Replication of periodic structure on 2D acrylic lens attained as a diffractive optical element in reflectance domain

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Abstract

In this attempt, the diffractive optical element (DOE) was designed and fabricated on 2D acrylic lens substrate. The periodic structure was replicated from master grating by ultra violet light technique. The replica modified 2D acrylic grating of uniform varying period attended as a DOE in reflectance domain. The 2D projection grating are the multiplayer interactive practical reality interactions test, the natural way of human-eye interaction of optical path, light easy to carry, fast installation, inexpensive and easy to design and shape. The overall integration solution will be widely useful for education and technical training, afterward simulation training and industrial presentation.

Introduction

The element which produces diverging or converging light rays by means of refraction is known as lens [1]. According to the construction, the simple lenses are divided into two types; convex and concave (planar or flat). These two types of lenses are further categorized with respect to curvature of the lens surfaces into biconvex, plano-convex, positive meniscus, negative meniscus, plano-concave and biconcave. Most of the optical lenses are made of plastic or glass. In these lenses, a great interest is being taken in plastic acrylic lens and is being applied recently to understand the basic physics laws in education training and technical training, simulation training and industrial presentation too. These lenses made up from clear acrylic, the simple acrylic lens would become 2D acrylic lens after its one side was frosted, also called double convex or double concave lenses. These characteristics or properties make the 2D acrylic lens easily to interact human-eye and as such the optical path of light easily carried. In addition to acrylic’s optical properties, its refractive index is 1.490–1.491, transmittance is 87.92%–92.6%, drying temperature is 167 °F–195 °F and drying time is 2.5–5.0 h [2].

An extensive development of improving the fabrication of high-resolution gratings and lens-lets are related to the enhancements in mechanical, optical and manufacturing techniques [3]. The manufacturing techniques are still limited by size, geometry, physical condition and complex fabrication process, making them difficult to control. This is basically because of time consuming, high cost and difficult in routine use. Besides, silicon, semiconductors, PMMA and PDMS as a structural material growing through variety of design choices by post processing technologies such as etching, coating, polishing, deposition and surface modification [4–6]. In addition, the modified and duplicate surface’s structure of micro and nanometer level has an important belonging to a material property such as physical, electrical, mechanical and optical [7]. The replica technology is considered a simple and efficient process for duplication of diffractive elements [8, 9]. In literature, the replication efforts have merely been made specifically for silicon, semiconductor, PMMA and PDMS as a substrate. Yet no attempt is available on acrylic substrate as a diffractive optical element (DOE) by replication technique. In this study, the diffractive master structure was achieved by silicon master grating of a uniform periodic structure. The fabrication process is followed by our previous group work [10]. Hereinafter, by using the optical adhesive and ultra violet (UV) system, the master periodic grating structure was magnificently replicated onto the frosted side of 2D acrylic lens but not onto the plain surface. The proposed replication method can be
considered a reasonable technique for acrylic substrate. It is the first attempt to flexibly utilize the 2D acrylic lens on frosted side for periodic structure. The fabrication process is a practical way to avoid from complex systems of high cost and low productivity.

**Fabrication of DOE**

Figure 1 illustrates the construction of the DOE. Since, the diffraction grating had no boundaries for the form of the grating surface, any substrate surface can be utilized \[1\]. Firstly, the standard 2D acrylic lens is taken which has one side frosted uniform structure on the surface while other side is plain. Next, for the replication photosensitive gel dispensed onto the acrylic frosted surface and master grating structure. Later, within 2 min the acrylic frosted surface installed onto the master grating then sited the structure for solidification and replication at 400 mW under UV light. After, 30 min exposition structure separated from the master grating substrate. The obtained DOE’s atomic force microscope 3D image and periodic structure are illustrated in figure 2. The figure 2(a) characterized the 3D AFM view where $25 \mu m \times 25 \mu m$ diffractive periodic structure are clearly observed. The AFM image of figure 2(b) illustrates the parameters as; $d_g \sim 76.306 \text{nm}$ (denotes grating depth), $\Lambda \sim 3039$ (denotes period). Moreover, the final DOE parameters are near to the original design, particularly for grating thickness and period.

**Characterization of DOE**

The 5 mm acrylic frosted (2D) element which has $\sim 41.261 \text{nm}$ (AFM measured) thick frosted or rough surface, as a reference with acrylic DOE are tested by UV–Vis–NIR double-beam spectrophotometer (Lambda 1050, Perkin-Elmer). The transmittance and reflectance of both elements are illustrated in figure 3. Firstly, the 5 mm 2D acrylic lens tested for transmittance and reflectance as shown in figure 3(a). The reflectance on 2D acrylic lens is tuned by changing the illumination wavelength of light from 300 to 1800 nm, which shows low reflectance percentage from 0.9% to 1.4%. The frosted surface causes a shift in electric field density, further leads to frequency change due to the acrylic Si–O backbone and generating different cross sections for its optical properties including absorption and scattering. Moreover, when the input light illuminates on the frosted surface by altering the wavelength the color spectrum range shows more resonance, later on shows major resonance peaks up to 1800 nm, means that frosted or rough surface have more influence at color spectrum range. Besides, the glowing transmittance is about 95% as illustrated in figure 3(a). Due to the minor effect of frosted surface, the refractive index differs, resonances dips occur at 1200, 1360, 1595, 1640 and 1760 nm.

The both reflectance and transmittance has meaningful usage for the future solar industry and single wavelength short range application using the 2D acrylic lens in basic optical physics laws demonstration as a
double concave and convex lens. Secondly, the same acrylic lens after replication from master periodic structure as illustrated in figure 3(b). The reflectance on acrylic DOE is tuned by changing the illumination wavelength of light from 300 to 1800 nm, shown reflectance percentage from 5% to 80%, having three major peaks from 998 to 1800 nm. Moreover, when the input light illuminate on the frosted surface, by altering the wavelength, the color spectrum range shows more resonance, afterwards shown major resonance peaks up to 1800 nm with low reflectance. In comparison, DOE has inclination from 300 to 720 nm, no any resonance peaks were observed, means acrylic DOE have authentic applications in reflection domain. Besides, DOE has low transmittance about 0.05%–0.20% as illustrated in figure 3(b). The color spectrum range was almost linear, no resonance dips and peaks. Also, from 900 to 1800 nm dips and peaks were observed and the reflectance of the DOE can be further improved from 5% to 10% by back side paint spray.

Figure 2. The atomic force microscope (AFM) images of replicated DOE (a) 3D-view (b) DOE periodic structure parameters.

Figure 3. Characterization of 2D acrylic lens via UV–Vis–NIR double-beam spectrophotometer (Lambda 1050, Perkin-Elmer), (a) reflectance and transmission of simple 2D acrylic lens, (b) reflectance and transmission of 2D acrylic lens after replica periodic structure.
Demonstration and discussion of acrylic 2D lens as DOEs

The fabrication of acrylic 2D lens as DOEs through replica technique made the acrylic material an important substrate in periodic structure. Till to date the acrylic has been ignored because of discriminating replication properties though to our understanding that factor was only applied on plain acrylic surface. Through this attempt, required surfactant enhancement for replication was achieved by utilizing the frosted side surface. Nowadays, frosted acrylic lens attends as a 2D double convex or double concave domain or application. This asset makes the 2D PDMS lens possible to easily interact human-eye and the optical path light is easily carried. Moreover, it is the low cost, rapid, simplest way which can be quickly constructed in any system design, makes it simple to explain the basic physics law in educational and technical training also in simulation training and industrial presentation. The replicated 2D lens as DOEs can be considered an improved candidate in above mentioned existing applications. This applied method has numerous advantages in fabrication such as transparency of acrylic does not affect or pollute compared to any post processing techniques which have always reduced the precision of substrate surfaces [12]. Secondly, the frosted surface structure as illustrated in figure 2(a) disturbs the visible range, but after periodic structure replication does not, as shown in figure 2(b). Due to these features, the processed any assembled shape and lens geometry can be replicated on the frosted acrylic element. Finally, the demonstration on both frosted and DOE are shown in figure 4. The DOE interrupts the spread of a wave that’s why the energy is spread into several distinct directions with different orders. DOEs can produce the spectrum of electromagnetic radiation. By examining this spectrum, anyone can understand the radiation properties of source. In other words, the light easily realized through medium or path from which it travels. Figure 4 illustrates the demonstration of both elements, in which 632.2 nm He Ne laser and display screen are used. Figure 4(a) demonstrates the frosted or 2D acrylic lens, where the big spot with side pixels are observed. The figure 4(b) demonstrated the proposed DOE according to the grating equation, the display sheet showed the grating spot.

Conclusion

The 2D acrylic lens as a DOE is fabricated and compared with the existing 2D acrylic lenses. This brings a new method for advanced DOE design and various areas of optical information processing. Existing 2D acrylic lens with the combination of proposed DOEs have interactive multiplayer real interactions demonstrations. Due to the light characterization, optical paths can be easily carried or interacted by human-eye, importantly the installation is fast, designing and shaping are easy and overall the optical setup is economical. As such this solution can be widely utilized in numerous optical applications.
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