadcasts, as a stream type for recording.

Received MPEG-2TS data is recorded on a disc as a Clip AV stream file (Fig. 1.3.2.1.1).

Fig. 1.3.2.1.1



Random Access High-speed Playback Function

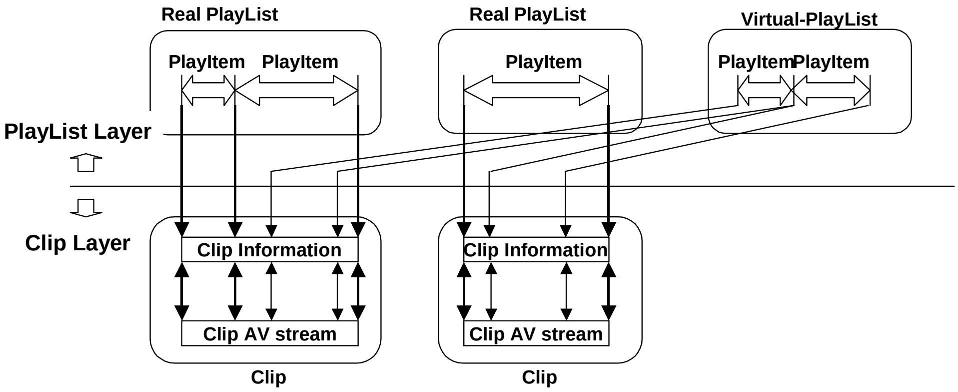
To achieve a function that enables random access to a desired scene in MPEG-2TS and high-speed playback, tables to obtain the record position of data corresponding to a playback time requested by the user are provided for each Clip AV stream file. The tables are stored in the Clip Information File shown in Fig. 1.3.2.1.1.

Editing and Marking Function

The PlayList file is provided for removing unnecessary scenes without copying or transferring recorded data like tape media, and editing material recorded on the disc without processing the original image (Fig. 1.3.2.1.1).

The PlayList file holds the playback order information necessary to designate what part of what Clip AV stream is played back (Fig. 1.3.2.1.2).

Fig. 1.3.2.1.2



The PlayList file also holds bookmark information to enable direct access to a favorite scene.

<u>Contents Search Function</u>

In each thumbnail related file shown in Fig. 1.3.2.1.1, thumbnails (representing a scaled-down version of picture) of the PlayList file and bookmarked scenes are stored. This enables the search for recorded contents and bookmarks by viewing thumbnail images.

1.3.2.2 File System Format

Main functions of the file system are described next.

<u>High-speed Response</u>

To shorten the response as much as possible from the time the disc is inserted until recording/playing back becomes ready, files other than Clip AV stream files are stored closely in certain area on the disc.

<u>High Reliability</u>

Even if stored data becomes impossible to read due to scratches or dust, cases of lost recorded contents should be avoided as much as possible.

Therefore, the file system has a mechanism that always copies the PlayList files, part of the thumbnail related files, Clip Information files, etc. to another recording area for backup.

1.3.3 Principal BD Specifications

What is described above is summarized in Table 1.3.3.1.

Table 1.3.3.1 Specifications of BD

Capacity	23.3／25／27GB (single layer)
Wave length of the laser	405nm
Numerical Aperture of the objective lens	0.85
Data transfer rate	36Mbps
Diameter of the disc	120mm
Thickness of the disc	1.2mm
Diameter of the center hole	15mm
Recording method	Phase change
Signal modulation	1-7PP
Data track	Groove recording
Addressing method	Wobble
Visual data	MPEG-2 video
Audio data	AC3、MPEG-1- Layer2、Others
AV multiplex method	MPEG-2 Transport Stream

The features of the BD format are summarized below.

* BD achieved a recording density five times greater than that of DVD, which uses a red laser, by adopting a blue laser and a high NA objective lens.

* A light transmission protection layer as thin as 0.1 mm, peculiar to BD, is determined to achieve a tolerance similar to the conventional one against disc inclination even in the case of a high-NA objective lens.

* Because the protection layer is thinner than a conventional disc, an error correction method superior to conventional method is used, making up for the weaknesses caused by a lesser thickness.

* A dual layer BD disc has also been defined for a future increase in capacity. Doubling the capacity will enable wider applications in the future.

* BD has the same shape as conventional CDs and DVDs. Considerations have been made for a chucking system which could provide mechanical interchangeability with conventional discs.

* The modulation technique for the signal is (1-7) modulation. To withhold the DC component of the signal, a new system called 1-7PP has been developed.

* As with conventional CDs and DVDs, BD also plans to provide all types of playback including the read-only type, write-once type, and the rewritable type. The rewritable type has already been standardized, and the format is defined so that all three types are interchangeable.

* The track format is groove recording. This is a result of consideration for interchangeability.

* The address format is the wobble type, which has meandering grooves. By simultaneously applying two types of modulation, an extremely high reliability has been achieved. Similarly to the data error correction method, BD also has a built-in function for a stable operation.

* The image recording method of BD is MPEG-2. This was chosen from the viewpoint of interchangeability of a current contents format.

* Sound recording method is the same as the most widely used one.

* BD employs the MPEG-2 transport stream recording method. This enables flexible editing of a digital broadcast that is recorded as is and where the data can be edited just by rewriting the playback stream. Although it is quite natural, a function for high-speed and easy-to use retrieval is built in.

BD parameters are defined with a good balance of conventional and new technologies in the best possible manner considering requests from the current market demands, interchangeability, and expandability in the future.

1.4. Dual layer Disc

With regard to the dual layer DVDs, read-only (ROM) disc is specified. However, in the Blu-ray (BD) standards, dual layer system is also defined for rewritable type discs. To achieve the dual layer disc, many new techniques such as super-thin recording films and assembly processes are needed. It can be said that continuous developments since 1994 produced results, i.e. the dual layer BD 1) 2). BD provides large recording capacities such as 46.6/50/54 GB (23.3/25/27 GB per layer). More than 4 hours of HDTV and more than 20 hours of SDTV can be recorded respectively. In addition, since recording and playback can be done from one side, user does not have to turn the disc over in the drive.

Fig. 1.4.1 shows a schematic drawing of the dual layer BD disc. In the BD standard, an information recording layer 100 μm away from the laser incident plane is defined as the L0 layer, and another information recording layer 75 μm away is called as the L1 layer. A phase change material is used as the recording media because of prior experience with DVD-RAM, DVD-RW, etc.

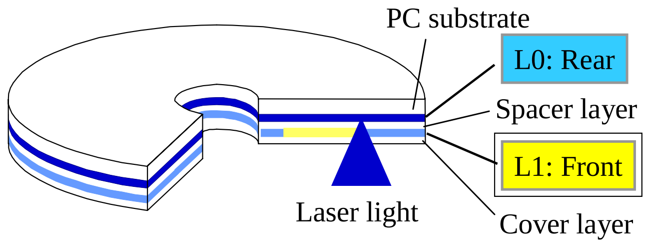


Fig. 1.4.1 Dual layer disc.

Fig. 1.4.2 is a comparison of the structures of the DVD (ROM) and BD dual layer discs. With the DVD, the rear and the front layers are formed separately on two substrates and then, the substrates are attached one on top of another with a UV-hardening resin adhesive. Because each substrate is 0.6 mm thick, a guide groove for tracking can be formed independently. On the other hand, in BD, the rear layer consisting of multi-layered films is formed on a 1.1 mm thick polycarbonate substrate with a guide groove for tracking, then the 25 μm thick spacer layer made of resin is formed. The front layer is formed on it, and finally the 75 μm thick cover layer is formed. The cover layer is too thin to form a guide groove. The first technological hurdle for BD is how to form this guide groove. A suggested forming method specifies that a guide groove for the front layer is transcribed on the spacer layer side like a stamping process 3).

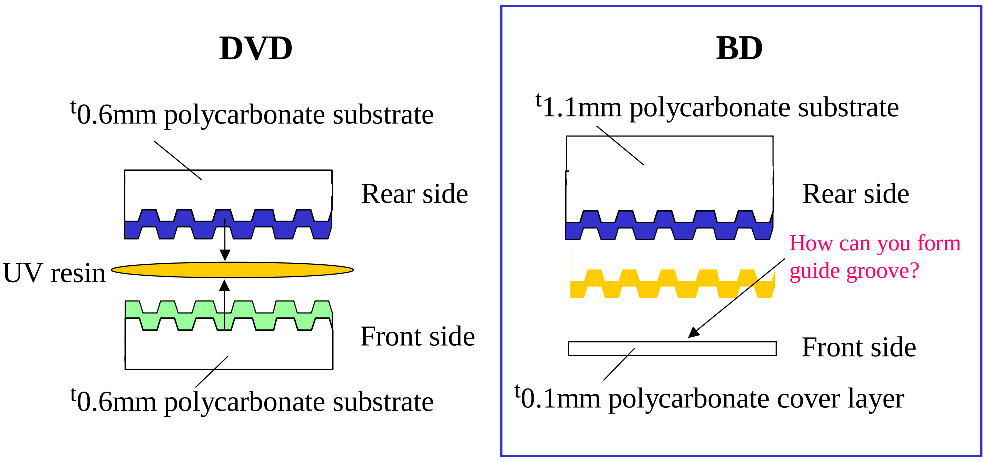


Fig. 1.4.2 Structural comparison between DVD and BD dual layer disc.

The second technological hurdle for the dual layer BD disc is the front recording layer. The following conditions are specified for the front layer (See Fig. 1.4.3).

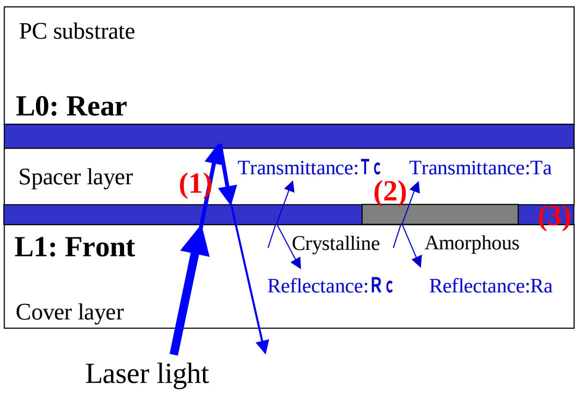


Fig. 1.4.3 The necessary condition on optical property of L1 layer:
1) Ta=Tc>50% and 2) large difference between Rc and Ra.

(1) Transmittance

Because in the dual layer disc the rear layer is recorded through the front layer, it is important that the front layer has a sufficiently large transmittance. It is natural that the front layer itself should be recorded and read with certain light power, therefore the target value of its transmittance is 50% to share light between both layers.

(2) The transmittance should not change before and after recording.

Since BD assumes random access recording, sometimes the rear layer is recorded or read while there are recorded areas and unrecorded areas mixed on the front layer. If the transmittances change depending on whether or not the area is recorded, the intensity of passed beams fluctuates and negatively influences the recording/reading of the rear layer. It is therefore desirable that the transmittance does not change between recorded and unrecorded states. Selection of the recording film material and the design of the multi-layer film are important.

(3) Balance of the cooling speed and crystallization speed

Phase change material becomes amorphous after high-power laser heating during recording followed by quick cooling and crystallizes with middle-power heating when being erased. To make the front layer semi-transparent, the reflection film and recording film tend to be thinner compared with conventional discs. However, there are problems with the former, where the cooling speed decreases after melting, and for the latter, the crystallization speed decreases.

In addition, it is desirable for the rear layer to be the same as a single layer considering the efficiency of development and production.

In consideration of the above-mentioned points, the development of the dual layer disc and the BD standardization were promoted. Fig. 1.4.4 shows the played-back signal (after limit equalizer) of the developed 50 GB disc. The signal characteristics are comparable to a single layer BD disc. The development of the dual layer disc will be the key for further enhancements of BD's charm as a large-volume recording media.

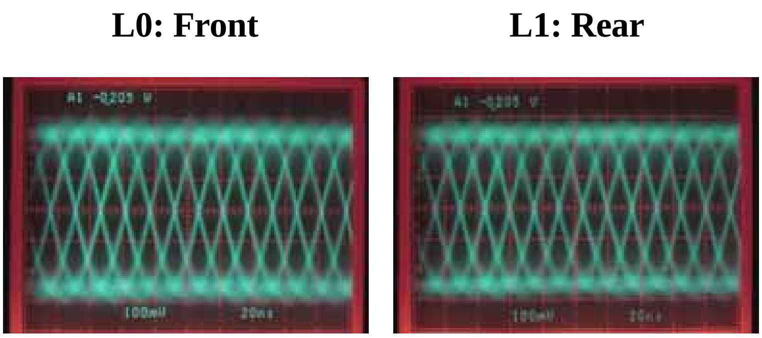


Fig. 1.4.4 Eye diagrams of readout signal from BD-Dual layer disc with capacity of 50GB.

[References]

1) K.A. Rubin et al: Proc. SPIE 2338 (1994) 247.
2) K. Nagata et al: Jpn. J. Appl. Phys. 38 (1999) 1679.
3) S. Hayashi et al: Technical Digest of ISOM2001, Taipei, Pd-33 (2001) 310.

1.5. Contents Protection System and Interface

Since BD assumes that the HD contents of digital broadcasts are being recorded, contents protection is more important than with conventional DVDs, on which only SD contents are recorded. Thus a new contents protection system (Content Protection System for Blu-ray Disc Rewritable) optimized for MPEG-TS recordings of digital broadcasts has been adopted.

Fig. 1.5.1 shows the outline of the contents protection system when digital broadcast contents are recorded. Before the start of recording, copy control information within the digital broadcast signal is detected. When copying is allowed as per the copy control information, the contents and copy control information are encrypted and recorded on the disc. During playback, recorded contents and copy control information are decoded and outputted from a device on which contents protection technology is installed.

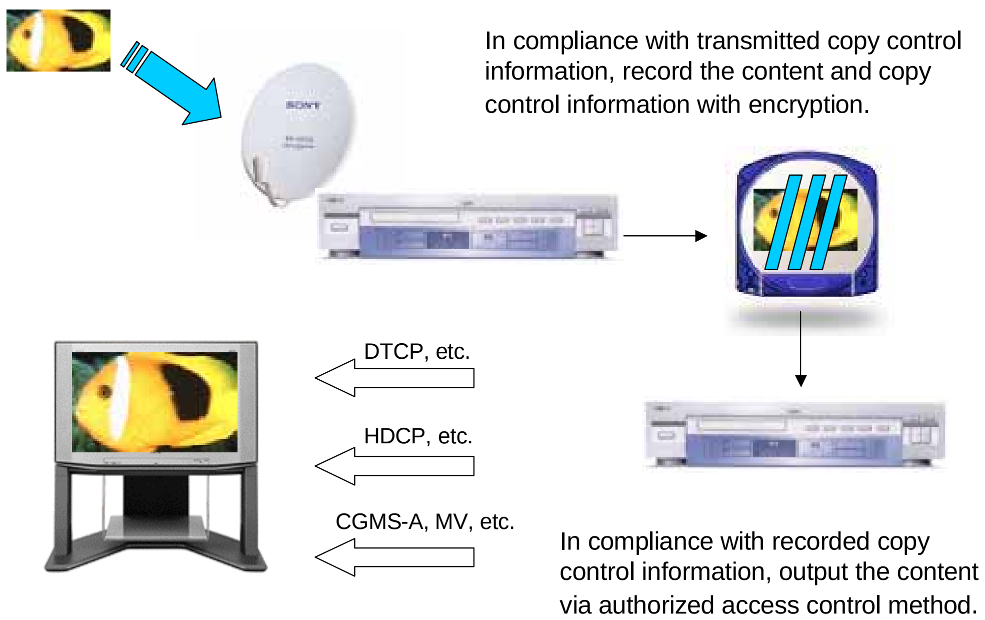


Fig. 1.5.1 Content Protection System

In the BD contents protection system, DES (Data Encryption Standard) with a key length of 56 bits has been adopted, and Triple DES with a key length of 112 bits has been adopted for the key generating process. In addition, for the exclusion of illegal devices (System Renewability) and for the prevention of illegal copying, RKB (Renewal Key Block) information and a Disc ID unique to the disc are written in ROM area of the disc. Each recorder (player) has a device key, which differs depending on the manufacturer or the machine. An encryption key is generated by combining the device key and RKB. Therefore, illegal devices can be excluded by updating the RKB information. Furthermore, illegal copying is also prevented by using a disc ID unique to the disc to generate the encryption key, because even a bit-by-bit copy cannot generate the encryption key.

In addition to such highly-secure coding during recording, by implementing the contents protection technology in the interface to output played-back contents, illegal copying and retransmission to the general public through Internet can be prevented. Before being outputted, contents are protected by DTCP *1) for MPEG-TS stream output using the IEEE 1394 interface and by HDCP *3) for baseband digital output using the HDMI interface *2) . In addition, CGMS-A and macro-vision copy control signal are added to the analog image signal.

* 1) Digital Transmission Content Protection: A contents protection technology corresponding to IEEE 1394, proposed by five companies: Hitachi, Intel, Matsushita, Sony, and Toshiba.

* 2) High-Definition Multimedia Interface: A baseband digital transmission system for home-use devices, proposed by seven companies: Hitachi, Matsushita, Philips, Silicon Image, Sony, Thomson, and Toshiba.

* 3) High-bandwidth Digital Content Protection: A contents protection technology corresponding to HDMI, proposed by Intel.

1.6 Hard-Coating for Bare Disc

BD is much more sensitive to scratches and fingerprints compared with DVD. Slight scratch or fingerprints will cause deterioration of error rates and/or loss of a tracking servo control. To avoid such problems, the first generation BD-RE (ver1.02) is protected with a cartridge case. A bare disc, however, is desired in order to downsize a disc drive. In addition, it is preferred to reduce the media manufacturing cost by making them cartridge-free.

Thus the hard-coat technology for the bare discs has been explored, aiming mainly at scratch- and fingerprint-resistances.

Hard-coatings have already been applied to some conventional optical media such as DVD-RW. UV-curable acrylic resin has been used as the hard-coat in such cases. Although they have a moderate scratch-resistance, higher hardness will be necessary for some BD applications. Moreover, a problem of fingerprint has not been considered. Therefore many kinds of materials have been investigated for alternative hard-coat. As a result, it was concluded that colloidal silica-dispersed UV-curable resin is one of the most promising candidates, in which scratch-resistance, optical property, and productivity are compatible[1].

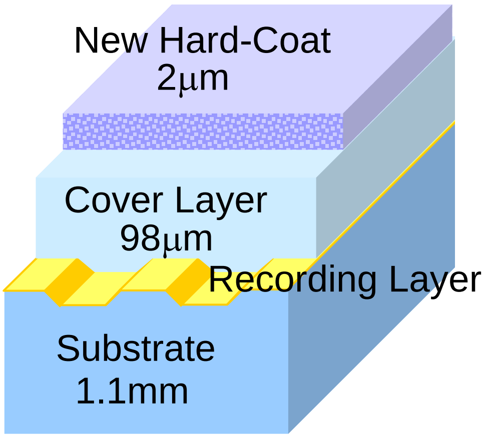


Figure 1.6.1 Cross section of BD with the new hard-coat.

The disc structure is shown in **Fig. 1.6.1**. A light-transmitting layer consists of a 98 µm thick cover layer and a 2 µm thick hard-coat. For example, both layers can be spin-coated successively[2]. In that case, a conventional UV-curable resin without colloidal silica can be used as the cover layer.

Typical properties of the hard-coat are outlined bellow. In **Fig. 1.6.2** shown are jitter values of BD-REs with (a) polycarbonate sheet, (b) conventional UV-curable hard-coat and (c) the new hard-coat, whose surfaces were worn away by rubbing with steel wool. In the disc (c), over 300 times of abrasion did not give rise to deterioration of the jitter value. For general use, you will be able to obtain a secure feeling comparable to that of DVDs by the conventional hard-coat (b), from a viewpoint of scratch-resistance. The new hard-coat (c) will be required, however, to enhance reliability of BD systems, and will open up wide variety of applications (*eg.* long-term data archiving, use for camcorder, etc.).

Regarding the problem of fingerprints, you may accidentally put your fingerprints on a blank disc before setting it on a recorder. Generally data signals recorded over fingerprints contain much more errors than ROM data signals read through fingerprints. This is the reason that fingerprint-resistance is viewed as more crucial property in BD-RE or BD-R, compared to BD-ROM.

Against such a background, BD-RE requires some kind of protective coating to reduce an impact of fingerprint. Additionally, we should establish the way to evaluate an affect of fingerprints to the BD system, if BD-RE mandatory requires such a protective coating. In BD-RE format, anti-fingerprint effect is to be quantified as follows (**Fig. 1.6.3**).

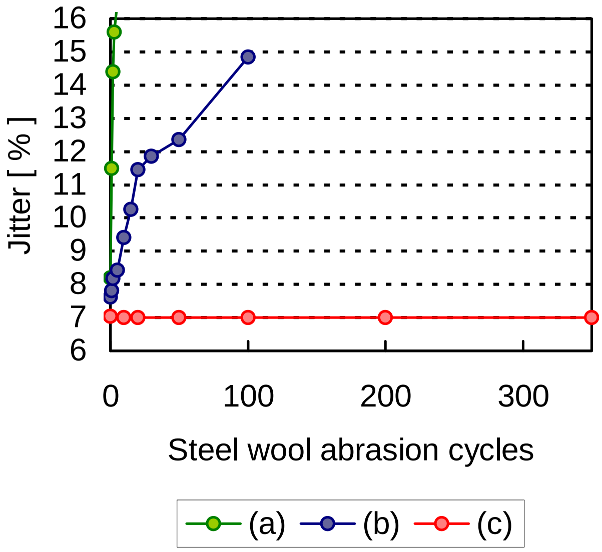


Figure 1.6.2 Changes of jitter value of BD-REs with (a) polycarbonate sheet, (b) conventional UV-curable hard-coat and (c) the new hard-coat, whose surface were worn away by #000 steel wool with a load of 100 g/cm². Random signals were written, followed by steel wool rubbing, and then jitter values were measured.

In the evaluation method, originally prepared artificial fingerprint (AFP) reagent is necessary[3)]. AFP reagent is a suspension which mainly consists of triolein (viscous fatty oil) and inorganic particle. Inorganic particle simulates insoluble ingredients and/or waxes included in actual fingerprint. It also has a function to enhance repeatability of AFP test. A procedure to put AFP onto the disc surface is based on that prescribed in JIS K2246:1994 with some modifications. In BD-RE format, SER shall be less than 4.2 x 10^{-3}, which is measured for the data signal recorded through AFP of prescribed level. This AFP level was determined with reference to the impact of fingerprint to DVD-RW/+RW/-RAM. In other words, BD-RE specification for bare disc guarantees the fingerprint-resistance, which is comparable or superior to that of recordable DVDs.

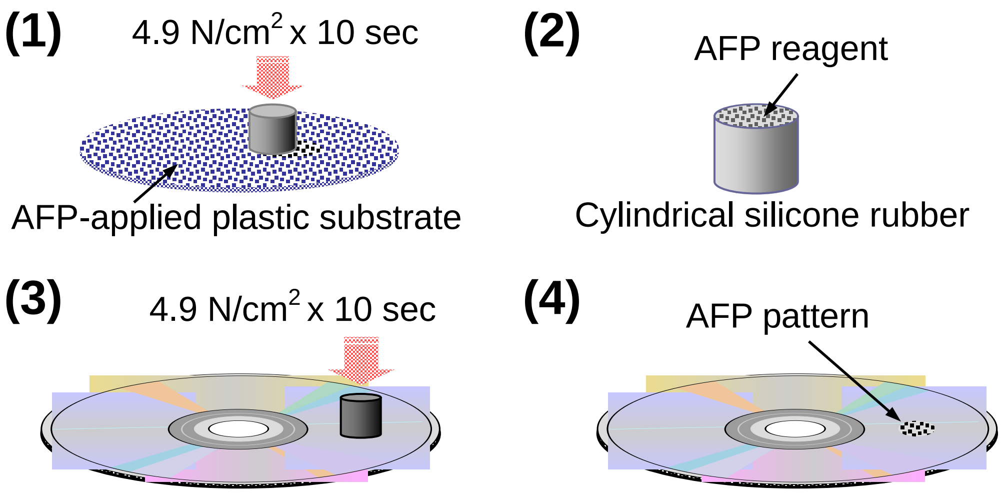


Figure 1.6.3 Procedure to put AFP onto BD-RE. Firstly AFP reagent is prepared by mixing triolein, #11 of JIS test powder 1, and methoxy propanol (5/2/60 in weight). Then next, (1) AFP reagent-applied plastic (polycarbonate) substrate is prepared by spin-coating method (*eg*, 100rpm for 1sec, then 5000rpm for 1sec), and cylindrical silicone rubber is pressed on the substrate, thus (2) AFP reagent is put on an end face of the silicone rubber. The silicone rubber shall be preliminarily ground with sand paper as prescribed in JIS K2246, prior to the procedure (1). And then (3) the silicone rubber is pressed onto the surface of the disc to be evaluated, thus (4) AFP-applied BD-RE is prepared. A bare BD-RE specification requires that SER of above AFP-applied BD shall be less than 4.2 x 10^{-3}, which is measured for the data signal recorded through AFP.

Actually, above-mentioned new hard-coat is easily endowed with an anti-fingerprint property. It is possible to upgrade fingerprint-resistance with maintaining the original hardness of the silica-dispersed hard-coat.

In **Fig. 1.6.4** shown are anti-fingerprint properties measured for different hard-coatings. AFPs were put onto the light-incident surfaces of (a) and (c), then bERs were measured (symbols for each sample are same as in **Fig. 1.6.2**). It must be noted that AFP level (*i.e.*, amount of AFP) applied to this evaluation is different from that in BD-RE specification, for experimental purpose.

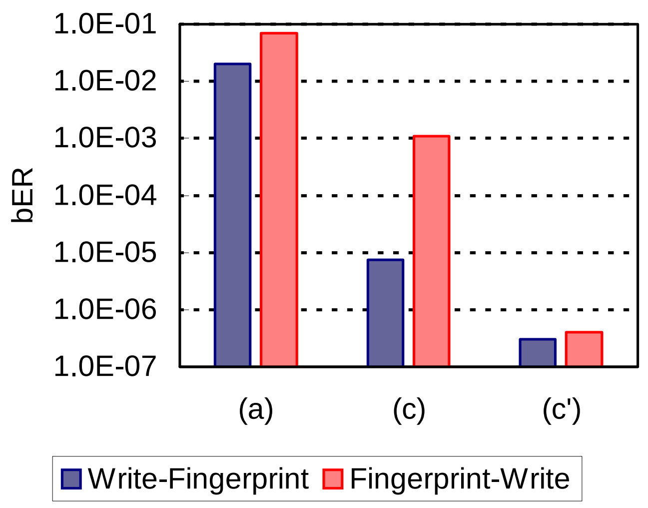


Figure 1.6.4 bERs measured after AFP adhesion. Blue bars represent bERs of the signals written before AFP adhesion, and red ones indicate bERs for the signals recorded after AFP adhesion.

As shown in **Fig. 1.6.4**, the impact of the fingerprint was severe in the disc (a), and tracking was not controllable in some cases. On the other hand, the disc (c) exhibited the bER of around 1.0×10^{-5}, which was measured for the data signal recorded prior to adhesion of AFP. In the disc (c'), anti-fingerprint property was improved with maintaining abrasion-resistance (see **Fig. 1.6.4**). It exhibited adequate fingerprint-resistance for the signals recorded both before and after the fingerprint adhesion.

Next, playability of AFP-applied BD-RE and DVDs was verified on commercial disc drives. As indicated in **Tab. 1.6.1**, BD with hard-coat (c) shows good fingerprint-resistance which is equal or superior to that of DVDs. From the aspect of recording motion picture, the disc (c) will allow rough handling comparable to that of DVDs.

For all the playability results, the disc (c) may be still sensitive to the fingerprint in terms of error rate, which is measured for the data signal recorded through fingerprints. However, playability could be further improved by using the anti-fingerprint hard-coating of type (c') due to the reduced bER especially for writing through FP.

Table 1.6.1 Recordability and playability test on commercial disc drives.

	Artificial fingerprint level		
	Heavy	Medium	Light
Disc (a)	R/W NG	R/W NG	OK
Disc (c)	OK	OK	OK
DVD-R	R/W NG	OK	OK
DVD-RW	R/W NG	OK	OK
DVD-RAM	R/W NG	Read NG	OK

*Commercial disc drives used in above test: BDZ-77 (Sony) for BD, DVR-55 (Pioneer) for DVD-R/-RW, and DMR-E50 (Panasonic) for DVD-RAM.
*Respective criteria were as follows: OK = both recording and playback normally completed; Read NG = recording operation completed (precise recording may not be done), but not playable; R/W NG = neither recording nor playback completed.

As shown in **Fig. 1.6.5**, the amount of AFP decreased drastically in discs (a), (c) and (c'), in this order. It implies a clear correlation between the amount of AFP and resulting bERs. In Fig. 1.6.6, shown is bER dependency on the area ratio of AFP. As can be seen from the figure, error rate depends almost entirely upon AFP area ratio, and is independent of the nature of the disk surface. In other words, the disks (c) and (c') are endowed with the property to afford lower fingerprint area ratio compared to the disc (a), when you apply fingerprints of the same level.

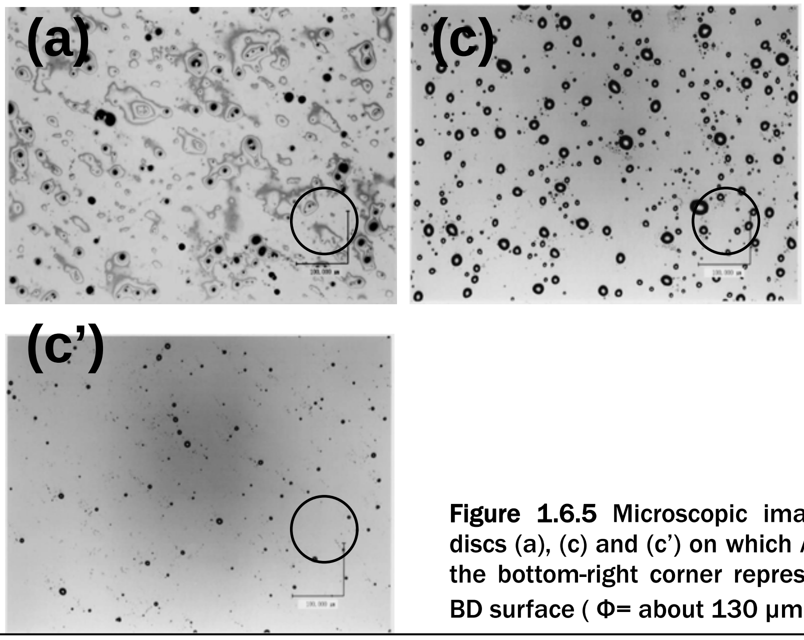


Figure 1.6.5 Microscopic images of surfaces of the discs (a), (c) and (c') on which AFP was put. Circles on the bottom-right corner represent a laser spot size on BD surface (Φ= about 130 μm).

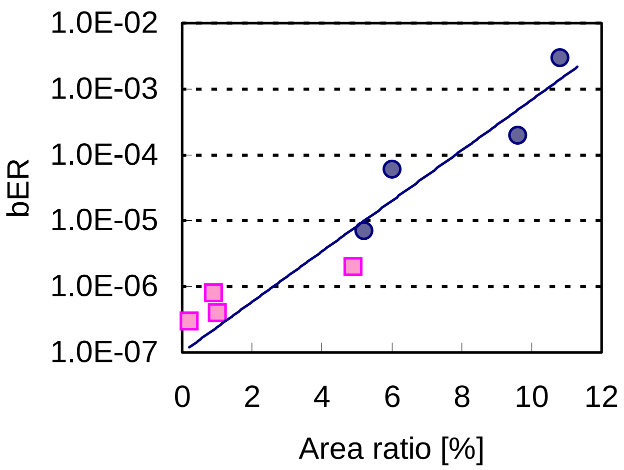


Figure 1.6.6 bER dependency on AFP area ratio. Circular dots represent the data obtained for the disc (c), and square ones for the disc (c').

Although only "fingerprint repellency" was described in this article, the discs (c) and (c') are superior to the disc (a) also in terms of "fingerprint removability". It should be noted that the new hard-coat (c') combined with the spin-coated cover layer has good production ability and will achieve the production cost comparable to that of recordable DVDs.

1) N. Hayashida, H. Hirata, T. Komaki, M. Usami, T. Ushida, H. Itoh, K. Yoneyama, and H. Utsunomiya, Jpn. J. Appl. Phys., 42, 750-753 (2003).
2) T. Komaki, H. Hirata, M. Usami, T. Ushida, N. Hayashida, H. Inoue, T. Kato, H. Shingai, and H. Utsunomiya, Jpn. J. Appl. Phys., 41, 3922-3923 (2002).
3) N. Hayashida, H. Itoh, K. Yoneyama, T. Kato, K. Tanaka, and H. Utsunomiya, Proc. of SPIE Vol. 5069, 361-368 (2003).

1.7. Blu-ray Discs and Cartridges

BD-RE V1.0 disc uses a cartridge in order to prevent harmful fingerprints. After the BD-RE V1.1, BD-R V1.0, and BD-ROM V1.0, all types of discs should be used without a cartridge thanks to the progress of the hard-coating technology described in 1.6. Only for special applications or for severe environments, a cartridge may be used.

Two kinds of Blu-ray cartridges had been defined, as shown in the figures below. As seen in Fig. 1.7.1-1.7.4, one has an opening for a printed surface and the other has an entirely sealed cartridge structure. The shielded cartridge was an option until August 31, 2003 and should not be used anymore. It should be possible to remove the disc from the cartridge.

Fig. 1.7.1:

The open type cartridge (front)

Fig. 1.7.2:

The open type cartridge (back)

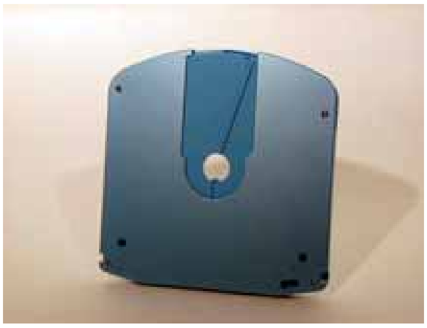


Fig. 1.7.3:

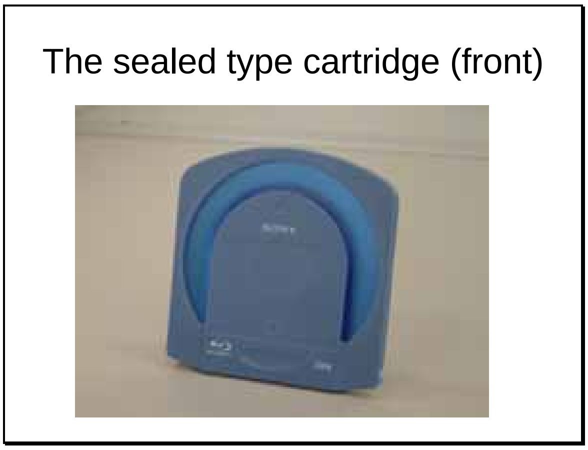
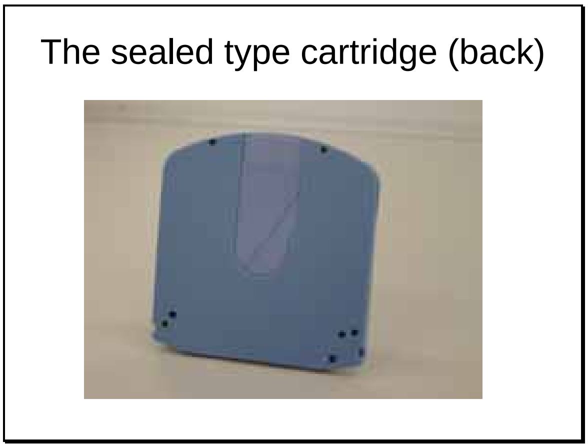
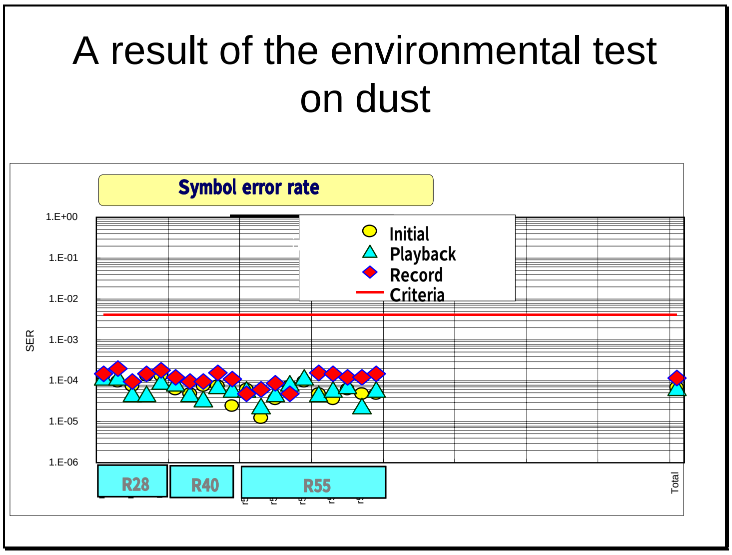


Fig. 1.7.4:



With respect to the open type cartridge, the mechanism for releasing the disc can be freely designed by the manufacturer of the cartridge as long as the cartridge fulfills all specifications. Results of a dust test of this open type are shown in the figure below.

Fig. 1.7.5:



This cartridge has a mechanism to latch the disc. The latch is not released until a disc is inserted. The recording side is closed. When latched, the disc is in close contact with the cartridge at the inner and outer perimeters to prevent dust. Data shown in the figure is a prediction for ten years of usage assuming a typical home environment. The error rate is far below the standard rate of 4.2E-3 per byte for Blu-ray (shown by the red line in the figure), and this durability is regarded as sufficient. It is expected that Blu-ray Discs can be treated a little more roughly, like VTR tapes, by adopting the cartridge.

The mechanism for releasing the disc can freely be designed by the manufacturer of the cartridge as long as the cartridge fulfills all specifications.

1.8. Roadmap of the Blu-ray Disc Standard

Figure 1.8.1 shows a roadmap of the Blu-ray disc standard. The rewritable type (BD-RE), the first standard, was issued in June 2002. The data transfer rate is the standard rate of 36Mbps (1x). The Blu-ray Disc Standard will be expanded from this fundamental rewritable type to cover all types. As described in 1.6, the hard-coating technology has made the use of BD possible without the cartridge. A bare disc is being planned to be specified as a standard in the read-only type (BD-ROM), the write-once type (BD-R) and the re-writable type (BD-RE) V2.0. These three types of physical specifications will be completed by October 2004. The storage capacity of all types of Blu-ray Disc will be 25GB (for single-layer disc) and 50GB (for dual-layer disc). User data can be recorded on BD-R at the double-speed rate (72Mbps) as well as the standard rate. BD-RE will be able to record at the rate of 1x to 2x as V2.0, rewritable at 1x by V1.0 drive already manufactured. Both the large capacity and the high data transfer rate of Blu-ray Disc are suitable for not only CE use but also PC use.

The read-only and write-once types have both been expanded from the rewritable type by adding the Differential Phase Detection method, a tracking system corresponding to pit, and by modifying optimum power control and recording strategies. In this way, consistent derivative standards will soon be introduced with the slogan "Transfer all features" and with the cooperation of engineers of the same specialty from participating companies. In addition, Blu-ray Disc will adopt as wide a variety of technology as possible. Some of them including R media will be introduced in Part 4.

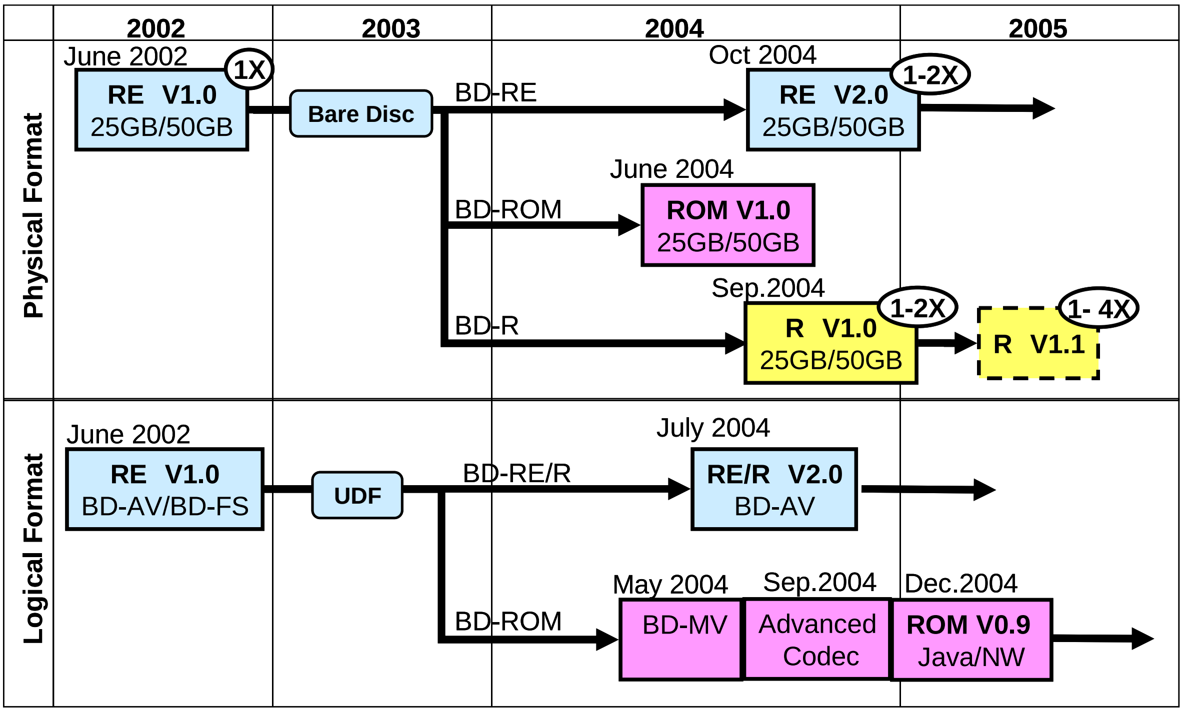


Figure 1.8.1 Roadmap of the Blu-ray Disc Standard

In parallel with the development of the physical specifications, the file system and the application specifications are also under development. BDFS, the file system for BD-RE, suitable for stream recording was developed and adopted to BD-AV V1.0 for video recording. Instead of BDFS, the file system will newly adopt UDF (Universal Disk Format), highly compatible with PC environment, which will be licensed as BD-AV V2.0.

The application format for the read-only disc (BD-ROM) will be prepared as BD-MV (Blu-ray Disc Movie) specifications V1.0 and enhanced version with internet access capability will be released as BD-MV V2.0. BD-MV will adopt at least one advanced CODEC besides MPEG2 in order to hold longer high definition movie contents at high picture and sound quality. V0.9 will be completed by September 2004 and it will be released as V1.0 after format verification. BD-MV V2.0, the enhanced version, is under development in parallel and V1.9 will be completed by December 2004.

The development of further high speed Blu-ray Disc is desirable since it needs lower recording power compared to DVDs because of a large NA value, and also it needs lower disc rotation speed because of a much higher density. The anticipated speed is much higher that previously achieved by conventional optical discs. Although the recording speed of the media itself limited the development in the past, the limiting factor for the use of Blu-ray is the capacity of the hardware. The transfer rate for data will advance from double speed to quadruple speed (144 Mbps).

Through the above-mentioned expansion, the first generation of Blu-ray family standards will be complete. For further development, additional speed and capacity will be necessary. In the future, the speed will be raised to eight times or more. Assuming that the limit of the disc rotation speed is 10,000 rpm, 12-time speed at the outer diameter is possible. This corresponds to a hard disc with a transfer speed of about 400 Mbps. Further, a large capacity standard of several hundred GB is expected following the CD (650 MB), DVD (4.7 GB), and BD (25 GB). To achieve this, both the hardware approach such as multi-value/multi-layer and the signal processing at the base of the Blu-ray system, which provides the highest density recording at present, and a software approach such as coding will be needed.

Since there is still enough capacity, approaches to compactness disc might emerge in the future. For example, like CD or DVD, if the capacity storable in media with a diameter of 8 cm is calculated, BD with one-sided single layer is able to store about 7.5 GB. Moreover, it has the capacity of 1.5 times as much as DVD with a diameter of 12 cm of one-sided single layer.