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Hybrid polymer-on-glass integrated optical diffractive structures for wavelength discrimination

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Abstract

We present novel compact planar configurations for wavelength discrimination. These configurations include multiple diffractive optical elements (DOEs) that are recorded in very thick photopolymer layers that are coated on one planar transparent substrate. The design, material parameters, recording procedures and experimental results for configurations are presented. For a configuration that was designed to discriminate three closely separated wavelengths, the results reveal that the wavelength separation could be as low as 3 nm at an operating wavelength of 1567 nm, for 80 μm thick photopolymer layers. The crosstalk between adjacent wavelengths was less than 2% for one DOE that is comprised of three sub-DOEs, each designed for a different wavelength. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Planar optics; Diffractive optical elements; Photopolymers; Wavelength discrimination

1. Introduction

Wavelength discrimination has become a widespread method for increasing the information carrying capacity of fiber telecommunication systems, by exploiting more efficiently the high bandwidth of optical fibers. Using wavelength discrimination techniques, a large number of communication channels can be transmitted simultaneously over a single fiber. To implement wavelength discrimination, several devices and configurations have been developed [1]. Unfortunately, these devices and configurations suffer from either a limited number of channels or complex alignments or bulkiness. To alleviate the spatial requirements, advanced configurations based on a planar optics [2] approach have been proposed. To ensure that the wavelength discrimination is high, it is necessary to resort to very thick optical recording layers, preferably organic photopolymers [3], because these also exhibit high diffraction efficiencies (DEs) and low shrinkage, even at relatively large thicknesses and/or large slant angles [4].

In this paper, we combine the advantages of planar configuration with the discrimination properties of very thick volume phase gratings in our new photopolymer-on-glass materials.

2. Design considerations

Fig. 1 shows a planar configuration for wavelength discrimination for a number of channels. In

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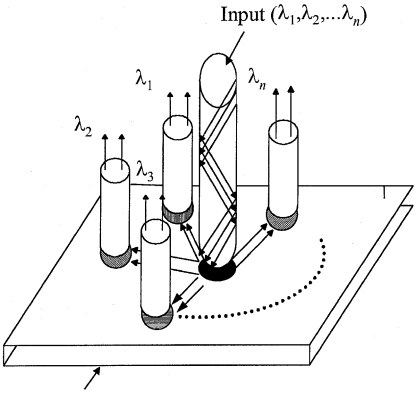

Fig. 1. Configuration of a planer wavelength discrimination system.

this configuration, one central input DOE comprises several superimposed sub-DOEs, each for a different operating wavelength. In addition, there are several peripheral single output DOEs, each for a specific wavelength. The input light containing n different wavelengths $\lambda_1, \lambda_2, \ldots, \lambda_n$ is coupled into the central DOE, where each sub-DOE diffracts one beam for a specific wavelength, so that it is trapped it inside the substrate and directed to a specific peripheral DOE, that couples it out. Since all the DOEs are recorded on the same substrate, the overall system can be very compact.

To obtain an efficient throughput and low crosstalk between the channels, each DOE must have high diffraction efficiency for its respective wavelength λ_i, while minimizing the diffraction efficiency for all other wavelengths. According to the coupled wave theory [5], one of the important design parameters for the planar DOEs is Δn, the refractive index modulation. To obtain high diffraction efficiency for reconstruction at the Bragg angle, Δn should be as large as possible. On the other hand, increasing Δn decreases the wavelength discrimination of the DOE, so that the wavelength separation between the channels must be increased to avoid crosstalk [5]. Consequently, an optimal value for Δn should be chosen. In our experiments we set Δn to achieve diffraction efficiencies of 90%. In order to calculate the maximal number of channels that our planar configuration can deal with, we first found the number of DOEs, m, which can be superimposed in one location. This depends on the maximum refractive index modulation of the recording material $\Delta n_{\max}$ and on the refractive index modulation for each DOE Δn_i, so that the sum of all Δn_i does not exceed $\Delta n_{\max}$. The DOEs were recorded in two different photopolymer materials, one having $\Delta n_{\max}$ of 0.06 and the other $\Delta n_{\max}$ ranging from 0.006 to 0.01.

3. Experimental procedures and results

The photopolymer materials were prepared by dissolving the poly(vinylbutyral) (PVB) binder in organic solvents, together with phenoxyethylacrylate (POEA) monomer, pentaerythroltriacrylate (PETA) crosslinking agent, N-phenylglycine electron transfer agent and erithrosine (xanthine) photosensitizer. These solutions were then casted onto precisely leveled optical glass substrates, and carefully dried to yield the desired layer thickness ranging from 20 to 80 μm. These coatings exhibit both large DEs reaching almost 100% for the thick layers, and good environmental stability.

To experimentally evaluate our wavelength discrimination configuration, we holographically recorded a three wavelength planar configuration in the photopolymers with exposures ranging from 20 to 80 mJ/cm^2. The thickness of the polymers was 20 μm with $\Delta n = 0.011$. The three specified operating wavelengths were: $\lambda_1 = 633$, $\lambda_2 = 647$, and $\lambda_3 = 676$ nm. All the DOEs were recorded at $\lambda = 514.5$ nm, so we had to adjust the recording geometry for each specified wavelength. The results for this configuration are presented in Fig. 2 and Table 1. Fig. 2 shows the DE as a function of wavelength for the input DOE, which contains three sub-DOEs. We can clearly see the three separate peaks, each occurring at a different specified wavelength. The spectral bandwidth seems to be larger than expected for $\lambda = 676$ nm, and the DE at the three wavelengths are not equal. These anomalies are probably due to variation of recording parameters, which must still be optimized. The measurements of diffraction efficiencies and crosstalk are summarized in Table 1.

We also evaluated a similar configuration for specified operating wavelength: $\lambda_1 = 1530$, $\lambda_2 = 1547$, and $\lambda_3 = 1564$ nm. The thickness of the polymers was $d = 80$ μm with $\Delta n = 0.0017$. Fig. 3 shows the results of DE as a function of wavelength for one of the single output DOEs. As evident, the spectral bandwidth is about 3 nm, and the wavelength peak occurs at 1567 nm. The measured DE was about 32%, which was lower than expected. This indicates that the material and recording parameters still have to be adjusted.

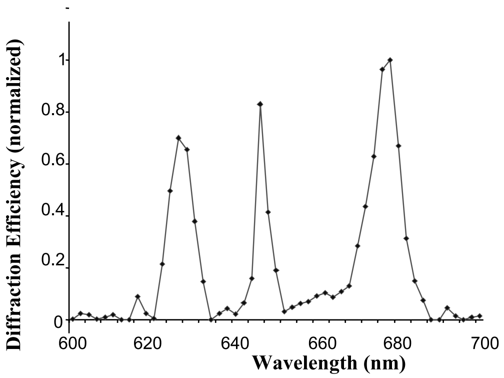

Fig. 2. Diffraction efficiency as a function of wavelength for the input DOE.

Table 1
Diffraction efficiencies and crosstalk for the three wavelengths of the input DOE

λ (nm)	633	647	676
633	55.8%	2.0%	0.5%
647	1.1%	82.3%	0.8%
676	0%	1.6%	91.3%

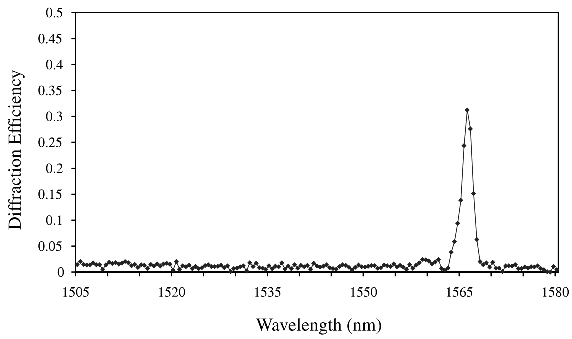

Fig. 3. Diffraction efficiency as a function of wavelength for $\lambda = 1564$ nm.

4. Concluding remarks

We presented a relatively simple, compact and modular wavelength discrimination planar configuration that was recorded in novel PVB photopolymer holographic recording materials on a glass substrate. As the thickness of the recording polymer material increases, it is possible to obtain relatively narrow spectral bandwidths at the visible and infrared regions so as to increase the number of wavelengths that can be discriminated without significant crosstalk.

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