Quality Evaluation and Longevity Estimation of Optical Disc as Long-term Recording Medium

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Abstract

Demand of optical discs such as CD-R, DVD-R, BD-R is expanding briskly as they are the means of data storage of texts, still images of digital camera and dynamic picture images of digital television. Although its reliability has been concerned domestically and internationally since short life medium have been broken into the market widely whose quality does not meet the standards, and also that there had been no necessary information regarding the specific standards of longevity. Archive Disc Test Center-NPO Entity have been practicing "optical disc longevity estimation test" since April, 2009 based on worldwide estimation test method of longevity of optical disc. Here we explain expert behaviour on optical disc and longevity estimation test method using acceleration test, and introduce our steps being taken for diffusion of optical disc which is reliable to use.

1. Introduction

Advantage of digitalization is its being easy for development, modification, duplication, convection and storage, which could be done much more efficiently than via analog method. Digitalization of information which is a great asset to individual, business, society and culture is a commonsense move in order to reutilise such information for the development of science, culture, society and business.

Technological innovation of digital equipment is dramatic, and amount and speed of throughput of information, traffic, transfer speed, cumulative dosage and speed of data, and bitwise cost have been improving amazingly drastically every moment. On the thought of long-term storage of digital data, it is important to consider which recording media should be used. As digital data is stored by being translocated from one media to another, the change of economic value brought by technological innovation of accumulation playback equipment including recording media could jeopardize the viability of playback equipment, cause the data to need migration regardless of the recording media's longevity or make migration difficult when the playback environment is ruined as the case may be. Recording media suitable for digital archiving of digital data's long-term storage is of long service life, large capacity, high speed data transfer and low cost, which magnetic disc, magnetic tape and optical disc could be named potentially. What is being used mainly nowadays is magnetic recording from the point of data transfer speed and recording capacity, although optical disc is also a promising entry due to it's being applicable for multi media, has large capacity, low cost and its playback equipment is widely diffused over the world. In order for optical disc to be long-term storage recording media, the quality evaluation method of optical disc needs to be standardised, and it will be efficient to store for a long term on optical disc that has been evaluated based on the international

standards. Here we are introducing abstract of ISO Standards regarding longevity estimation test method of optical disc and activities of the third party organization, Archive Disc Test Center-NPO Entity who practices its testing method.

2. Efforts for Reliability of Optical Disc

Domestically, with the Ministry of International Trade and Industry's encouragement in early 1990's, a group regarding standardisation of system which assays optical media was set up by companies in Hamamatsu area, added by powerful companies outside the area, and research on standardisation was promoted. Meanwhile, in the United States, research on the case where optical disc is used for the purpose of digital storage of mainly images by NIST (National Institute of Standards and Technology) and other companies was carried out, whose accomplishment was prepared by Technical Committee 42 of ISO as a mean of evaluation of expected longevity value effected by temperature and relative humidity of CD-R etc and standardised as ISO 18927 in 2002.

Since 2002, CDs21 Solutions (Chairman: Dr. Heitarou Nakajima), a private organisation which consists of optical disc related companies has been testing the longevity of CD-R sold in the market, and with the knowledge gained through the tests, it developed the optical disc longevity estimation test method cooperating with OSTA (Optical Storage Technologies Association), a private organisation of optical disc in the United States and NIST, with its being established as standardisation at ECMA (European Computer Manufacturer Association) in June, 2007 as ECMA-379, which was suggested as standardisation into ISO (the International Organization for Standardization) and established as ISO/IEC 10995 as an international testing method.

3. Failure Factor and Longevity Estimation of Optical Disc

Failure of optical disc is defined as "The point where the damage of digital data unrepairable with playback signal occurs, being caused by physical factor occurred by aged deterioration of recording film characteristic while being stored for a long term under the general storage environment".

Mean time to failure (MTTF: Mean Time to Failure) which shows the longevity of general products is defined as "average time to failures with the modeling assumption that the failed system is not repaired" in JIS Z8115. Unrepaired item means "a failed item that is not to be repaired or unrepairable item". Time to failure of optical disc is not MTTF but defined as operating time of 5% of time to failure (95% of survival probability) in order to avoid defective replay of recorded and stored data.

Primary quality of optical disc before aged deterioration is, to cite DVD, maintained by establishing jitter rate of after recording

for recording disc and one of the time of manufacture for ROM. Jitter rate and recorded data's error rate correlate with each other, and data quality that has been recorded on the disc could be figured out without signal conditioning such as 8/16 demodulation. Error correcting code is added to DVD and standardised in order for recorded data to play stably, responding to primary error, deterioration error, errors caused by defects such as scratches or stain on the surface of the disc. Therefore, failure in optical disc could be considered as the state where error correction is impossible. For DVD, value of PI error (Parity of Inner-code) of successive 8 ECC blocks before error correction is defined as below 280 in ECC (Error Correction Code), a digital error correction code, which is used to determine the DVD's failure. Other optical disc systems have similar definitions, and failure needs to be determined basing on each standards.

Longevity deterioration of optical disc caused by physical factor is considered to occur as the characteristic of functional lamella such as recording film which configures recording layer or reflective film changes due to the chemical reaction of such as moisture diffusion. When deterioration factor is applicable for chemical kinetics as such, apply Arrhenius model or Eyring model to the connection of given stress and rapidity of response, and longevity estimation test could be conducted by acceleration test of temperature and humidity stress.

4. Arrhenius Model and Eyring Model

S. Arrhenius was born in 1859 in Sweden, well known for Arrhenius's formula, which expresses temperature dependence of rate constant for reaction by activation energy. In 1903 he was awarded the Nobel Prize in chemistry for electrolyte theory of disaggregation.

$$t = A \exp(\Delta H/kT) \qquad (1)$$

t is kinetic constant, A is pre-exponential factor, ΔH is activation energy, k is Boltzmann constant (8.617×10^{-5} eV/K), T is absolute temperature (273.15+degree Celsius).

Temperature dependence of kinetic constant of many chemical reactions are expressed in formula (1) in Arrhenius model, and general model has been established which shows how reaction proceeds according to the formula.

H. Eyring was born in Mexico in 1901, an American chemist who developed activated complex theory (transition state theory). Activated complex theory is focused on transitional chemical species around the top of activation barrier of reaction, and the transitional chemical species are called activated complex or transition state. Activated complex theory considers reactant and activated complex are at equilibrium with each other, and the reaction is the second phase.

$$A + B \cdot AB\ddagger \cdot P \qquad (2)$$

A, B are the reactants, AB‡ is activated complex, P is product. Figure 1 shows reaction in activated complex theory in section.
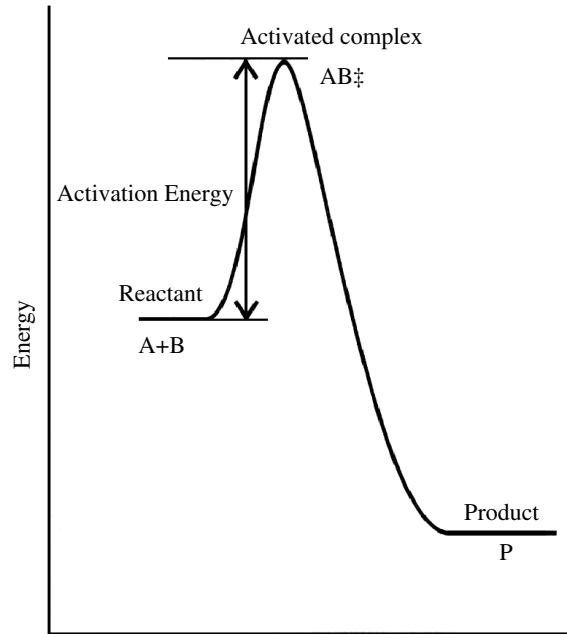

Fig.1 Reaction sectional view

Formula shown below is Eyring formula.

$$t = AT \exp(\Delta H/kT)\exp((B+C/T) \times RH) \qquad (3)$$

t is kinetic constant, A is pre-exponential factor, T is pre-exponential temperature factor, ΔH is activation energy, k is Boltzmann constant, T is absolute temperature, B and C are exponent and constant of percentage humidity and RH is percentage humidity.

In ISO/IEC 10995 to be explained later, reduced Eyring formula is used.

$$T = A \exp(\Delta H/kT)\exp(B \times RH) \qquad (4)$$

Eyring formula is scalable as below;

$$T = AT \exp\{\Delta H/kT + (B+C/T) \times S_1 + (D+E/T) \times S_2 + \ldots\} \quad (5)$$

Related stresses except for temperature could be added.

5. ISO/IEC 10995

ISO/IEC 10995 ("10995") defines evaluation method of longevity estimation of DVD-R/-RW/-RAM, +R/+RW. Longevity estimated here means the expected longevity stored at 25℃ ambient temperature, 50% percentage humidity and the lower limit of 95% confidence interval when probability of survival is 95%. Longevity in case of DVD±R/RW, is the time it takes until it reaches PI error rate of defective replay.

Take longarithm natural in simplified Eyring formula as below;

$$\ln(t) = \ln(A) + \Delta H/kT + B \times RH \qquad (6)$$

Transform it, converting y into ln (t), ln (A) into a_0, $\Delta H/k$ into a_1, $1/T$ into x_1, B into a_2, RH into x_2, it could be shown as below;

$$y = a_0 + a_1x_1 + a_2x_2 \qquad (7)$$

This could be considered as multiple regression equation of explanatory variable 2. Number of individuals needed for multiple linear regression analysis could be figured out from formula (8) as 4 and over since explanatory variable is 2 figured by formula (7).

Number of individuals－explanatory－1
=Number of individuals－2－1>0 $\qquad (8)$

As shown above, the results of at least 4 temperature and humidity conditions are necessary in acceleration test of Eyring model. In 10995, longarithmic mean of time to failure is figured using 4 conditions of 85℃/85%RH, 85℃/70%RH, 65℃/85%RH, 70℃/75%RH.

10995 presupposes that longevity data distribution follows log-normal distribution, and shows the analysis procedure for figuring out longevity estimation value. Time to failure is figured by regression expression, practicing acceleration test of an optical disc sample under 4 conditioned described above. Cumulative distribution of failure data uses median rank method of order statistics with lognormality graph as accumulated total distribution of failure data under each conditions, and confirms whether it's being within range of estimate or not.
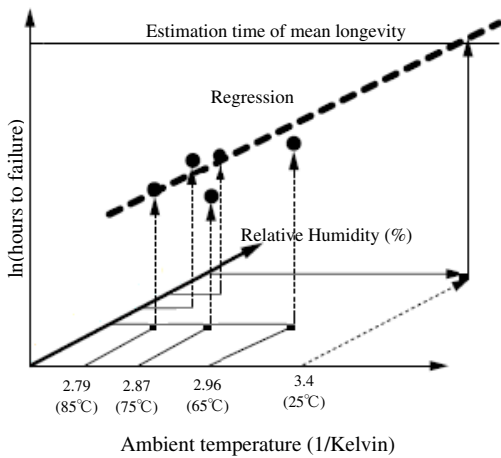

Fig.2 Abstract of longevity estimation in Eyring model

Speaking more specifically, longevity data is a vertical line in lognormality graph under each condition, and logarithmic root-mean-square deviation expressed by the slope is equal to sumption of sample taken from the same parent population. By confirming this, it could be verified that failure under each condition is within the range of 10995 model. Figure 3 shows the cumulative failure distribution.
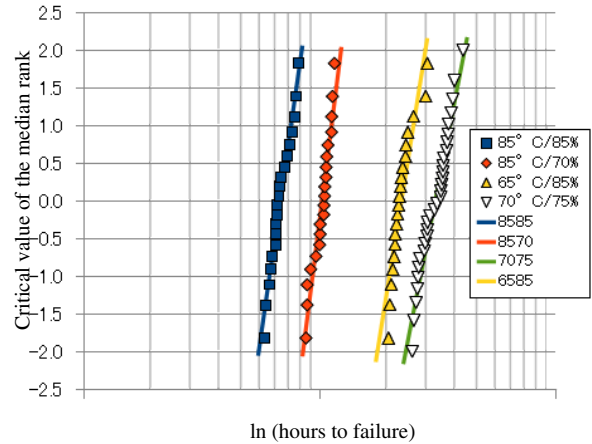

Fig.3 Cumulative Failure Distribution

Figuring out the logarithmic mean value of failure data under each condition from lognormality graph, constant term and partial regression coefficient, or ln (A), $\Delta H/k$, B in simplified Eyring formula are figured by multiple linear regression analysis. Using figured constant term and coefficient in simplified Eyring formula, longevity estimation mean value under storage condition could be figured, assigning absolute temperature 298.15K (25℃) and 50%RH to the equation.

Caluculate acceleration coefficientdata under each condition (the ration of longevity estimation mean value in acceleration test to one in storage condition), and normalise the longevity data of storage condition.
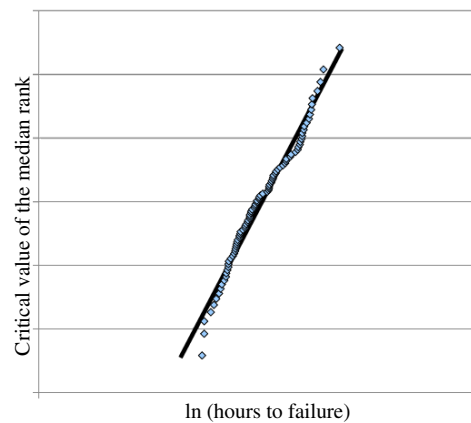

Fig.4 Normalised Longevity Estimation Using Acceleration Factor

In 25℃/50%RH in case of 90% of confidence interval, with probability of survival being 95%, longevity expected at 95% confidence level is estimated.

6. Migration of Digital Data

Recording media in which digital data is recorded has duration of life, and in order to store the digital data for a long term, condition confirmation of recording media every few years and restore the data to new media depending on deterioration state

is necessary. Migration (Transition of data) of optical disc has standards such as ISO/IEC 29121 and JIS Z6017, method to determine the deterioration level of the data of the recorded optical disc and migrate data as appropriate from the point of view of preservation of continuousness.

Initial performance test

When newly recording digital data to optical media, primary recording test is conducted in order to determine whether it is recorded with good characteristics or not. The test method is to detect error numbers and error rate, and determine the optical disc being good or failure according to the test result. Each standard is established with criterion for judgment for a case where the tested optical disc is used for storage, and is set for error number of replayable on drive and error rate to be below substantially even if deterioration of the optical disc proceeds in the future in the usable level.

Periodical performance test

Each standard requires testing the state of optical disc regularly. Recommended test cycle is 3 years or less, though it is preferable that it is done appropriately according to the storage environment of the optical media, frequency in use and estimated longevity. Regular testing method is the same as primary test, error number and error rate are assayed, and data copy is required in the appropriate manner when it is determined that migration is necessary according to the criterion for judgment.

7. Archive Disc Test Center-NPO Entity

Archive Disc Test Center-NPO Entity ("ADTC" http://n-ADTC.org) was established in August 2008 in order to support users to determine the optical disc being suitable for long-term storage, conducting longevity estimation of optical disc who record and store documents, images and motion picture in optical disc.

Since March 2009, center laboratory of ADTC began longevity estimation test. Longevity estimation is tested in center laboratory of ADTC in conformity with ISO/IEC 10995, targeting DVD±R disc for testing. The type of test object disc will be enhanced accordingly as the test system is completed.

Figure 5 shows the appearance of center laboratory of ADTC. In order to conduct acceleration test, constant temperature reservoir and PI error measuring instrument for DVD±R are equipped. Figure 6 shows the qualification logo mark which is given to the disc which is estimated as archival grade (longevity of more than 30 years) when stored at 25℃ and 50%/RH.

Center laboratory of ADTC moved in April 2011 to Tokyo City University Advanced Research Laboratories, and proceeds with collaborative research of long-term storage of optical disc in the future, collaborating with Professor Toshiaki Yokoi of The Department of Environmental and Information Studies, Information Media.

Fig.5 Appearance of Center Laboratory of ADTC

Fig.6 Qualification Logo Mark Issued By ADTC

5. Conclusion

Here we addressed optical disc as digital archiving recording media, explaining longevity of optical disc and longevity estimation test method.

Research on longevity of recording disc such as CD and DVD has been conducted and standards of longevity estimation were established domestically and internationally. Such organization who conducts longevity estimation test based on these standards as ADTC began its operation, which leads to the thought that quality-stable optical disc as long-term storage recording media will be widely used.

It is a fact that disc whose characteristics are unstable ended up being distributed as the result of price competition after optical disc developing as consumer use and spreading worldwide. Meanwhile, in order to store an enormous quantity of data for a long term, it is important to store at lower cost, and economic dimension should not be ignored. Joint research of recording media for long-term storage between industry and academia is considered to be very meaningful, achieving a balance between characteristics of recording media and its cost, playing the role of defusing inexpensive and stable recording media.

Author Biography

Takao IHASHI- ・Sony veteran of 30 years, responsible for virtually all the optical media technology research and launch at Sony. Collaborated with Dr. Nakajima side-by-side when launching CD-DA and CD-R. Doubled business as president at START Lab in 3 years prior launching Bifröstec. Chairman of the "CDs21 Solutions" Committee.

Representative member of the "Council for Green Product Chain of Optical Discs".

Toshio SUZUKI-・In 1980, graduated from the University of Elector-Communications in Japan. From 1980 to 2009, worked for PIONEER CORPORATION and engaging in the development of optical disk systems including LaserDisc playback system, DVD-R/RW physical format creation and recording system, content protection system, etc.. From 2010, joined in Bifröstec Inc. and an administration officer of Archive Disc Test Center.