



**Archival Disc**

**White Paper:  
Archival Disc Technology**

**2<sup>nd</sup> Edition**

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**SONY**

**Panasonic**



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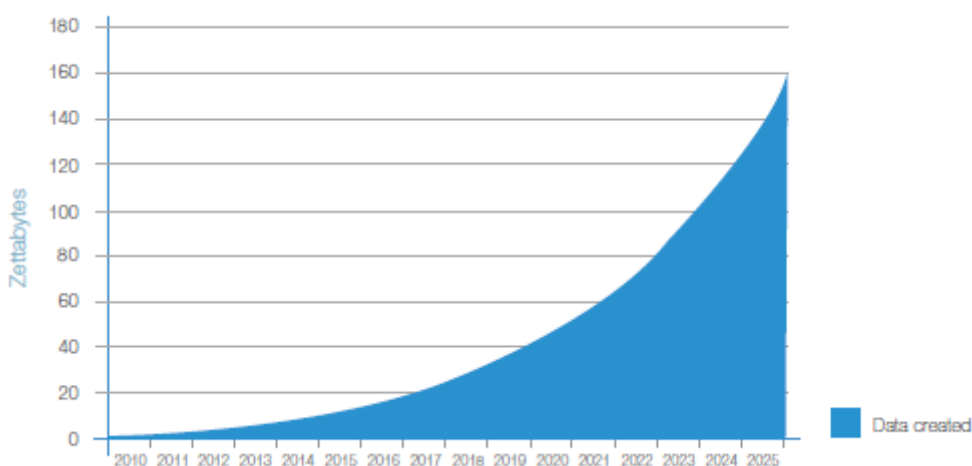
## 1. Introduction

Due to widespread network environments and improved computer processing speeds, audio, still images, and video are being produced at an ever-increasing speed, 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). Recently, IDC also reports that the total global volume of data will grow even further to 163 ZB by the year 2025 (Fig.2). Thus an ever-growing need to archive this burgeoning volume of data for the purposes of compliance, academic research, preservation of cultural assets, and providing new value through data analysis. On the other hand, as data archiving involves a significant cost burden, it can be argued that 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 indispensable 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)

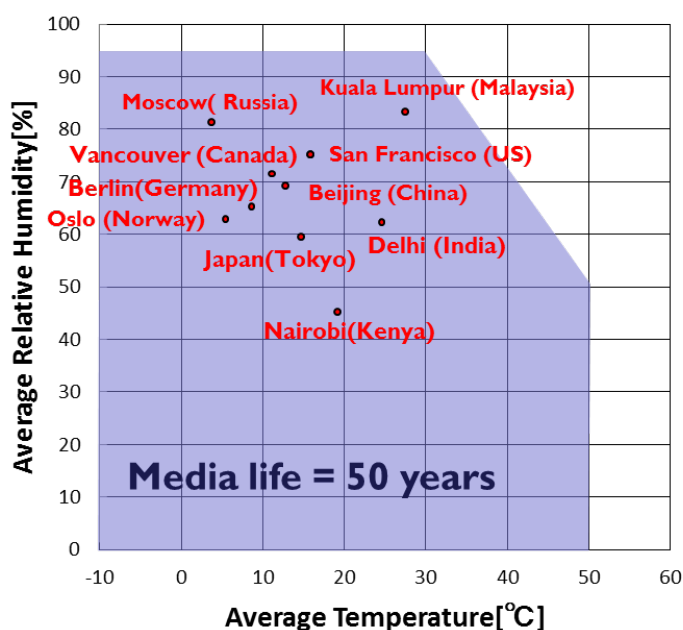


**Figure 2.** Predicted volume of data produced and stored globally

Source : IDC's Data Age 2025 study, sponsored by Seagate (April 2017)

As data centers choose to archive data on storage media with a short lifespan, investment required to continually migrate this data to upgraded media becomes considerable and ultimately puts a strain on 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 costs.

Many data centers are eliminating air conditioning with the aim of serving as ‘green data centers’ with a low environmental burden and reduced operational costs. Optical discs offer high performance and help satisfy the needs of these ‘green data centers.’ Figure 3 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 shaded area on the diagram. As such, optical discs enable realization of eco-friendly data centers with lower operational costs in any city around the world.



**Figure 3.** Average temperature and relative humidity of major global cities

Since optical discs use laser-based, non-contact optical process to write and read data, covering the data recording surface with 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 environmental durability of optical discs.

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

Second is resistance to solar storms. Data recording on optical discs does not use electromagnetism, so stored data is entirely unaffected by geomagnetic events.

In summary, optical discs are a highly promising form of storage media that meets data center needs, including low environmental burden, low operational costs, and high durability. This White Paper describes the Archival Disc (AD), a new optical disc which achieves greater data capacity in addition to the properties above.

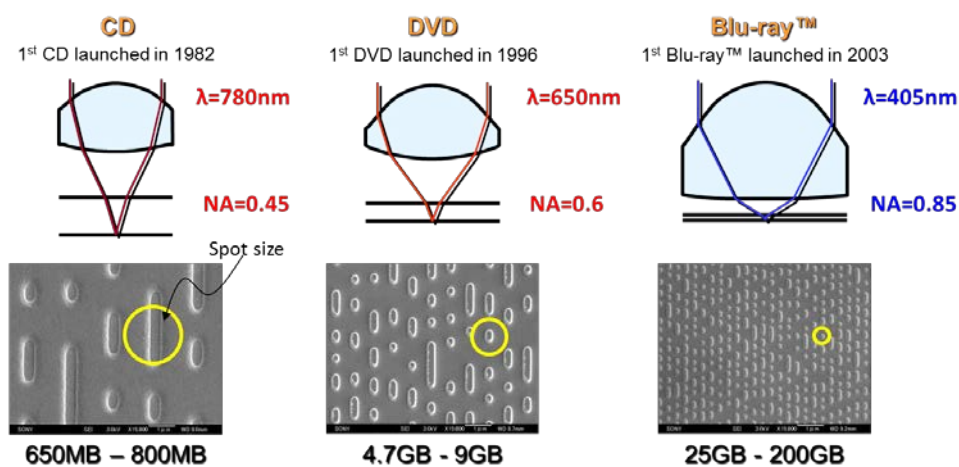
## 2. Optical Disc Technology

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™.

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

Initial discussions for successor to CD were centered on their usage in AV field, including video information such as movies. But in light of 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 recording of video content. This led to the creation of DVD, for which laser wavelength was shortened from infrared to red, while numerical aperture (N.A.) of objective was raised to 0.60 to reduce spot size for recording and playback. Meanwhile, mark size and track pitch were reduced to enable high-density recording. With development of single-sided, double-layer discs, maximum capacity was increased to 9 GB.

With Blu-ray Disc™, laser wavelength was further shortened to blue-violet and the N.A. of 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. 4). Meanwhile, reduced data bit length has meant that 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 4.** CD, DVD, Blu-ray Disc™ playback spot and recording mark shapes

Process of optical disc evolution from CD to DVD and Blu-ray Disc™ has always allowed 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 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 5. The first-generation, with a recording capacity of 300 GB per disc, was launched to the market in 2015. The second-generation, with a recording capacity of 500 GB per disc, has a target launch after fall 2018. Panasonic and Sony will then utilize mutual respective technologies to expand the disc recording capacity to over 1 TB as the third-generation. The technologies to be adopted for each generation of disc are described below.

(1) 1<sup>st</sup> 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 guide grooves and on land area between 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) 2<sup>nd</sup> generation: 1<sup>st</sup> generation + high-density inter-symbol interference elimination technology

Next-generation inter-symbol interference elimination technology will be fitted to drives to rectify reduced playback spot resolution caused by higher recording density. Burden on device development, including optical and disc technology, will be minimized and the disc capacity increased to 500 GB.

(3) 3<sup>rd</sup> generation: 2<sup>nd</sup> generation + a multiple-level recording/playback technology

A multiple-level recording/playback technology and high SNR optical technology will be adopted to raise disc capacity to over 1 TB.

Over the course of each generation, disc capacity will be raised without changing base optical parameters or three-layer disc structure, making it easier to minimize disc manufacturing costs and ensure drive system's backward compatibility. New disc materials will be developed with greater reliability and higher SNR, helping to increase capacity in each generation and thus enable high-precision recording suitable for archiving.

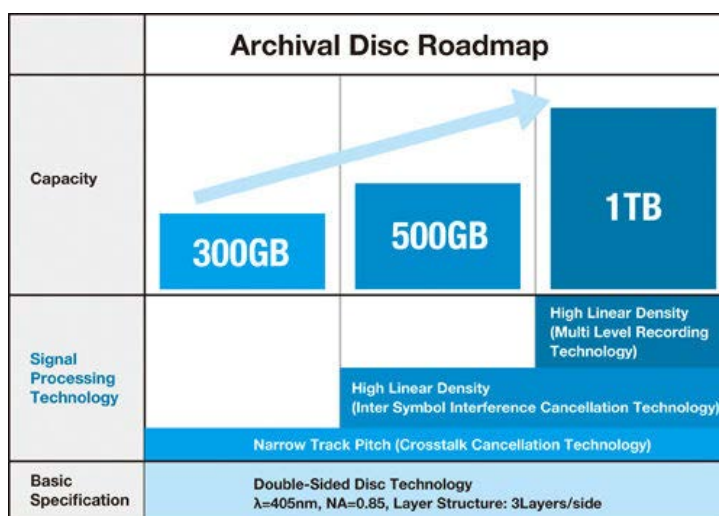


Figure 5. Archival Disc Roadmap

## 3.2 Disc Structure

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. 6). This structure has been established in conventional optical discs and is already commercialized. A spiral data track on one side has opposite rotational direction to the one on the other side. This configuration makes it possible to record and/or playback simultaneously on both sides, which gives double the transfer rate achieved with one-sided recording or playback. Address structure, which has been developed for the AD format, is maintained in the 2<sup>nd</sup> generation, with a recording capacity of 500 GB per disc. It will be also maintained in the 3<sup>rd</sup> generation, so that the disc manufacturing process will not have to be changed to retain low cost disc capability.

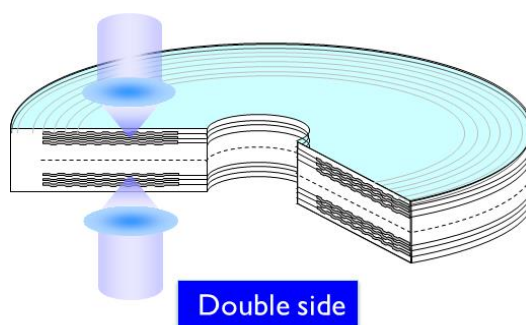


Figure 6. AD disc structure

## 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. Since this recording film has 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 storage reliability to be achieved at the same time.

There are several remarkable advantages from a disc-manufacturing perspective: this recording film has high electric conductivity and can be sputtered by DC voltage under a relatively low vacuum. This feature enables short cycle time and allows choice of a variety of recording ingredients to reduce disc cost. Meanwhile, a second-generation AD disc conforming to AD-Ver. 2.0 standard has a more advanced recording material having better signal amplitudes in 250 GB per side recording.

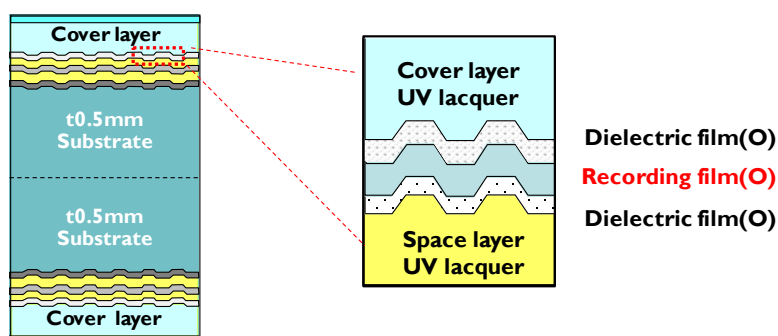


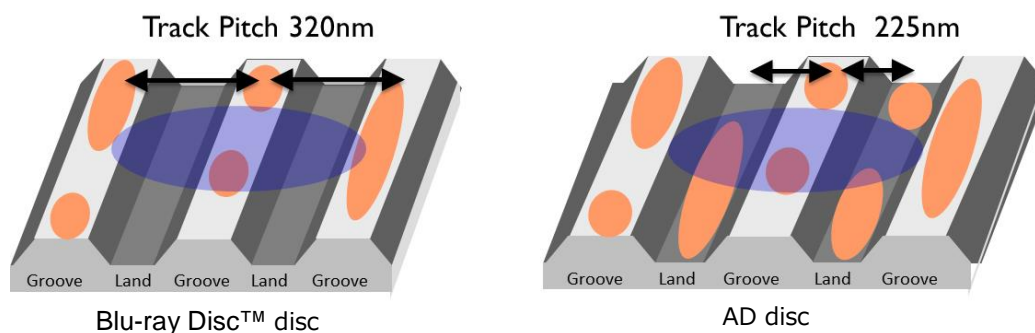
Figure 7. AD disc recording film

## 3.4 Physical Format

This section describes new technologies adopted for 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 recording capacity of each layer. This means that radial recording density is improved by 40% in comparison with Blu-ray Discs™. A new defect management system with 3.5 Logical Format (detailed later) has been adopted to overcome servo error signal crosstalk issues and to enable a narrow track pitch.



**Figure 8.** Land-and-groove recording

### (2) Physical address format

A physical address has been applied to 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 groove tracks have a physical address, but a new format has now been adopted to obtain physical addresses for both groove tracks and land tracks, thus enabling land-and-groove recording, which is a key feature of AD. At the same time, AD physical address format sufficiently reduces noise caused by wobbled track to playback signal during data playback, ensuring high read performance.

### (3) Zone format system

AD uses a zone format system to control data recording density to a physical address as defined by wobbled track. Using this system, it is possible to obtain a data address for a block of data from 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 disc.

### (4) New recording/playback technologies and data format for the 2<sup>nd</sup> generation AD

In the second-generation AD, linear density is increased to raise disc capacity from 300 GB to 500 GB. Following technologies were newly introduced.



- 
- Improved recording technology to form fine recording marks accurately
  - Inter-symbol-interference elimination technology for decoding data from weak signals
  - New data format with improved linear recording efficiency by 7%
  - New channel modulation code enabling lower data error rates
  - Advanced error correction code

With the advanced error correction code, an error rate of less than  $1E-19$  can be realized after error correction. This capability is guaranteed even when all the error correction code units have defects whose lengths are 1mm or so as long as random symbol error rate is less than  $1E-2$  before error correction.

## **Reduced bit Cost and Future Compatibility**

With conventional optical discs, data recording density could be increased by modifying disc track structure, but with AD zone format system it will be possible to realize 500 GB disc capacity by simply updating zone format parameters, without the need to change physical address structure of the 300 GB AD disc. This means that for ADs, there will be no need to change the format even if the recording density is increased: this contributes to a significant advantage of reducing bit unit price. Meanwhile, the fact that physical structure of 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 latest drive systems. The zone format system will also be implemented to the 1 TB AD disc in the future.

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## 3.5 Logical Format

### 3.5.1 Disc Management

AD disc adopts double-sided, triple-layer land-and-groove format, and user can treat them as large-capacity optical discs. In addition, a reverse groove on each side enables simultaneous access to both side of disc. As it is possible to record to lands and grooves simultaneously, it is also capable to improve transfer rate by using multiple optical heads. Additionally, as disc management adopts a single-sided closed structure, it is not dependent on drive structure, while unique logical sector numbers (LSNs) are defined for each physical location on disc for easier playback compatibility. Defect management and 'logical over write' (LOW) features are also provided so that a file system capable of controlling conventional optical disc will be capable of controlling AD with ease.

### 3.5.2 Defect Management

Defect management feature is incorporated into AD such that even if a defective block is present within user area, data can be alternatively recorded to spare areas on inner and outer areas of disc, thereby improving data reliability.

Defect management system of AD also has new features that protect reliability of recording performance against problems such as influence from 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 disc, thereby minimizing performance loss in recording control and maximizing ease of use by non-specialists. In regards to 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 disc.

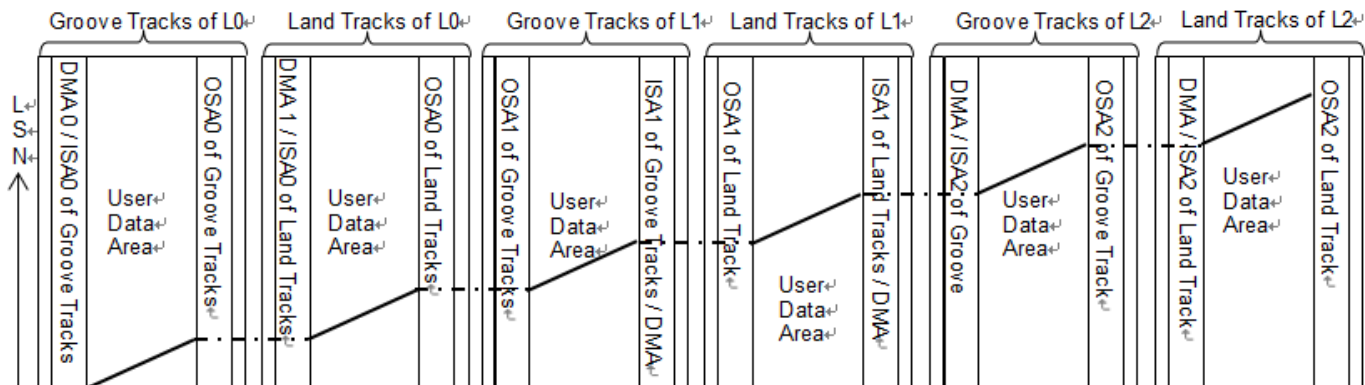
With AD, it is not necessary to fill unused portions to be able to close SRR or disc, meaning that close operation can be made shorter than for conventional sequential recording media like DVDs. Additionally, by using Defect Management's linear replacement function, it is possible to perform LOW over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

### 3.5.4 OPC Area Management

AD allows more areas to be assigned for write power adjustment than before, and uses a structure whereby optimum power control (OPC) areas can be optionally allocated via disc drive. By defining this OPC range information (OPCRI) within disc definition structure (DDS), total number of available reuses is increased by at least as much as the overall capacity of 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 user areas (volumes) accessible to user, meaning that users can access these areas using appropriate LSN. LSN allocation method is shown in Figure 9 below.



**Figure 9.** LSN allocation method

Specifically, LSNs are allocated sequentially to groove tracks of L0 layer from inner perimeter to outer perimeter, and then to land tracks of L0 layer from inner perimeter to outer perimeter. After L0, LSN are then allocated on L1 following a similar rule in 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 drive and its control system compatibility.

## 3.6 Signal Quality Measurement

An index called ‘distribution derived-maximum likelihood sequence error estimation’ (d-MLSE) has been used for playback signal quality evaluation in the 2nd generation AD discs. The index is based on ‘partial response maximum likelihood’ (PRML) detection method same as i-MLSE for the 1st generation, but with an improved calculation procedure for higher recording density. The index makes it possible to accurately quantify playback signal quality of the 2nd generation AD discs. Figure 10 shows measurement results for symbol error rate (SER) and d-MLSE when various types of playback stress are applied to a 500 GB AD disc. A strong correlation can be seen between two variables.

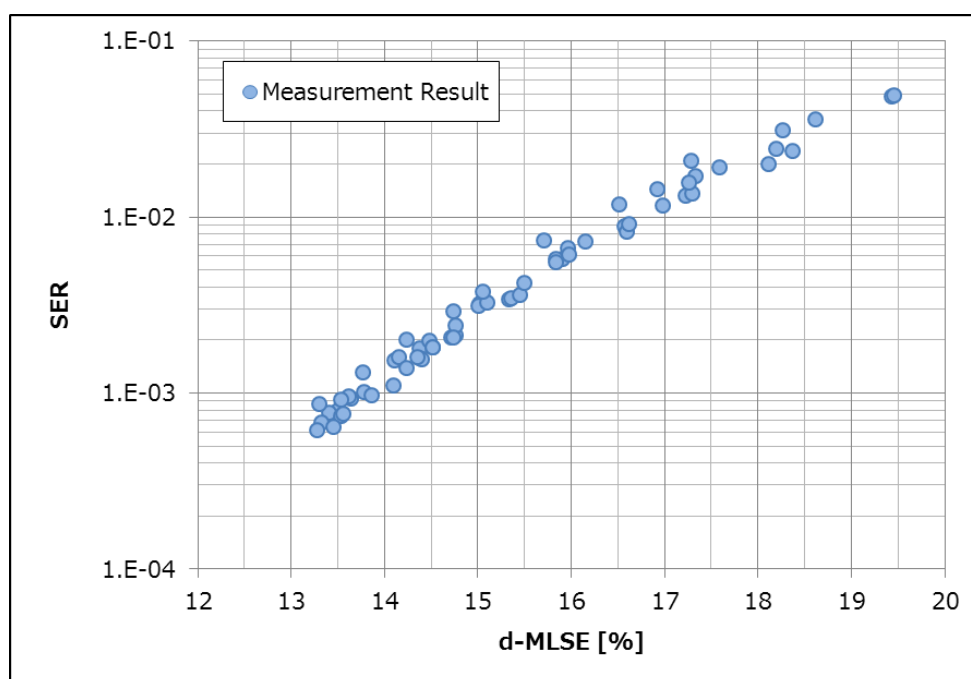


Figure 10. d-MLSE signal quality evaluation index and SER

## 3.7 Specifications for 500 GB AD

Main parameters of 500 GB AD discs are shown in Table 1 below in comparison with 300 GB AD discs. In order to facilitate backward compatibility with Blu-ray Disc™ discs, main parameters for AD discs have been kept at the same specifications as those for Blu-ray Discs™ (\*see Blu-ray Disc™ White Paper). 300 GB AD discs have 1/1.422 times narrower track pitch, 1.055 times higher linear density, and twice the surface area due to its double-sided nature compared with 100 GB Blu-ray Disc™ specifications. Meanwhile, 500 GB AD discs have 1.549 times higher linear density, same track pitch, and same double-sided structure compared with 300 GB AD specifications.

**Table 1.** Main parameters of AD discs

<b>【Main parameters】</b>	<b>【AD 300GB Specifications】</b>	<b>【AD 500GB Specifications】</b>
Disc diameter	120mm	
Total nominal thickness	1.2mm	
Double sided disc	Triple Layer (TL)/Side	
Cover Layer thickness	57.0um	
Recording polarity	High to Low	
Recording method	Land & Groove	
Data Zone inner radius/ outer radius	24mm/58mm	
Track pitch	0.225um	
Addressing method	Wobbled Grooves with addresses	
Maximum user data transfer rate	359.65Mbps	
Channel modulation	17PP	110PCWA
Error correction code	64KBLDC+BIS	256KB Extended-RSPC
Total efficiency	81.738%	87.850%
Nominal Channel bit length	53.0099nm	34.216nm
Nominal Data bit length	79.5149nm	51.324nm
User data capacity 120mm	300.00572GB	500.12357GB

d-MLSE and SER specifications (defined in **3.6 Signal Quality Measurement**) for each layer of 500 GB AD discs are given in Table 2 below.

**Table 2.** d-MLSE and R-SER specifications for each 500 GB AD disc layer

<b>【Signal Quality Evaluation Index】</b>	<b>【Specifications】</b>
d-MLSE required for disc with Tester	L0 $\leq$ 14.5% L1 $\leq$ 14.5% L2 $\leq$ 14.5%
SER required for disc with Tester	$\leq$ 1.0E-2

## 4 Long-term Archiving

### 4.1 Media Lifetime

As explained in Chapter 3.3, the recording film of AD discs has high reliability because of its extremely high oxidation resistance and corrosion resistance. The mark formation principle involving a physical change of the recording material also makes the media highly reliable. Fig. 11 shows the estimated lifespan of AD discs which was derived from accelerated life tests while referring to ISO/IEC16963.

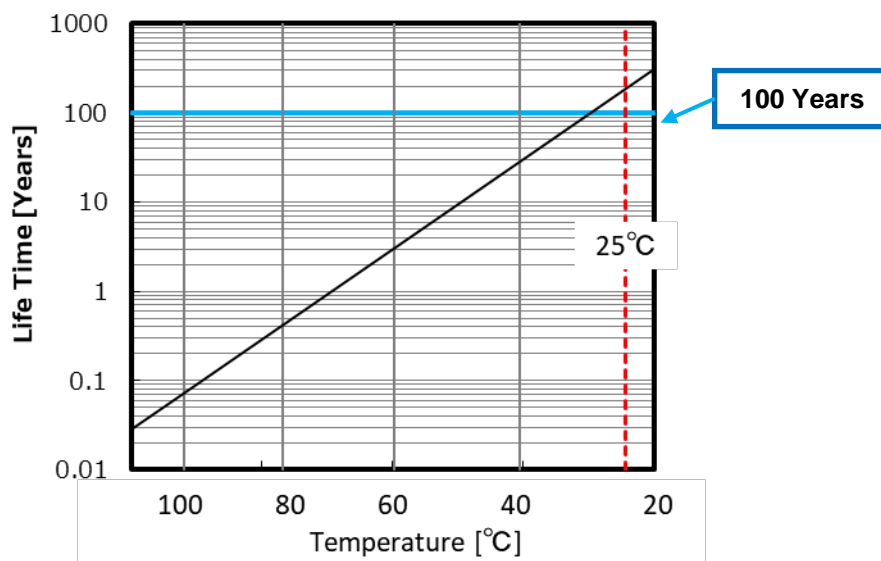


Figure 11. Long-term storage reliability of AD discs

The tests were conducted under five different temperature and relative humidity conditions such as 65°C/80%, 75°C/80%, 85°C/60%, 85°C/70%, and 85°C/80% to measure times at which playback data error rates reach a criterion. The graph shows temperature dependence of the 95% survival lifetime prediction under 50% relative humidity. The estimated lifespan of AD discs with our newly-developed recording material is very satisfactory: more than 100 years at 25°C/50%.

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## 4.2 Disc Tilt and Its Variation 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 DVD, and results in little tilt occurring after long-term storage. This helps to prevent degradation of playback signal quality when disc is played in a drive. With discs that have a single-sided structure, such as CDs and Blu-ray Discs™, 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 top or bottom surfaces of 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 disc is inserted into a drive. With a single-sided structure, tilt can readily occur in disc, due simply to temperature rise in drive bay when 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 discs be stored in an appropriate cartridge or case, and kept vertical or flat.



## 5 The Future

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

3rd generation disc will have an identical physical structure, with greater linear density by introducing a multiple-level recording technology taking the capacity to over 1 TB. Playback result of four-level recording on the second-generation AD disc is shown in figure 12. As can be seen, each signal level is separated clearly, which indicates that each mark is recorded properly. A low enough data error rate of 6.54E-4 was confirmed.

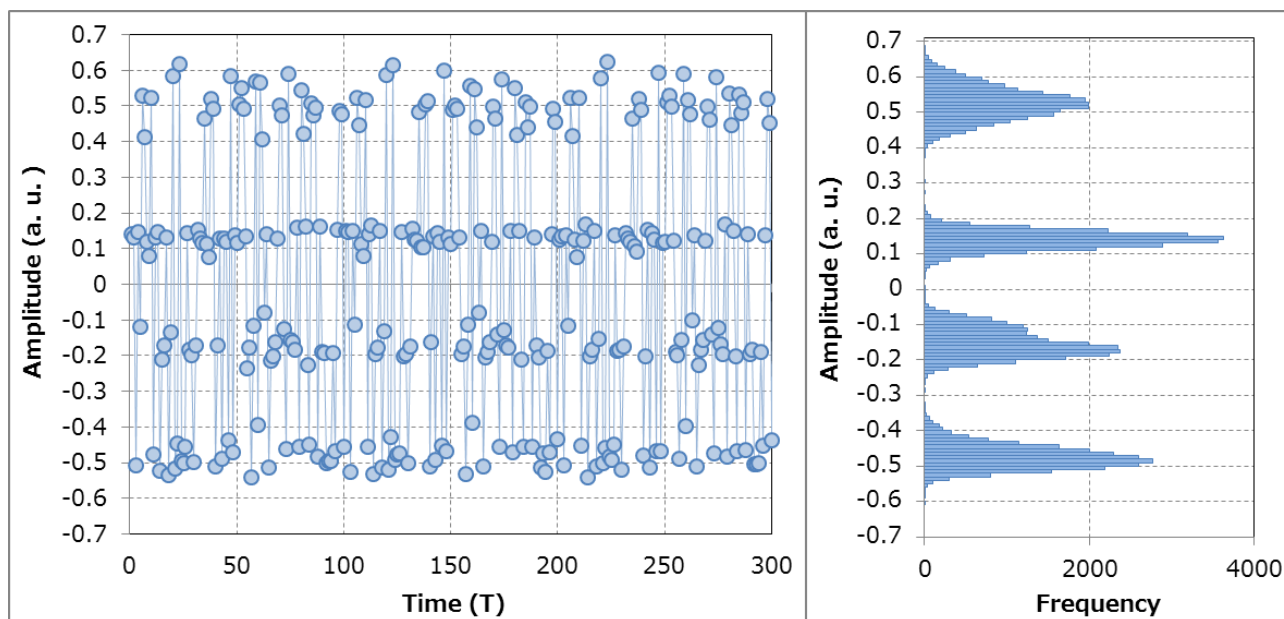


Figure 12. 3<sup>rd</sup>-generation AD multiple-level recording/playback performance

An advanced cross-talk canceling technology is also under development and we have a good prospect on realizing a narrower track pitch. As such, AD standard will use the same basic specifications for laser wavelength, NA, and disc layer structure as 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. AD standard is a highly promising means of storage for low-cost archiving as data volumes grow ever larger in the future.