Diffractive Axicon application note

Introduction

A Diffractive Axicon (DA) is a kind of Diffractive Optical Element (DOE) that transforms a laser beam into a ring shape (a Bessel intensity profile). An Axicon also images a point source into a line along the optical axis and increases the Depth of Focus (DOF). Each Diffractive Axicon product is defined by its ring propagation angle.
The calculated ring's width (RW) is equal to ~1.75xDiffraction Limit (DL_{SM}) at $1/e^2$ size of the input for Single Mode laser beam.

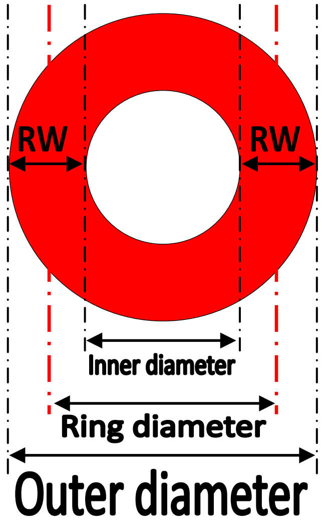
For multimode beam the Ring width will equal to:

$$RW = \sim DL_{SM} \cdot (M^2 + 0.75) = \sim \frac{4\lambda \cdot EFL}{\pi D} \cdot (M^2 + 0.75)$$

Where:

EFL – effective focal length
λ - Wavelength
D - Input Beam Size
M^2 - M^2 value of input laser beam

Definitions of sizes for Diffractive Axicon



General specifications of Diffractive Axicons

Materials:	Fused Silica, Sapphire, ZnSe, Plastic
Wavelength range:	193 [nm] to 10.6 [um]
DOE design:	2-level (binary) to 16-level
Diffraction efficiency:	75% - 96%
Element size:	Few mm to 100 [mm]
Damage threshold:	>3 [J/cm^2] in 7 [nS] pulse @ 1064 [nm]
Coating (optional):	AR/AR Coating
Custom Design:	Almost any ring diameter

Typical applications

Atomic traps	Generating plasma in linear accelerators
Axicon resonators in lasers	Laser Corneal Surgery
Optical Coherence Tomography (OCT)	Laser Drilling/Optical Trepanning
Telescopes	Solar concentrators

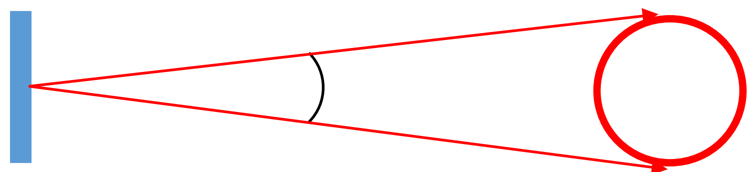
Advantages of the Diffractive Axicon

Allows very small angles	Aberration free
Positive and negative configurations	Compact solution for larger angles – (fab. on thin window)
Exceptionally precise shape and angle	Plastic available for low power applications in low price
Fab. on Fused Silica or ZnSe (for infrared app.)	Arrays of micro Axicons
Can accept very small incident beams	

Principle of operation and design considerations

The principal of operation is similar as for basic focus lens.

Unlike a Refractive Axicon (RA), which is defined with an apex angle or a cone angle, a Diffractive Axicon (DA) is defined by its divergence angle. The divergence angle defines ring diameter in specific distance.



Diffractive Axicon

The divergence angle β can be calculated from the diffraction grating equation:

$$\beta = 2 \cdot \sin^{-1}\left(\frac{\lambda}{\Lambda}\right)$$

The ring diameter can be calculated from a geometrical point of view:

$$D = 2 \cdot \mathrm{WD} \cdot \tan\frac{\beta}{2}$$

λ	Wavelength
Λ	Diffraction period
WD	Working distance
D	Ring Diameter

Example for finding the divergence angle:

- Wavelength: 355 [nm]
- EFL: 50 [mm]
- Desired Ring Diameter: 0.2 [mm]

$$\beta = 2 \cdot \tan^{-1}\left(\frac{0.2}{2 \cdot 50}\right) = 0.2292 \text{ [deg]}$$

Relation between Divergence Angle, and Cone Angle or Apex Angle of a Refractive Axicon:

$$D = 2 \cdot WD \cdot \tan[(n-1) \cdot \alpha]$$

$$\beta = 2 \cdot [\sin^{-1}(n \sin \alpha) - \alpha] \approx 2\alpha \cdot (n-1)$$

$$\theta = 180 - 2\alpha$$

n Refractive index
α Cone angle
θ Apex angle

Another example for finding the divergence angle (β =?):

- Cone angle: 0.25 [deg]
- Material Fused Silica
- Wavelength: 355 [nm]

$$\beta = 2 \cdot [\sin^{-1}(1.4761 \cdot \sin 0.25) - 0.25] = 0.238 \text{ [deg]}$$

<u>Key parameters for Refractive and Diffractive Axicons:</u>

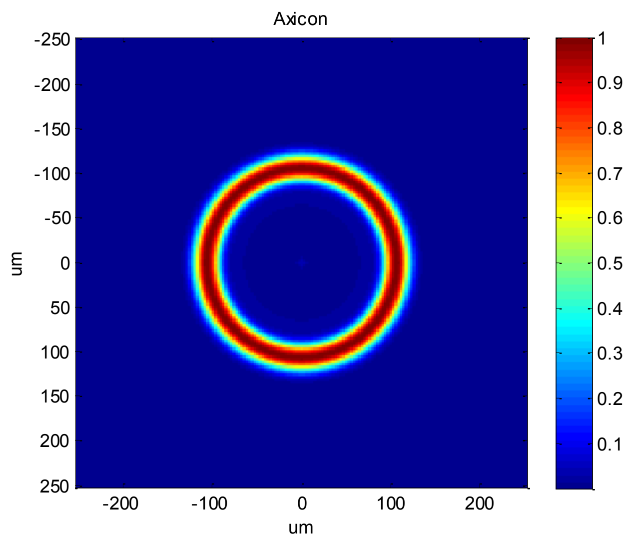
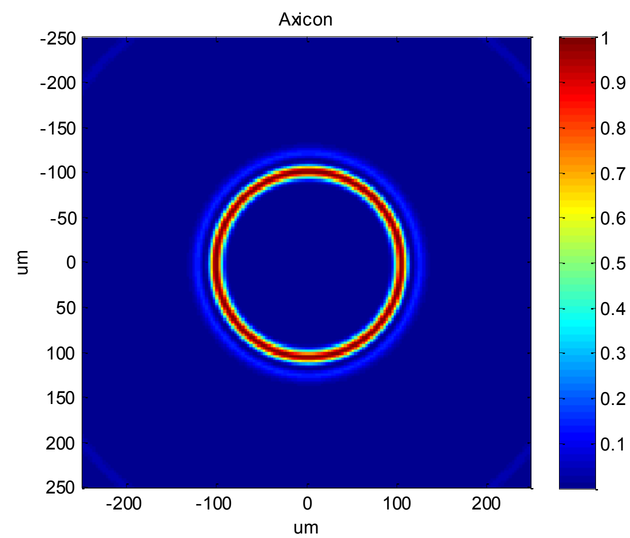
Diffractive Axicon	Refractive Axicon
Divergence angle	Cone angle or Apex angle
Wavelength	Refractive index
Working distance	Working distance

Comparison between binary and multilevel Diffractive Axicon

A binary (or two levels) Diffractive Axicon can be an affordable alternative to a multilevel model or to a refractive element.

In the table below, we show simulation results corresponding to a specific example, with the following parameters:

- Wavelength: 1064 [nm]
- Beam diameter: 6 [mm]
- Laser: TEM_{00} Gaussian
- DOE clear aperture: 9.2 [mm]
- Ideal lens f=100 [mm]

<table>
<tr><th>Refractive or Multilevel Diffractive Axicon</th><th>Binary Diffractive Axicon</th></tr>
<tr><td>
</td><td>
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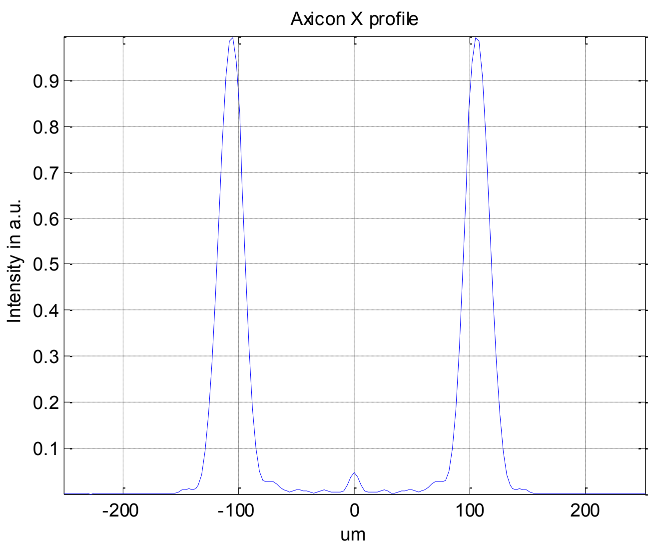
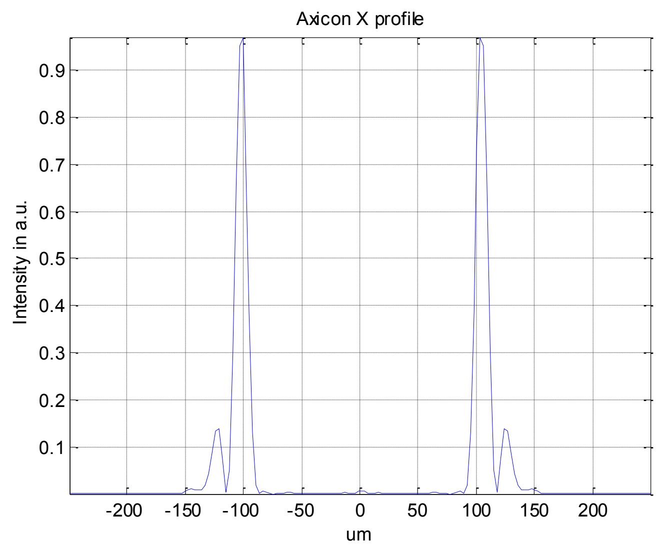
<tr><td>
</td><td>
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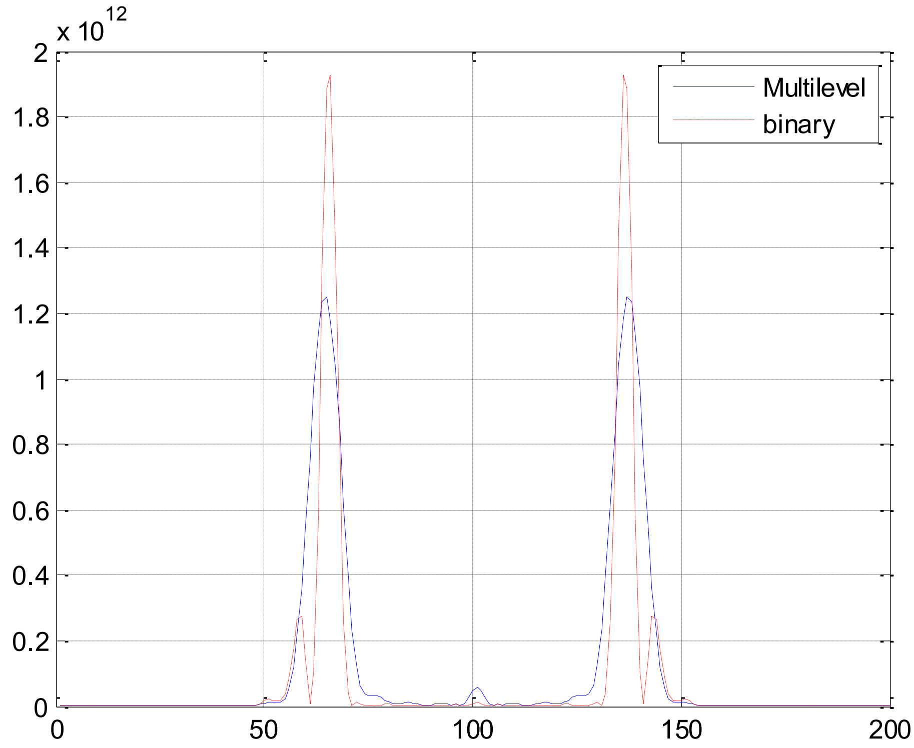
Superposition of profiles:



	Refractive or Multilevel Diffractive Axicon	Binary Diffractive Axicon
Ring width (@1/e^2)	~1.75 x diffraction limit	~ 1 x diffraction limit
Peak power		x 1.56 relative to multilevel
Efficiency	97.5 %(~100 % refractive)	80 % (including side ring)

Sensitivity to mechanical tolerances

Similar to other optical elements with axial symmetry, the Diffractive Axicon is sensitive to centration relative to the optical axis. The Diffractive Axicon is not sensitive to input beam size & M^2 (beam quality) of the laser. Other mechanical tolerances have low effect on functionality.

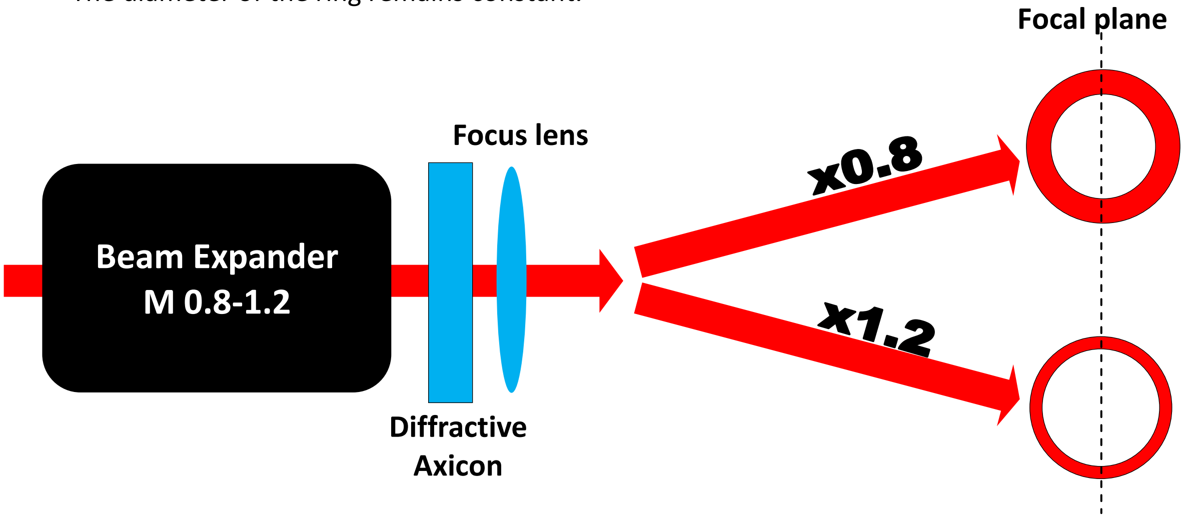
Summary table of tolerances:

Tolerance	Value	Remark
Tilt X,Y	< 5 deg.	Small amount of energy goes to Zero Order
Shift X,Y	Sensitive	Uniformity along ring
Tilt Z	No effect	
Shift Z	Yes	Depends on optical setup
Beam size	No effect	
M^2	No effect	
Polarization	No Effect	

Typical optical setups TBD

1) Controlling ring width by placing Variable Beam Expander before Diffractive Axicon.

   The diameter of the ring remains constant.



2) Controlling Ring diameter by placing DA after focusing lens.

   Ring diameter will reduce linearly with distance between diffractive pattern and image plane/ focal plane.

   Ring width will remain constant.