Holographic Optical Disc

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The holographic disc is a high capacity, disk-based data storage device that can provide the performance for next generation mass data storage needs. With a projected capacity approaching 1 terabit on a single 12 cm platter, the holographic disc has the potential to become a highly efficient storage hardware for data warehousing applications. The high readout rate of holographic disc makes it especially suitable for generating multiple, high bandwidth data streams such as required for network server computers. Multimedia applications such as interactive video and HDTV can also potentially benefit from the high capacity and fast data access of holographic memory.

Figure 1 is the conceptual diagram of data readout from a holographic disc. The system stores digital holographic images on a flat, disk-shaped medium. Stored images are organized in different tracks. The disc can spin continuously and it can also move across tracks to allow the laser pickup to access the entire surface area of the medium. For each storage location, many angle-multiplexed holograms are recorded and overlapped using a suitable multiplexing method.

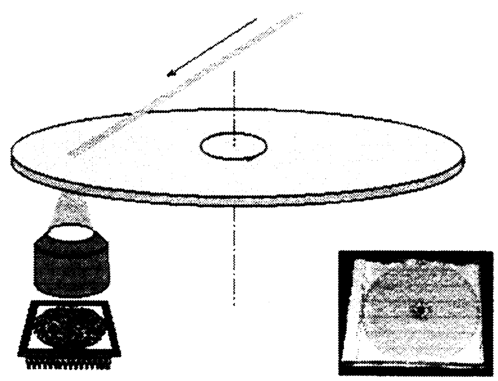

Figure 1. Data Readout from Holographic Disc.

The complete holographic disc-based ROM system consists of three separate modules. The first is the recording module. This is where the holograms are recorded onto a fresh disc. This module includes both the reference and signal beam paths and it contains components such as the SLM and the scanners. The recording module is similar to the CD-ROM mastering device, and as such it could be large and bulky if necessary. The second is the readout module which was shown in figure 1. This is where the holographic images are retrieved from the disc and converted to electrical signals by an appropriate detector array. This module contains light modulators, scanners, and other electronics. The readout module should be compact and portable. The third module is a device to replicate the recorded master hologram and efficiently produce copy discs in volume.

Figure 2 is the schematic drawing of the recording module. The setup consists of a diode pumped green laser source at 532 nm. In the signal arm, an SLM is illuminated by a plane wave, and the disc to be recorded is located at the Fourier plane of the SLM. A detector array is placed at the image plane of the SLM. In the reference arm, a beam deflector and a 4-f imaging system are used to scan the angle of the reference beam to implement angular multiplexing. During recording, the deflector scans the reference beam through all reference

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angles. At each reference angle a light exposure is given to the medium. Besides angular multiplexing, we can also rotate the disc to implement peristrophic multiplexing. After all multiplexed holograms are recorded, the disc moves to the next spot and the process starts again until the entire disc is recorded. We usually use photopolymer as the storage medium. The disc we record is typically 12 cm in diameter (standard DVD platter size). The disc is fabricated by laminating a layer of 100μm thick medium onto a glass substrate. We use a pair of f/1.1 lenses in system, and the recording spot size is about 0.6 mm. The number of pixels in each hologram is about 180,000.

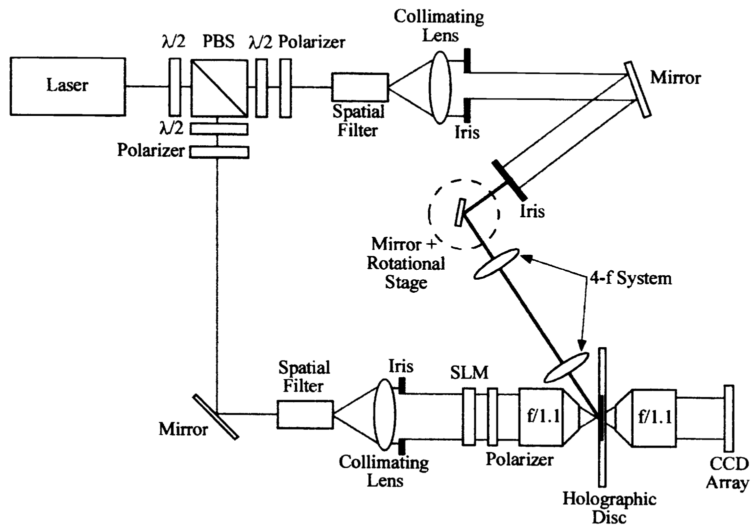

Figure 2. Schematic diagram of the recording setup.

When the holographic image is readout from the spinning disc, the reconstructed images could be shifted, distorted, or defocused. These may be caused by disc wobble, disc decentration, and by mechanical deformation in the disc substrate. When these happen, the readout holographic image is degraded and the bit error rate becomes exceedingly high. In order to maintain image alignment and good pixel registration, we have designed a servo system that detects the readout error in the hologram and automatically compensates for the disc error in real time. Figure 3 is the schematic of our holographic disc system. The laser beam (from the top) passes through the modulator and enters the scanner. The scanner can change the laser beam propagation direction

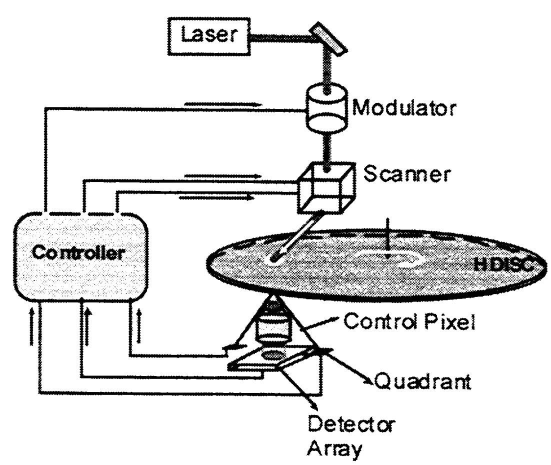

Fig. 3. Schematic of the holographic disc

along two orthogonal axes in space. The laser beam is directed to the disc and the stored images are read out. Alongside the main readout image, there are two separate pixels in each hologram which we call control pixels. The control pixels are directed to two quadrant photodetectors, respectively. If the disc were at still and at correct position, the control pixels would be focused at the center of each quadrant detector. Since the disc spins continuously, the control pixels actually sweep across the detector, as does the main reconstructed image. We pulse the laser to readout a stationary image onto the detector array. The laser pulse timing is slaved on the gap-crossing of the left control pixel. As the laser fires, the holographic image is registered, and the signals from the quadrant photodetectors are sampled. A controller derives the appropriate error signals from the quadrant detector, and drives the scanner to compensate for image shift and rotation in real time.

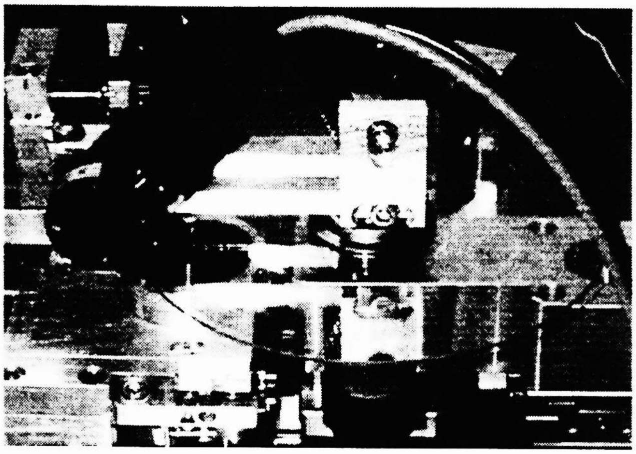

Fig.4. Picture of the implemented system.

Figure.4 is a picture of the disc system that we have implemented. We use frequency doubled YAG laser as the light source. An external electro-optic modulator is used to pulse the laser. The beam deflectors in the module are miniature galvo mirrors. The disc is fabricated by laminating a layer of holographic photopolymer onto a glass substrate. We have achieved pixel-matched readout of digital data from the disc spinning at 600 r.p.m.

The readout data rate from the disc can be written as

$$R = N_P/\tau \qquad (1)$$

Where N_P again is the number of pixels per page, and τ is the transit time it takes to reach the next hologram. Obviously, the faster the disc spins, the shorter the transit time, and the higher the data rate. At the spinning speed (600RPM) that we use, the transit time is about 0.17 msec. Since N_P is 180,000 in our system, the data readout rate is about 1Gbit/sec from the holographic disc. A natural question to ask is why not spin the disc faster, so the transit time is smaller and the optical data rate is even higher? Indeed 600 RPM is not even close to the kind of speed used in hard disk drives, or in high speed CD-ROM drives, which typically can be several thousand RPM. The limit to achieving even greater readout rate is the decrease in dwell time as disc spin rate increases. The time window in which the probe laser can fire and readout a satisfactory image becomes narrower as the disc spins faster.

The dwell time is given by the expression below:

$$\tau_{DWELL} = \frac{\Delta x}{2F \cdot \omega \cdot \sin((\theta + \phi)/2)\cos((\theta - \phi)/2)} \qquad (2)$$

where Δx is the amount of image shift that can be tolerated, F is the focal length of the imaging optics, and ω is the angular velocity of the disc. θ and ϕ are the angles of incidence of reference and signal beams, respectively. For our system, $\Delta x = 2\ \mu m$, F = 13 mm, $\omega = 62.8$ rad/sec, and the dwell time τ_{DWELL} is about 2 μsec.

The number of photons integrated by a detector cell is given by

$$N_{PHOTONS} = \frac{P_{LASER} \cdot \eta \cdot \tau_{DWELL}}{N_P \cdot 4 \times 10^{-19}\ \mathrm{J/Photon}} \quad (3)$$

Where P_{LASER} is the laser power, η is the diffraction efficiency, and N_P is again the number of pixels per hologram. For P_{LASER} =100 mW, $\eta = 10^{-3}$, the number of integrated photons is $N_{PHOTONS}$ = 3,000. For a quantum efficiency of 0.3, the number of signal electrons generated at each detector cell is 900 electrons. The CCD detector and associated amplifiers in our system has a combined noise figure measured at about 250 electrons. Therefore with 2 μs dwell time, the signal to noise ratio of the detector is about 3.6. Shorter dwell time would make the detector noise contribution more and more significant.

The present 1Gb/sec optical data rate is already orders of magnitude faster than CD or DVD specifications. The high data rate in holographic disc is due to the parallelism in data readout, i.e., data are readout one page (thousands of pixels) at a time. We note that the data rate discussed here is the optical, not electronic, data rate. The present CCD detector in the system has a 16 Mb/sec output bandwidth. To bring electrical signals out of the holographic disc system at 1Gb/sec requires the use of either a multi-channel CCD, or a high speed CMOS sensor.

If an application calls for data rate greater than 1Gb/sec, the solution is to use Q-switched lasers. A Q-switched laser with low average power can have a very high peak power and sufficient pulse energy to boost the data rate by orders of magnitude. As an example, the present system uses a 100 mW CW laser pulsed for 2 μs, corresponding to a pulse energy of 200 nJ. If a pulse laser with 2 μJ average pulse energy is used as the readout laser, we could spin the disc 10 times faster, work with a dwell time of 200 nanoseconds (which is long compared to the typical pulse width of pulse lasers) and generate sufficient number of signal electrons for good detector SNR.

REFERENCES:

1. G. Zhou, A. Pu, O. Ivanova, F. Mok, and D. Psaltis, "Implementation of holographic disc", in *Proc. Int'l Symp. Opt. Mem.*, Tsukuba, Japan. 1998. p. 14.
2. H.-Y. S. Li and D. Psaltis, "3D holographic disk", *Appl. Opt.*, **33**(17), 1994. P.3764.
3. G. Zhou, A. Pu, O. Ivanova, and F. Mok (invited paper), "Output interface for holographic memories", in *Optoelectronic Interconnects*, J. Bristow and S. Tang, Editors, Proceedings of SPIE, Vol. 3632. 1999, pp. 292-296.
4. G. Zhou, Y. Qiao, F. Mok, D. Psaltis, "A holographic system for fingerprint identification", *Opt. Photon. News*, March 1996. p.43.
5. U.-S. Rhee, H. J. Caulfield, C. Vikram, and J. Shamir, *Appl. Opt.*, **34**(5), 1995. P. 846.
6. G. J. Steckman, I. Solomatine, G. Zhou, D. Psaltis, "Characterization of PMMA-PQ photopolymer for holographic storage", Opt. Lett., **23**(16), 1998. P.1310-1312.
7. W. J. Gambogi, A. M. Weber, and J. Trout, "Advances and applications of DuPont Holographic Polymers", *SPIE Proc.* **2043**. 1993.