Diffractive Optics: An Overview for Industrial Applications

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Abstract: This article is a review of the activities at University of Sao Paulo on diffractive and microoptics. It describes several types of microdevices, with selected applications. Their common characteristic is the low-cost fabrication processes.

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1. Introduction

Diffractive optics has emerged from holography [1], and diffractive optical elements (DOEs) are being used in great number of applications such as beam shaping, optical interconnects and filtering. Their main advantages over traditional refractive optical elements are their reduced size and weight and the possibility of being mass fabricated [2,3]. It is desirable in some instances to combine DOEs with refractive components in order to achieve special functions or desired levels of performance. From these applications the so-called hybrid optics, has emerged [4]. Since 1997 researchers from University of Sao Paulo have been working on diffractive optics, microoptics and computer-generated holography. In this paper some selected applications involving micro-optics are described, including computer-generated holograms [5], microlens and Fresnel lens arrays [6,7], as well as a diffractive phase-shift photolithographic masks operating in proximity printing mode [8]. A common characteristic of all these devices is the low-cost fabrication process. Amorphous hydrogenated carbon (a:C-H) thin film, also known as diamond-like carbon (DLC), has been employed as structural material in these optical microelements [9].

2. Diffractive Optics Applications

In this section we describe some selected applications of the optical devices fabricated at University of Sao Paulo.

2.1 Computer-Generated Holograms

This first application presents a hybrid binary surface-relief computer generated phase hologram and a continuous parabolic surface-relief phase element capable of splitting a monochromatic laser beam into an arbitrary number of lines over a high angle [5]. Since binary DOE was designed by using scalar diffraction theory, its fan-out angle is limited to approximately 6°. In order to increase the fan-out angle a parabolic lens array is employed which acts as a low f-number divergent beam element. The binary surface-relief was generated into one side of a quartz substrate and the parabolic profile was generated into a thick photo resist on the other side of the quartz substrate. Figure 1a shows a schematic view of the hybrid DOE. Figure 1b shows the experimental setup used to obtain the optical reconstruction of the hybrid phase element. The reconstruction images were obtained by using a CCD camera placed in the other side of the screen (an A4 paper sheet). Three images were recorded to capture the split of the multiple beams over 90°.

2.2 Improvement of Photodetector Efficiency by Using Microlens Radiation Concentrators

In this application we report a technique to improve the coupling efficiency of planar Metal-Semiconductor-Metal (MSM) photodetectors, by using a microlens array seated on top of the uncovered semiconductor area between the MSM metal fingers [6]. The microlenses was patterned by e-beam lithography. They redirect light to photoabsorptive areas, with no associated penalty in any figures of merit, including the speed of response.
Figure 1. (a) Schematic view of a hybrid DOE (cross section and the cylindrical microlens array); (b) optical reconstruction of the hybrid phase element. A CCD camera was placed in the other side of the screen (an A4 sheet of paper). Three images were recorded to capture the split of the multiple beams over 90°.

The schematic view of the structure of the microlens array fabricated on top of the MSM device is shown in Figure 2a, and a SEM picture of the final structure is shown in Figure 2b. Figure 2c shows the response of the MSM with (solid line) and without (dotted line) microlens array. It can be seen that a 65% improvement on the optical coupling efficiency is achieved.

Figure 3: (a) Structure of the MSM photodetector with the integrated microlens array on top; (b) photocurrent response with (solid) and without (dotted) lens array; (c) SEM picture of the fabricated lens array.

2.3 Fresnel Lens Array for Passive Infrared Motion Sensors

This is an application of low-cost Fresnel lens array in polymeric material, which acts as infrared radiation concentrator (8-14 µm wavelength range). A mold insert was fabricated in hard steel by a laser ablation process, and a polymer replica was generated by thermo injection process. The lens array is to be used in passive infrared motion sensor applications [7]. A laser ablation process (Nd:YAG laser source) was employed to fabricate the phase modulation structure directly into a hardened steel surface in a relatively low-cost and short time process. Figure 4 shows the resulting mold insert. Its surface was then acoustically polished by Novapoli Co., and a specular 3D Fresnel set of figures was obtained.
2.4 Diffractive Phase-shift Photolithographic Mask

In this application we propose a phase and intensity modulation diffractive phase shift photomask, fabricated using a DLC thin layer on top of a fused silica (SiO$_2$) substrate. The goal is to improve the resolution of a proximity printing lithography system [8]. When illuminated, the mask projects the required pattern onto a plane 50 μm behind the mask. Test structures were exposed and results obtained from both contact and proximity (50 μm gap) modes were compared, figure 5. One can observe that the line obtained by proximity exposure is clearly resolved.

3. Conclusions

This paper illustrates some applications of diffractive optics, microoptics and computer-generated holography, resulting from the research activities at University of Sao Paulo. A common characteristics of all these applications is that the devices were implemented by low-cost fabrication process. The authors would like to thank CNPq (process # 151908/2007-9). This work is part of the INCT - Óptica e Fotônica (INOF).

5. References