Present and future applications of phase-change recording technology

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Abstract

the Blu-ray Disk (BD) standard following the successful CD and DVD format is designed for consumer high-definition video recording. The high capacity of up to 54 GByte per side has been achieved by pushing the conventional phase-change recording technology towards its limits. With BD the evolutionary technological path has now come to an end. Novel and unconventional technologies must be pursued towards accomplishing higher capacities beyond 100 Gb/inch² and higher data transfer rates. In this paper some BD system aspects are investigated and future applications of phase-change recording are discussed.

Introduction

Optical storage offers a reliable and removable storage medium with excellent robustness and archival lifetime at very low cost. In the low-cost, high-volume consumer electronics (CE) market the CD and DVD are the dominating optical disk standards for data, audio and standard-definition (SD) video application. The rewritable recording technology for both standards is phase-change (PC). PC has been successful in the low-cost market due to intrinsic high signal-to-noise-ratio (SNR), simple drive technology, high level of ROM compatibility and last but not least the potential for doubling the storage capacity by dual-layer recording. The moderate level of e.g. data reliability, cyclability and writing data rate of PC technology are acceptable for consumer application.

Last year the Blu-ray Disk (BD) standard based on laser light with a center wavelength of 405nm has been announced. As for CD and DVD the rewritable disk technology is PC and -for the first time- a rewritable dual-layer PC disk is specified offering a storage capacity of up to 54 GByte [1]. The BD standard is mainly driven by high-definition (HD) video applications. HD broadcasting has started and is expanding in the US and Asia.

In the dual-layer BD standard all technical parameters have been pushed to its practical limits. In particular the high numerical aperture (NA) optics in combination with a cover layer thickness of nominal 75µm for the first semitransparent layer and 100µm for the reflective layer can be considered as a limit for a conventional removable disk system. Thinner cover layers make the disk more sensitive regarding read and write through dust, scratches and fingerprints on the disk surface. Especially in the case of cartridge-free disk handling by the consumer, special attention must be drawn to guarantee sufficient read/write reliability and long-term data archival. Special techniques like disk hard-coating [5] are considered to make BD highly abrasion resistant, even under repeated wiping. However, bare disk handling always means that fingerprints cannot be avoided.

In this paper we show some measurements regarding the sensitivity of the BD format on fingerprints and compare the results with DVD. Finally we discuss the phase-change technology for next generation storage application.

BD system sensitivity on fingerprint

For the measurements a number of real fingerprints were taken at the outer diameter of both BD and DVD rewritable disks. Artificial fingerprint patterns as typically used for CD and DVD test disks do not reproduce real conditions in case of BD. For both DVD and BD disks the focus error, the track error and the HF data signal are monitored to evaluate the performance from servo point of view and data retrieval capabilities.

The applied measurement procedure on single layer phase-change BD and DVD was as follows:

- Recording of tracks on BD (80 nm channel bit length corresponding to 23.3 GB disk capacity) and for comparison on DVD
- Applying a number of different fingerprints
- Mapping of fingerprints by focusing onto the disk surface and measuring the reflected sum signal amplitude
- Measuring focus error (FE), track error (TE) servo signals and HF data signal through fingerprints

- Recording through fingerprint with a) nominal recording power and b) 30 % increased recording power
- Measuring the HF signal through fingerprints
- Removing the fingerprints carefully with water and soft detergent
- Measuring the HF signal of tracks recorded before and after applying the fingerprints

Some typical fingerprint maps taken on a BD are shown in figure 1. The corresponding FE and TE servo signals (see fig. 2) are worst for fingerprint #2 and nearly reaches the maximum signal amplitude. Strong dropouts in the sum signal occur especially in case recordings were made through the fingerprints (right side of fig. 2). In figure 3 the HF data signal envelope and the correlated data-to-clock jitter has been measured for fingerprint #2. For the less absorbing fingerprints #9 and #10 the HF dropouts are not so severe and acceptable jitter values could be achieved. However, writing through fingerprints results in highly degraded recordings, which can easily exceed the correctable burst error length of the BD error correction of about 9mm. Even with locally increased writing laser power up to 30% the recordings through fingerprints could not be improved significantly.

The same measurements as for BD have been carried out for DVD (see fig. 4). As expected, the deterioration of FE and TE servo signals is significantly smaller compared with BD. Even for the worst fingerprint #4 the HF dropout and the correlated data-to-clock jitter increase are less severe (see fig. 5). An important difference between DVD and BD was found for writing through fingerprints: unlike BD, recordings on DVD could be improved by increasing the laser power by 30%.

Summary

The emerging BD format comprising rewritable, write-once and read-only disks brings together all attributes to become the next generation disk standard beyond CD and DVD. However, due to the thin cover layer thickness, the disk shall be protected by a hard coat against scratches and shall preferably be protected by a cartridge. For bare disk handling special attention must be drawn to avoid or remove fingerprints. The comparison of data for BD and DVD clearly indicates a significant higher fingerprint sensitivity of the current BD system. Reading a BD track through fingerprints results in stronger deterioration of servo signals, stronger decrease of the HF signal envelope and higher data jitter. In addition, writing a BD through characteristic fingerprints cause bad or unreadable recordings, which cannot be improved by increased laser power as for DVD.

Although BD will hardly become as tolerant against disk imperfections and fingerprints as CD and DVD, the read performance through fingerprints might be sufficient, especially if the servo stability is further improved to make the system more robust. Hence BD-ROM might be sufficient reliable even without cartridge. For BD writing the disk surface shall be free of any imperfections like dust scratches and fingerprints.

Future optical recording technology

Since the invention of CD the optical disk storage techniques have made substantial progress through a combination of laser wavelength reduction, increase in the objective lens NA, coding improvements and better inter-symbol-interference (ISI) and cross-talk management. However, this conventional technological migration path encounters physical and engineering limits. For example, the diffraction limit of light puts a limit on the practical spot size, the further reduction of the laser wavelength requires expensive quartz optics and higher NA objective lenses in combination with thinner (beyond the BD system) or negligible disk cover layer entail high sensitivity to any kind of disk surface imperfection. Hence BD will most probably be the last conventional 12cm disk format following the traditional CD and DVD. Consequently the question arise: which technology comes next and is phase-change technology an option for the next generation optical data storage beyond BD?

The authors believe that in the short-term evolutionary technologies such as media super-resolution (SuperRENS [2], MAMMOS [3]), solid immersion lens (SIL) [4] , high-transmission four-layer PC and deep-UV recording approaches seems promising to increase the areal storage towards 150 Gb/inch². For the longer term volumetric storage systems like holographic and two-photon multi-layer recording techniques appear most promising to further push the storage density greater than 200 Gb/inch² and perhaps even exceeding 1Tb/inch².

The key issue for all future technologies is an inexpensive yet reliable removable write-once or preferably erasable medium. Key features of the read/write hardware are: high data transfer rate, low power dissipation, potential for miniaturization and low manufacturing costs.

References
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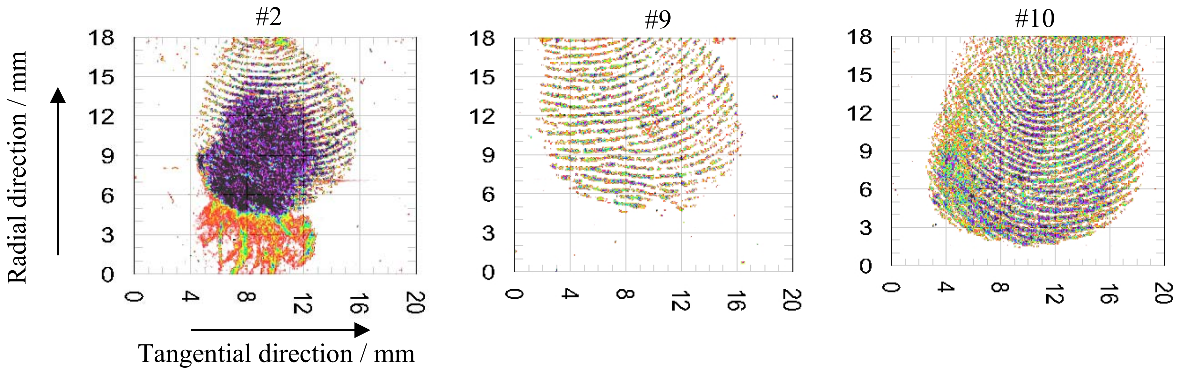

Fig. 1: Reflectivity map of different fingerprints (# 2,9,10) on a BD disk surface.
(Reflectivities are coded by colour (white: R=100% (maximum), red: R=90%, yellow: R=70%, green: R=60%, blue: R= 40%, violet: R=30%, black: R=0% (minimum))

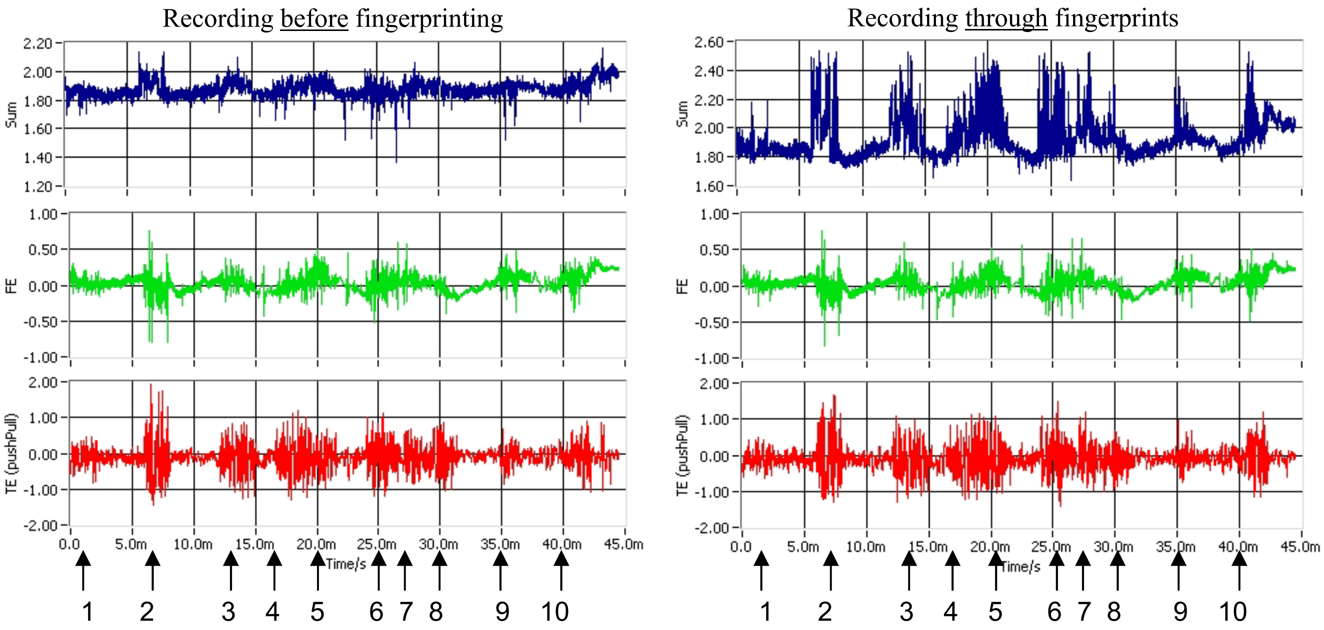

Fig. 2: Deterioration of BD servo signals (FE signal s-curve 4Vpp, TE signal push-pull 4Vpp). Black arrows mark position of 10 different f ingerprints around the outer disk radius. For recording through fingerprints no significant change was observed in case of 30% increased laser power.

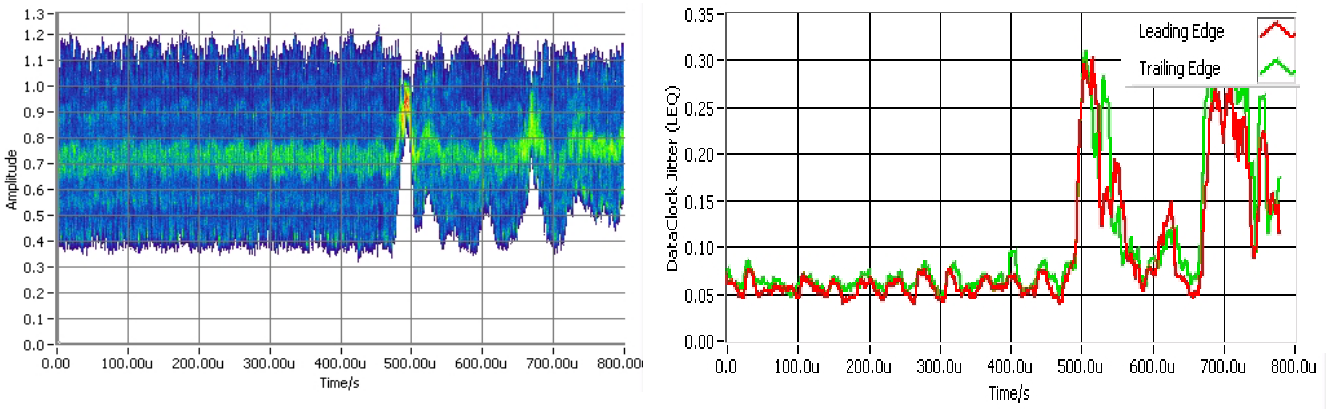

Fig. 3: BD HF signal envelope and data-to-clock jitter (measured with limit equalizer) through the left fringe of fingerprint #2. Recording was done before fingerprinting.

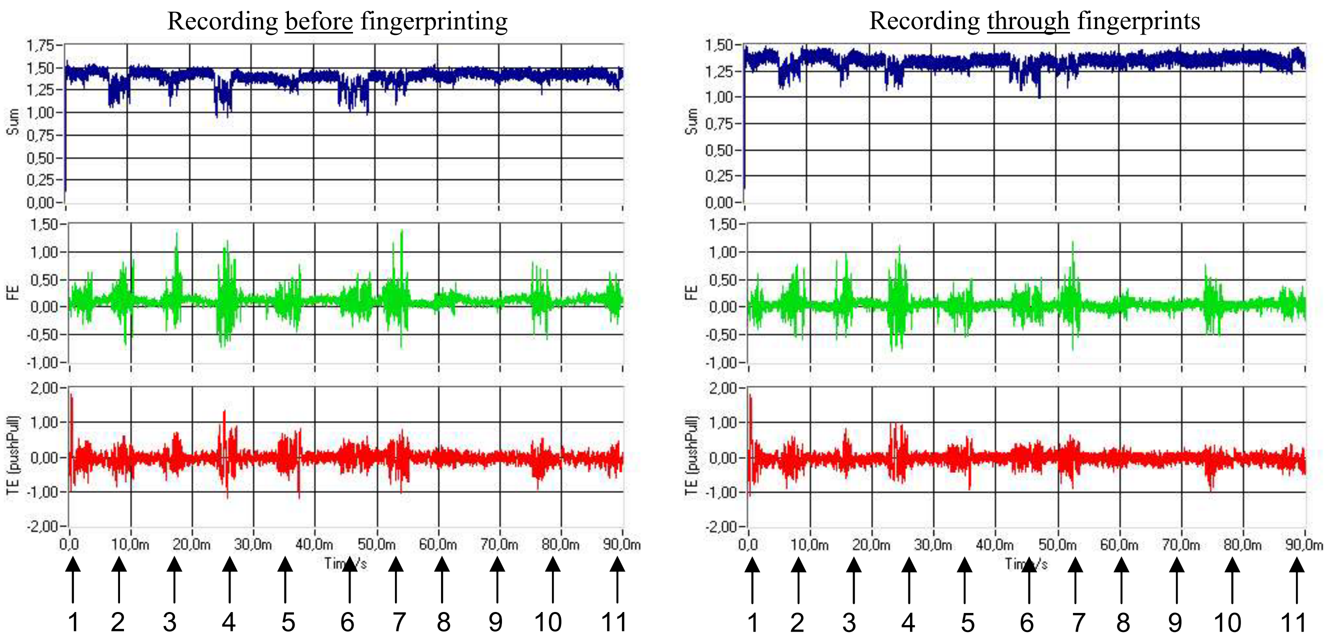

Fig. 4: Deterioration of DVD servo signals (FE signal s-curve 4Vpp, TE signal push-pull 4Vpp). Black arrows mark position of 11 different f ingerprints around the outer disk radius. For recording through fingerprints the laser power was increased by 30%.

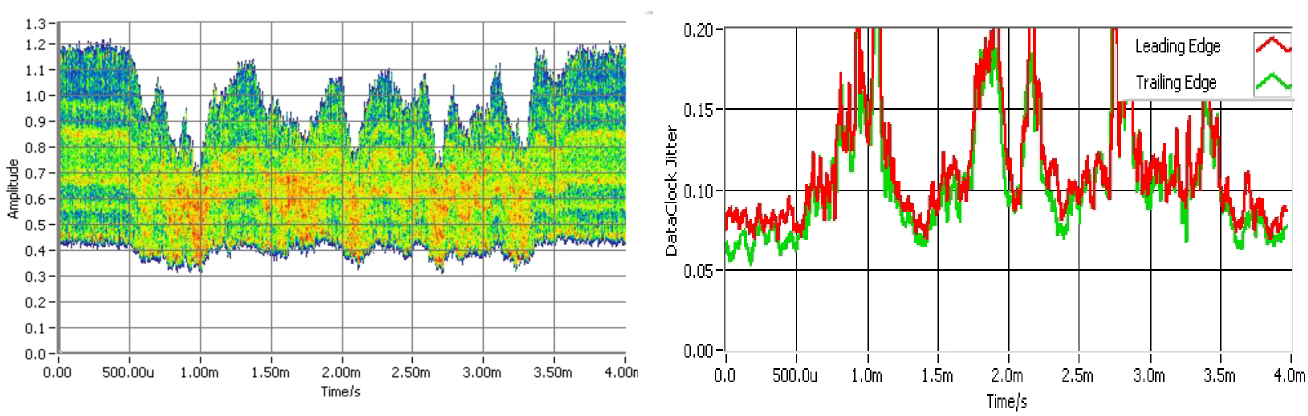

Fig. 5: DVD HF signal envelope and data-to-clock jitter through fingerprint #4. Recording was done before fingerprinting.