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A New Method for Holographic Data Storage in Photopolymer Films

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Conventional holographic storage methods, such as angle or wavelength multiplexing, superimpose multiple holograms in the volume of the recording material. The number of holograms that can be stored is typically proportional to the thickness of the material. Recently, photopolymer films have been developed that are inexpensive, easy to fix and have a relatively large dynamic range, making them good candidates for high density data storage. An example of this material is DuPont's HRF-150-38 photopolymer film [1,2]. The storage density achievable with these materials is limited due to their thickness of tens of microns. In this paper we present two results. First, a new holographic multiplexing method (peristrophic multiplexing) that significantly increases the storage density achievable in thin films is demonstrated. In addition, an exposure schedule that maximizes the utilization of available dynamic range of the photopolymer is derived.

The setup used to demonstrate peristrophic multiplexing is shown in Figure 1. The setup is similar to a conventional angle multiplexing arrangement, where either the angle of the reference beam is scanned or the material is rotated around the y-axis. For peristrophic multiplexing, the material is rotated around the z-axis instead. After each hologram exposure, the material is rotated in plane. The rotation shifts the reconstructed image off the detector or the stored hologram becomes non-Bragg matched, allowing for another hologram to be stored at the same location. This process repeats until the maximum rotation angle of 180° is reached. For materials greater than ~1mm in thickness, the Bragg match criterion will determine the required peristrophic rotation angle before a new hologram can be stored at the same location. Otherwise, the reconstructed image is shifted off the detector first with the rotation. Peristrophic multiplexing can also be realized by rotating both recording beams around the z-axis. To further increase the storage density, other multiplexing techniques can be combined with peristrophic multiplexing.

An exposure schedule for the HRF-150-38 photopolymer was derived by first measuring the diffraction efficiency versus the exposure energy as shown in Figure 2. The amplitude of the recorded gratings can be obtained by taking the square-root of the diffraction efficiency. This curve can then be fitted for $E > E_o$ to the following equation,

$$A(t) = A_{sat}\left(1 - e^{-\left(\frac{E-E_0}{\tau}\right)}\right) \qquad (1)$$

where E is the exposure energy . The slope of equation (1) multiplied by the exposure energy gives the amplitude of the written grating. By setting the mth hologram's grating amplitude equal to the m-1th grating amplitude, a recursive formula can be derived that results in M holograms with equal diffraction efficiencies. The exposure energy for the mth hologram is given by Equation (2), where E_m and E_{m-1} are the exposure energies for the mth and m-1th holograms, respectively.

$$E_m = E_{m-1} e^{\frac{E_{m-1}}{\tau}} \qquad (2)$$

The dynamic range is fully utilized by scaling the initial recording energy to $E_1 = \tau/M$, where M is the total number of holograms to be recorded.

Peristrophic multiplexing was demonstrated using the setup shown in Figure 1. A second rotation stage was added to rotate the material in the y-axis in order to implement angle multiplexing as well. The signal and reference beam were initially incident on the film at ±30° to the normal (z-axis). Cartoons were presented to the optical system by using a spatial light modulator (SLM). The photopolymer to be exposed was located in-between the Fourier plane and the image plane to ensure uniformity of the presented image. The peristrophic rotation required to filter out a stored hologram was experimentally determined to be ~3° while the rotation required to Bragg mis-match an angle multiplexed hologram was also ~3°. For each peristrophic multiplexing position, five angle multiplexed holograms were stored. A total of 295 holograms were recorded in about a half cm^2 area with an average diffraction efficiency of better than 10^{-6}. Figure 3 shows the reconstruction of one of the 295 holograms.

In summary, we have demonstrated that peristrophic multiplexing makes it possible to store several hundred holograms in thin films. Whereas previously this capability was only possible with materials ~1cm thick. Therefore, this approach makes it possible to fabricate compact 3-D holographic disks with high storage density.

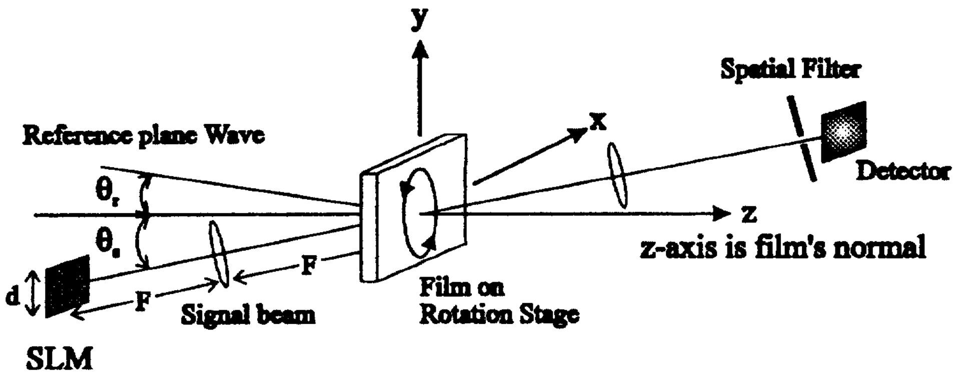

Figure 1: Peristrophic multiplexing setup.

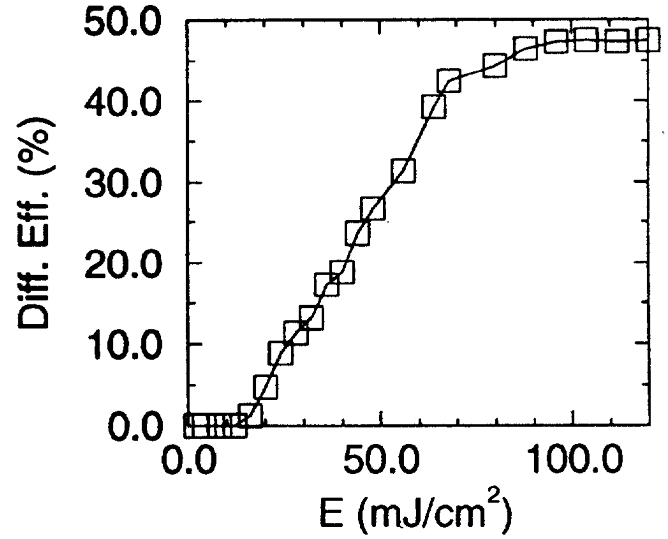

Figure 2: The diffraction efficiency as a function of exposure energy.

Figure 3: One reconstructed hologram out of 295.

References

1. W. K. Smothers, T. J. Trout, A. M. Weber, D. J. Mickish, 2nd Int. Conf. on Holographic Systems, Bath, UK (1989).
2. K. Curtis and D. Psaltis, Applied Optics, 31, 7425 (1992).