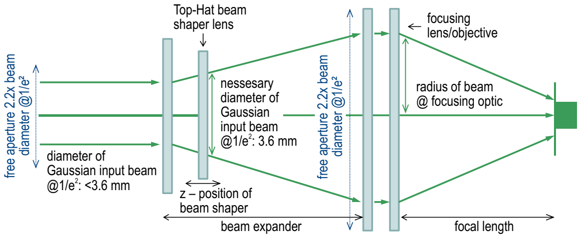
3. Beam shaper within beam expander (Top Hat size @ $1/e^2 < 90\ \mu m$).

Top Hat size is determined by numerical aperture (NA) of focused beam and is given by:

$$\approx \frac{3.2\ \mu m}{NA} \Rightarrow \approx 5x \text{ diffraction limited @ 1064 nm (10x @ 532 nm)}$$



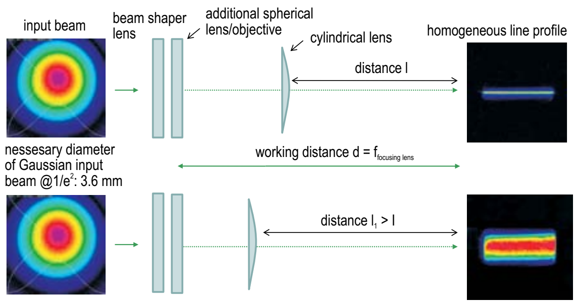
A further and even more flexible possibility is to introduce GTH-3.6-1.75FA into the beam path within a beam expander. The user has the possibility for an easy "fine tuning" of beam diameter at the position of GTH-3.6-1.75FA by shifting shaper along z-axis. It's just necessary to consider that the beam diameter at the position of GTH is 3.6 mm @ 1/e². The resulting Top-Hat size is given by:

$$\approx \frac{3.2\ \mu m}{NA} \Rightarrow \approx 5x \text{ diffraction limited @ 1064 nm (10x @ 532 nm)}$$

NA represents the numerical aperture of focused beam and is given by:

$$NA = \frac{\text{beam radius @ focusing optic}}{\text{focal length of focusing optic}}$$

Homogeneous line generation with additional cylindrical lens



If an additional cylindrical lens is used, one can generate homogeneous line profiles. By varying the distance l the width of line profile (short axis) can be changed from near diffraction limited size to several millimeters. We recommend the use of a cylindrical lens or lens system with a focal length of = 1.8 m.

FBS — TOP HAT BEAM SHAPING LENS

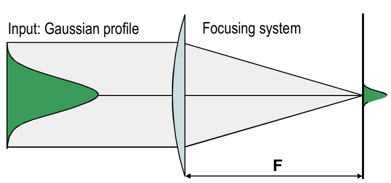
- **New Diffractive Beam Shaping Concept ! based on Fourier methods**
- **Transforming Gaussian TEM_{00} beam into square or round homogeneous Top-Hat profile**
- **Top Hat size is near diffraction limited and is given by: ~λ /NA**
- **Achievable Top Hat sizes: 1 µm – 200 µm**

SPECIFICATIONS

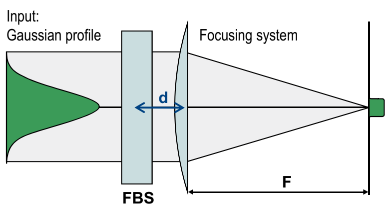
Material	fused silica	
Diameter	25.4 mm	tolerance ±0.1 mm
Input Beam	TEM_{00}, different models for diameter@1/e²: 2.0 ... 10.0 mm with 0.5 mm step	tolerance ±5%
Necessary Free Aperture	2.2x (or better 2.5x) beam diameter@1/e²	along total beam path
Top Hat Size	1.5x diffraction limited Gaussian spot	square form (round optional)
Homogenity	+/- 2.5%	rel. to average intensity within tophat
Wavelength	different models for: 1064 nm, 532 nm or 355 nm	others on request
Transmission	> 99%	AR/AR coating
Efficiency	> 95%	of input energy within tophat profile
Damage Threshold	4 J/cm² @ 532 nm, 10 ns	
Free Aperture	23 mm	

FBS OPERATION INSTRUCTIONS

FBS – Top-Hat Fundamental Beam Mode Shaper



Without FBS Beam Shaper: Gaussian-profile at focal plane



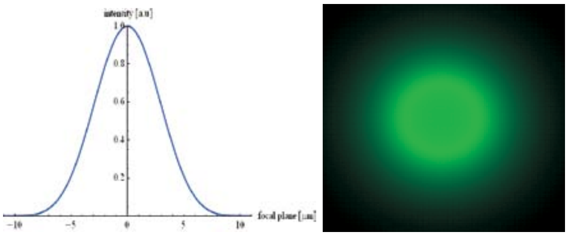
With FBS Beam Shaper: Top-Hat-profile at focal plane

– FBS works together with focusing system (FS)
– Top Hat size just depends on wavelength (λ) and numerical aperture (NA) of focused beam
– Distance d between FBS and FS up to several meters

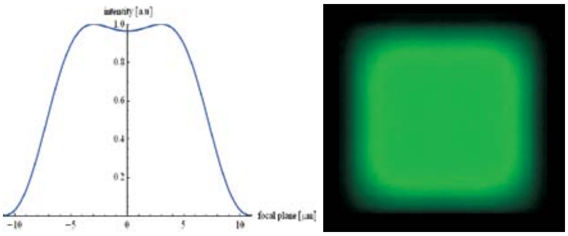
Intensity distribution at focal plane

Main FBS advantages:

- Smallest achievable Top-Hat size: ≈ always 1,5x of diffraction limited Gaussian-spot @ 1/e²
- Achievable Top Hat profiles: square or round
- Diffraction efficiency: > 95% of energy in Top Hat
- Homogeneity: modulation < ±2.5%
- Depth of focus: similar as for Gaussian beam
- Insensitive to misalignment, ellipticity and input diameter variation: ±5-10%



Without FBS shaper: diffraction limited Gaussian profile



With FBS shaper: near diffraction limited Top Hat profile

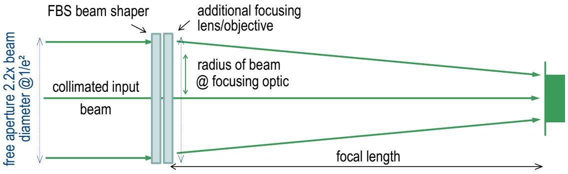
Optical setup for FBS Top-Hat beam shaper

Independent of optical setup the user has to consider that:

- The free aperture along the total beam path have to be at least 2.2x (better 2.5x) bigger than the beam diameter @ 1/ e²
- The Top Hat size is always given by: $\frac{\lambda}{NA}$
  λ is the used wavelength;
  NA is the numerical aperture of focused beam and is given by: $\frac{\text{beam radius @ focusing optic}}{\text{focal length of focusing optic}}$

There are different possibilities to integrate the FBS beam shaper into an optical setup.

1. Beam shaper directly in front of a focusing optic/objective

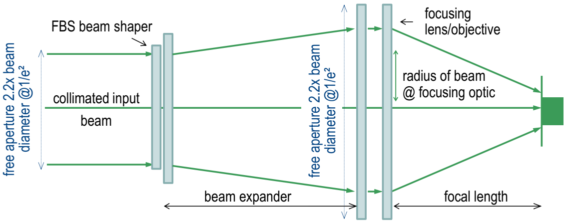


By introducing the FBS beam shaper into the beam path in front of a lens/objective the initial diffraction limited Gaussian spot will be transformed into a homogeneous Top-Hat profile.

When a Gaussian TEM_{00} input beam with a diameter of 5 mm@ 1/e² is used the diameter of the free aperture along the total beam path have to be at least 11 mm (better 13 mm).

If for example a wavelength with 532 nm, a Gaussian TEM_{00} input beam with a diameter of 5 mm@1/e² and a focusing lens with f=160 mm is used, ones will get a homogeneous Top Hat profile with a diameter of 34 µm.

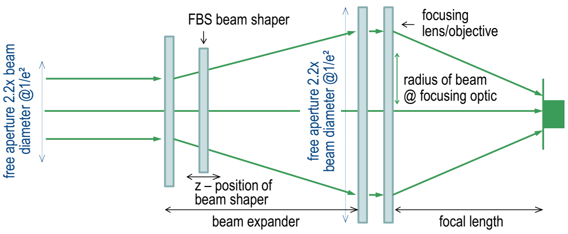
2. Beam shaper in front of a beam expander



There is also the possibility to introduce the FBS beam shaper into the beam path in front of a beam expander. This leads to a higher numerical aperture of focused beam and to a smaller Top Hat profile.

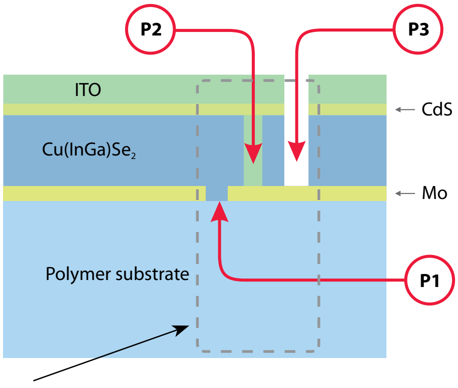
Example: A Gaussian beam with a diameter of 5 mm@1/e² illuminates the FBS beam shaper and is afterwards increased by a beam expander to a beam diameter of 8 mm. With an focusing optic with f=50 mm the user can generate a Top Hat with a diameter of 7 µm. The needed free aperture increases with the expanded beam. For a beam with a diameter of 8 mm the free aperture have to be at least 18 mm.

3. Beam shaper within a beam expander



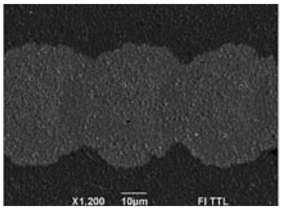
A further and even more flexible possibility is to introduce the FBS beam shaper into the beam path within a beam expander. The user has the possibility for an easy "fine tuning" of beam diameter at the position of FBS beam shaper by shifting shaper along z-axis.

Scribing of CIGS-solar cells

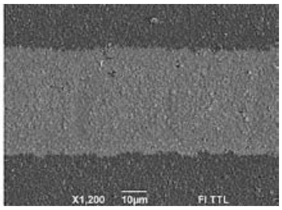


- Wasted area, reducing efficiency → need of smallest scribing lines
- Cut quality influence efficiency → need of small HAZ, no debris, smooth edges
- High scanning speed for high throughput → need of small pulse overlap

P1 – „Scribing“



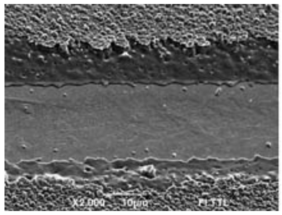
Gaussian Profile



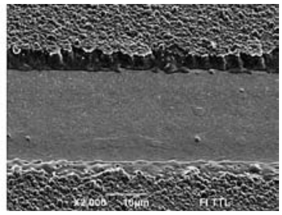
FBS-Top-Hat Profile
small overlap, smooth edges

Removal of a front contact in ZnO(1 µm)/CIGS/Mo/PI structure. Laser PL10100/SH, 10 ps, 370 mW, 100 kHz, 532 nm; scanning speed 4.3 m/s, single pass.

P3 – „Scribing“



Gaussian Profile



FBS-Top-Hat Profile
small HAZ, smooth edges

Tilted SEM pictures of the P3 scribe in ZnO(1 µm)/CIGS/ Mo/PI structure. Laser PL10100/SH, 10 ps, 370 mW, 100 kHz, 532 nm; scanning speed 60 mm/s, single pass.

Raciukaitis et. al, JLMN-Vol. 6, No. 1, 2011

RECOMMENDED ACCESSORIES

Zoom Beam Expander
See page 7.4

Two Axes Translation Polarizer Holder
840-0240
See page 8.98

990-0060 CONTINUOUSLY VARIABLE ATTENUATOR / BEAMSPLITTER

- **Divides laser beam into two beams of manually adjustable intensity ratio**
- **Convenient 90° angle between reflected and transmitted beams**
- **Negligible beam deviation**
- **Large dynamic range**
- **Broadband transmission**
- **Weight – 0.16 kg**

Continuously Variable Attenuator/Beamsplitter is designed for down to 100 fs laser pulses. It consists of 2 high-performance polarizing optics components placed in precision opto-mechanical holder 840-0197. Variable attenuator/beamsplitter incorporates a high-performance Polarizing Cube Beamsplitter which reflects s-polarized light at 90° while transmitting p-polarized light.

A rotating λ/2 waveplate is placed in the incident polarized laser beam. The intensity ratio of those two beams may be continuously varied without alteration of other beam parameters by rotating the waveplate. The intensity of either exit beam, and their intensity ratio, can be controlled over a wide dynamic range. Pure p-polarization could be selected for maximum transmission, or pure s-polarization for maximum attenuation of the transmitted beam.

Multiple Order Half Waveplate and Cube Polarizing Beamsplitters

SPECIFICATIONS

Damage threshold	200 mJ/cm^2 pulsed at 1064 nm, typical
Antireflection coating	R < 0.25% all entrance and exit surfaces
Extinction ratio	T_s/T_p < 1:200

Catalogue number	Central wavelength, nm	Clear aperture, mm	Price, EUR
990-0061-10	1064	9	465
990-0061-15	1064	14	495
990-0061-20	1064	17	515
990-0064-10	532	9	465
990-0064-15	532	14	495
990-0064-20	532	17	515
990-0065-10	355	9	596
990-0065-15	355	14	656
990-0065-20	355	17	706

Achromatic Air-Spaced Waveplate and Glan Laser Polarizing Prism

SPECIFICATIONS

Damage threshold	0.5 J/cm^2 10 ns, 10 Hz at 1064 nm
Antireflection coating	R < 1% all entrance and exit surfaces
Extinction ratio	T_s/T_p < 1:10000

for Broadband Region

Catalogue number	Central wavelength, nm	Clear aperture, mm	Price, EUR
990-0060-10VIS	450-680	9	1290
990-0060-12VIS	450-680	11	1395
990-0060-10IR	700-1000	9	1290
990-0060-12IR	700-1000	11	1395
990-0060-10FIR	950-1300	9	1290
990-0060-12FIR	950-1300	11	1395