WHITE PAPER

Defect Management Capabilities of Various DVD Technologies

Sponsored by Hitachi-LG Data Storage, Inc.; Hitachi Maxell, Ltd.; LG Electronics Inc.; Matsushita Electric Industrial Co., Ltd. (Panasonic); Samsung Electronics Co., Ltd.; and Victor Company of Japan, Limited (JVC)

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May 2004

Introduction

DVD became popular because of its ability to store full screen, TV quality video. Its capacity of 4.35 GB (4.7 billion bytes) and robustness was quickly adopted for data file interchange. The initial DVD-Read Only structure expanded into recordable (write once) and rewritable (re-recordable) media that allow users to conveniently transfer information to an interchangeable disc that can be read in other systems. Media interchange is a key advantage of optical storage over fast, inexpensive hard drives.

Interchange of read-only, recordable, and rewritable media is possible because all DVD discs have a common physical data structure. The data frames, error correction (ECC) blocks, recording frames, and physical sectors that constitute the data format are a fundamental element of every DVD disc. Multiple recordable and rewritable formats each have different track structures that demand unique write drive capabilities, and create other compatibility issues that may affect read drives. High confidence levels in data integrity may require special defect management methods. Information in this paper supports five important conclusions.

1. Compatibility issues caused by different DVD formats are resolved in many current drives.
2. All DVD discs contain bytes capable of detecting and correcting errors from most defects.
3. Readability of discs with severe defects in data areas is unpredictable because drives differ.
4. Rewritable discs can employ defect management to relocate data to defect-free areas.
5. Only DVD-RAM currently offers comprehensive, drive-based defect management.

Compatibility

DVD-Read Only receiving systems require contiguous ECC blocks. Recordable DVD-R and +R (also referred to as DVD+R) media have minimal compatibility problems unless discs are incrementally recorded. DVD-R then uses linking blocks that fragment ECC blocks, requiring special read drives that can seamlessly reassemble each ECC block. +R discs avoid this problem through use of lossless linking. Rewritable defect management systems also fragment ECC blocks and require special read data processing prior to error detection and correction.

Rewritable DVD-RW and +RW (often referred to as DVD+RW) discs have lower reflectivity than read-only and recordable media, and have similar linking issues. Rewritable DVD-RAM has other compatibility issues related to a higher user data rate, unique connection zones, both land and groove recording, smaller track pitch, and exclusive DVD-RAM sectors containing both pre-embossed and rewritable information.

Many current DVD read drives, and some write drives, support multiple recordable and rewritable structures, but older drives may have compatibility problems. Although many modern drives can cope with different media structures, significant quality differences between media and drive manufacturers can cause interchange failures that may be improperly assigned to compatibility issues.

DVD Media Defects

High DVD information densities require data dimensions comparable to a wavelength of light, therefore data integrity is sensitive to even microscopic defects. Natural variations in media manufacturing processes result in substrate, information layer, metallization, and bonding defects.

Recordable DVD-R and +R media use a defect-sensitive, organic dye layer that is modified by a high intensity laser beam during write-once recording. Rewritable DVD-RW, +RW, and DVD-RAM discs are more complex, using a phase change alloy recording layer that is contained between transparent dielectric layers. Direct overwrite requires crystallization of the alloy at an intermediate recording power level, and local melting at high laser power followed by quenching. Although these operations avoid an intermediate erase step, repeated write cycles gradually degrade the alloy layer. Rewritable standards require a capability of at least 1000 overwrite cycles. A unique recording layer and randomization of overwrite locations allow over 100,000 overwrite cycles for DVD-RAM media.

Media longevity is not always related to the above issues, and often depends on recording system quality, handling, and storage. DVD-RAM discs are available in protective cartridges, enhancing their longevity, but the optional bare discs are appealing because of their lower cost.

DVD Error Detection and Correction

DVD discs containing only addressing and data would be unreadable because of defects and high data densities. Interchange is feasible because powerful Reed-Solomon Product Code bytes are embedded with the information in ECC blocks, enabling detection and correction of errors from defects as large as 2 mm in diameter. Although read drives employing feed-forward methods could correct errors from 5 mm diameter defects, defect sizes must be smaller because of read drive servo limitations. Standards require defect diameters of 0.3 mm or less.

DVD Drives

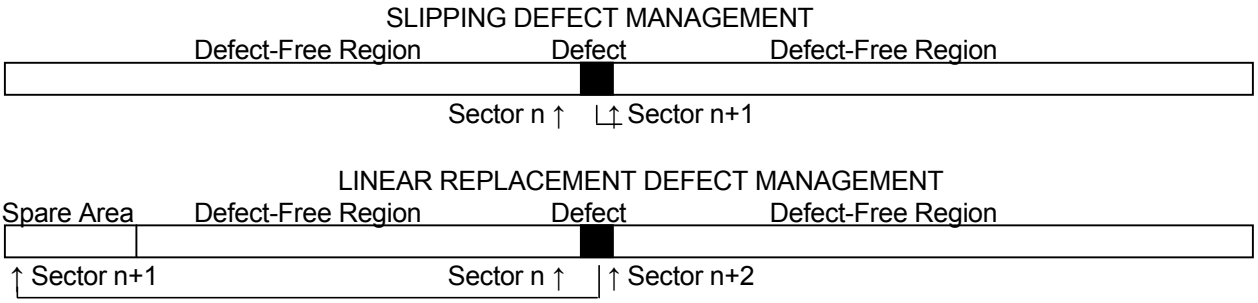
Drives do more than just process write or read data. Two servomechanisms interpret the reflected laser beam to maintain accurate radial position and focus with accuracies comparable to a wavelength of light. Another servo maintains precise rotational speed. Defects result both in data loss as well as loss of critical servo information, requiring servo reacquisition after emergence from a defect before valid data is available. This latency results in error lengths that exceed those of the corresponding physical defects. Although all drives have similar error detection and correction capabilities, their servo performance can vary in the absence of drive standards. As a result, drives respond differently to media flaws, and discs having significant defects can function in one drive but fail in another.

Although some read failures can be overcome by read retries, write failures always result in a permanent recorded defect. Special defect management methods that mask severe errors are available for certain media types. Application of these methods depends on suitable drive or software capabilities.

Defect Management

Recordable discs cannot conceal defects, because the required pre-formatting would make write-once discs unusable. Rewritable structures may detect and correct erroneous data associated with defects under drive or software control. Defect management requires a verification, or certification, process that detects defective blocks. Methods for this can include feedback from running OPC while writing, detection of excessive drive servo signals, or error flags from the error correction system during reading.

After defective blocks are detected, defect management can then flag unusable locations and relocate data to a defect-free area. Both defect and relocated addresses must be registered and safeguarded, otherwise information could not be accurately written and retrieved. Two different defect management methods can be used. Slipping marks a defect and sequentially moves data to the next good region. Linear replacement marks the defect and moves data to a non-contiguous, designated spare area. Both defect management methods create fragmented ECC blocks that must be reassembled by the read drive. Slipping can be used by the media manufacturer or by the user when the disc is initially formatted. Linear replacement must be used for subsequent reformatting or data relocation. Media standards may state that these processes are optional. As a result, users must independently confirm whether certification is used during format, write, and read operations.



Defect management can be either drive-based or software-based, depending upon which controls the process. Drive-based methods are specific to media type, while software-based methods can be universally applied to various rewritable media. The Optical Storage Technology Association (OSTA) issues standards for a Universal Disc Format (UDF), early versions of which were used for DVD-Video. Later versions incorporated sparing methods that can be used for software-based defect management, together with recommendations for their use with DVD-RW and +RW. UDF requires an appropriate device driver and file system driver in both the recording and receiving systems.

DVD-RW Defect Management

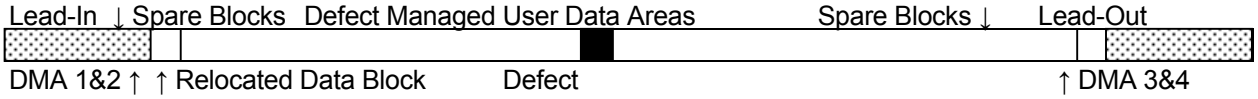
DVD-RW drives flag but do not replace defective sectors. The R-Information zone that precedes lead-in contains a Recording Management Area consisting of a Power Calibration Area followed by a Defect Status Bitmap. Every ECC block is represented in the bitmap that results from optional certification by the manufacturer or is optionally updated when the disc is reformatted. DVD-RW is designed for sequential recording, such as streaming A/V. Although conventional DVD-Video players cannot access the Defect Status Bitmap, many A/V applications are not sensitive to defective sectors. Because drive-based defect replacement is not available, DVD-RW discs may not be suitable for computer data storage. Software-based defect management could be provided by UDF.

+RW Defect Management

Standards for +RW media do not define a defect management system, but instead defer to a future planned Mount Rainier standard (MRW) that is drive-based and requires a compliant write drive and recording system. Although CD-MRW drives are currently available, +MRW awaits planned recording drive and operating system support. Because there is no current +MRW specification, legacy drives may subsequently have compatibility problems. In the interim, a software-based UDF defect management system can be used with +RW.

DVD-RAM Defect Management

Since 1998, comprehensive, drive-based defect management has provided a high level of data security on full random access DVD-RAM media. Four identical Defect Management Areas (DMA), two at the end of lead-in, and two more at the start of lead-out, provide four redundant lists of defective sectors and their replacement sectors, securely backing up this critical information.



The Primary Defect List in each DMA is generated during formatting, with optional initial certification by the manufacturer, when slipping is used to move individual defective sectors. A Secondary Defect List in each DMA can be generated by linear replacement of defective or deteriorated sectors during read or write operations after formatting. Entire 16 sector blocks are then replaced using spare blocks located in the first and last of the 35 CAV zones. A fixed Primary Spare Area is located at the beginning of the Data Zone. The Supplementary Spare Area at the end of the Data Zone is available if the Primary Spare Area is filled, but is otherwise available for user data.

The DVD-RAM media standard defines non-binding guidelines for defect identification applicable to either slipping or linear replacement. Since certification is also optional, according to the media standard, users must determine which options are used during format, write, and read operations.

Summary

Successful data file interchange requires that errors from media defects do not overpower error detection and correction algorithms that are integral to every DVD disc. Read-only and recordable media defects cannot be concealed. Defect management for rewritable media can detect severe errors traceable to manufacturing flaws or to subsequent handling, storage, or recording defects. Data can then be relocated to defect-free areas using either drive-based or software-based methods. Defect management can also compensate for the gradual degradation of the rewritable alloy layer that is a normal result of repeated overwrite cycles.

Only DVD-RAM currently offers comprehensive, drive-based defect management. Future planned Mount Rainier drive-based systems for +RW are expected to provide similar capabilities. DVD-RW drives flag but do not replace defective sectors. Because some defect management functions are optional, according to media standards, users must determine which ones function during format, write, and read operations for specific media types, drives and recording software. Buyers should seek suppliers that provide such information in user manuals, web sites, and other publications.

Resources

www.mscience.com/iso.html lists media standards with links to their sources.
www.mscience.com/link.html provides links to many informative web sites.