Glass diffractive optical beam shaper for laser applications

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Applications, such as pico-projectors need a rectangular beam distribution – so called flat hat distribution. SCHOTT presents a diffractive optical element (DOE) made out of glass that shapes the Gaussian light distribution of the laser source into a flat hat distribution. Design and measurements for different designs are compared showing the good performance of the SCHOTT DOEs.

1 Introduction

Applications, such as pico-projectors with laser sources or medical laser skin treatment, require a rectangular homogeneous beam distribution – so called flat hat distribution. However, many lasers emit only Gaussian shaped light (due to the fundamental - TEM00 - mode).

SCHOTT presents a glass diffractive optical element (DOE) that shapes the Gaussian light distribution into a flat hat. Optical glasses have the significant advantage of high laser durability, low scattering losses, high resistance to moisture, chemicals, and temperature compared to polymer DOEs. The glass DOEs were manufactured by using SCHOTT's precise molding technology.

The design as well as measurement results of manufacturing SCHOTT DOEs are presented in comparison.

2 Introduction into DOEs Design

In order to understand how a phase DOE works we repeat the result of scalar diffraction theory for the case of Fraunhofer diffraction, where the diffracted electric field E_{dif} on a screen (with coordinates x, y, z) can be calculated from [1], [2]:

$$E_{dif}(x,y,z) = C \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} P(x_0,y_0)\cdot e^{-ik\frac{xx_0+yy_0}{z-z_0}}\, dx_0 dy_0 \ , \qquad (1)$$

where C = C(x,y,z) is a factor that we ignore here for simplicity, $k = 2\pi/\lambda$, and $P(x_0,y_0)$ is the pupil function at the position x_0 and y_0. Eq. 1 is the two dimensional Fourier transform of the pupil function. The diffracted electric field E_{dif} corresponds to the required light distribution on the screen (= flat hat). The pupil function is the required phase DOE. This means, in the case of Fraunhofer diffraction, the DOE can be calculated by inverse Fourier transform of the diffracted electric field on a screen. -In most practical applications the far-field approximation (Fraunhofer diffraction) cannot be used and thus Fresnel approximation must be used instead.

In addition, Eq. (1) assumes a homogeneous light distribution, which is not the case when using laser illumination with Gaussian distribution. Thus the calculation of the DOE (pupil function) is a complex mathematical problem, which is iteratively solved and implemented in commercial software as illustrated in example [3].

DOEs are designed to use the 1st diffraction order and the continuous phase is approximated by a staircase function - typically an 8 or 16 level quantization – resulting in a theoretical diffraction efficiency of 95% or 98%, respectively [1]. This maximum efficiency can be archived (should this be "achieved") using Blaze technique [5] where the height h of the DOE structure (corresponding to 2π phase difference) must be chosen to [4]

$$h = \frac{\lambda}{n(\lambda)-1}\ , \qquad (2)$$

with λ the vacuum wavelength and n the refractive index of the material at wavelength λ.

3 Glass DOE manufacturing by precise molding

SCHOTT uses a fast replication technique for the DOE manufacturing which is capable of producing mass quantities. In this precise molding process a replication master is first manufactured by lithography. Then the DOE is manufactured in a clean room facility as follows, see Fig. 1: A piece of glass is heated to a temperature where the glass is deformable. Then the glass is pressed into the final shape. Eventually, the glass is cooled down. The correct thermal management of the cooling step is essential for the accuracy of the DOE which can be coated (with anti-reflective coating) and sold to the customer. SCHOTT offers the following glasses that are especially suited for our DOE manufacturing process: P-LaSF47 (n_d = 1.8016), P-SK57 (n_d = 1.5843), N-LaF33 (n_d = 1.7821), and P-SF67 (n_d = 1.8998). These glasses show a very high performance concerning repeatability and accuracy of the pressed DOE structures.

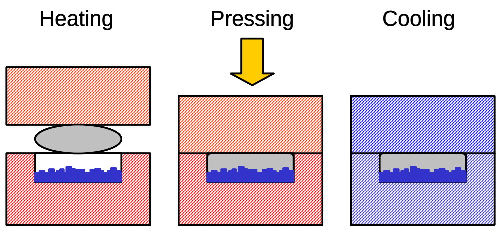

Fig. 1 Sketch of SCHOTT's precise molding process for DOE manufacturing.

4 Design and measurement results

Two different designs were made that convert the Gaussian light distribution into a flat hat distribution. Both designs used a green laser at 532 nm with a (measured) $1/e^2$ full beam width of 2.64 mm. The 1st design produced a flat hat with dimensions 9 cm x 9 cm at 1 m distance on a screen, see Fig. 2.

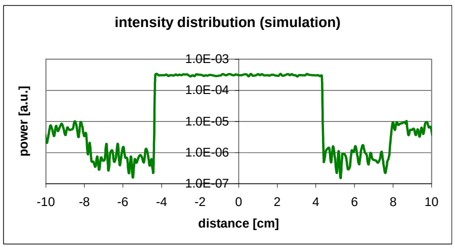

Fig. 2 *Design results (line cut) of the flat hat on a screen.*

Due to better manufacturability an 8 level DOE was designed with 1.10 µm pixel size. The laser width must be very accurate~~ly~~ since the flat hat is very sensitive to the laser parameters [6]. Fig. 2 shows the measurement results of the manufactured glass DOE.

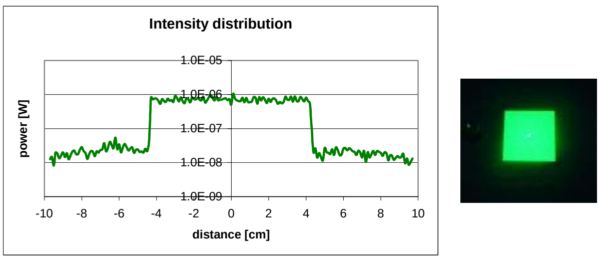

Fig. 3 *Measurement results (line cut) of the design from Fig. 2 (left) and a photograph of the flat hat image on the screen (right).*

As it can be seen by comparing Fig. 2 with Fig. 3 the design results and the measurement results of the manufactured DOE are agreeable. Also the homogeneity of the flat hat is very good for both, simulation and measurement.

In the second design the same laser was used but the flat hat was shifted out off center in order to "remove" the zero diffraction order from the flat hat, see Fig. 4. The flat hat dimension was again 9 cm x 9 cm in 1m distance on a screen.

The DOE was again an 8 level design due to better manufacturability with 1.10 µm pixel size. The laser emitted at 532 nm with a (measured) $1/e^2$ full beam width of 2.64 mm.

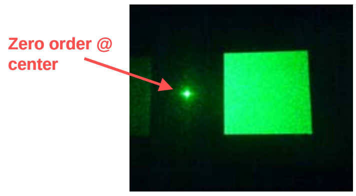

Fig. 4 *Photograph of the image on a screen of the 2nd DOE design with zero order at the center and flat hat off center.*

Due to manufacturing issues the zero diffraction order can emerge inside the flat hat. This can be avoided by shifting the flat hat off center as shown in Fig. 4. But typically an off center flat hat has lower diffraction efficiency and lower light homogeneity.

5 Summary and Conclusion

Different DOE designs were presented together with the DOE manufacturing method suitable for mass manufacturing. The measurement results are in ~~good~~ agreement with the simulation results. Thus a flat hat can be designed and manufactured by SCHOTT according to customer needs. In addition glass DOEs have the advantage of significant better thermal, mechanical, and chemical durability as well as withstanding a high light intensity as emitted by lasers.

6 Acknowledgement

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