Design and fabrication of plastic diffractive / refractive hybrid lenses for image communication

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Abstract

We discuss the design and fabrication of CCD or C-MOS imaging lenses with hybrid diffractive / refractive optics. The hybrid lenses are made of optical grade plastic materials. We have been able to significantly reduce the number of elements while maintaining very high optical quality. This paper describes the conception, design, fabrication and evaluation of hybrid lenses in comparison with conventional refractive lenses. The new lens has excellent optical quality, very light weight, compact size and low manufacturing cost.

Introduction

In contrast to conventional optical elements that form images with either reflection or refraction of light, the diffractive optical elements (DOE) utilize diffraction and interference effects. A surface-relief diffractive element alters the phase of an incident wavefront with a grating structure. Once the desired phase alterations are calculated, the physical grating structure is determined by using a "Modulo 2π " operation on the phase profile. The "Modulo" operation essentially collapses the phase profile to a series of zones, whose location determines the generated wavefront. By correctly sculping the profile within each zone, diffractive surface can be "blazed" so that the incident energy can be directed into a particular diffraction order. For most diffractive elements that can be manufactured presently, scalar diffraction theory can be used to determine the optimum zone profile.

The limited number of optical quality plastic materials provides an ideal opportunity to utilize the unique properties of DOE. Achromatization and arbitrary wavefront correction can be utilized to improve optical system performance while often reducing the number of required elements. By using a diffractive surface, a hybrid diffractive/refractive singlet can be used to provide an achromatic well-corrected element. The presented hybrid imaging lenses design represents a single material optical system that is diamond-turned in acrylic. The optical design provides a cost-effective approach to producing high-performance, lightweight lenses for use in image communication such as personal communications services (PCS), digital still camera (DSC), international mobile telecommunication (IMT-2000).

Hybrid lens design

Figure 1 depicts a comparison of the principle of focusing in refractive lens and diffractive lens. Because of the variation of refractive index with wavelength a single element refractive lens has a variation of focal length with wavelength. The most difficult aspect in designing an all plastic imaging system has been the lack of adequate materials for color correction. Diffractive structures are ideal for providing color correction due to the effective Abbe' number of -3.451 in visible wavelength ranges.

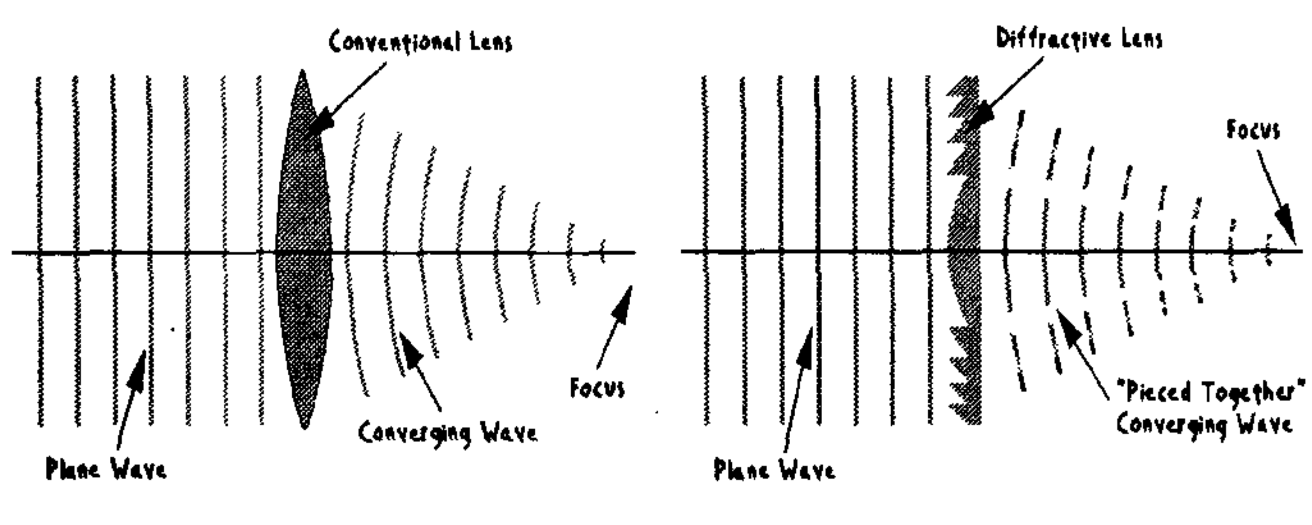

Fig. 1. Principle of focusing in refractive lens and diffractive lens

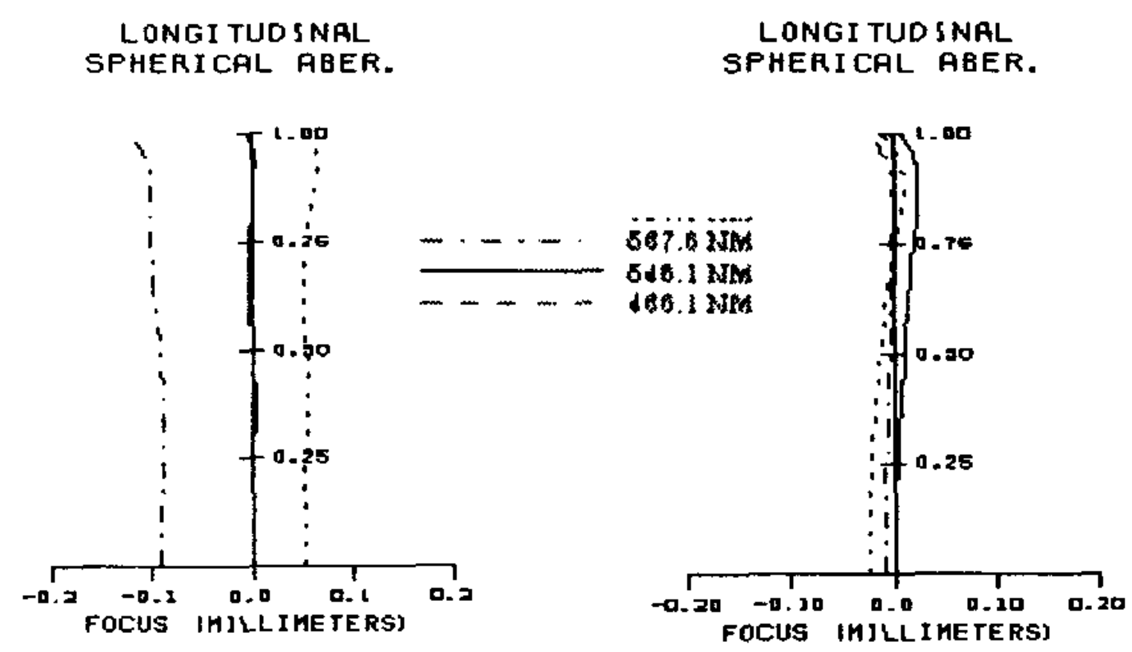

Fig. 2. The comparison of longitudinal color corrections between refractive plastic lens and diffractive plastic lens.

By incorporating a diffractive structure into refractive lens, it became possible to balance the longitudinal and lateral color. Figure 2 shows the comparison of longitudinal color corrections between refractive plastic lens and diffractive plastic lens.

Our hybrid optical design specification is F/2.8, 6.6mm effective focal length (EFL) single lens (singlet). The image plane fits the format of a 1/4" color CCD (charge coupled device) sensor. The lens is shown in figure 3. The rear surface is consist of diffractive / refractive hybrid surface. The hybrid lens design is well corrected for both lateral and longitudinal chromatic aberrations. The lens will be a good choice for color CCD camera applications such as DSC, PCS and IMT-2000.

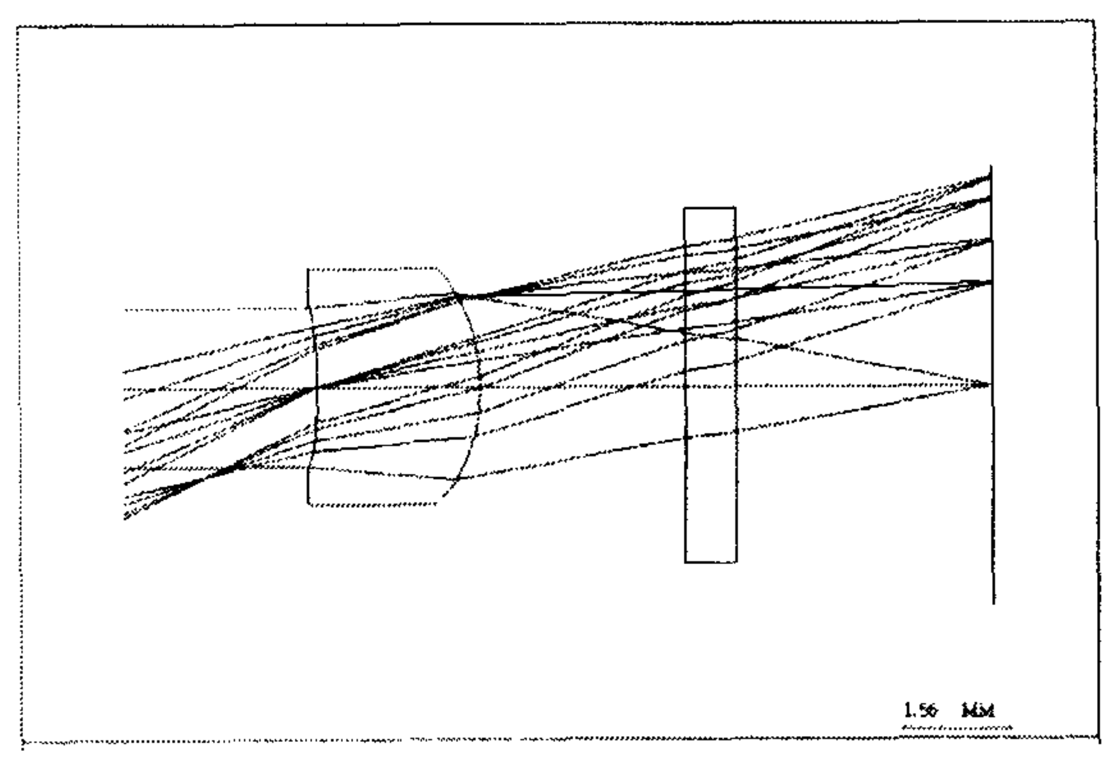

Fig. 3. The layout of the hybrid diffractive/refractive lens system (F/2.8, EFL=6.6mm)

Fabrication and Results

After designing the hybrid diffractive/refractive lens which has phase quantity controlled by DOE, we have fabricated the plastic (PMMA) hybrid lens directly by the diamond turning machine. The figure 4 shows the binary pattern of designed DOE on the aspheric substrate according to the phase quantity (optical path difference; OPD) .

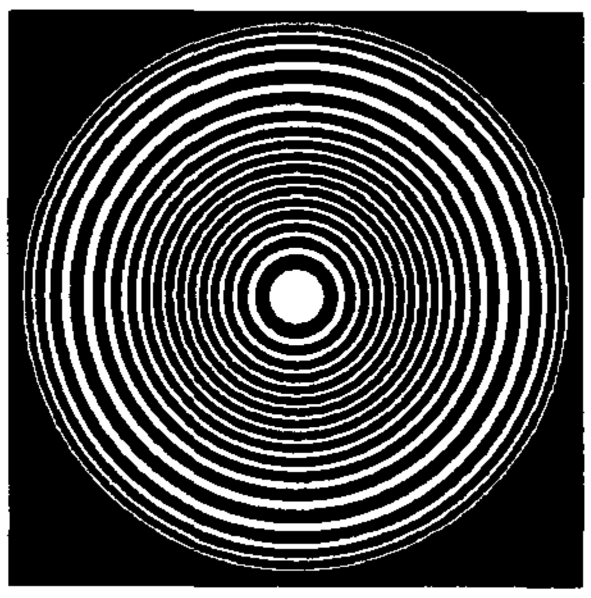

Fig. 4. The binary pattern of designed DOE on the aspheric substrate.

The figure 5 shows the measurement of relief structure of diffractive /refractive surface. The difractive surface has 18 zones with a minimum feature size of 55.4 ㎛, the maximum depth of each zone is 1.08 ㎛.

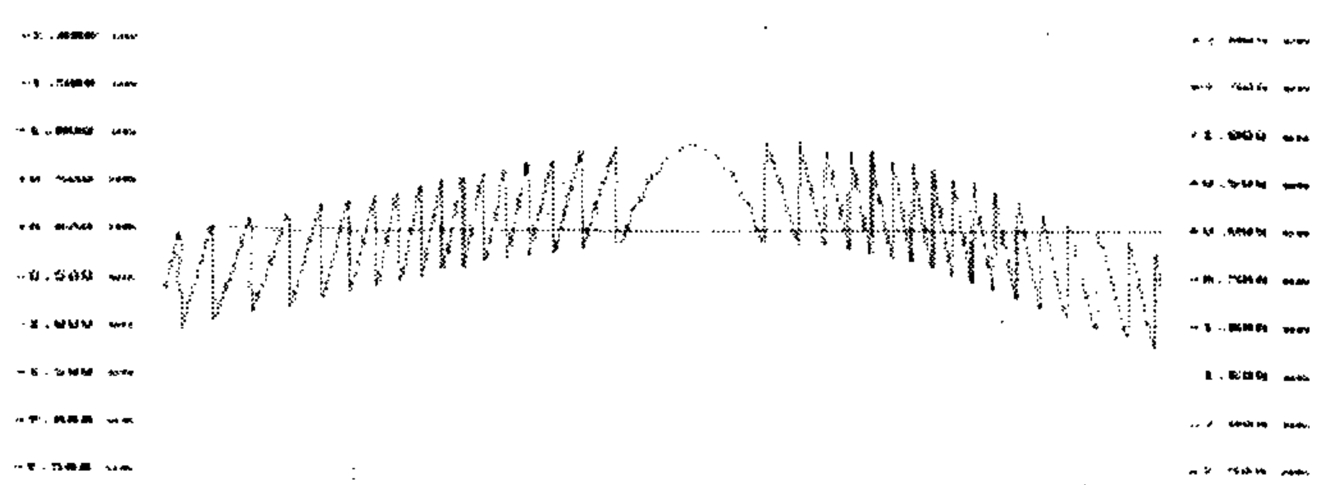

Fig. 5. Measurement of diffractive surface of fabricated hybrid lens.

Figure 6 is a 3-D plot of the diffractive surface across the clear aperture from a Wyko surface profilometer.

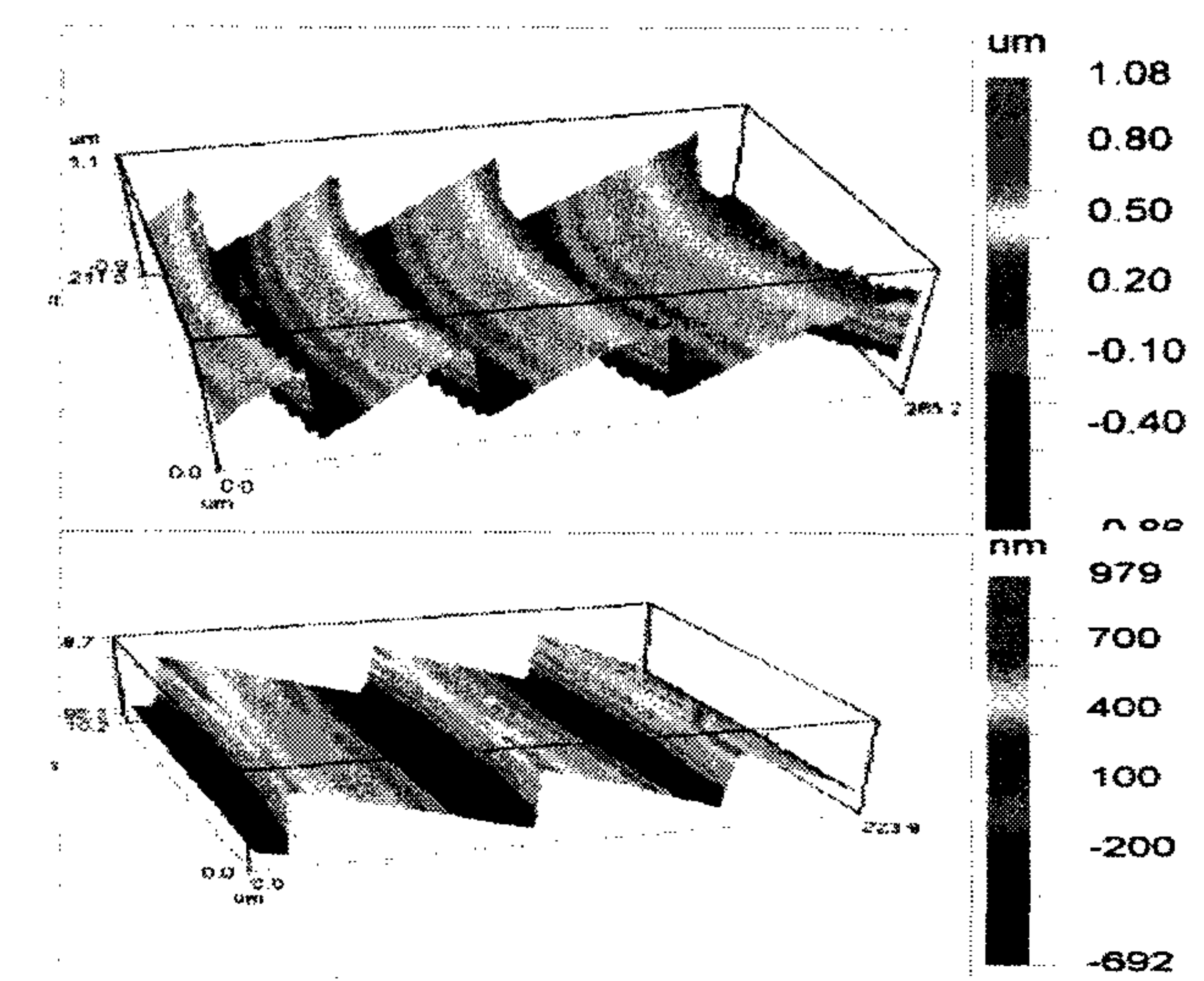

Fig. 6. 3-D plot of the diffractive surface across the clear aperture (center and edge area respectively)

The requirements for obtaining high diffraction efficiency are developed with scalar theory. The general performance of diffractive surface is dependent upon the placement accuracy of the zones and the departure of the zone profiles from their theoretical shape. The zone placement errors result in wavefront deviations from the desired shape and the deviations from the theoretical blazed profile result in a reduction of diffraction efficiency. The figure 7 shows the picture of color image with high performance taken by our new hybrid lens.

Fig. 7. Photograph of color image taken by hybrid diffractive / refractive prototype lens system.

Conclusion

By utilizing diffractive optics technology, a high-performance hybrid diffractive/refractive lens designed and fabricated. The single material system is chromatically well correct, which would not be possible without diffractive surface. The new design form would provide excellent optical quality, very light weight, compact size and low manufacturing cost as imaging lens for applications such as image communication.

References

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