High density holographic versatile disc (HVD) system using collinear technologies

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Abstract: Collinear Holography was proposed by OPTWARE Corporation, in which the information and reference beams were aligned co-axially and modulated by the same SLM. With this unique configuration the optical pickup can be designed as small as the DVD′s, and can be placed on one side of the recording disc. A 2-dimensional digital page data format was used and the shift-multiplexing method was employed to increased recording density of HVD. As the servo technology is being introduced to control the objective lens to be maintained precisely to the disc in the recording and the reconstructing process, a vibration isolator is no longer necessary. In HVD, the pre-formatted meta-data reflective layer was used for the focus/tracking servo and reading address information, and the dichroic mirror layer was used for detecting holographic recording information without interfering with the preformatted information. Experimental and theoretical studies suggest that the holographic material is very effective to increased recording density of the system. HVD will be compatible with existing disc storage systems, like CD and DVD, and enable us to expand its applications into other optical information storage systems.

Key words: optical data storage system; optical memory; volumetric recording; holography

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0 Introduction

With the development of digital technology, we are enter to the Big Data Era. The necessity for large capacity, high data rates and long life time storage equipment has been increased. Optical disc is a candidate of long life time data storage system, but the capacity and data rate are not suitable for the necessary of Big Data Era. Holographic data storage system (HDSS) is a different technology of optical storage system. In the holographic technology, two coherent beams are necessary. The one is information beam including user data we want to record, the other is reference beam. During the recording process, they interfere with each other and the interference pattern is recorded in the media, called hologram. In the reconstructing process, the information beam can be reconstructed when the reference beam incident on the hologram. Because the two beams are separate, we call this HISS conventional 2-axis holography. This method was proposed in the 1960′s[1]. In this method, data transformation is a 2-dimensional (2-D) page data and record in the media volumetrically. Due to their large storage capacities and high transfer rates, HISS should become a promising candidate of next-generation of storage system. Within the last several years, unique demonstration platforms using holography have been proposed[2-4]. However, these 2-axis HISS still have essential issues for practicality[5]. Holographic recording has been known for over 40 years and never been commercially available. It is clear that a technological breakthrough is necessary.

Holographic Versatile Disc (HVD) system using Collinear Technology is a new technology for HDSS[6]. This technology can produce a small, practical HDSS more easily than conventional 2-axis holography. In this paper, we review Collinear Technology and report the study of the high density recording in HVD. We propose a concept of meta-data layer on the preformatted reflective layer that is used to assure and data interchangeability in the optical disc technologies (like CD and DVD) and is applied to HVD. The structure of HVD and construction of optical setup are presented. A simple numerical model to be used to analyzes Collinear holography is also introduced.

1 Collinear technology and HVD structure

Collinear Technology as a new read/write method for HISS is very promising and differs from conventional 2-axis holography. As shown in Fig.1, the unique feature of this technology is that 2-D page data are recorded as volume holograms generated by a co-axially aligned information beam and a reference beam, which are displayed simultaneously by the same SLM, the information pattern in the center and reference pattern circled it, and interfere with each

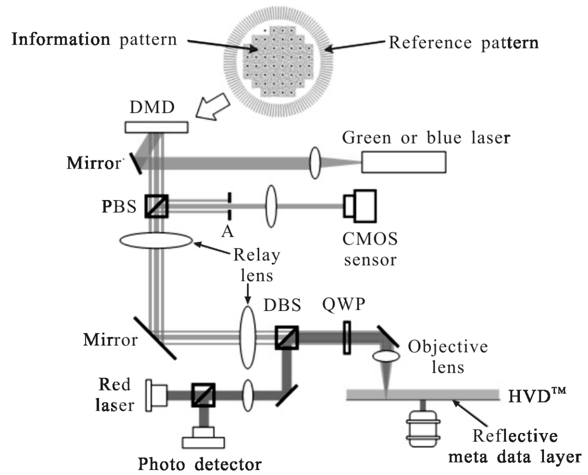

Fig.1 Optical configuration of the HVD drive system using Collinear Technology. In recording process, information pattern, in the center and reference pattern, out ring, are displayed simultaneously by the same SLM, and information beam and reference beam interfere with each other in the HVD media through a single objective lens. In reconstructing process, only the reference pattern is displayed on the SLM. The reconstructed beam is send back to the same lens by a reflective interlayer in the HVD, and reflected to a CMOS image sensor by a polarized beam splitter. Red laser is used to servo control and locate holograms.

other in HVD media through a single objective lens. In reconstructing process, only the reference pattern, outer ring pattern, is used for creating a reference beam. The reconstructed image beam is send back to the same lens as used in the recording process by a reflective interlayer in HVD, and reflected to a CMOS image sensor by a polarize beam splitter.

In HVD system, the green(or blue) and red laser beams are combined to the same axis and are transmitted through a single objective lens. For this reason, a special disc structure of HVD has been designed. Figure 2 shows the six layers structure schematically. On the base layer there are pre-formatted emboss pits and meta-data layer. The material in the meta-data layer is a rewritable phase

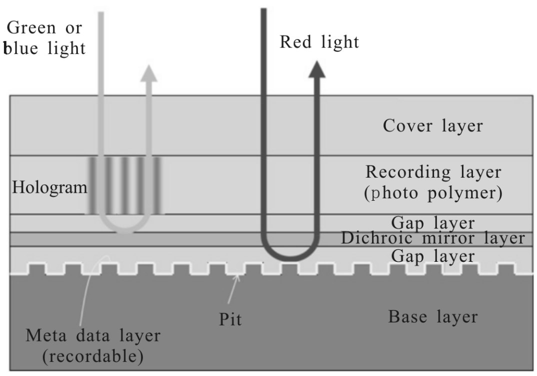

Fig.2 Schematic illustration showing a reflective structure. Base layer which contains pre-formatted emboss pits and meta data reflective layer is used to reflect red laser for servo and locate holograms. Dichroic mirror layer eliminates the diffraction noise caused by embossed pits. Recording medium layer is photo polymer

change material, like DVD-RW. It is used to write address information by red laser and reflect red laser for servo and locate holograms. In order to eliminate the diffraction noise into the recording media caused by the embossed pits, a dichroic mirror interlayer is placed between the recording layer and the reflective layer. The red laser beam for optical servo control will reach to the pre-format meta-data reflective layer. However, the green (or blue) laser beams for forming hologram is perfectly reflected by this dichroic mirror interlayer. Figure 3 shows image quality comparison between with and without dichroic mirror interlayer, respectively. The dichroic mirror interlayer eliminates diffraction noise effectively [5]. The holographic material used in the recording layer is photopolymer, which has a dynamic range(M/#) more than 10.

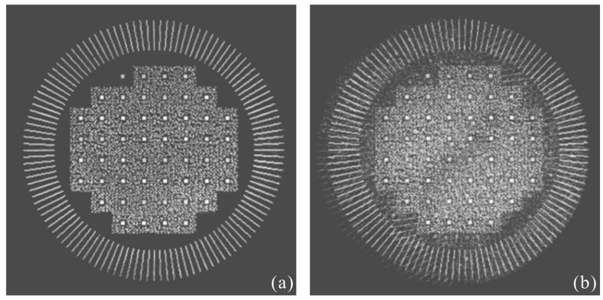

Fig.3 Reconstructed images from HVD (a) with and (b) without dichroic mirror interlayer. The result is very clear that dichroic mirror interlayer eliminates diffraction noise effectively

The green or blue laser is used to read and write holograms. A red laser that is not sensitivity is used for optical servo control to adjust the focal point of the objective lens onto the disc correctly and to locate the holograms address in HVD. The green (or blue) and red laser beams are combined on the same axis and separated by a dichroic mirror layer in the disc. This method will enable us to construct a small volumetric optical disc storage system, compatible with existing disc storage systems, like CD and DVD. On the other hand, shift multiplexing method is used in HVD [7-8]. Because the hologram recording layer is separated optically from the pre-formatted meta-data layer, the shift pitch can be arbitrarily adjusted based on the location information obtained from the pre-format meta-data layer, and the storage capacity can be changed freely, this is the concept of the selectable capacity recording format[5,7].

With the special structure of HVD, the hologram can be located by retrieving address information on the pre-formatted meta-data layer. In addition, based on this layer, focusing servo and tracking servo technology which are widely used in existing optical disc, like CD and DVD, can be used in the recording and the reconstructing process. This will precisely maintain the distance and the relative position of the objective lens and the disc, and the holograms can be recorded and reconstructed in a HVD accurately even if there is axial deflection or radial runout. Furthermore a vibration isolator is no longer necessary[7].

In HVD, the holograms are recorded at a shift pitch in the radial and the tangential directions of the disc, so-called the shift-multiplexing method. The recording density can be improved by reducing this shift pitch. Because the hologram recording layer is separated optically from the pre-formatted layer, the shift pitch can be arbitrarily adjusted based on the location information obtained from the pre-formatted layer, and the storage capacity can be changed freely, this is the concept of the selectable capacity recording format. For example, in the case of a data page size 32 Kbit recorded in a ϕ120 mm disc, as shown in Fig.4, a shift pitch of 200 GB/disc is 13 μm, 500 GB/disc is 8 μm, and 2.2 TB/disc is 4 μm [7]. Experiments have proven that the shift selectivity of the HVD system is 3 μm [6,9]. And the tracing pitch in the pre-formatted layer of HVD used presently is 1.6 μm.

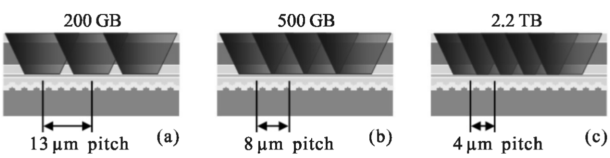

Fig.4 Conceptual diagram of a preformatted reflective layer in HVD is used to assure data interchangeability

2 System tolerance

In order to produce a small, practical and low cost HVD system, the investigation of system margins is very important. The tilt margin and wavelength margin compared with conventional 2-axis holography, and de-focus and de-track margins compared with DVD have been studied in experiments. In the experiment a thickness of 500 μm media is used.

The tilt margin of the HVD compared with conventional 2-axis holography is shown in Fig.5. The diffraction efficiency of the hologram is calculated from the sum of the brightness of the center part pixels, which come from the information pattern of a reconstructed image received by CMOS image sensor. At 50% diffraction efficiency, symbol error count is lower than 100, and at this point the tilt angle is up to 0.18 degree. From Fig.5, it is indicated that the tilt margin of collinear technology is over eight times larger than that of conventional 2-axis holography for the same thickness of the media[6,10].

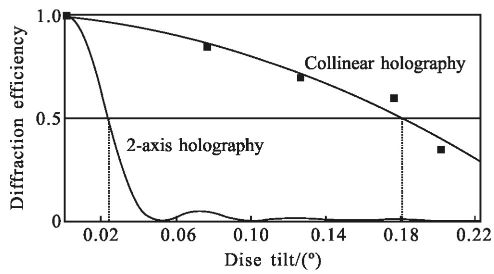

Fig.5 Tilt margin analysis of diffraction efficiency at medium thickness of 500 μm

In order to analyze the wavelength margin, the laser source of HVD system, as shown in Fig.1, is exchanged to a dye laser pumped by an Ar^+ laser to change the wavelength. In the recording process, the write pattern, as in Fig.1, is recorded into a disc at a certain wavelength. As for the reconstruction process, the reconstructed image of the page pattern is received by a CMOS sensor at a different laser wavelength in the recording process. Experimental results obtained at different laser wavelengths are summarized in Fig.6. It is noted that the wavelength margin at 50% diffraction efficiency of collinear technology is over three times larger than that of conventional 2-axis holography for the same thickness of the media[6,11]. The symbol error is counted from a reconstructed image in the decoding process, even if the laser wavelength in the reconstructing process is shifted by $\Delta\lambda$=3 nm in the recording process, the symbol error count is lower than 100, and reproduction of user data is possible [11].

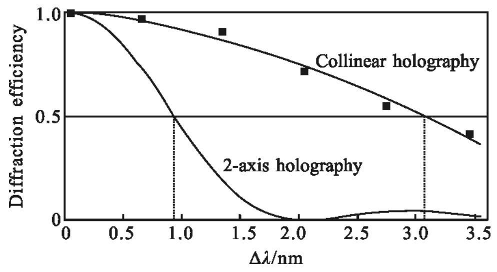

Fig.6 Wavelength margin analysis of diffraction efficiency at medium thickness of 500 μm

The defocus margin and de-truck margin of the HVD compared with DVD′s specifications are shown in Fig.7 and Fig.8. When the symbol error count is under 100, the reconstructed image can be decoded to user data completely. The results of the experiment indicate that both the defocus margin and de-truck margin of collinear technology are over six times larger than those of DVD′s specifications.

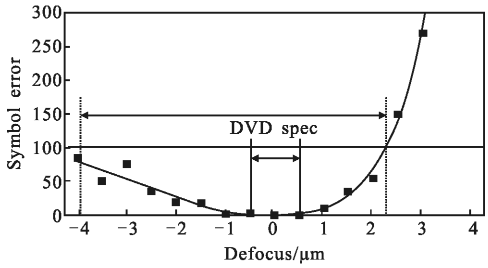

Fig.7 Defocus margin analysis of symbol error count compared with DVD specification

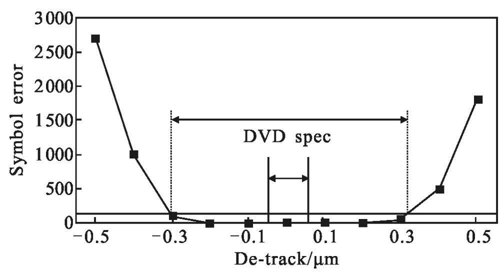

Fig.8 De-truck margin analysis of symbol error count compared with DVD specification

3 Conclusion

We have reviewed Collinear Technology, a new technology for HDSS, and HVD system. Using this technology, 2-D page data can be recorded as volumetric holograms generated by an information beam and a reference beam that are bundled on the same axis, and irradiated on the HVD media through a single objective lens. The optical configuration and disc structure are indeed very effective for materializing a small optical storage system with huge density. With its unique selectable capacity recording format of HVD shows both downward and upward compatibility of different disc capacities.

The tilt margin and wavelength margin of Collinear Technology are over eight and three times larger than that of conventional 2-axis holography. The number of symbol errors in the reconstructed data page images at different wavelengths is calculated and the data page can be decoded to reproduce the user data until the tilt angle of the disc is 0.18 degree and the light source is 3 nm, at which point the angle of the disc and the laser wavelength in the reconstruction process differs from those in the recording process. The wavelength margin is sufficiently large for a laser diode to be used as the light source of an HVD system. The defocus margin and de-truck margin of collinear technology are also over six times wider than those of DVD′s specifications. These wide system margins enable us to design and to make small, practical and low cost HVD products more easily. Collinear technology can construct HVD systems with CD and DVD upper compatibility.

Further investigations are underway to develop the high power, small size and low cost laser, to test the reliability of the media, to balance the data density and the transfer rate by incorporating newly designed optical and electronic components. Theoretical discussion is proposed that why Collinear holographic storage systems have significant advantages compared to other HDSS. An HVD system is only one of the applications of Collinear Technology. In future, Collinear Technology will not only be compatible with existing disc storage systems, like CD and DVD, and also enable us to expand its applications into other optical information storage systems.

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