Consumer Holographic ROM Reader with Mastering and Replication Technology

Ernest Chuang, Kevin Curtis, Yunping Yang, and Adrian Hill
InPhase Technologies, Inc., 2000 Pike Road., Longmont, Colorado 80501
ernestchuang@inphase-tech.com

Abstract: A novel holographic ROM design allows a compact low-cost consumer drive with lensless readout in a 10mm drive height. A two-step mastering method enables high-efficiency holographic masters for fast replication using planewave illuminations.

OCIS codes: (210.2860) Holographic and volume memories; (090.0090) Holography; (210.0210) Optical Data Storage

1. Introduction

Holographic data storage has progressed rapidly in the last few years, with recent work demonstrating storage densities as high as 350 bits/μm^2 and user data transfer rates exceeding 20 MBytes/s. However, much of the work in holography has traditionally been focused on recordable drives due to the greater difficulties in building a low cost drive system suitable for consumer use, as well as a feasible replication process for mass-producing distributable media. Previous proposals for ROM systems have included a method for sector-by-sector replication from a holographic master to a target disk by simultaneous illumination from an array of mutually incoherent reference beams [1], and also a system based on conventional serial-readout optical disc in which multiple DVD-like patterns are replicated to a target disk from a set of amplitude mask masters [2].

However, these architectures suffer from the choice of either using a complex process requiring the swapping of multiple masters during replication, or using a holographic master in which the holograms may not have sufficient strength for efficient replication, particularly at high density. Also disk-based systems tend to have difficulties introduced by the need for maintaining rotational symmetry of the holograms over the disk area. In this paper we introduce a card-based ROM system with lensless imaging for a very simple, compact, and low-cost reader design, and also a two-step mastering process for generating a holographic data master with much higher diffraction efficiency than would otherwise be possible using a standard page-wise recording process.

2. System Geometry

The basic recording configuration of the system is shown in Figure 1(a). We use a van der Lugt geometry with the spatial light modulator (SLM) placed in the path of a focusing beam, in order to allow recording near the Fourier transform plane without any lenses between the SLM and holographic medium. This is important because it allows lensless re-imaging of the data page when read out with a phase conjugate beam as shown in Figure 1(b). The object beam is filtered by a Nyquist polytopic aperture both on recording and readout, and the reference beam is changed in angle, to store holograms with a combination of polytopic and angle multiplexing.

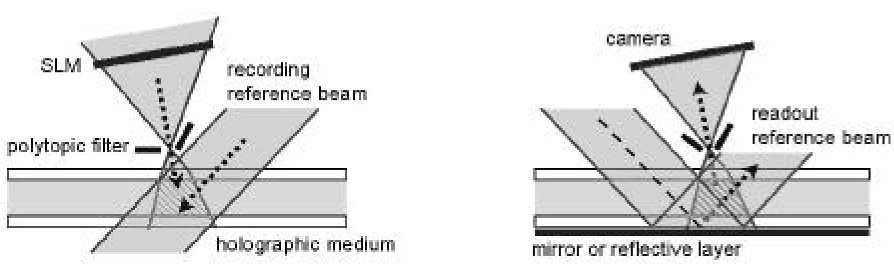


Fig. 1. System geometries for (a) recording and (b) lensless readout.

Transmission geometry holograms are recorded, but readout is performed by reflecting the reference beam from a mirror or reflective layer on the other side of the media. The reflective layer is added after recording. This configuration keeps all drive components together on the same side of the media, while preserving the advantages of transmission geometry holograms, which are more tolerant to shrinkage and thermal effects compared with reflection holograms. With high bandwidth pages recorded in the transmission geometry, thermal effects can largely be compensated by tuning the angle and wavelength of the reference beam on readout, whereas for reflection geometry holograms, even at the optimum angle and wavelength the data page may still not be fully recoverable.

3. Drive Layout

Using the geometry described above, it is possible to assemble a very compact consumer drive for playback as shown in Figure 2(a). The system uses a wavelength-tunable VCSEL as the laser source to allow for temperature compensation, and only needs to provide a planewave to the hologram, adjustable in angle by a miniature mirror actuator for addressing the angle-multiplexed pages. For a limited angular span, the beam can be slightly oversized and allowed to shift at the media to avoid the need for a lens relay system. An aperture is positioned for filtering the polytopic multiplexed holograms, and a CMOS sensor can retrieve the reconstructed holograms without any additional imaging optics. Sub-Nyquist oversampled detection [3] is used to recover the data without need for pixel matching servos, with only a fractional increase in the required array size. With all components on the same side of the media, the entire assembly can be arranged on an optical head that moves over the media surface by an X-Y translation mechanism.

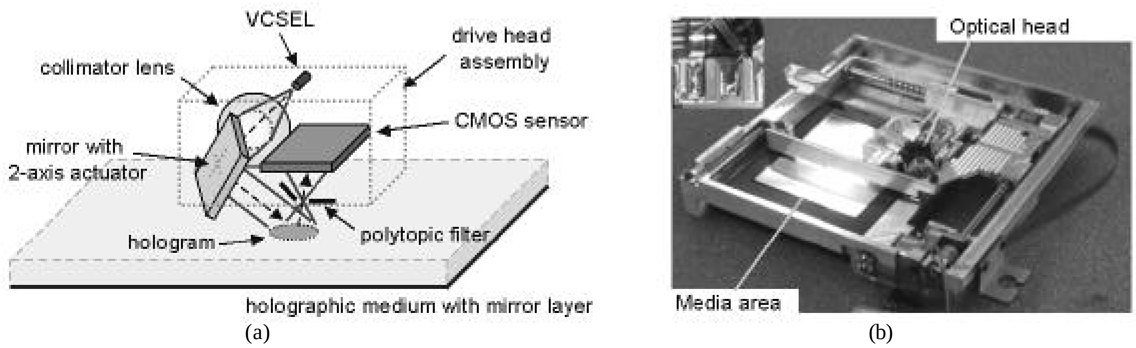


Fig. 2. (a) Example layout of components, and (b) photograph of actual drive evaluation unit (68x63x10mm).

Figure 2(b) is a photograph of an evaluation unit for the drive mechanics. This unit was developed in collaboration with Alps Electric Co. and Hitachi Maxell. It includes a functioning X-Y mechanism and 2-axis actuated mirror with beam collimation optics. The external drive dimensions are about 68 x 63 x 10 mm. Storage capacity could range from about 2 – 8 GB of user data on a 25 x 25 mm media card, with currently available low cost red lasers. With development of low cost blue lasers, this could be raised to 12 – 24 GB for the same size.

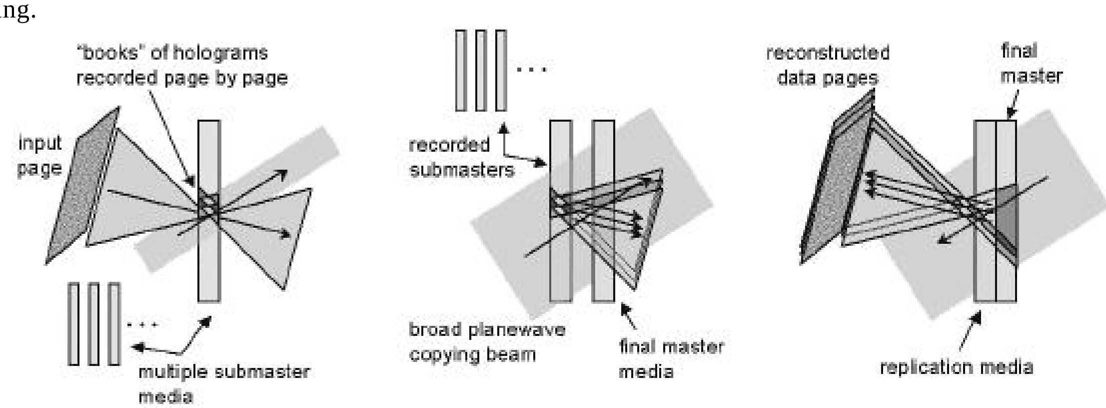
4. Mastering and Replication

Replicating holograms from a holographic master to a blank media has previously been demonstrated by reading the master with an appropriate reference beam and positioning the blank media behind the master such that it captures the light interference between the transmitted reference and the diffracted hologram, thus duplicating the holographic data to the new media, such as shown in Figure 3(c). In the case of card media containing arrays of angle and polytopic multiplexed "books" (hologram stacks), a single broad planewave illuminating the master media will simultaneously reconstruct a hologram page that was recorded at that angle from every book, which are then simultaneously copied in parallel to the replicate media. This is then repeated for all reference beam angles used in the master to complete the replication process.

However, this normally presents difficulties at high storage densities, because of the low diffraction efficiencies that result from dividing the limited dynamic range of the recording media among a large number of holograms sequentially exposed at the same location, and also by any additional overlap between neighboring spatial locations. Diffraction efficiencies will typically be around 10^{-3} or less, resulting in a large difference between the signal and reference beam intensities incident on the blank media for the copying exposure. Beam ratios around 1:1 are usually optimal, whereas large imbalances lead to poor modulation depth of the interference pattern, weaker holograms, and considerable waste of the media dynamic range. This ultimately has an impact on limiting the achievable storage density and transfer rate of the system.

To address this issue, we have developed a two-step approach to mastering as shown in Figures 3(a) and 3(b). In the first step, all holograms are recorded page by page as usual, but divided among multiple "submaster" media. Each submaster contains all of the book locations, but only a subset of the total angular range. For example a target of 30 pages per book could be divided among 3 submasters with 10 pages each. This effectively multiplies the available dynamic range by the number of submasters used, allowing for much stronger hologram recordings. In the second step, all holograms in the submasters are recombined to a single final master by essentially the same process used for replication, illuminating each submaster together with the final master with a series of broad planewaves to copy pages from all book locations in parallel. This parallel recording eliminates the sequential exposure of overlapping books that would ordinarily be a reduction factor for the available dynamic range. Diffraction efficiencies can actually be amplified from the submaster to the final master, resulting in a single master media containing all holograms at a much stronger level than would be possible under a conventional one-step process where all pages are sequentially recorded directly into the master.

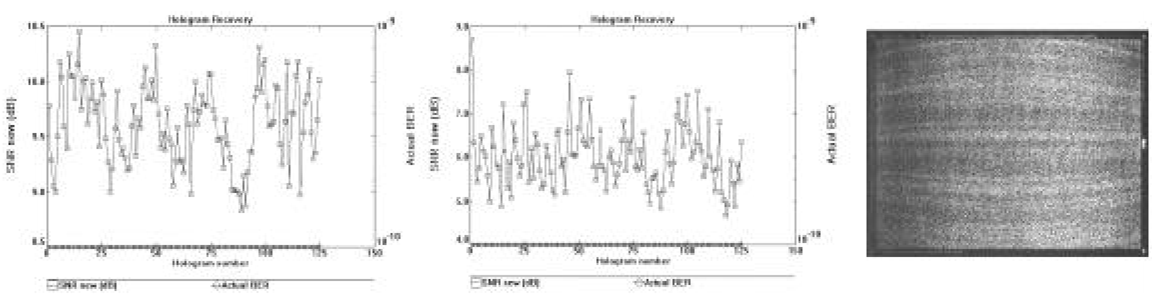
Replication would be performed as described earlier. For the system architecture presented in this paper, a reflective layer would be applied to the replicated media as a final step, allowing subsequent readout but no further copying.



(a) (b) (c)

Fig. 3. Mastering process (a) Step 1, page-wise recording of multiple submasters, (b) Step 2, copying from submasters to single final master, and (c) replication from a single master.

We have experimentally demonstrated the two-step mastering and replication processes for an array of 5 x 5 books of 5 pages each. Figure 4 shows recovered SNR for all 125 pages from the original submaster and final replicated media, and also a typical hologram data page from the final replicated media, with 30kBytes user data per page. No bit errors were detected at any step. Sub-Nyquist oversampled detection with a ratio of 3/2 was used in this test.



(a) (b) (c)

Fig. 4. Experimental mastering and replication of 125 holograms. (a) Measured SNR from submaster, (b) SNR from replicated media, and (c) sample hologram from replicated media

Acknowledgment: We would like to thank Alps Electric Co. and Hitachi Maxell for their collaboration on this project.

References

[1] F. Mok, G. Zhou, and D. Psaltis, "Holographic read-only memory", in *Holographic Data Storage*, H. J. Coufal, D. Psaltis, and G. Sincerbox, eds., (Springer-Verlag, New York, 2000).

[2] E. Chuang, H. Yamatsu, K. Saito, and S. Kobayashi, "Holographic read-only-memory system for high-speed replication", JJAP **42**, 976-980 (2003).

[3] M. Ayres, A. Hoskins, and K. Curtis, "Image oversampling for holographic data storage", presented at ISOM/ODS 2005, ThE4 (2005).