Diffractive Optical Elements: A Novel Concept for Automotive Lighting

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We present a methodology to design and incorporate polymer based laser illuminated rear end lights in automotives using diffractive optics. The design of the diffractive optical elements is computed in MATLAB and realized experimentally by an optical UV lithography setup. Replication into polymer like poly(methyl meth)acrylate (PMMA) has been done with the help of polydimethylsiloxane (PDMS) soft stamps using hot embossing.

1 **Introduction**

Advancements in illumination technology in automotive industry are heading towards the use of coherent light sources for high resolution vehicle headlamps [1] as well as high quality designed rear and interior lighting. While for front end illumination, numerous amount of work has already been done, laser illuminated rear end illumination is yet to be explored. Contrary to the incoherent light sources for rear end illumination like halogen lamps and LEDs which are poorly formable using bulky refractive optical elements (ROEs), laser illuminated diffractive optical elements (DOEs) provide an alternative for desired illumination patterns, small size and bulk fabrication. Here, we present a complete process to design and fabricate DOEs for automotive rear end lights.

2 Concept and design

The proposed idea is to use binary as well as multilevel gratings for predefined intensity distribution in laser based rear end illumination system. Single grating cells diffract the incident light at a predefined position on the observation plane. As can be seen in figure 1, multiple grating cells are combined together for projection of the desired intensity pattern.

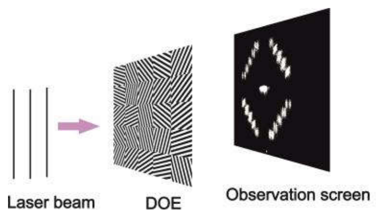

Fig.1 *Rear end light design concept.*

The phase profile of the DOE, which is combination of several grating cells is computed using Rayleigh-Sommerfeld diffraction integral in far field (Fraunhofer approximation) [2] implemented using MATLAB. Each grating cell is characterized by its period, groove depth, orientation and diffracts the incident light at a desired position in the observation plane as can be seen in figure 2.

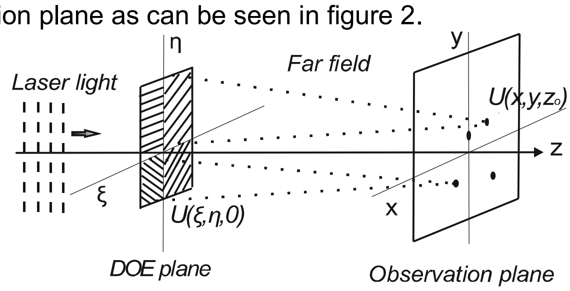

Fig.2 *Diffraction through combination of four grating cells.*

For binary gratings, *d* (groove depth) is chosen such that the phase φ is either 0 or π.The displacement of the pattern from center point $U(0,0,z_o)$ depends on the period of the grating cell and on the orientation. The individual 2-D grating cells are then combined together depending on the desired pattern using piezo sample stage.

3 Lithography setup and fabrication

In order to do fabricate the computed patterns, an optical lithography setup is employed as shown in figure 3.

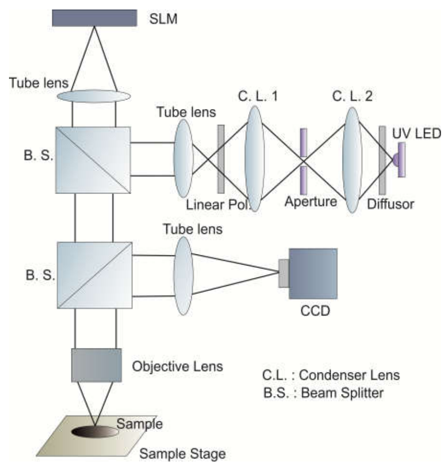

Fig.3 *UV lithography optical setup.*

A high power LED with wavelength of 405 nm and approximately 400 mW optical power is collimated using Köhler illumination system [3] with a diffuser and a lens for homogenously illuminating the SLM (Holoeye HEO 6001) with pixel pitch of 8 µm and a resolution of 1920x1080 pixels. In order to pattern sharp structures, an additional beam splitter is used to monitor the projected pattern on the sample surface. The designed DOE pattern is displayed onto the SLM using the Holoeye built-in software, which is then exposed to UV light for 20 seconds to project the displayed structure on the sample. We used positive photoresist (Shipley S1813) with approximately 700 nm µm thick homogenous layer (required *d*=653 nm for *φ*=*π*) spin coated on silicon substrate. After exposure the photoresist is developed using developer MF-26A for approximately 60 to 90 seconds and thoroughly rinsed with distilled water to remove the uncured resist as seen in figure 4.

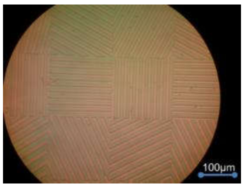

Fig.4 *Desired pattern on sample.*

As the photoresist on the silicon wafer is unstable at high thermal loads, it is not suitable as master stamp for replication using hot embossing. In order to overcome this issue, polydimethylsiloxane (PDMS) is used to prepare a soft stamp [4]. PDMS is coated onto the structured surface of the silicon substrate and cured on room temperature. The PDMS layer is manually removed from the substrate and used as a soft stamp in hot embossing machine. We used the commercial hot embossing machine HEX03 from Jenoptik. For replication of the desired structure we used poly(methyl meth)acrylate (PMMA) polymer with thickness of 500µm. The hot embossing process starts with heating the polymers up to 140° C which is higher than the glass transition temperature of 105° C of the PMMA [5]. A pressure of 6kPa was applied for 5 min. After cooling down to a release temperature of 40^{0} C, PDMS mold is removed from PMMA manually. The complete replication process is shown in figure 5.

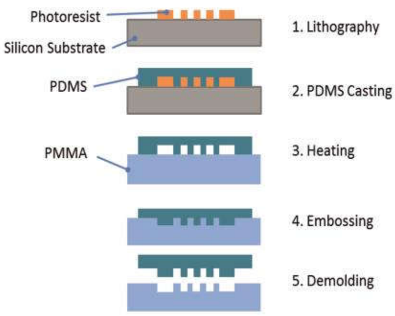

Fig.5 *Process chain for polymer DOEs [4].*

After replication of the desired structures into PMMA, the structures are illuminated with laser pointer having wavelength of 652nm and the resulting pattern is observed which is in close resemblance to the desired one as can be seen in figure 6.

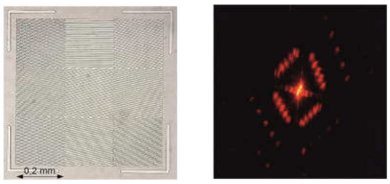

Fig.6 *Fabricated DOE on PMMA and corresponding projected intensity distribution.*

4 Conclusion

We presented a cost effective method to design and fabricate diffractive optical elements (DOEs) in polymers such as poly(methyl meth)acrylate (PMMA). The DOEs are especially designed to shape coherent light sources with an intended future use as automotive rear lights. For the design, the DOE is first computed by means of the RS diffraction integral and fabricated in photoresist with the aid of a self-developed maskless lithography setup. It is then transferred into polymer through soft embossing process. The fabrication process is simple and suitable for bulk fabrication and enables the design of thin polymer rear light.

5 Support

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6 References

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