Archival Disc

White Paper: Archival Disc Technology

1st Edition

July 2015

SONY

Panasonic

Content

1 Introduction

Widespread network environments and faster computer processing speeds have led to more and more devices being connected to the Internet. These devices are producing audio, still images, and video at an ever-increasing pace, to the point where the American IT research company IDC predicts that the total global volume of data produced and stored will reach 44 ZB (zettabytes; ZB = 10^{21} Bytes) by the year 2020 (Fig. 1). There is thus an ever-growing need to archive this burgeoning volume of data for the purposes of compliance, academic research, preservation of cultural assets, and supplying new value through data analysis. Since data archiving carries a significant cost burden, it can be argued that businesses operating data centers that handle large volumes of data are faced with a particularly strong need to reduce the cost of storage (initial and operational costs). Optical discs represent a highly promising form of storage media to suit this demand, but in order to truly fulfill the needs of these data centers in future, it will be necessary to increase disc capacity.

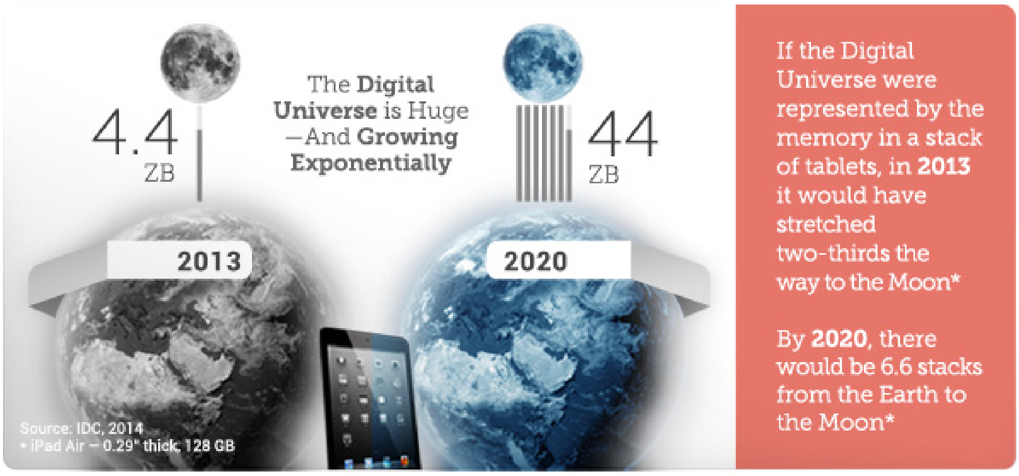

Figure 1. Predicted volume of data produced and stored globally in 2020

Source: IDC's Digital Universe, The Digital Universe of Opportunities: Rich Data and the Increasing Value of the Internet of Things, sponsored by EMC (April 2014)

When data centers choose to archive data on storage media with a short lifespan, the investment required to continually migrate this data to upgraded media becomes considerable and ultimately puts a strain on the data center’s business. However, optical discs can be used to safely archive data for over 50 years without any need for data migration, allowing data centers to supply their services at lower cost.

Many data centers are eliminating air conditioning with the aim of serving as 'green data centers' with a low environmental burden and cheaper operational costs. Optical discs offer high performance and help satisfy the needs of these 'green data centers.' Figure 2 shows the average air temperature and relative humidity in major cities around the world. Optical discs are capable of storing data for over 50 years in any kind of environment represented by the blue area on the diagram. As such, optical discs enable the realization of eco-friendlier data centers with lower operational costs in any city around the world.

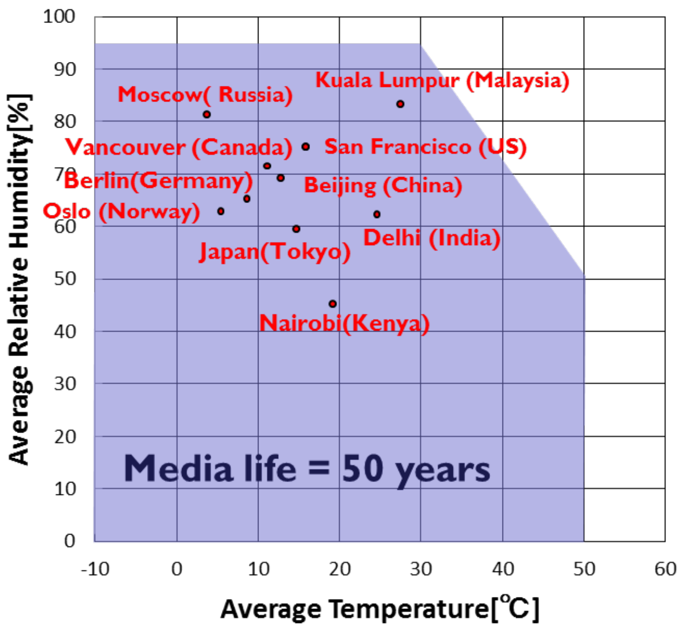

Figure 2. Average temperature and relative humidity of major global cities

Meanwhile, since optical discs use a laser-based, non-contact optical process to write and read data, covering the data recording surface with a protective film makes it possible to achieve high environmental durability without any loss of writing or reading performance. Two examples are given below to illustrate the environmental durability of optical discs.

The first is resistance to seawater. Even after an optical disc containing data is immersed in seawater for a period of five weeks, the data can be accessed without any problems by simply washing and then drying the disc.

The second is resistance to solar storms. Data storage on optical discs does not use electromagnetism, so the stored data is entirely unaffected by geomagnetic events.

To summarize everything up to this point, optical discs are a highly promising form of storage media in that they meet a range of data center needs, including low environmental burden, low operational costs, and high durability, but it will undoubtedly be necessary to increase capacity per disc. This White Paper describes the Archival Disc (AD), a new optical disc which achieves this greater data capacity.

2 Optical Disc Technology

The optical disc industry is one in which Japan has led the world, evolving as music and video products developed from Compact Disc (CD) to Digital Versatile Disc (DVD) and Blu-ray Disc™.

The first time a 12-cm optical disc entered the market came with the release of the CD on October 1, 1982. The CD spread around the world as a handy means of enjoying high-quality music. At that time, the basic software for personal computers required only 10 floppy disks, but when it could be supplied on a single CD-ROM instead, the optical disc quickly became a ubiquitous presence in the field of IT.

The first discussions for a successor to the CD centered on their use in the AV field, including video information such as movies. But in light of the CD market, it was subsequently considered essential that any new optical disc should cover both AV and IT usage, and that capacity therefore be increased to facilitate the recording of video content. This led to the creation of the DVD, for which the laser wavelength was shortened from infrared to red, while the numerical aperture (N.A.) of the objective was raised to 0.60 to reduce the spot size for recording and playback. Meanwhile, the mark size and track pitch were reduced to enable high-density recording. With the development of single-sided, double-layer discs, maximum capacity was increased to 9 GB.

With the Blu-ray Disc™, the laser wavelength was further shortened to blue-violet and the N.A. of the objective was raised to 0.85 to produce a recording capacity that is approximately five-fold that of a DVD. Blu-ray Disc™ recording capacity has now reached a maximum of 200 GB per disc thanks to the use of double-sided, triple-layer discs (Fig. 3). Meanwhile, reduced data bit length has meant that the Blu-ray Disc™ is comfortably able to achieve a transfer rate suitable for recording and playback of digital HD video, even at the same revolution speed as a DVD.

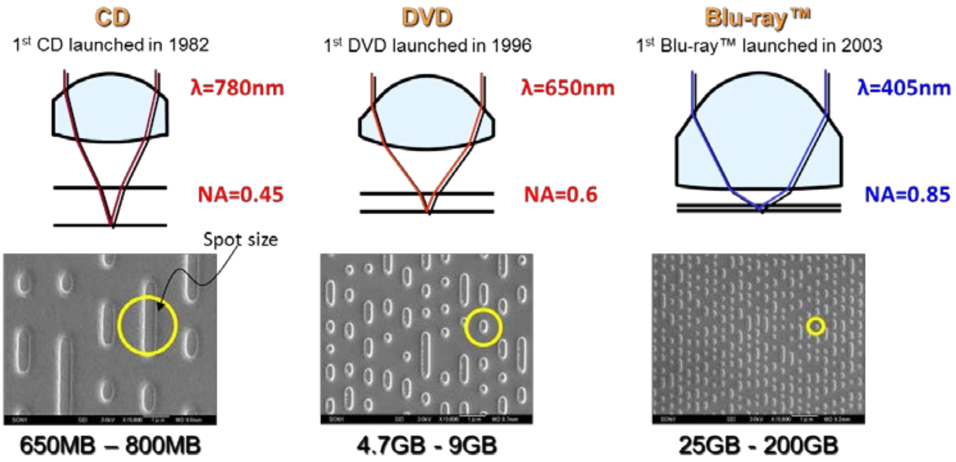

Figure 3. CD, DVD, Blu-ray Disc™ playback spot and recording mark shapes

The process of optical disc evolution from CD to DVD and Blu-ray Disc™ has always allowed for backward compatibility—DVD recorders/players are compatible with CD, while Blu-ray Disc™ recorders/players are compatible with CD and DVD—meaning that customers have been able to upgrade to the new standard without any loss of convenience. Panasonic Corporation and Sony Corporation are now able to announce details of the Archival Disc (AD) standard developed by the two companies to extend this optical disc evolution into new fields of application and enable stable, high-speed recording and playback of ever-greater volumes of digital data.

3 Archival Disc Technology

3.1 Archival disc roadmap

The roadmap for the AD standard is illustrated in Figure 4. The first-generation system, with a recording capacity of 300 GB per disc, has a target launch date of summer 2015. Panasonic and Sony will then use their respective technologies to expand the disc recording capacity to 500 GB for the second generation and 1 TB for the third generation. The technologies to be used for each generation of disc are detailed below.

(1) 1st generation: Double-sided, triple-layer disc technology; narrow track pitch crosstalk-cancelling technology
A land-and-groove recording method has been deployed, in which signals can be recorded both on the guide grooves and on the land area between the grooves, resulting in greater track density. Crosstalk noise generated between adjacent tracks is cancelled out by newly-developed crosstalk-cancelling technology to ensure sufficient playback signal quality without read errors.

(2) 2nd generation: 1st generation + high-density inter-symbol interference elimination technology
Next-generation inter-symbol interference elimination technology will be fitted to drives to rectify the reduced playback spot resolution caused by the higher recording density. The burden on device development, including optical and disc technology, will be limited and the disc capacity increased to 500 GB.

(3) 3rd generation: 2nd generation + a multiple-level recording/playback technology
A multiple-level recording/playback technology and high SNR optical technology will be adopted to raise the disc capacity to 1 TB.
Over the course of each generation, disc capacity will be raised without changing the base optical parameters or the three-layer disc structure, making it easier to minimize disc manufacturing costs and ensure device backward compatibility. New disc materials will be developed with greater reliability and higher SNR, helping to raise capacity in each generation and thus enable high-precision recording suitable for archiving.

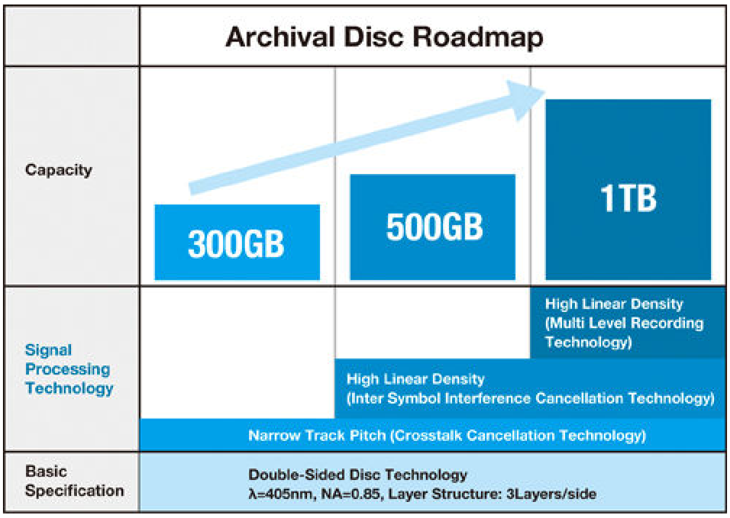

Figure 4. Archival Disc roadmap

3.2 Disc structure

The AD has a double-sided structure, which gives it a capacity double that of a single-sided disc, and with three layers per side (Fig. 5). This structure has been established in conventional optical discs and is already commercialized. The main feature of AD is a technology to record and/or playback simultaneously on both sides, which gives double the transfer rate achieved with one-sided recording or playback.

The address structure, which has been developed for the AD format, will be maintained in each generation, so that the disc manufacturing process will not have to be changed.

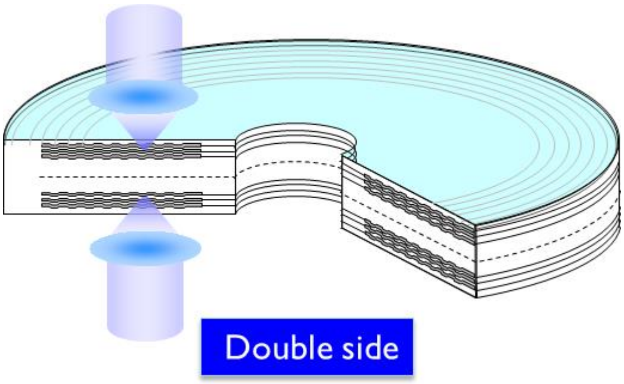

Figure 5. AD disc structure

3.3 New recording material

A simple layer structure has been newly developed for use as AD disc recording film, in which an oxidized recording material is sandwiched by an oxidized insulator in which marks can be easily formed by laser irradiation.

Because this recording film has the unique characteristic of appropriate optical absorption, a high recording velocity is possible. Additionally, as mentioned above, all recording films use an oxidized material, allowing high reliability performance to be achieved at the same time.

There are several advantages from a disc-manufacturing point of view: this recording film has high electric conductivity and can be sputtered by DC voltage under a relatively low vacuum. This feature enables short takt time and allows the choice of a variety of recording ingredients to bring down disc cost. Meanwhile, a new defect management system has been adopted that uses the 3.5 Logical Format (detailed later), which overcomes the drawback of influence from the recording state of other layers and thereby allows greater freedom of optical design for the recording film. This should help to further reduce media costs.

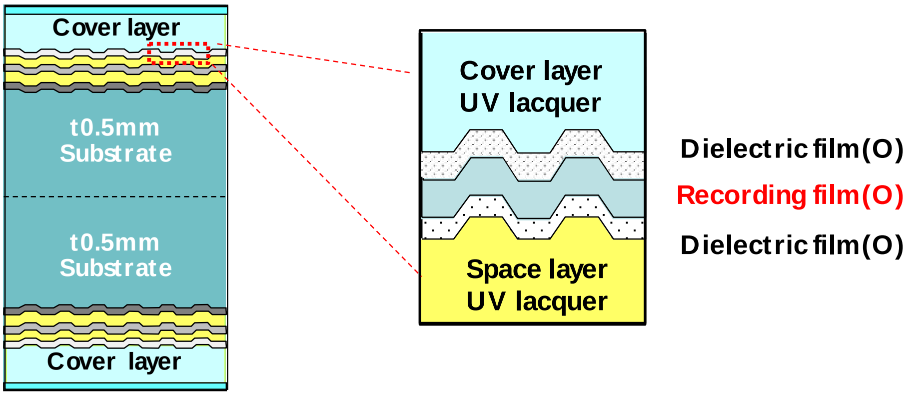

Figure 6. AD disc recording film

3.4 Physical format

This section describes the new technologies adopted for the AD physical format.

(1) Land-and-groove recording technology and crosstalk-cancelling technology

AD is based on conventional optical disc technologies, with land-and-groove recording technology and crosstalk-cancelling technology applied to maximize the recording capacity of each layer. This means that radial recording density is improved by 40% over Blu-ray Discs™. A new defect management system has been adopted that employs the 3.5 Logical Format (detailed later) to overcome the problems of servo error signal crosstalk and to enable a narrow track pitch.

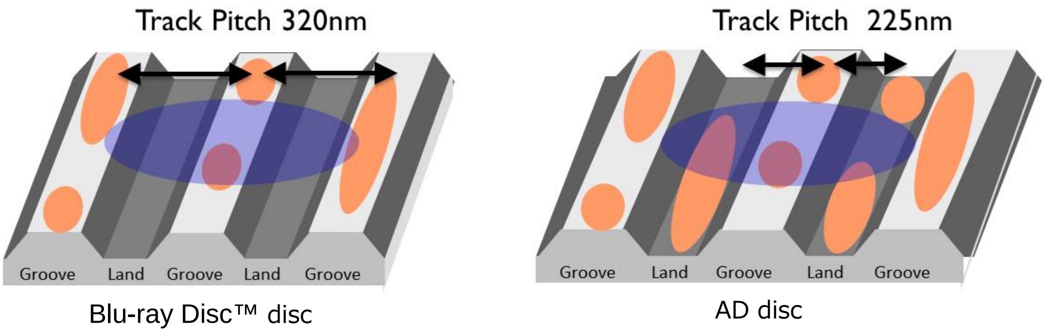

Figure 7. Land-and-groove recording

(2) Physical address format

A physical address has been applied to the optical disc tracks in the form of a wobbled track, to be able to enable instant access to a designated data recording/playback position. With conventional groove track recording, only the groove tracks have a physical address, but a new format has now been adopted to obtain physical addresses for both the groove tracks and the land tracks, thus enabling land-and-groove recording, which is a key feature of AD. At the same time, the AD physical address format sufficiently reduces noise caused by the wobbled track to the playback signal during data playback, ensuring high read performance.

(3) Zone format system

AD uses a zone format system to anchor the data recording density to a physical address as defined by the wobbled track. Using this system, it is possible to obtain a data address for a block of data from the physical address being read that is in accordance with a predetermined zone format. This makes it possible to record data to and playback from specific locations on the disc.

The application of these new technologies will lead to the following benefits.

Stable random access

Using the new physical address format with significantly improved read performance will allow stable random access, even under extreme temperature conditions or after long periods of storage.

Reduced bit cost and future compatibility

In conventional optical discs, data recording density can be increased by modifying the disc track structure, but with the AD zone format system it will be possible to increase data recording density by simply updating zone format parameters, without the need to change the physical address structure of the disc. This means that for ADs, which support this zone format system, there will be no need to change the format whenever recording density is improved: this affords a significant advantage in terms of reducing the bit unit price of future discs. Meanwhile, the fact that the physical structure of the disc remains unchanged will make it easier to ensure backward compatibility, so that data recorded on discs stored over long periods can always be accessed with high reliability using the latest drive systems.

3.5 Logical format

3.5.1 Disc management

AD discs use a double-sided, triple-layer land-and-groove format, but the user can treat them as high-capacity optical discs. Meanwhile, a reverse spiral groove on each side enables the simultaneous access of both side of the disc. It is also possible to record to lands and grooves at the same time, so it is also possible to improve the transfer rate by using multiple optical heads. Additionally, disc management uses a single-sided closed structure, so it is not dependent on drive structure, while unique logical sector numbers (LSNs) are defined for each physical location on the disc for easier playback compatibility. Defect management and 'logical over write' (LOW) features are also provided so that a file system capable of controlling the conventional optical disc will be capable of controlling the AD in an easy fashion.

3.5.2 Defect management

A defect management feature is incorporated into AD such that even if a defective block is present within the user area, the data can be alternatively recorded to spare areas on the inner and outer areas of the disc, thereby improving disc reliability. The defect management system of AD also has new features that protect the reliability of recorded data against problems such as influence from the recording state of other layers and servo error signal crosstalk variance that results from the new land-and-groove recording format. It is now possible to perform recording control using disc management only, without actually accessing the disc, thereby minimizing performance loss in recording control and maximizing ease of use by non-specialists. As regards the arrangement of spare areas, defect management areas and suchlike, a format has been optimized for write-once recording, including the recording of data is sequentially, starting from the deepest layer.

3.5.3 Recording management

With ADs, significant emphasis has been placed on ensuring compatibility with conventional write-once discs, with a sequential recording mode used so that existing applications can be easily applied to AD. Like conventional optical discs, AD also allows for multiple Sequential Recording Ranges (SRRs) to be used simultaneously. Setting multiple SRRs makes it possible to reserve multiple writable locations on the disc.

With AD, it is not necessary to fill unused portions to be able to close the SRR or the disc, meaning that the close operation can be made shorter than for conventional sequential recording media like DVDs. Additionally, by using the Defect Management's linear replacement function, it is possible to perform LOW over previously-recorded user data.

3.5.4 OPC area management

AD allows more areas to be assigned for write power adjustment than previously possible, and so uses a structure whereby optimum power control (OPC) areas can be optionally allocated via the disc drive. By defining this OPC range information (OPCRI) within the disc definition structure (DDS), the total number of available reuses is increased by at least as much as the overall capacity of the disc is increased.

3.5.5 User area management

AD uses a triple-layer land-and-groove format. Logical sector numbers (LSNs) are allocated to the user areas (volumes) accessible to the user, meaning that users can access these areas using the appropriate LSN. The LSN allocation method is shown in Figure 8 below.

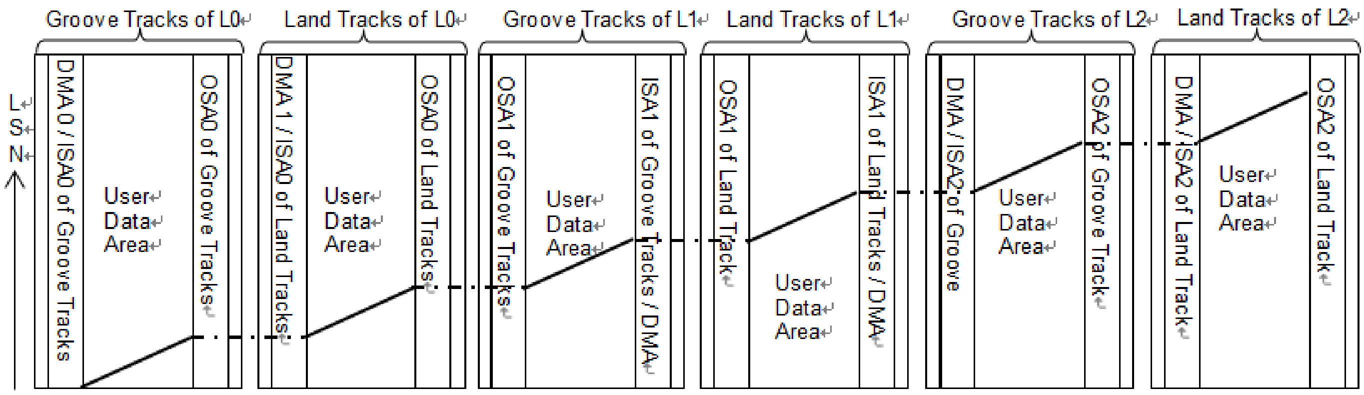

Figure 8. LSN allocation method

Specifically, LSNs are allocated sequentially to the groove tracks of the L0 layer from the inner perimeter to the outer perimeter, and then to the land tracks of the L0 layer from the inner perimeter to the outer perimeter. After L0, LSN are then allocated on L1 following a similar rule in the direction of outer to inner, and then again similarly to L2.

LSNs are allocated separately to user areas (logical space) on each recording side, but it is also possible to combine both sides and treat them as a single logical space (one volume) depending on the drive and its control system compatibility.

3.6 Signal environment

An index called 'integrated maximum likelihood sequenced error' (i-MLSE) has been used for playback signal quality evaluation in AD discs. This index is based on the 'partial response maximum likelihood' (PRML) detection method, which makes it possible to accurately quantify playback signal quality. Figure 9 shows the measurement results for symbol error rate (SER) and i-MLSE when various types of playback stress are applied to a 300-GB capacity (1st generation) AD. A strong correlation can be seen between the two variables.

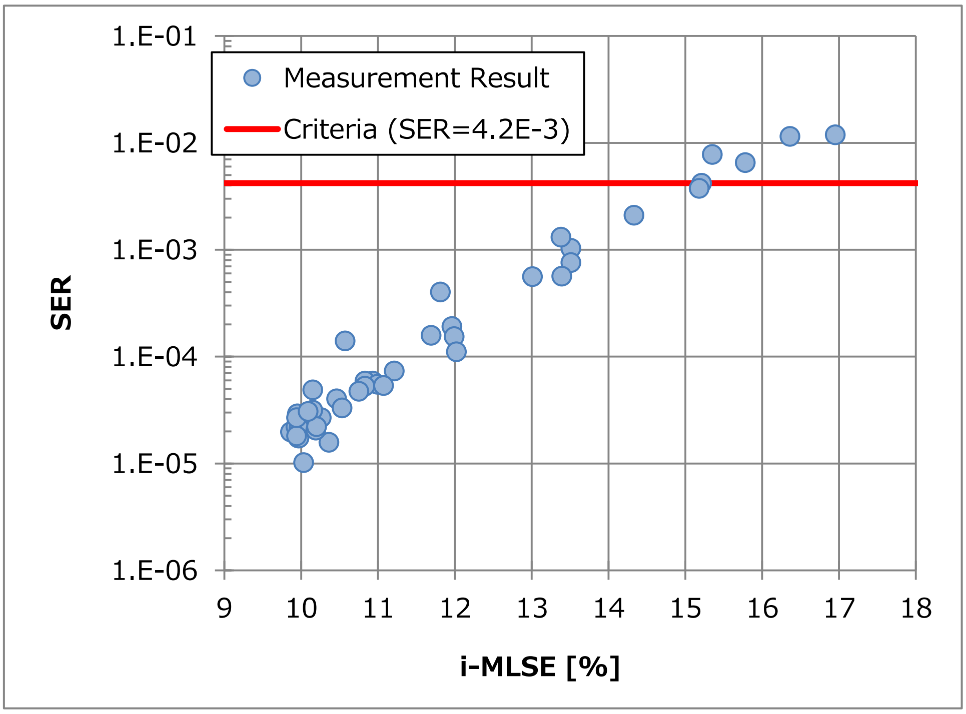

Figure 9. i-MLSE signal quality evaluation index and SER

3.7 Specifications for 300-GB AD

The main parameters of AD discs are shown in Table 1 below. In order to facilitate backward compatibility with Blu-ray Disc™ discs, the main parameters for AD discs—including laser wavelength, NA, and cover layer thickness—have been kept at the same specifications as those for Blu-ray Discs™ (*see Blu-ray Disc™ White Paper). Compared to 100-GB Blu-ray Disc™ specifications, AD discs have a 40% higher radial density, 5.5% greater linear density, and twice the surface area due to their double-sided nature, resulting in a capacity of 300 GB. The maximum user data transfer rate for AD discs is 359.65 Mbps.

Table 1. Main parameters of AD discs

Main parameters	Specifications
Laser wavelength	405 nm
NA	0.85
Disc diameter	120 mm
Total nominal thickness	1.2 mm
Double-sided disc	Triple Layer (TL)/Side
Cover Layer thickness	57.0 µm
Recording polarity	High to Low
Recording method	Land & groove
Data Zone inner radius/ outer radius	24 mm/58 mm
Track pitch	0.225 µm
Addressing method	Wobbled Grooves with addresses
Channel modulation	17PP
Error correction code	64KBLDC+BIS
Total efficiency	81.738%
Maximum user data transfer rate	359.65 Mbps
Nominal channel bit length	53.0099 nm
Nominal data bit length	79.5149 nm
User data capacity at 120 mm	300.00572 GB

The i-MLSE and Random-SER (R-SER) specifications (defined in **3.6 Signal Environment**) for each layer of the AD disc are given in Table 2 below.

Table 2. i-MLSE and R-SER specifications for each AD disc layer

Signal Quality Evaluation Index	Specifications
i-MLSE required for disc with Tester	L0 $\leq$ 11.0% L1 $\leq$ 11.5% L2 $\leq$ 12.0%
R-SER required for disc with Tester	$\leq$ 2.0E-4

4 Long-term Archiving

4.1 Media lifetime

Chapter 3.3 in this article explains that the recording film used for AD has oxidizing resistance and weather resistance that confer high reliability. The principle governing mark formation involves a physical material change, and oxidization also makes the media highly reliable. To illustrate the archival properties of data recorded onto AD discs, Fig. 10 shows measurement results for storage reliability.

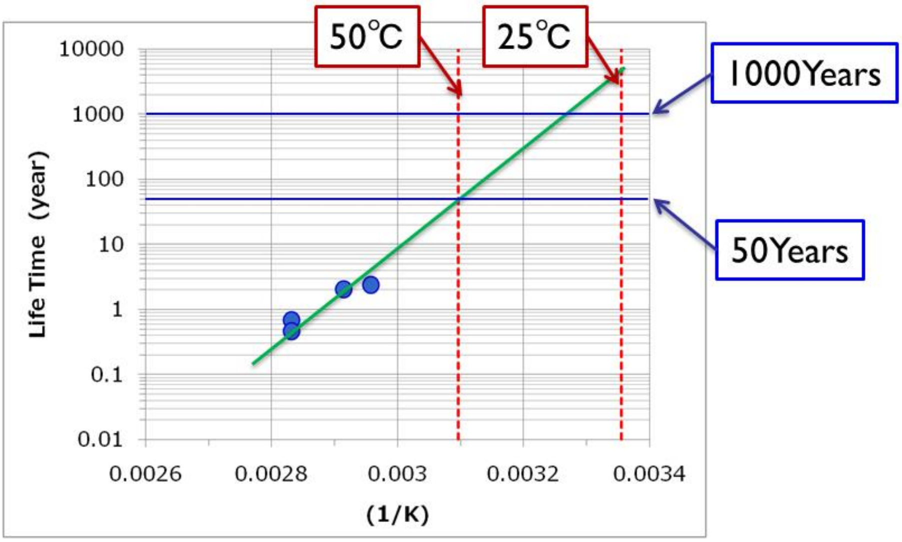

Figure 10. Long-term storage reliability in AD discs

Tests under four different environmental conditions were implemented with ISO16963 – 65°C/80% humidity, 70°C/75%, 80 °C/70%, and 80 °C/80%. The Arrhenius equation was used to derive an acceleration coefficient from the test results, which then enabled the time for the playback data error rate to reach a set criterion to be calculated for ambient temperatures of 25 °C and 50 °C. The estimated lifespans for AD using our newly-developed recording material are very satisfactory: 50 years in a 50-°C environment, and more than 1,000 years at room temperature.

4.2 Disc tilt and variation in tilt in response to temperature changes

AD discs have a symmetrical structure with an A-side disc and B-side disc, each approximately 0.6 mm thick, stuck together back to back. This is a similar structure to a DVD, and results in little tilt occurring after long-term storage. This helps to prevent degradation of playback signal quality when the disc is played in a drive. With discs that have a single-sided structure, such as CDs and Blu-ray Discs™, the plastic base, resin adhesive layer and recording layer are layered unidirectionally, meaning that each layer can expand or contract in an in-plane direction at different ratios during long-term storage. This can lead to slight deformation of the top or bottom surfaces of the disc, known as tilt. Since double-sided discs are likely to undergo virtually identical warping on both sides, tilt is kept to a minimum.

This double-sided symmetrical structure is effective not only for long-term storage, but also for coping with the rise in environmental temperature that may occur immediately after the disc is inserted into a drive. With a single-sided structure, tilt can readily occur in the disc, due simply to the temperature rise in the drive bay when the drive starts up. This can lead to faults such as degradation of laser spot quality during recording and playback; however, with a double-sided disc structure, it is largely possible to prevent any occurrence of tilt that might be caused by such temperature increases.

However, even with a double-sided AD structure, excessive force or warping is fatal to long-term storage, and so it is always recommended that the disc be stored in an appropriate cartridge or case, and kept vertical or flat.

5 The Future

As was explained in the roadmap in Chapter 3, after the 1st generation, we aim to evolve the AD into a 2nd and 3rd generation. Preparations for this evolution are already under way, and we are engaging in detailed discussions about the road ahead.

The 2nd generation disc will have an identical physical structure, with greater linear density taking the capacity to 500 GB. Next-generation inter-symbol interference elimination technology will be deployed to rectify the reduced playback spot resolution caused by the higher linear density. It has already been affirmed that this will enable us to achieve high linear density data recording and playback for a 500 GB-capacity disc without changing the optical system or the disc (see Fig. 11).

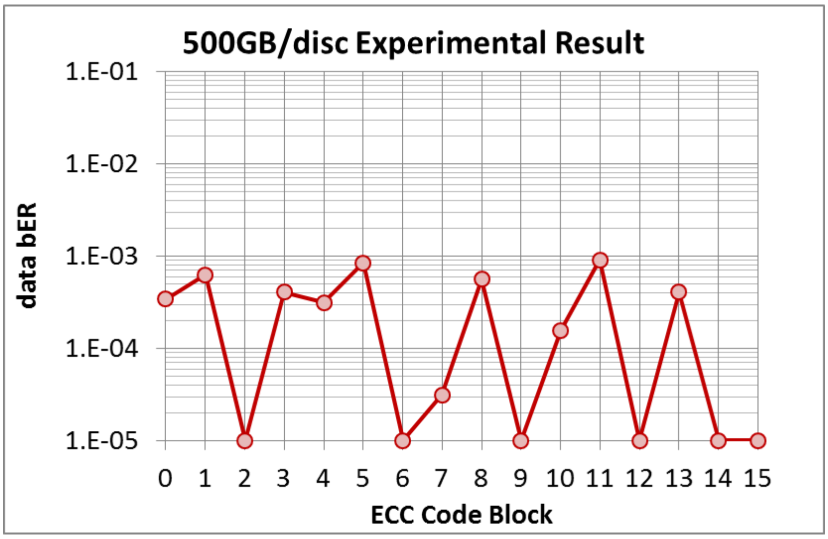

Figure 11. 2nd-generation AD recording/playback performance

For the 3rd-generation disc, we will develop high SNR optical technology and new recording materials that offer high reliability and high SNR. We will maximize the device performance by adopting a multiple-level recording/playback technology to further enhance the data recording linear density, and thus raise the disc capacity to 1 TB.

As such, the AD standard will use the same basic specifications for laser wavelength, NA, and disc layer structure as the reliable Blu-ray Disc™, but with upgraded narrow track pitch and high linear density technologies. It will be evolved to achieve ever greater recording capacities. The AD standard is a highly promising means of storage for low-cost archiving as data volumes grow ever larger in the future.