Optical Diffuser / Homogenizer Application notes

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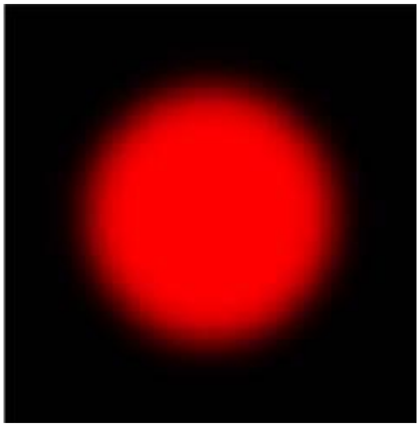
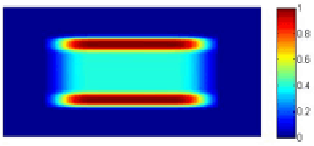


Introduction



An optical Diffuser/Homogenizer (DF/HM) diffractive optical element (DOE) transforms a single or multi-mode input beam into a well-defined output beam, characterized with a desired shape, and homogenized flat-top intensity (or other intensity profile, see below).
Holo/Or's optical diffuser DOE is mainly used for high power laser applications, when uniform exposure is needed, with accurately defined sharp shaped edges, while enabling high efficiency.
The most common diffuser shapes are: round, square, rectangular, elliptical and hexagonal, however, almost any shape of image can be designed. It is also possible, to tailor the intensity distribution of the image, so that different areas receive more/less energy, as in the picture at the right.

Typical features and applications

Features:	**Applications:**
• Works with single or multi-mode input beams • Glass or plastic materials • NO centration requirement • Any output shape or symmetry • Uniform/Tailored intensity profile • Small transfer region • Exact diffusion angles • Single element / surface	• Laser homogenizing/shaping • Laser material processing: perforation, ablation, derailing, marking, scribing and welding • Medical/aesthetic laser treatment • Beam shaping for Excimer lasers • Hot spot reducer

Specifications

Materials:	Fused Silica, Sapphire, ZnSe, Plastics
Wavelength range:	193[nm] to 10.6[um]
DOE design:	Binary (2-level) and up to 16-levels
Diffraction efficiency:	75% - 98%
Element size:	2[mm] to 100[mm]
Coating (optional):	AR/AR Coating
Custom Design:	Tailored shape and intensity distribution
Pattern angles @532[nm]:	Few mRad to ~41deg

General definition

A diffractive diffuser (HM) splits incident beam in semi random directions in order to achieve a desired shape of intensity profile in the far field or focal plane.
This method enables to design an element that will produce any arbitrary shape, intensity profile with precise angle and size of the output.
The diffuser performance strongly depends on the incident beam parameters. In general, one can distinguish between two qualities:

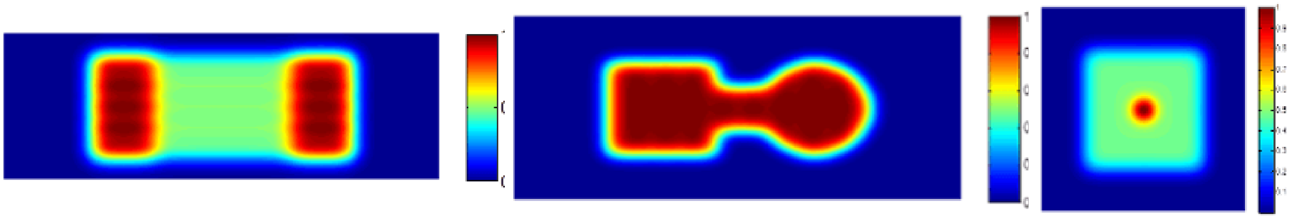
1. Highly coherent beam (and quasi-single mode) with M^2 <~5

Multi-Mode laser beams (with M^2 > 5)

Best results in terms of intensity profile, uniformity, efficiency and transfer region for single mode lasers can be achieved by using Top Hat (TH) designs like in (http://www.holoor.co.il/Diffractive_Optics_Products/Diffractive_Beam_Shapers/BeamShaper_home.htm).
When the incident beam is more complex to define – by having an arbitrary intensity distribution and not a near-to-perfect Gaussian (higher M^2) one, diffractive optical diffusers become the preferred solution.

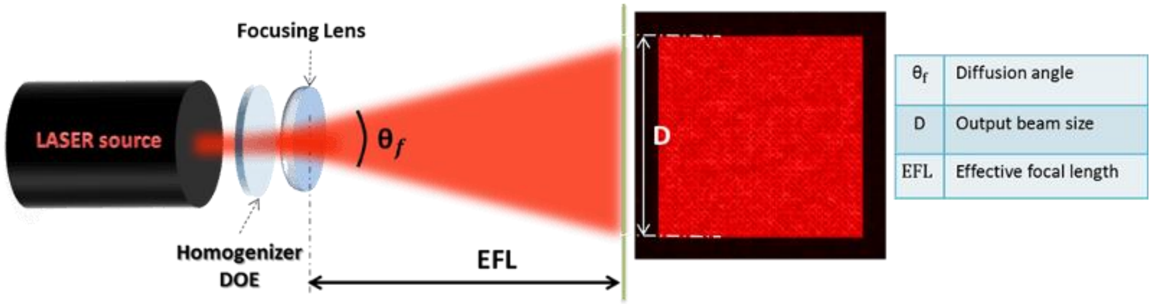
Examples of custom shapes

In addition to basic shapes as square, rectangular, round, elliptical, and line we can design any arbitrary shape. Below we show a few examples as illustration:



Operation principle and design considerations

1. Minimum required parameters needed to chose/design a diffuser:
    a. Wavelength
    b. Output shape and intensity profile (Flat-top or customized)
    c. Divergence angle (of output shape) or image size and EFL
    d. Beam quality (M^2)
2. Common diffuser/homogenizer elements are manufactured on a DOE window. Since the diffuser defines a certain diffusion angle, the customer is able to control the image size on the image plane by choosing a focusing lens with a correct EFL. Typical setup includes: a laser, a Homogenizer/Diffuser DOE and a focusing lens as presented below:



3. The optical parameters of the diffuser can be easily calculated from geometric point of view:

$$D = 2 \times EFL \times \tan\frac{\theta_f}{2}$$

See also our interactive optical calculator for Diffuser/Homogenizer:
http://holoor.co.il/Diffractive_Optics_Products/Calculators.htm

4. Holo/Or has the capability to design an integrated solution by combining a DOE window and a specific focusing lens into one single hybrid element. Here, the diffractive pattern will be etched on the Plano side of the focusing lens (plano-convex lens). The advantages of this solution include less optical surfaces, compact dimension and low weight.
5. The minimum diffusion angle is equivalent to approximately 5-10 times the diffraction-limit. In addition, a larger angle ratio (to a certain level) will increase the performance quality. The formula for the diffraction-limited spot diameter at 1/e2 (D.L.spotsize) follows:

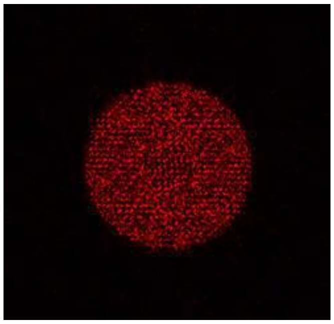
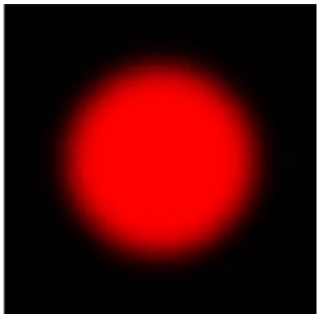
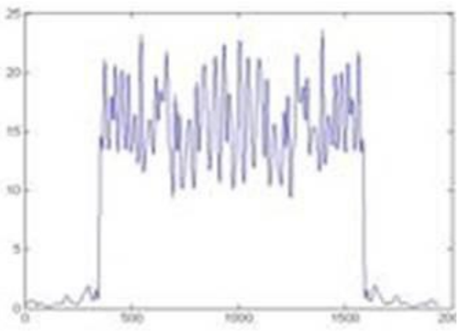
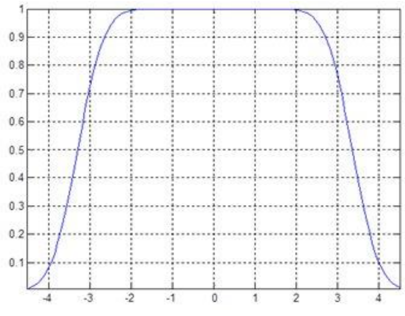
$$\frac{4 * L * \lambda}{\pi * D} * M^2 = D.L.\,spot\ size$$

L = Working distance
λ = Wavelength
D = Input beam size on focusing element
M^2= Beam quality value of input laser beam

6. The edges of the diffused beam are generally steep and well defined. The ratio between input divergence angle to the HM's diffusion angle, determines the ratio of the transition region to the well-homogenized region of the output beam.
7. We recommend keeping the input beam size (1/e2) under 67% of the clear aperture, to maintain good power efficiency results. This will ensure 99% energy throughput for Gaussian intensity distribution
8. Additional improvement in the uniformity performance may be achieved by using a high M^2 input beam.

Beam shaping: single-mode versus multi-mode:

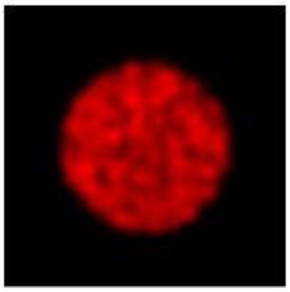
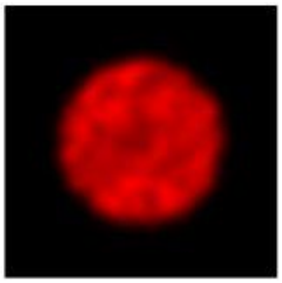
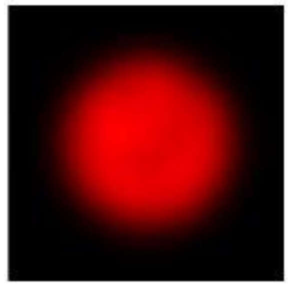
Table of properties for TEM00 and Multimode beams:

	Gaussian input beam (TEM00**)**	**Multimode input beam**
Image precision	Very Good	Very Good
Uniformity	Interference pattern (Speckles)	Uniform (more modes = better uniformity)
Intensity density	Good	Very good
Edge steepness (transfer region)	Very steep	Reduced steepness with larger M^2
Efficiency	Depends on design	Depends on design
Zero Order	Sensitive	Reduced sensitivity with larger M^2
Output image (typical)		
Typical 1-D intensity profile (typical)		

Additional remark: The "noisy" oscillations or speckled output intensity profile of the diffuser in the Gaussian input case is due to interference. Nevertheless, many metrology applications benefit from speckled pictures. For material processing applications, the thermal distribution of energy is more important than a point intensity value. There is also a natural smoothing effect in many (but not all) applications, which erases most signs of fluctuations.

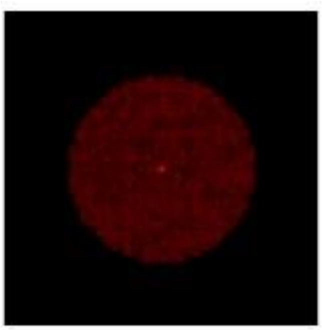
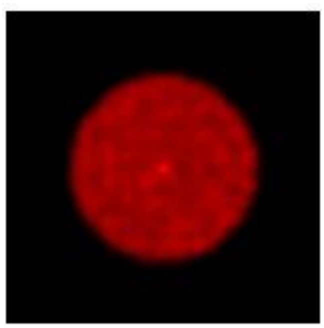
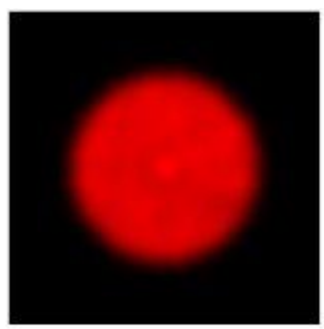
Effect on output shape - comparison between different beam qualities (M^2 values)

1. Edge of the shape becomes wider
2. Speckles are reduced and intensity profile becomes more uniform

M^2 = X (low)	**M^2 = 2*X**	**M^2 = 4*X**	**M^2 = 8*X**
			

Zero-Order effect:

The figures below show the Zero-order for the same element with different M^2 values of input beam. One can see that with a low M^2 input beam the Zero-order is concentrated in a smaller area, causing it to look much stronger than its neighboring area.

M^2 = X (low)	**M^2 = 2*X**	**M^2 = 4*X**
		

High homogeneity series (RH/HH/XH)

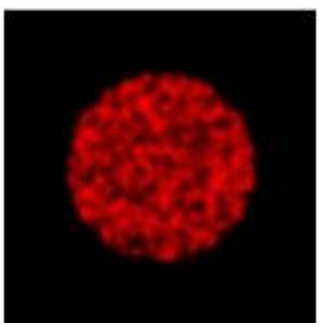
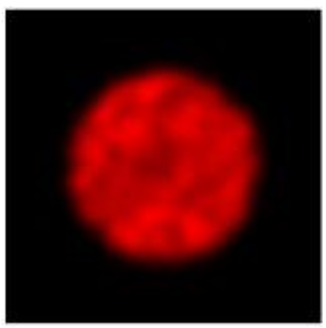
Holo/Or developed a new class of diffusers/homogenizers with enhanced performance referred to as the high homogeneity series (Homogeneity can be defined as the average intensity over an area unit). Its advantages are higher homogeneity, and lower zero order. This corresponds well with input beams of lower M^2, and for applications where it is impossible to use a Top-Hat beam shaper product.

This DOE design includes two diffractive surfaces. The first decreases the coherence of the incident beam and the second surface shapes the beam.

Advantages and disadvantages of HH relatively to HM are displayed in below table:

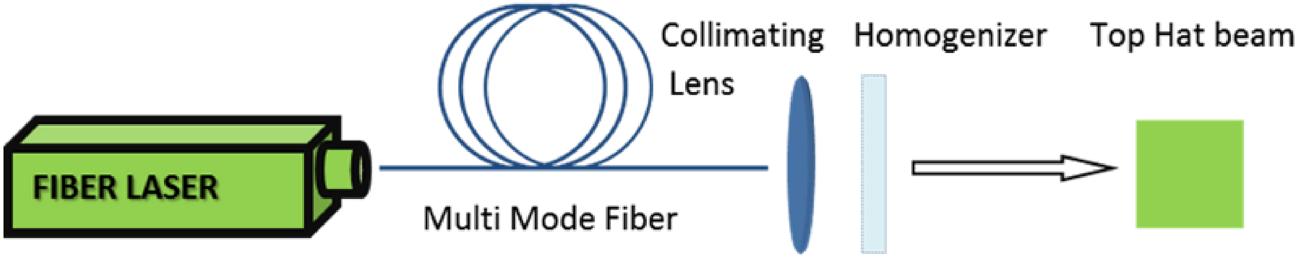
parameter	**HH vs. HM**
Homogeneity	Much better
Efficiency	Slightly less
Zero Order	Significantly reduced
Transfer region	Larger

This can be illustrated with the figures below:

HM	**HH**
	

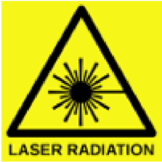
Application example - Optical Setup with MM fiber

The optical setup below shows a laser coupled to a MM fiber to achieve uniform intensity distribution in the far field or alternatively in the focal plane when used with a focusing lens.
The number of modes in the output is proportional to the fiber length and core diameter. Each mode of the fiber's output will propagate through the diffractive Homogenizer to create an interference pattern in the focal plane. However, in contrast to a single mode beam, the multi-mode contains many of these modes. Each mode is creating a different pattern that overlap with each other. In the focal plane, this creates a well-averaged uniform output. The setup does not require any specific property of the laser beam parameters.



Safety

General recommendations when working with a laser
http://web.princeton.edu/sites/ehs/laserguide/appendixB.htm

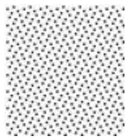


- Locate beam at waist level or below. Do not place beam at eye level.
- Close and cover your eyes when stooping down around the beam (where you will pass the beam at eye level).
- When leaning over a table, beware of beam directed upward.
- Enclose as much of the beam as possible.
- Do not direct beam toward doors or windows.
- Terminate beams or reflections with fire-resistant beam stops. Anodized aluminum or aluminum painted black (which is not necessarily fire-resistant) can work well for this purpose.
- Use surfaces that minimize specular reflections (mirror-like reflection).
- Locate controls so that the operator is not exposed to beam hazards.
- Make sure warning/indicator lights can be seen through protective filters.
- If you can see the beam through your laser eyewear, you are not fully protected.
- View applications remotely.
- Do not wear watches or reflective jewelry around Class 3B or 4 lasers.
- Do not wear neckties around Class 4 open beam lasers.
- In reality, all interlocks can fail.
- The best defense is good understanding of the hazards.

Recommendations for alignment:

- Isolate process.
- Use lowest practical power.
- View diffuse reflections only.
- Use IR/UV viewing cards/eyewear.
- Where possible, use HeNe alignment lasers

Handling:

Use gloves	Mechanical damage	Chemical	Dust
			

Installing / sensitivity for mechanical tolerances

Optical diffusers are very straightforward to install inside an optical system.

Parameter	Effect	Comments
Z-translation (along optical axis)	Not sensitive	As long as all diffracted rays enter the focusing element
X-Y translation	Not sensitive	
Tilt X,Y	Zero Order slightly increases	
Tilt Z	Not sensitive	Output shape rotates
Incident beam size	Not sensitive	Have to be larger than minimum defined in spec
Polarization	No effect	

FAQs

Q: What is the difference between Top-Hat beam Shaper and Diffuser?
A: Comparison table between TH and HM:

Parameter	Top Hat element	Diffuser / Homogenizer element
Incident beam	M^2 <1.3(TEM00)	Any
Output shape	Any	Any
Output Shape precision	Excellent	Good
Uniformity	Very good	Depends on input beam, more uniform with larger M^2 of input
Edge steepness (transfer region)	<= diffraction limited spot	Depends on M^2 of input beam less steepness with larger M^2 of input)

Q: What will happen if I use other laser wavelength than specified (designed) wavelength?
A: Using a diffuser element at a wavelength other than the design:

1. Each diffuser element is manufactured to be wavelength-specific. The diffractive etching pattern is unique for a given diffusion angle at a given wavelength. Therefore, using a diffuser element at a wavelength other than the design will result in a new diffusion angle as well as output beam size, proportional with the ratio of ~used λ / design λ.
2. The etching depth is optimized for a certain design wavelength, and use at another wavelength will cause energy migration in the beam, with some portion of the diffused power moving to the non-homogenized zero order, appearing as a central peak in output beam.

Nonetheless, our mask inventory can be used flexibly to produce a wide variety of diffusion angles over a wide wavelength spectrum, and only our etching process need to be optimized per requirement/customer.

Q: What is the recommended distance between DOE to the focusing lens? Can it be few millimeters?
A: For HM elements the distance between the DOE and a Focusing system is not important, as long as the clear aperture of the Focusing system will be large enough (~1.5 x HM size at lens position) to prevent energy losses due to truncation.

$$1.5 \times D = 3 \times \text{distance} \times \tan\frac{\theta_f}{2}$$

>> Click here for optical diffusers standard products