Sintec Optronics

Measurement of Laser Beam Profile and Propagation Characteristics

1. Laser Beam Measurement Capabilities

Laser beam profiling plays an important role in such applications as laser welding, laser focusing, and laser free-space communications. In these applications, laser profiling enables to capture the data needed to evaluate the change in the beam width and determine the details of the instantaneous beam shape, allowing manufacturers to evaluate the position of hot spots in the center of the beam and the changes in the beam's shape.

Digital wavefront cameras (DWC) with software can be used for measuring laser beam propagation parameters and wavefronts in pulsed and continuous modes, for lasers operating at visible to far-infrared wavelengths:
- beam propagation ratio M^2;
- width of the laser beam at waist w_0;
- laser beam divergence angle θ_x, θ_y;
- waist location $z\text{-}z_0$;
- Rayleigh range z_{Rx}, z_{Ry};
- Ellipticity;
- PSF;
- Wavefront;
- Zernike aberration modes.

These parameters allow:
- controlling power density of your laser;
- controlling beam size, shape, uniformity, focus point and divergence;
- aligning delivery optics;
- aligning laser devices to lenses;
- tuning laser amplifiers.

Accurate knowledge of these parameters can strongly affect the laser performance for your application, as they highlight problems in laser beams and what corrections need to be taken to get it right.

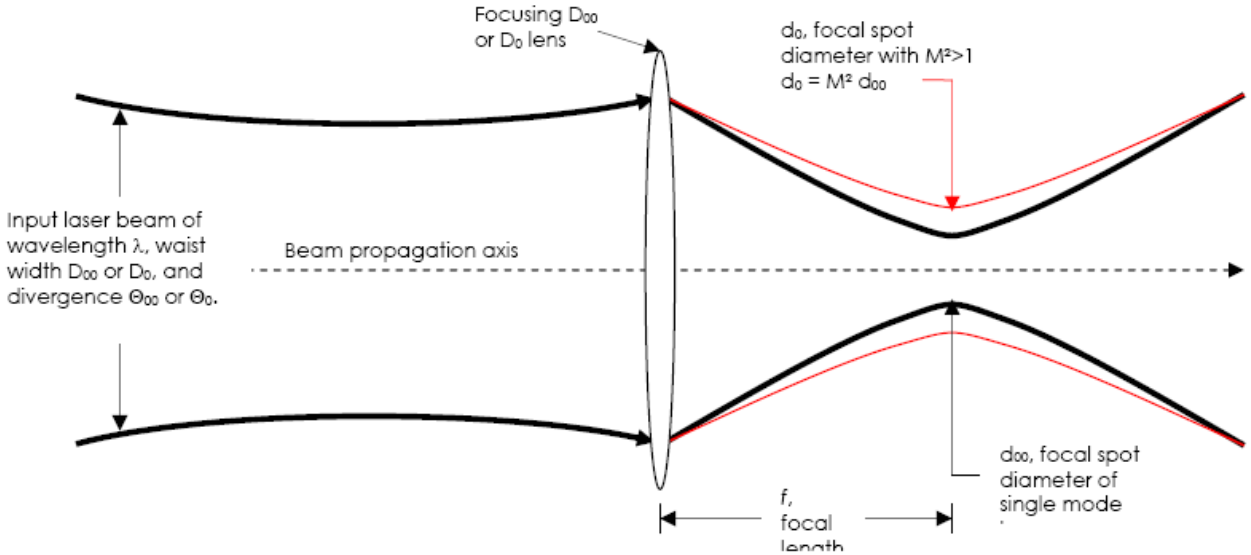


Figure 1. Characteristics of a laser beam as it passes through a focusing lens.

2. Beam Propagation Parameters

M², or Beam Propagation Ratio, is a value that indicates how close a laser beam is to being a single mode TEM_{00} beam. This in turn relates to how small a spot a laser can be focused. For a laser beam propagating through space, the equation for the divergence, Θ, of a pure Gaussian TEM_{00} unfocused beam is given by:

$$\Theta_{00} = 4\lambda / \pi D_{00} \quad (1)$$

where D_{00} is the waist diameter of the beam, and λ is the wavelength. Actual beams with additional modes often start with a larger beam waist, D_0, and/or have a faster divergence Θ_0. In this case Equation (1) becomes:

$$\Theta_0 = M^2 4\lambda / \pi D_0 \quad (2)$$

where Θ_0 and D_0 are the divergence and width of a higher mode beam and M² is greater than 1 and is named the "Beam Propagation Ratio" per the ISO 11146 standard. When a pure Gaussian laser beam is focused, the diameter of the focused spot is defined by:

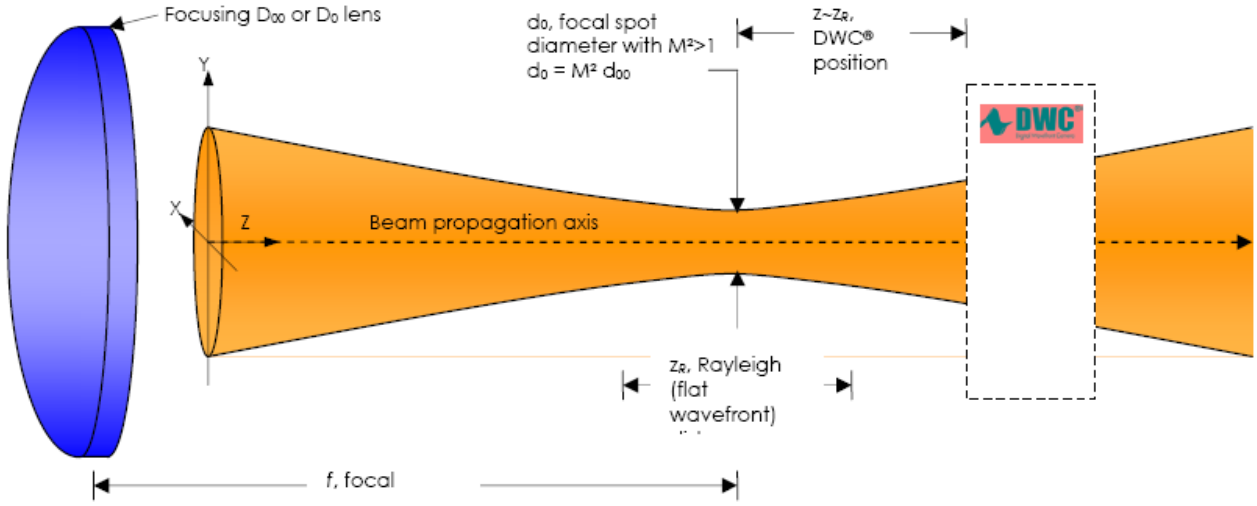
$$d_{00} = 4\lambda f / \pi D_{00} \quad (3)$$

where D_{00} is the ideal focused spot diameter, f is the focal length of the lens, and is placed one focal length from the lens as shown in the Figure 1. However, when a distorted or multimode beam is focused, Equation (3) becomes:

$$d_0 = M^2 4\lambda f / \pi D_0 \quad (4)$$

Apart from M², the measured beam propagation parameters characterizing laser beams are:

$w_0 = d_0/2$– the waist radius in X (horizontal) and Y (vertical) directions;
$z\text{-}z_0$ – the distance between measurement and waist planes;
z_R – the Rayleigh range, for which the radius of curvature R of the wavefront is minimal;
θ – the divergence angle of the measured laser beam far from the waist;
R – the radius of curvature of the wavefront in the measurement plane.



3. Measurement of Propagation Parameters with DWC

3.1 Principle

Propagation parameters are measured by DWC on real beams by focusing the beam with a fixed position lens of known focal length, and then measuring the characteristics of the artificially created beam waist and divergence.

Measurement of the beam propagation parameters with DWC is based on the simultaneous measurement of the high-resolution images of intensity and wavefront. The wavefront is computed starting from two slightly defocused beam intensity images acquired on one CCD camera inside DWC by mathematical computations involving the two images and the difference between them (Figure 2). From the wavefront, the beam propagation parameters are obtained by straightforward but tedious computations.

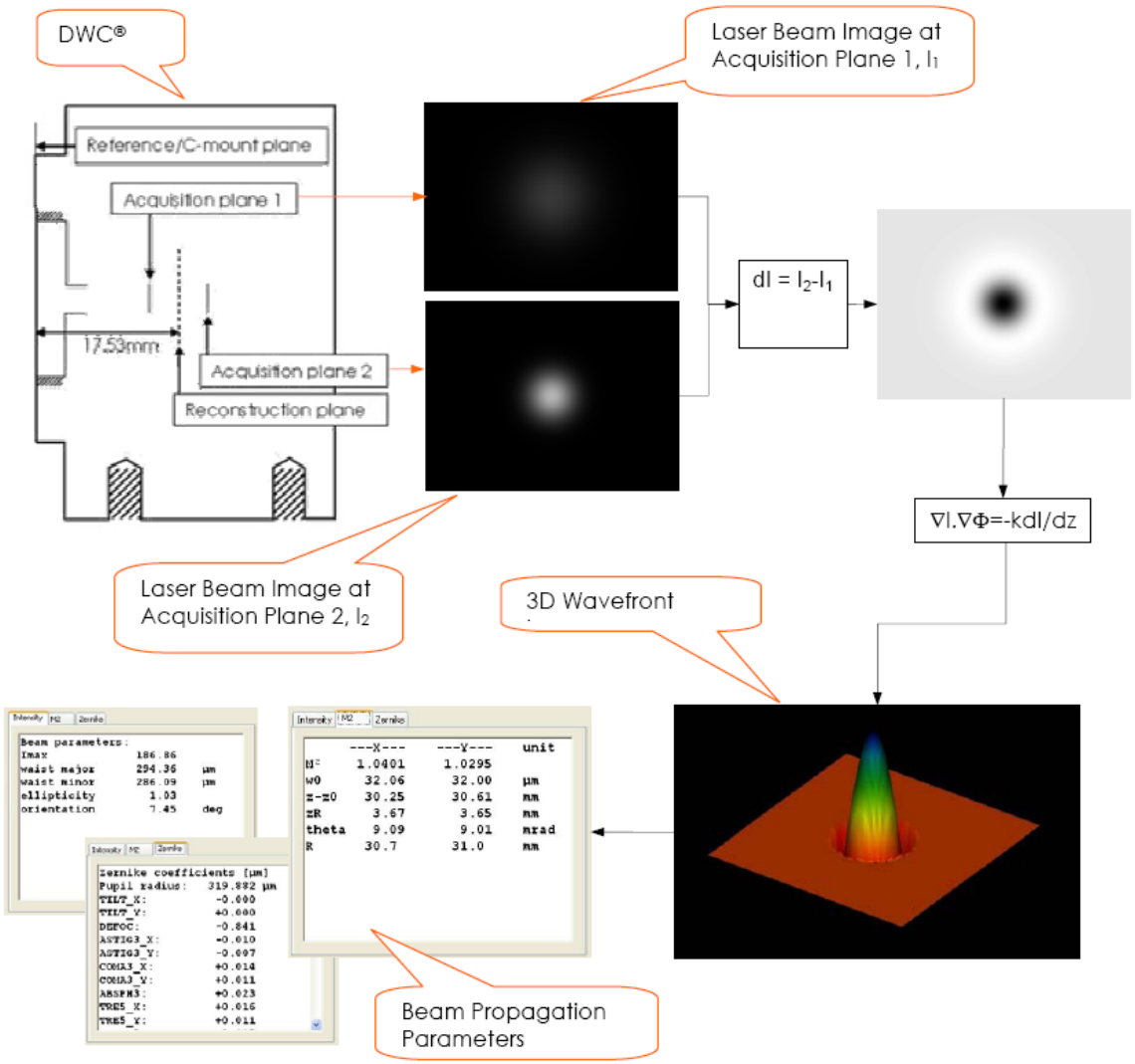


Figure 2. Principle of DWC: Acquisition of two images in real time at two different focal planes, wavefront extraction and computation of beam propagation parameters.

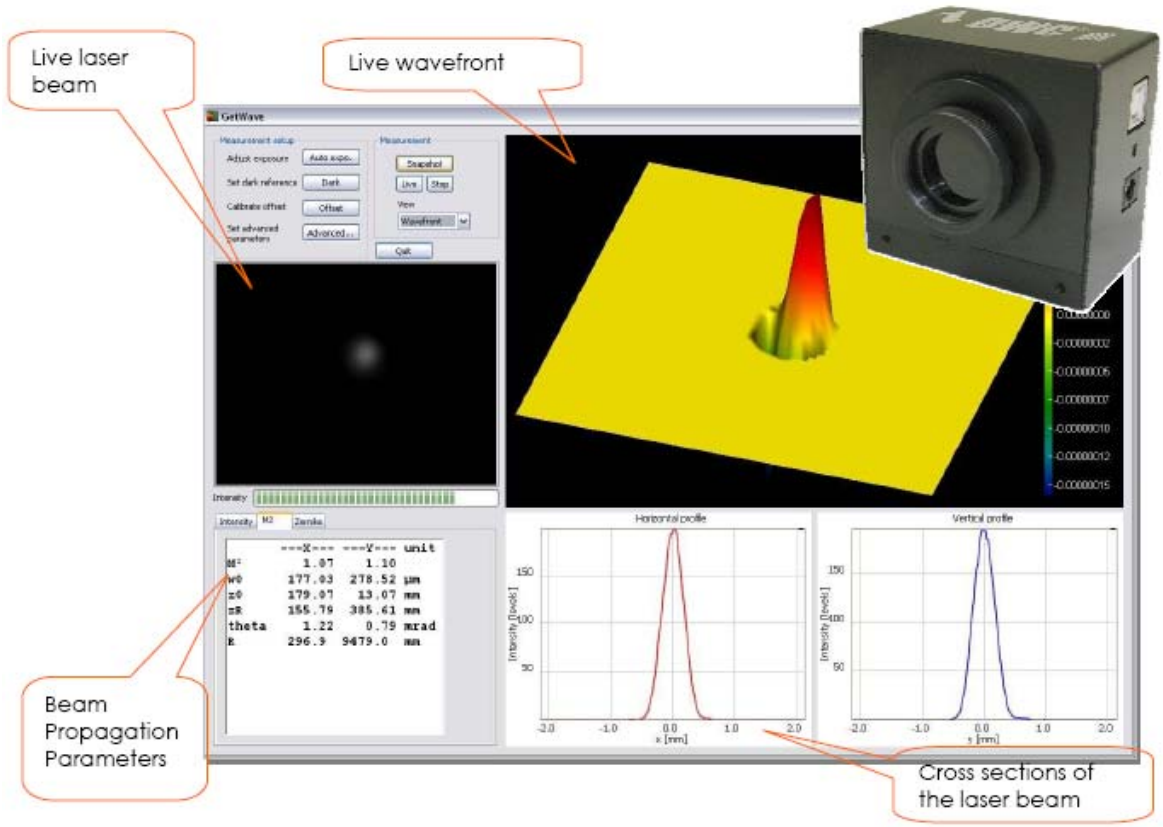


Figure 3. DWC and the Graphic User Interface of its associated software.

3.2 System Set-up

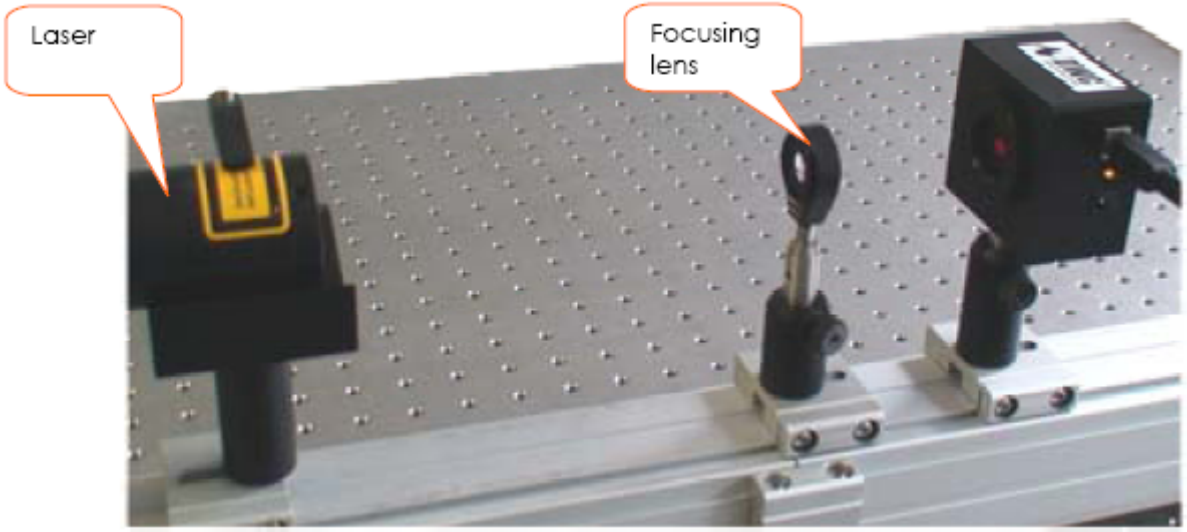
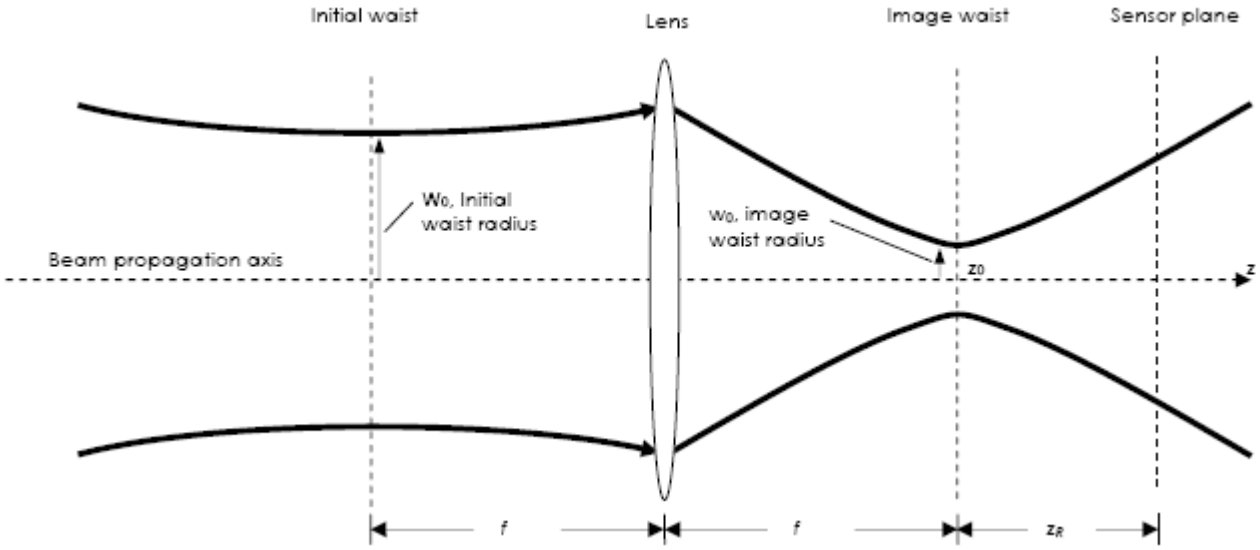


Figure 4. Example of a setup for measurement of laser propagation parameters with DWC.



VIS/NIR Beam Profiler: STCam CCD

Our CCD is developed to provide excellent sensitivity from the VIS to NIR spectral range. Thanks to its high resolution and its small pixel size, the STCam is a high performance tool for laser beam analysis of continuous wave (CW) and pulsed laser modes. Due to its high dynamic range the STCam captures even higher laser modes with outstanding detail.

The passive cooled sensor of the STCam is constructed without cover glass to avoid interference patterns. For sensor protection a low distortion neutral density filter is integrated. The STCam supports the ultra-fast FireWire IEEE 1394b interface with data transfer rates up to 800 Mbit/s. The plug and play design facilitates easy and flexible integration and operation.

The portable STCam is designed to be used in a variety of applications in industry, science, research and development, including:

- Laser beam analysis of CW and pulsed lasers,
- Quick control of laser modes and adjustment errors,
- Test equipment for scientific research,
- Near-Field and Far-Field analyses of lasers, LED devices and other light sources.

The enhancement of product quality, process reliability and efficiency are just a few of the many benefits of our unique beam profiler cameras. The STCam includes the specifically designed analysis software, STRayCi, which supports Windows XP/Vista operating systems. Its sophisticated software architecture opens up new opportunities in laser beam analysis according to ISO standards.

The concept of the STCam enables easy adaption to standard optical imaging systems, attenuators and opto-mechanical components ensuring highest flexibility. This includes:

- Microscope lens and beam expander,
- UV-Converter and IR-Converter,
- Fixed and variable attenuators, etc.

ACCESSORIES

Neutral Density Filter: To expand the power range of the STCam several absorptive and metallic-coated neutral density filters are available, which are specified by optical densities ranging from OD 1.0 to OD 4.0.

FireWire Component: We offer different FireWire PCI / PCI Express cards for installation direct into the PC. Standard FireWire cables are suitable for industrial applications and are available in various lengths.

Trigger Device: To synchronize the STCam with pulsed laser systems, our trigger device is perfectly suited. This frequency and delay generator is software controllable and enables the synchronization of up to four beam profilers with different delay times simultaneously.

	CCD-1201	CCD-1301	CCD-2301	CCD-2302
SENSOR DATA				
Format	1/2”	1/3”	2/3”	2/3”
Active area	6.5x4.8mm	4.8x3.6mm	9.0x6.7mm	8.5x7.1mm
Number of pixel	1388x1038 (1.4MPixel)	1292x964 (1.2MPixel)	1388x1038 (1.4MPixel)	2452x2056 (5MPixel)
Pixel size	4.65x4.65µm	3.75x3.75µm	6.45x6.45µm	3.45x3.45µm
Spectral response without cover glass	350-1100nm	350-1100nm	350-1100nm	350-1100nm

Laser beam diameter min/max	46.5/4mm	37.5/3mm	64.5µm/5mm	34.5µm/5.5mm
Sensor cooling	passive	passive	passive	passive
CAMERA FEATURES				
Lens Mount	C-Mount	C-Mount	C-Mount	C-Mount
Bit depth (output)	14Bit	14Bit	14Bit	14Bit
Dynamic (signal to noise)	60dB (1:1000)	59dB (1:900)	67dB (1:2200)	54dB (1:500)
Frame rate	up to 15Hz	up to 30Hz	up to 16Hz	up to 9Hz
Exposure time	100µs-1s	100µs-1s	100µs-1s	100µs-1s
Interface	FireWire (IEEE1394b)	FireWire (IEEE1394b)	FireWire (IEEE1394b)	FireWire (IEEE1394b)
I / O connector	12-Pin Hirose	12-Pin Hirose	12-Pin Hirose	12-Pin Hirose
Mode	CW or pulsed	CW or pulsed	CW or pulsed	CW or pulsed
Trigger	TTL-signal	TTL-signal	TTL-signal	TTL-signal
Combinable with	IR-/UV-Converter Beam expander Attenuator	Microscope lens Beam expander Attenuator	Beam expander Attenuator	Beam expander Attenuator
SPECIFICATIONS				
Mechanical dimensions (WxHxL)	60x60x103.8mm	60x60x103.8mm	60x60x103.8mm	60x60x103.8mm
Weight	300g	300g	300g	300g
Electrical requirements	DC 8V-36V	DC 8V-36V	DC 8V-36V	DC 8V-36V
Storage temperature*	-10°C…+60°C	-10°C…+60°C	-10°C…+60°C	-10°C…+60°C
Operating temperature*	+5°C…+45°C	+5°C…+45°C	+5°C…+45°C	+5°C…+45°C
Regulations	CE, RoHS	CE, RoHS	CE, RoHS	CE, RoHS

* without condensation

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Neutral Density Filter

Our neutral density filters allow broadband attenuation for a spectral range from VIS to NIR. Due to their excellent surface quality the absorptive and reflective filters enable precise beam attenuation for low power applications. The level of attenuation is specified by the optical density. Filters with different optical densities can be combined. A filter adapter is available to mount the filters on the STCam aperture.

Reflective ND filter		Absorptive ND filter
NDR-10 / NDR-20 / NDR-30 / NDR-40		NDA-10 / NDA-20 / NDA-30 / NDA-40
Optical density*	1.0 / 2.0 / 3.0 / 4.0	1.0 / 2.0 / 3.0 / 4.0
Spectral range	200nm - 1200nm	400nm - 700nm / 700nm - 1200nm
Material	UV-Fused silica (Coating: Metal)	Schott glass
Flatness	1λ @ 300nm	λ/10 @ 632.8nm
Scratch-Dig	40 - 20	40 - 20
Parallelism:	3arcmin	10arcsec
Optical density tolerance	±5%	±5%
Power (Pmax)	< 1W	< 1W
Intensity (Imax)	0.75W/cm2	1W/cm2
Diameter	□=25mm/25.4mm	□=25mm/25.4mm
Operating temperature	< 100°C	< 100°C
Filter threads	Filter thread / Filter mount	Filter thread / Filter mount
Filter adapter	C-Mount thread / Filter thread	C-Mount thread / Filter thread

CO2 Laser Beam Profiler

The high performance STCL system is based on industry's unique imaging technique. It is designed for monitoring high-power CO2 lasers in best performance. Thanks to its high resolution and its incomparable real-time capabilities, this highly efficient beam profiler is optimized for laser beam analysis of continuous wave (CW) and pulsed laser systems. The STCL system ensures beam profiling:

- By high frame rates and high resolution,
- Without optical components in the beam path,
- Without scanning techniques, fluorescent materials or toxic fumes through acrylic mode burns.

The STCL supports the ultra-fast FireWire IEEE 1394a/b interface with data transfer rates up to 800 Mbit/s. The plug and play design facilitates easy and flexible integration and operation.

The compact and portable STCL is designed to be used in a variety of applications in industry, science, research and development, including:

- Laser beam analysis of CW and pulsed lasers,
- Quick control of laser modes and adjustment errors,
- Test equipment for scientific research,
- Near-Field and Far-Field analyses of lasers.

The enhancement of product quality, process reliability and efficiency are just a few of the many benefits of our unique beam profiling system.

The STCL system includes the specifically designed analysis software, STRayCi, which supports Windows XP/Vista operating systems. Its sophisticated software architecture opens up new opportunities in laser beam analysis according to ISO standards.

ACCESSORIES:

Attenuation Units: The water-cooled attenuation units are based on zinc selenide (ZnSe) and are designed for a 10° / 45° angle of incidence. Due to its excellent performance the unit can be used up to laser powers of 3kW and intensities of 5kW/cm2.

FireWire Components: We offer different FireWire PCI/PCI Express cards for installation direct into the PC. Standard FireWire cables are suitable for industrial applications and are available in various lengths.

Trigger Device: To synchronize the STCL system with pulsed laser systems, our trigger device is perfectly suited. This frequency and delay generator is software controllable and enables the synchronization of up to four beam profilers with different delay times simultaneously.

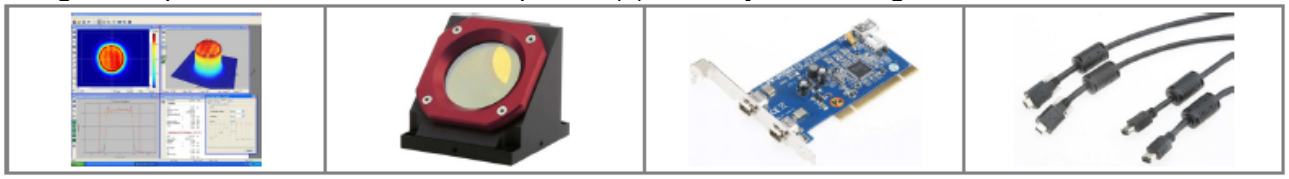
Technical Specifications:

	STCL200	STCL500	STCL500
IMAGE CONVERTER			
Spectral sensitivity:	8µm - 12µm	8µm - 12µm	8µm - 12µm
Clear aperture:	20mm	30mm	30mm
Laser beam diameter (1/e2):	1mm - 10mm	2mm - 15mm	2mm - 15mm
Intensity range* :	20W/cm2 - 2.000W/cm2	20W/cm2 - 2.000W/cm2	20W/cm2 - 2.000W/cm2
Input power (max):	200W (250W, 30s)	500W (550W, 30s)	500W (550W, 30s)
With attenuation unit 0°:	up to 2kW	up to 2kW	up to 2kW

With attenuation unit 90°:	up to 2.5kW	up to 3kW	up to 3kW
Effective pixel size:	x=39µm / y=36µm	x=55µm / y=51µm	x=30µm / y=29µm
Effective pixel size with 2x binning:	x=78µm / y=73µm	x=110µ m / y=102µ m	x=60m / y=58µm
CAMERA FEATURES*			
Sensor:	CCD	CCD	CCD
Resolution (with 2x binning):	752 x 580pixel (367 x 288pixel)	752 x 580pixel (367 x 288pixel)	1384 x 1038pixel (688 x 518pixel)
Frame rate (with 2x binning):	up to 25Hz (up to 50Hz)	up to 25Hz (up to 50Hz)	up to 15Hz (up to 25Hz)
Interface:	FireWire (IEEE1394a)	FireWire (IEEE1394a)	FireWire (IEEE1394b)
Mode:	CW or pulsed	CW or pulsed	CW or pulsed
SPECIFICATIONS			
Mechanical dimensions (WxHxL):	298x141x76mm	340x165x92mm	340x165x92mm
Weight:	2.6kg	3.3kg	3.4kg
Electrical requirements:	AC120V/240V; 48 - 63Hz; 320W	AC120V/240V; 48 - 63Hz; 570W	AC120V/240V; 48 - 63Hz; 570W
Storage temperature** :	0°C…+60°C	0°C…+60°C	0°C…+60°C
Operating temperature** :	+5°C…+35°C	+5°C…+35°C	+5°C…+35°C
Humidity:	20%...80%	20%...80%	20%...80%
Regulations:	CE, RoHs	CE, RoHs	CE, RoHs

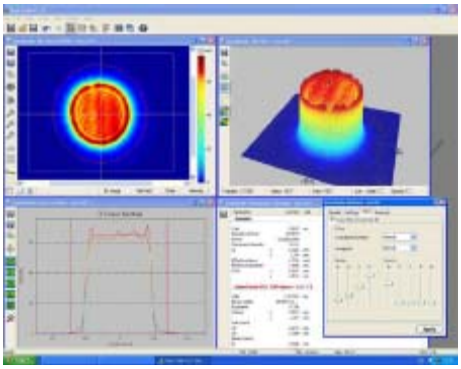
* different parameters on request
** without condensation

Design and specification of the described product(s) are subject to change without notice.



Laser Beam Profiling Software STRayCi

Our sophisticated beam profilers are available with the specifically designed analysis software, STRayCi, which supports Windows XP/Vista operating systems. It is available as 32 Bit / 64 Bit version and can control up to eight beam profiler cameras on a single computer.



Due to its clearly designed menu structure, STRayCi shows self-explanatory functions, which help the user to access quickly standard settings. Incomparable visualization modes, extensive analytical capabilities as well as new developed correction algorithms ensure the highest accuracy in laser beam analysis.

A wide range of beam width techniques e.g. 2nd Moment, Knife Edge, Moving Slit, Plateau, Gauss-Fit can be applied to determine quick and reliable standard beam parameters. The unique measurement tool enables the continuous monitoring of beam parameters, beam position and power density distribution. Helpful features like AOI Tracking, AOI Optimization, Zoom Functions, Look-Up Tables, etc. simplify the laser beam analysis.

The extraordinary graphical and analytical tool of STRayCi can be used for live data (LiveMode) and stored data (SaveMode) simultaneously, while each mode has its own individual functions. This makes STRayCi the most advanced analysis software on the market.

STRayCi is equipped with flexible data and image output capabilities. This permits the user to store data and images in the format that is compatible with their needs.

A clearly arranged and printable protocol view displays the chosen measurement parameters as well as the most important laser beam analysis results.

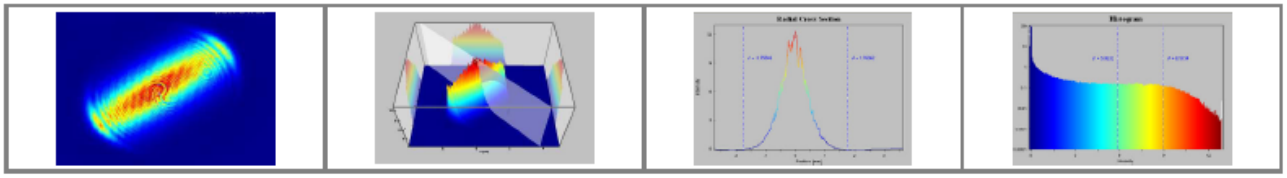
STRayCi is compatible with guidelines of the international standard organization for laser beam measurements:

- ISO 11145: Vocabularies and symbols
- ISO 11146: Beam width, propagation ratio,…
- ISO 11670: Beam positional stability,…
- ISO 13694: Beam power density distribution,…

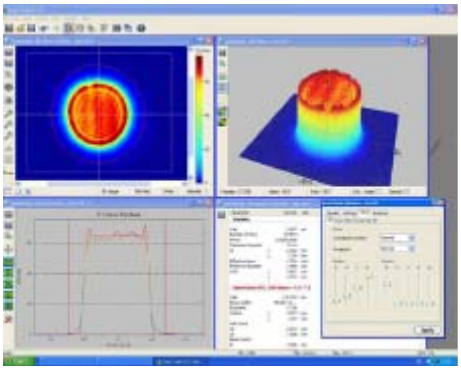
STRayCi works only with a USB software protection lock. It is a hardware based security solutions to protect and encrypt the software against piracy.

MINIMUM SYSTEM REQUIREMENTS:

- Windows XP / Vista
- Pentium IV / AMD Processor
- 128 MB graphic card, Open GL V1.4 compatible
- 100 MB free memory
- PCI / PCIe slot for FireWire card
- USB port for dongle connection
- CD / DVD-ROM drive for software installation
- Internet access for update request



STRayCi Special Features



REAL-TIME BEAM PROFILING
2D / 3D intensity plots / Cross sections / Histogram
Pointing stability (x-y fluctuation, COG- position analysis, ect.)
Parameter stability (intensity, power, center x-y, beam size)
Parameter results (beam statistics, beam width, beam parameter)

CAMERA CONTROL
Multiple camera support
Different measure types
User-selectable exposure time and gain factor, auto-exposure time
Floating average and variable brightness

ANALYSIS FUNCTIONS
Beam statistics (power, max intensity, COG, etc.)
Beam width (2nd Moment, Gauss / Super-Gauss-Fits, Plateau, Knife Edge, Moving Slit, ect.)
Beam parameter (beam width, ellipticity, uniformity, etc.)

CALIBRATION AND CORRECTION TOOL
Background subtraction, auto-background
Pixel correction technology (offset correction, linearity, etc.)
Power calibration

OTHER FEATURES
User-defined Area of Interest (AOI)
AOI tracking and optimization
Color palettes incl. auto-contrast function
Zoom functions
2D profile arithmetic operations, filters, transformations, etc.
E-mail support

FLEXIBLE OUTPUT
Data: txt, tiff
Image: jpeg, png, bmp, gif, tiff
Protocol: pdf