Volume storage in photorefractive disks

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ABSTRACT

We describe a photorefractive 3-D optical disk for data storage. The information is stored at several recording locations on the disk as angle-multiplexed holograms. Design parameters that affect alignment sensitivity and diffraction efficiency are considered.

1. INTRODUCTION

There has been much interest recently of storing information holographically in 3-D materials such as photorefractive crystals and photopolymers. Advantages of such systems include high storage density and fast parallel readout. Such storage systems are "page oriented," where each page is recorded and retrieved by using angle-multiplexing or wave-length multiplexing.

The theoretical storage density of volume holograms is $1/\lambda^3$ per unit volume (where λ is the wavelength used). This comes to about 10^{13} bits/cm^3. In practice, however, it is not possible to achieve this kind of density due to limits in dynamic range of the recording material, noise, and mainly because of the numerical aperture and space-bandwidth product of the optical system. Typical systems have a storage densities of around 10^9 bits/cm^3. To compete with semiconductor memories, it is necessary to build larger memories by using larger crystals.

One approach is to increase the thickness of the crystal. In the extreme, such a system would have a fiber-like structure. Another approach would be to increase the area of the crystal and record on multiple locations. In order to do this, it is necessary to either bring the recording beams to the recording location, or vice versa. In the former, we can use beam steering devices such as acousto-optic deflectors to obtain fast access. The drawback of this approach is that it requires a huge space-bandwidth product in the optical system. In the other approach—bringing the recording location to the recording beams—the simplest approach is to use a disk configuration where the disk rotates to access the recording locations. Such a system is shown in Figure 1. This sytem is relatively slow, but is easy to build.

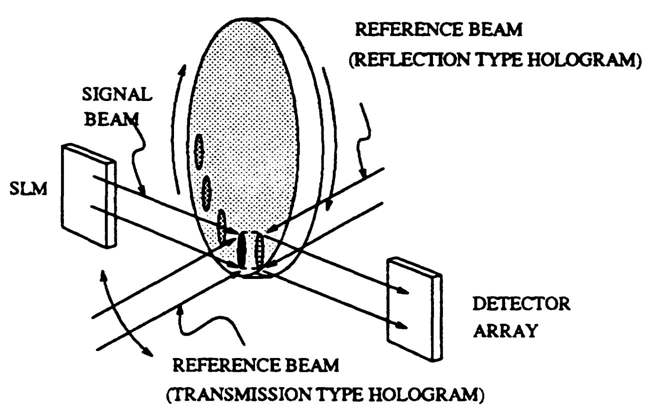

Figure 1. 3-D disk system

2. 3-D DISK SYSTEM

The 3-D disk we use is a $LiNbO_3$ crystal of 1.5 inch diameter. Holograms are recorded at several locations on the crystal, and are accessed by rotating the disk. At each location, angularly multiplexed holograms are recorded and different pages of information are readout by changing the reference beam angle.

In our exeriment, we recorded on 20 locations along the rim of the disk, with 100 angularly multiplexed holograms at each location. This gives us a total of 2000 holograms. The holograms were recorded as reflection-type near-image-plane holograms using the 488 nm line of an Argon laser. We used an Epson LCTV as the spatial-light modulator which has 320×220 pixels and is about 1.3 inches diagonal. This was demagnified to about 2×3 mm^2 for recording on the crystal.

3. ALIGNMENT SENSITIVITY

One of the problems of using 3-D disk system is alignment errors due to rotation of the disk. For image plane holograms, an error of $\Delta\phi$ in rotation angle will result in a position error of $\Delta x = R\Delta\phi$ where R is the distance from the hologram to the disk center (assuming the magnification factor is one). One way of reducing this problem might be to record in the Fourier plane, since Fourier plane holograms are shift invariant. Unfortunately, when the disk rotates, not only does the hologram translate, it also rotates. As a result, the displacement for an error of $\Delta\phi$ in rotation angle is $\Delta y = F \sin\theta \, \Delta\phi$, where F is the focal length of the Fourier transform lens and θ is the angle between the signal beam and the reference beam. This is comparable to the displacement when recording in the image plane.

In general, when we record a hologram anywhere between the image plane and Fourier plane, the reconstructed image rotates by the same angle that the disk rotates. What changes is the center and the radius of rotation. By arranging the reference and signal beam angles and the disk geometry, the best that can be done is to minimize the radius of rotation to zero, and have the image rotate around the center of the image. This was demonstrated experimentally.

4.DIFFRACTION EFFICIENCY

The holograms on the 3-D disk can be recorded either as transmission type holograms or reflection type holograms. The concern here is to maximize diffraction efficiency while having it as uniform as possible when the reference beam angle and rotation angle of the disk changes. This is important since photorefractive crystals are anisotropic. Since we require rotational symmetry, the natural choice is to use a c-cut crystal with the c-axis of the crystal parallel to the rotational axis of the disk, since the c-axis is the highest axis of symmetry of the crystal. For lithium niobate, it turns out that it is best to record reflection type holograms.

5. CONCLUSION

To minimize alignment error due to disk rotation, we have shown that recording in the Fourier plane is not optimum. Instead, it is best to record some distance from the image plane such that the image rotates around the center of the image.

We have demonstrated recording 2000 high resolution gray-scale images on a lithium niobate disk as reflection type holograms.

5. ACKNOWLEDGEMENT

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6. REFERENCE

1. D. Psaltis, A. Yamamura, H.-Y. Li, "Mass storage for digital optical computers," SPIE Critical Reviews Series, Digital Optical Computing, vol. 1214-08, Los Angeles, Jan. 1990.
2. D. Psaltis, "Parallel optical memories," *BYTE* Sept. 1992, pp. 179–182.