Equal Fanout Optical Interconnects Using Dupont Photopolymer Films

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ABSTRACT

In this paper, concerning with the practical applications of substrate guided wave optical interco one-to-many surface-normal fanout devices with equalized fanout energy distribution are addresse then demonstrated. DuPont photopolymer film HRF-600X001-20 is used in our experiment optimum recording beam intensity is investigated for obtaining large dynamic region of diffr efficiency versus exposure dosage. Based on the experimental diffraction efficiency curve, 1-to-5 and 9 surface-normal fan-out devices are fabricated operating at a wavelength of 850 nm. Output en fluctuations of ±4% and ±10% are obtained for the two devices.

1. INTRODUCTION

Optical interconnects have been demonstrated to be one of the most important alternatives to overco the bottlenecks of electrical interconnects[1,2]. Among many optical interconnect demonstrations, subst guided wave optical interconnects, using holographic optical elements (HOEs) combined with internal reflection in dielectric or semiconductor substrates, are efficient approaches for intra- and in module interconnections, optical clock distributions, and optical backplane buses[2-5]. Several types of many surface-normal optical interconnects have been reported using Dichromated Gelatin (DC hologram elements integrated on wave guiding glasses[3-5]. However, achieving an equal fan-out ene distribution and a coupling-in HOE with a high diffraction efficiency still remains a critical issue unsolv Furthermore, the wet-processing requirement affiliated with DCG complicates the problem[6]. In pract the non-uniformity in a 1-to-many fan-outs device makes it more difficult to integrate the device w optical detector arrays or other optical signal processing elements.

In this paper, DuPont photopolymer films are used as the volume hologram recording material. So related issues of equalization of fanout energy distribution will be discussed, and the experimental resu be demonstrated at an operating light wavelength of 850 nm.

2. HOLOGRAM FORMATION in PHOTOPOLYMER FILMS

DuPont photopolymers are promising holographic films due to its dry processing, long shelf life, good photospeed, and volume phase holographic properties[7-10]. The holographic photopolymer is usually coated from solvent onto a clear support, typically Mylar polyester film. A removable cover sheet is used as a protecting cover. The thicknesses of photopolymer are available from 10 to 50 μm.

HRF 600X001-20 (20 μm thick) is selected as the recording material because it exhibits lower scattering and higher diffraction efficiency[10]. The film can be used to record interference pattern after removing the cover sheet and laminating the film to a glass plate. The hologram formation mechanism in the photopolymer is known to be a three-step process. First, an initial exposure records the interference pattern, which causes initial polymerization and diffusion of the monomer molecules to bright fringe area from the dark fringe neighborhood in the photopolymer. A higher concentration of polymerization means a higher refractive index. Second, a uniform UV light is required for dye bleaching and complete polymerization. Third, a baking process can further enhance index modulation in the hologram formed. Higher refractive index modulation in this type of photopolymer film has been reported, and a large dynamic range of diffraction efficiency as a function of exposure time can also be achieved by adjusting light intensities of the two recording beams[7,8].

3. EQUALIZATION of FANOUT ENERGY DISTRIBUTION

For a substrate guided wave optical interconnect with ideal 1-to-n uniform surface-normal fan-outs, as shown in Figure 1, the diffraction efficiencies for the coupling-out holographic optical elements are given by[11]

$$DE_i = 1 / (n - i + 1). \qquad (1)$$

In Eq. (1), the subscript i (i = 1, 2, 3, ..., n) represents the order of the coupling-out HOEs in the designed substrate guided wave optical fan-out device. According to Eq. (1), an ideal 1-to-5 uniform fan-out device needs 20%, 25%, 33%, 50%, 100% diffraction efficiencies for the successive coupling-out HOEs. For a 1-to-9 fan-out designing, diffraction efficiencies in the order of 11%, 12%, 14%, 16%, 20%, 25%, 33%, 50%, 100% are needed for the coupling-out HOEs. The key to obtain a uniform fan-out energy distribution is to find an optimum recording light dosage which can provide an accurate diffraction efficiency between 10% and 100%. Diffraction efficiency adjustment of each HOE is always required based on the highest efficiency achievable in practice.

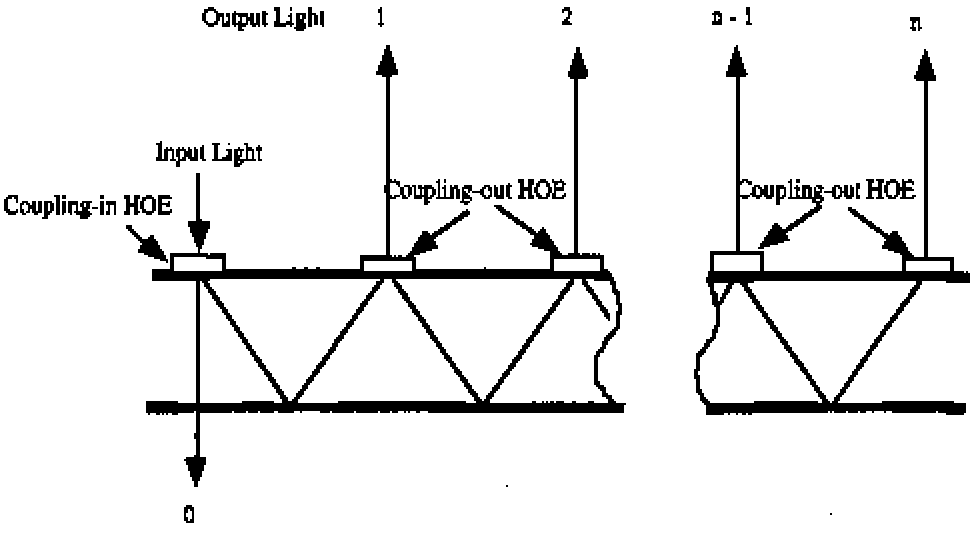

Figure 1 HOE based surface-normal fan-out optical interconnect.

4. EXPERIMENTAL RESULTS

A two-beam interference method[3] is employed to fabricate both the coupling-in and coupling-out HOEs. An Argon ion laser operating at 514 nm is used in the hologram recording. The reconstruction wavelength is set to 850 nm, which is the emitting wavelength from most commercially available Vertical Cavity Surface Emitting Lasers (VCSELs). The diffraction angle for each HOE is designed to be 45°, greater than the 41.3° critical angle of the total internal reflection for BK-7 glass substrate. The Bragg phase matching condition[12] and the Snell's law are applied to calculate the diffracted angle in the hologram medium and then to convert the recording angles to those in air[3].

For our experiment setup, different beam intensities and beam intensity ratios are investigated to find an optimum recording light power. At a fixed recording intensity and beam ratio, a set of single holograms with exposure time from 0 to 80 seconds at an interval of 5 seconds are recorded. The holograms are post-exposed 5 minutes under UV light and baked for 1 hour at 120°C. A Coherent Ti:Sapphire tunable laser is used to measure the diffraction efficiencies of HOEs at 850 nm. The optimum recording condition is found to be that the intensity ratio of the two recording beams is about 1:1 and the total

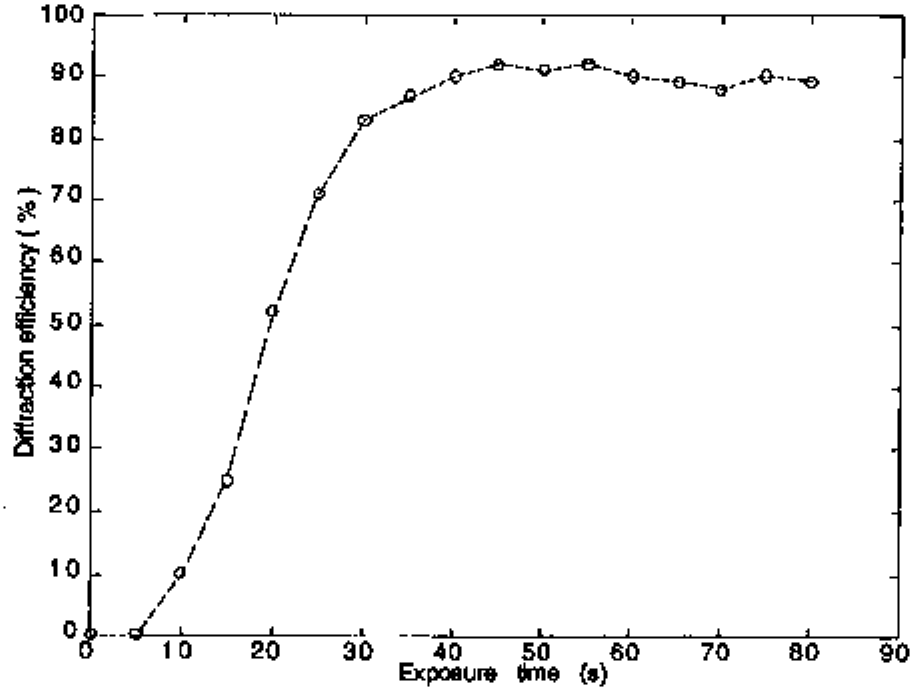

Figure 2 Diffraction efficiency versus exposure time for DuPont photopolymer HRF 600X001-20 (20 μm thick). The film thickness is 20 μm. The recording light wavelength is λ_C = 514 nm. The ratio of two recording beams is about 1:1. The total intensity of the beams is ~ 3.0 mW/cm^2. Efficiency is measured at λ_T = 850 nm.

intensity of the two beams is ~ 3.0 mW/cm^2. The diffraction efficiency versus the exposure time under such a condition is given in Figure 2. We can see that the higher efficiency (>90%) occurs at 40 s exposure time, and different diffraction efficiencies ranging from 0% to ~90% are obtained between 0 s and 40 s. This large dynamic region make it easy to get accurate diffraction efficiencies required for uniform fan-out devices. The curve remains almost flat when the exposure time is larger than 40 s. This is caused by the saturation of the modulation of the refractive index[9].

To integrate HOEs with different diffraction efficiencies on one photopolymer film, a 6 cm long thin mask with an opening slit of 6 mm across is used. This mask is placed in front of the film during HOE recording. The film is translated twice the thickness of the substrate sequentially between exposures. The exposure time corresponding to the diffraction efficiency at each designed position is obtained from Figure 2.

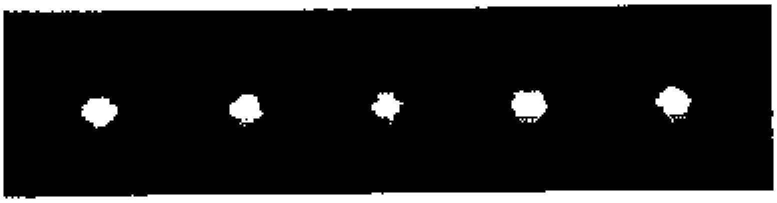

Figure 3 Far field image for a 1-to-5 fan-out result at $\lambda_r = 850$ nm.

Figure 4 Far field image for a 1-to-9 optical fan-out device.

Figure 3 shows the CCD image of a 1-to-5 fan-out device, for which a glass substrate (3.15 mm thick) is employed. Relative to the average among the fan-outs, the intensity distribution from channel 1 to channel 5 are 1.04, 0.99, 0.96, 1.03, 0.98, with a maximum deviation about ±4%. This shows that it is possible to precisely control the output intensity uniformity. In Figure 4, we show the experimental result for a 1-to-9 device. The intensity non-uniformity among the fan-outs is within ± 10% (see Figure 5). This is larger than that of 1-to-5 fan-out device, mainly due to the fact that the more fan-outs, the more difficult to control the diffraction efficiencies of the HOEs. For example, it is difficult to experimentally control the neighboring diffraction efficiencies of 11% and 12% precisely. The diffraction efficiency versus the deviation of the input signal from surface-normal for the 1st channel of the 1-to-9 device is also tested. We found that a ± 0.5 degree deviation of the input signal from surface-normal position can lead to 10% deviation of the maximum diffraction efficiency. The diffraction efficiencies of the coupling-in HOEs for these two devices are measured to be about 90%.

The non-uniformity of the fan-outs of the devices is caused by the deviation of the required diffraction efficiency of the HOE at the recorded position, cleanness of the glass, and the laminating process. Non-ideal interface quality between the glass and the photopolymer film causes non-uniform energy distribution as well. Another important factor influencing the output fluctuations of the device is the alignment of the device relative to the input reconstruction laser beam. Furthermore, Dupont photopolymer would experience some degree of shrinkage after UV curing and baking. This shrinkage affects the slanted angle of the hologram gratings, which leads to the deviation of the maximum diffraction efficiency from surface-normal incident position[8]. From Figure 6 , we can see that the deviation angle is a function of the exposure time, which controls the diffraction efficiency as shown in Figure 2. Further improvement can be made by taking these effects into consideration.

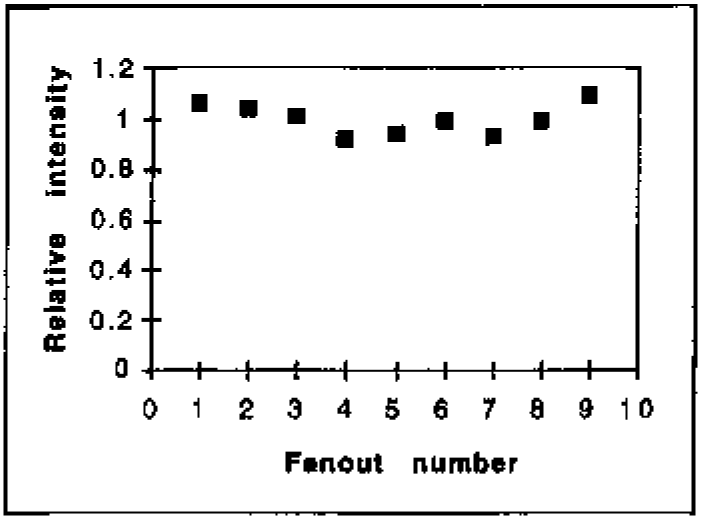

Figure 5 Relative intensity distribution measured. The intensity fluctuation is within ± 10%.

5. SUMMARY

We present the experimental results for the fabrication of 1-to-many uniform fan-out device for surface-normal optical interconnects. Satisfactory results are demonstrated for a 1-to-5 and a 1-to-9 fan-out devices at 850 nm. This approach can be easily employed to fabricate uniform fan-out devices at other wavelengths. It should be noted here that the optimum recording condition depends on the reconstruction

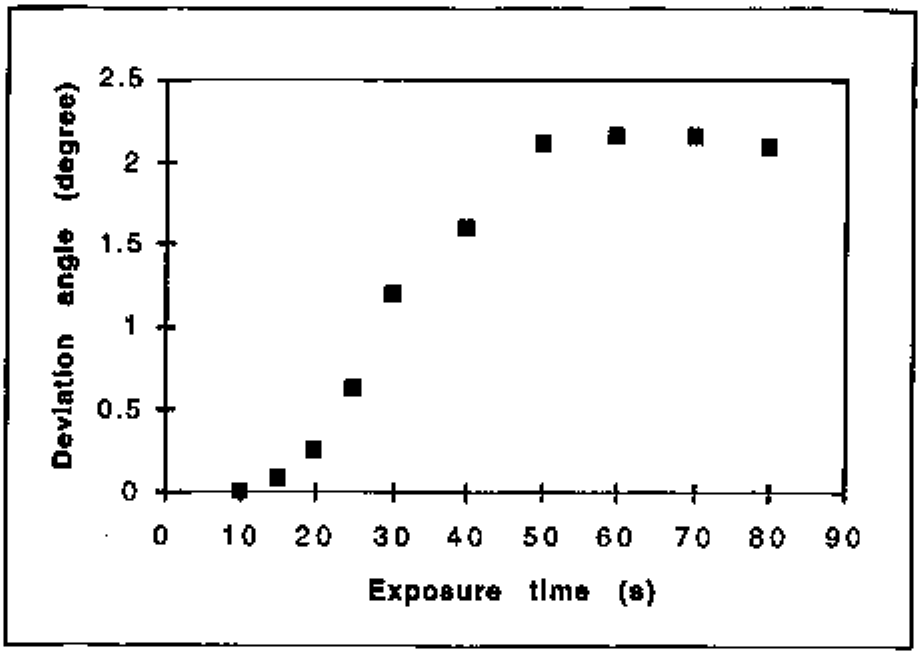

Figure 6 Deviation of the maximum diffraction efficiency from surface-normal incident position versus the exposure time. The recording conditions are same as those in Figure 2.

wavelength which affects the holographic grating slanted angle. With the fan-out uniformity problem solved, it is expected that these substrate guided surface-normal optical fan-out HOEs will find wide applications in many integrated optics and optoelectronic applications. These include optical backplane bus , optical clock distribution, and optical true-time-delay lines[13,14]. By employing these uniform fan-outs devices, the non-uniform power distribution concerning with these optical interconnects are no longer an obstacle. This also ease the integration of such devices with photodetector arrays for practical system designs. Meanwhile, the uniform fan-outs device can also be served as an optical array illuminator[15] distributing optical power to optical logic gates and bistable devices in optical computing. Furthermore, the uniform fan-out optical interconnects can be packaged with VCSELs, photodetector array, and optical processing elements for inter multi-chip module (MCM) and intra MCM parallel optical processing. This approach is currently under investigation.

6. ACKNOWLEDGMENT

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