

# Optical vortex phase plate application notes

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## Introduction

In various laser applications, there is a need to convert a Gaussian laser beam into a donut-shaped energy ring. Our Optical Vortex phase plate achieves exactly that.

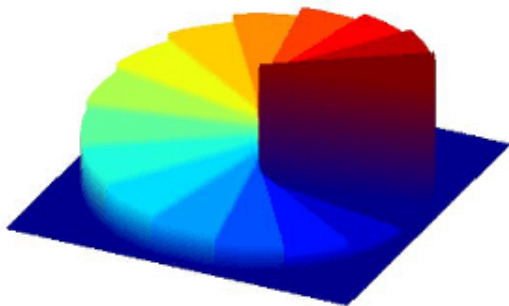
Typical applications include:

- Solar coronagraphs (astronomy)
- High-resolution microscopy
- Optical tweezers for particle trapping & manipulation
- Lithography
- Quantum optics

This application note is meant to aid the user's understanding of the functionality and performance parameters of our diffractive optical vortex element.

## Operation Principle:

The optical vortex phase plate is a unique optic, whose structure is composed entirely of helical or spiral phase steps, whose purpose it is to control the phase of the transmitted beam. The winding "staircase" surface structure is depicted in the Figure 1 immediately below:



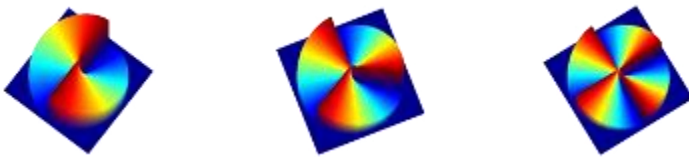
**Figure 1:** Winding "Staircase" surface profile of diffractive vortex phase plate.

The total etching depth from the top to bottom of "staircase" is a function of the design wavelength and the substrate's optical index. Generally, this depth is of the same order of magnitude as the design wavelength. Therefore, each vortex phase plate is wavelength specific.

If a customer wishes to use an optical vortex phase plate for a slightly shifted wavelength, we can simulate upon request what performance is expected.

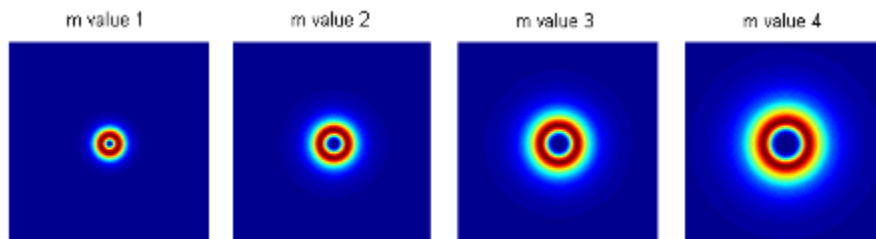
### Topological Charge

The topological charge, denoted in the relevant literature as  $m$ , refers to the number of  $2\pi$  cycles (i.e. "staircases") that are etched around 360 degree turn of diffractive surface. In Fig.1 above, one "staircase" cycle covers entire 360° turn of surface, so  $m=1$  for *that* vortex phase plate. In Fig.2 below, the surface profiles are illustrated for optical vortex phase plate with  $m=2$ ,  $m=3$  and  $m=4$ .

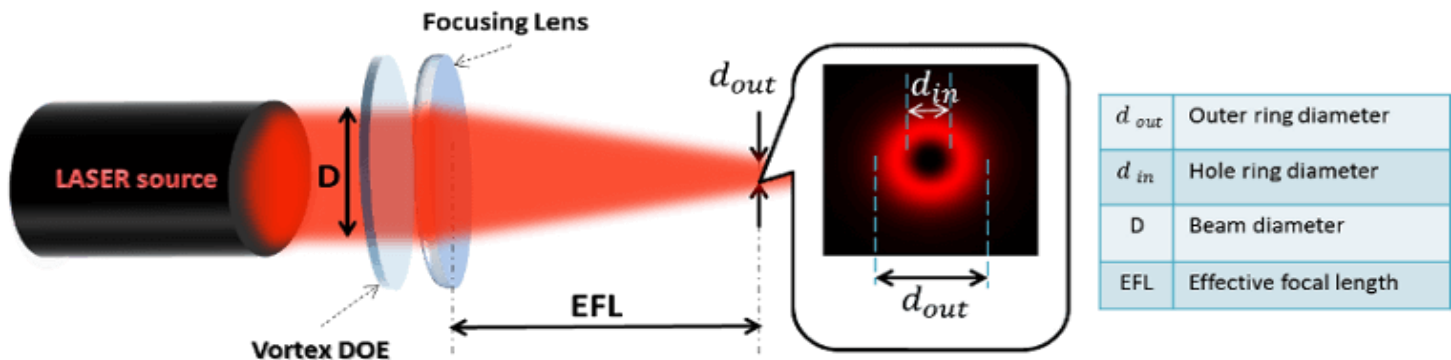


**Figure 2:** Surface profiles for vortex phase plates with  $m=2$ ,  $m=3$  and  $m=4$ .

One main effect of a higher topological charge is an increase in the angular momentum of the vortex beam by a factor of  $m$ . Another effect is to magnify the ring intensity pattern dimensions by a factor of  $m$ , as illustrated in the below simulation.



**Figure 3:** Simulated "far-field" intensity images of Vortex beams with variable  $m$  value.

Design Considerations

**Figure 4:** Typical Set-up for Vortex phase plate system.

The optical vortex requires as input a collimated **Single Mode** (TEM00) Gaussian input beam, which it converts to a TEM01 axially symmetric mode.

The advantage of working with a larger **input beam** is twofold. First, a larger beam reduces somewhat the sensitivity of the output to DOE alignment tolerances. Secondly, a larger input beam will enable achieving a smaller vortex spot, which is often a desired outcome in many applications.

The two translation stages in fig.4 above are meant to give the user precise control of elements' locations, to reduce tolerance effects. This is discussed further in the section on Tolerances.

All optics in the beam path should be of high quality, i.e. **low irregularity** figure, so as not to introduce wave-front errors which could degrade performance. This includes mirrors which should have **high flatness** specification. Here, too, a larger beam size incident on the mirror will reduce its sensitivity to localized aberrations.

It is recommended to work with the optical vortex phase plate **in the waist of the laser**. Nonetheless, if the beam has a **small divergence angle** ( $<1^\circ$ ), there should not be any noticeable effect on the output quality, but only on the exact working distance.

If, due to mechanical or other constraints, the DOE will be located at a distance from the beam waist, it is important to take this distance into consideration, along with the beam divergence, in the designing of the DOE. Otherwise, the resultant wave-front aberration can generate an interference/ripple pattern over the output beam, whose intensity will grow as a function of the DOE's distance from waist and the divergence angle.

When designing the desired output Vortex beam size, it is important to be familiar with the physical limits of the minimum spot size. The formula for the diffraction-limited spot diameter at  $1/e^2$  follows:

$$\frac{4 * L * \lambda}{\pi * D} * M^2 = D.L. \text{ spot size}$$

L: Working Distance

$\lambda$ : Wavelength

D: Input Beam Size

$M^2$ :  $M^2$  value of input laser beam

## Characteristics

- **High Power Threshold**
- **High Efficiency:** >90%
- **Sensitivity to X-Y displacement:** 5% of the input beam, in order to keep acceptable performance.
- **Rotation insensitive:** For round shape.
- **Sensitivity to working distance:** smaller than 50% of the spot size in order to keep acceptable performance.

## Sensitivity to Alignment and Beam Centricity:

When one goes about designing a set-up that includes a DOE, one should take care to ensure control and stability of these system parameters.

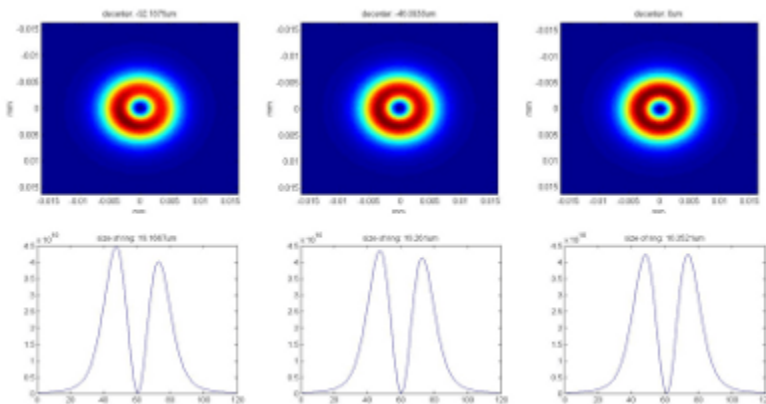
As depicted in the typical set-up of figure 4, accurate translation stages, high quality laser beams, spatial filter and beam expander all contribute to the stability of the optical system.

The performance specifications depend on the relative displacement. Therefore, the system can be made less sensitive by expanding the input beam prior to the design. For example, for an input beam of 10mm diameter, a 5% tolerance gives 0.5mm, while for a beam diameter of 2mm, a 5% tolerance affords only 0.1mm.

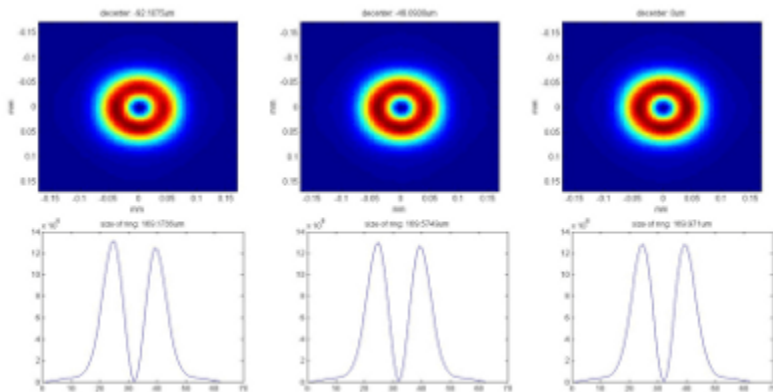
## Simulated Effects of Tolerances on Vortex Beam Profile

The best performance will be obtained for a well-positioned perfectly aligned part, located precisely in the plane of the nominal working distance. To illustrate the sensitivity of vortex performance to different tolerance parameters, several graphs are included here for a standard vortex phase plate (WD: 100mm,  $\lambda$ : 633nm).

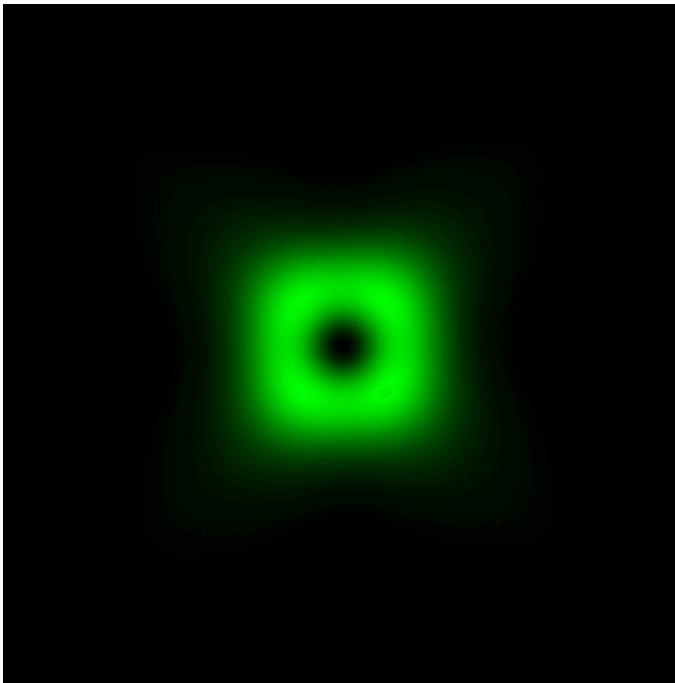
**Fig. 5:** Effect of x/y axis de-centering (92 $\mu$ m, 46 $\mu$ m, 0 $\mu$ m) of **8mm** input beam on optical vortex phase plate



**Fig. 6:** Effect of x/y axis de-centering (92 $\mu$ m, 46 $\mu$ m, 0 $\mu$ m) of **15mm** input beam on optical vortex phase plate



### Square Donut Shape Vortex



#### Features:

- Not sensitive to beam size
- Very stable to defocusing
- Stable to decentering
- Available for different wavelengths
- High efficiency
- Good uniformity contrast

#### Technical specifications:

- Spot size about 2 times diffraction limit
- Efficiency  $\sim 90\%$  ( $\exp^{-2}$ )
- Uniformity contrast 7% (corners vs. valleys)

### Articles

- [Mode-matched phase diffractive optical element for detecting laser modes with spiral phases](#)
- [Influence of Beam Polarization on Laser Cutting Efficiency](#)

>> Click [here](#) for vortex phase plate standard products