Comparison of transmission and 90-degree holographic recording geometries

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Most of the recent large-scale holographic recording demonstrations in photorefractive crystals were done using the 90-degree geometry[1] due to its large storage capacity, small inter-pixel crosstalk, and relative insensitivity to holographic scattering and fanning. However, 90-geometry has small dynamic range and recording speed. Typical values of the dynamic range measure (M/#) and sensitivity (S) are 1.5 (cm^{-1}) and 0.05 (cm/J), respectively. To make practical holographic memory systems, we need an order of magnitude increase in M/# and at least two orders of magnitude increase in S.

We found that we can increase both M/# and S by one order of magnitude if we use transmission geometry with in-plane (or extraordinary polarization). We actually measured M/#= 40 cm^{-1} and S=0.3 (cm/J) using such a geometry. To check the repeatability of the results, we performed holographic recording and erasure experiments with a few congruent $LiNbO_3$: Fe crystals. All the crystals were annealed to result in an absorption coefficient of 0.5-0.6 cm^{-1}. The crystals used in the transmission geometry were x-cut, and those used in the 90-degree geometry were 45-degree cut. The experimental results are summarized in tables 1-3. In this table, sensitivity (S) is the initial slope of the recording curve normalized to recording intensity and crystal thickness.

Doping (wt. %)	Thickness(mm)	M/# (per cm)	S (cm/J)
0.01	20	1.25	0.057
0.015	20	1.81	0.059
0.015	20	1.22	0.052
0.05	20	1.74	0.050

Table 1. M/# and sensitivity for 90-degree geometry

Doping (wt. %)	Thickness(mm)	M/# (per cm)	S (cm/J)
0.01 (#1)	5	6.36	0.071
0.015 (#2)	4.5	5.64	0.071
0.03 (#3)	5	13.7	0.107

Table 2. M/# and sensitivity for transmission geometry (ordinary polarization)

Doping (wt. %)	Thickness(mm)	M/# (per cm)	S (cm/J)
0.01 (#1)	5	14.28	0.157
0.015 (#2)	4.5	16.25	0.204
0.03 (#3)	5	40.1	0.321

Table 3. M/# and sensitivity for transmission geometry (extraordinary polarization)

The results in Tables 1-3 clearly indicate the advantage of the transmission geometry with extraordinary polarization over the 90-degree geometry. One reason for this advantage is the larger electrooptic coefficient of $LiNbO_3$ for the case of extraordinary (or in-plane) recording and read-out r_{33}. It is not possible to use extraordinary polarization in the 90-degree geometry due to the right angle between the recording beams. Therefore, we must use r_{13} which is almost 3 times smaller than r_{33}. In addition, the maximum space charge field (due to space-charge limitations) that we can record in a photorefractive material is proportional to grating period^2 which is smaller in the 90-degree geometry. Figure 1 shows the theoretical variation of the M/# with the grating vector along with three experimental results for recording and read-out with out-of-pane (or ordinary) polarized beams. Figure 1 clearly shows the advantage of the transmission geometry over the 90-degree geometry.

One advantage of the 90-degree geometry is better angular selectivity resulting in the possibility of packing more holograms in the same angular range using angle multiplexing. However, in many large-scale data storage experiments, the maximum number of holograms that can be recorded at the same location is limited by the minimum diffraction efficiency needed. In many cases we do not multiplex more than a few thousand holograms in the same location, and transmission geometry can be used for multiplexing a few thousand holograms. Another advantage of the 90-degree geometry over the transmission geometry is the insensitivity to holographic scattering and fanning. However, with the invention of two-center holographic recording method[3] that does not suffer from holographic scattering and fanning even in the transmission geometry, this deficit can be overcome. Finally, interpixed crosstalk noise is smaller in the 90-degree geometry, but the performance of the transmission geometry can be made comparable in this regard by using methods proposed for the reduction of the interpixel crosstalk.

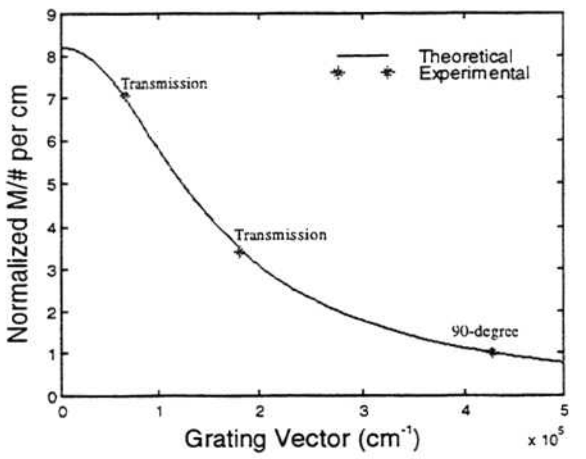

Figure1. M/# vs. grating vector

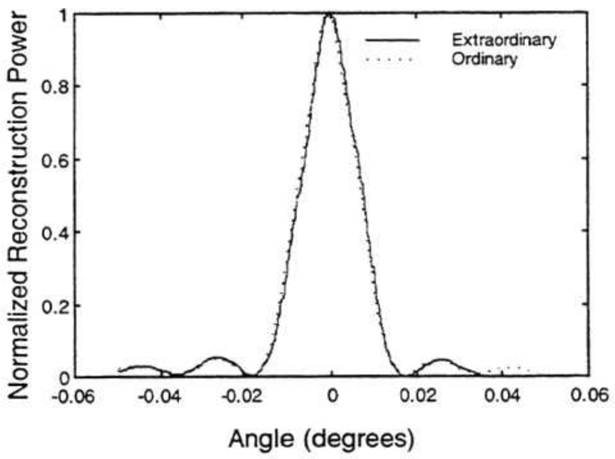

Figure2. Selectivity curve for transmission geometry

To compare the performance of the transmission geometry with ordinary and extraordinary polarizations, we performed both theoretical and experimental analysis of the selectivity and signal to noise ratio. Our theoretical analysis shows that the difference between the angular selectivity of a transmission geometry hologram in two cases is less than 4%. This result is confirmed by the experimental result for the selectivity curves of holograms of a low bandwidth image shown in Figure 2. To check the quality of the reconstructed image, a transmission geometry Fourier-plane hologram of a data mask with 40 micron by 40 micron pixels is recorded and then read-out using 488 nm light of an Ar ion laser. The crystal used in these experiments is a 4 mm thick x-cut $LiNbO_3$ sample doped with 0.015 wt. % Fe_2O_3. The reconstructed image is captured by a CCD camera. Then the signal to noise ratio (SNR) is calculated for the reconstructed image. The reconstructed images along with the calculated values of the SNR are shown in

Figure 3. To observe the effect of noise and crosstalk, we have also shown the SNR of the imaging system with and without the crystal in its place. As shown in Fig. 3, there is no problem in using extraordinary polarization, in the geometry where very large dynamic range (M/#~40 cm^{-1}) was measured.

Figure 3. Image quality and signal to noise ratio for a transmission geometry holographic recording system: (a) system without crystal, (b) system with crystal, (c) reconstructed image from a hologram recorded with extraordinary polarization, (d) reconstructed image from a hologram recorded with extraordinary polarization.

References:

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