TRIOPTICS
See the Difference

WaveSensor & WaveMaster®

Flexible and precise wavefront measurements

Passion for optics

TRIOPTICS develops and produces the world's largest range of optical measurement and manufacturing technology for the development, quality control and production of lenses, lens systems and camera modules.

WaveSensor & WaveMaster®

Spatially-resolved quality inspection across the entire sample aperture

The quality requirements placed on optics are becoming more and more rigorous. And thus the time and expense needed for the development of lens designs are increasing as well. Theoretical calculations of the image – on-axis and off-axis – are becoming more exacting.

To ensure the implementation of the complex optical designs after production, a qualified measuring technology must also be used. Wavefront measurement is particularly well-suited for this purpose, since it determines the image quality on a spatially-resolved basis, i.e. over all field angles, and across the entire sample aperture. In contrast to traditional MTF testing, this not only results in a point-based measure of quality, but also in a continuous alignment across the entire aperture.

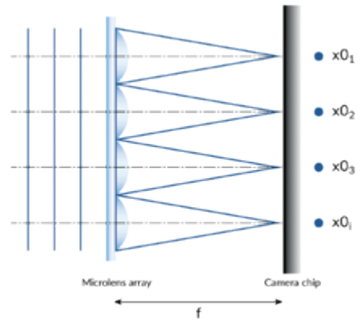
In comparison to design data or master samples, wavefront measurements provide results for the following parameters:

- Size of wavefront (PV and/or RMS)
- Zernike coefficients
- PSF (point spread function)
- Image quality using MTF (modulation transfer function)
- Strehl ratio
- Wedge angle
- Focal length (optional)

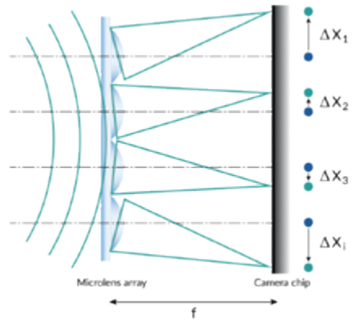
The measurement principle

TRIOPTICS systems perform the wavefront measurement using a Shack-Hartmann sensor. The sensor consists of a microlens array in whose focal plane a camera is arranged. An incoming wavefront hitting the lenses of an array is divided into many small areas. An aberration triggered by a sample lens causes a tilting of the wavefront, which is associated with a measurable displacement of the individual focal point positions.

This allows the local tilts of the wavefront to be determined and a numerical integration enables a highly accurate reconstruction of the wavefront. With their wide dynamic range of more than 2000 λ, Shack-Hartmann sensors can be used to measure wavefronts with large aberrations.



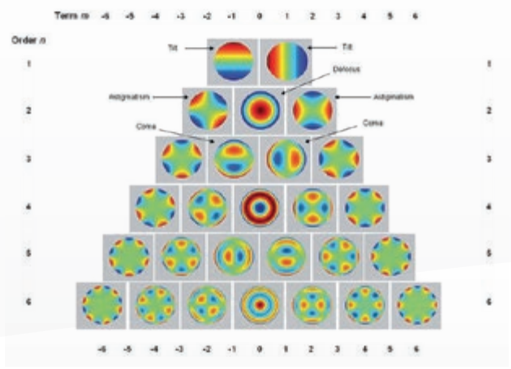
A) Plane-parallel wavefront creates equidistant focal points on the camera chip



B) The aberrated and thus tilted wavefront causes the focal points to shift. The wavefront is reconstructed based on the size of the shift

The measured wavefront is analyzed by Zernike polynomials. This allows a numerical representation of any imaging aberrations of the sample, e.g. spherical aberrations (defocus), astigmatism and coma. There are two main sources of imaging aberrations: design of the lens (symmetric aberrations) and/or manufacturing errors (asymmetric aberrations).

The effects of aberrations are also characterized by the point spread function (PSF), the modulation transfer function (MTF) and the Strehl ratio. These values are also obtained from the wavefront.



Zernike polynomial up to the 6th order

Measurements can be performed using two methods

Reflection

Measurements in reflection provide information about the topography of the sample surface to determine strictly shape deviations of individual surfaces.

Transmission

Measurement in transmission provides information about the optical properties of the entire lens or lens system. The measured wavefront is influenced both by the surfaces and by the refractive index variations of the materials used.

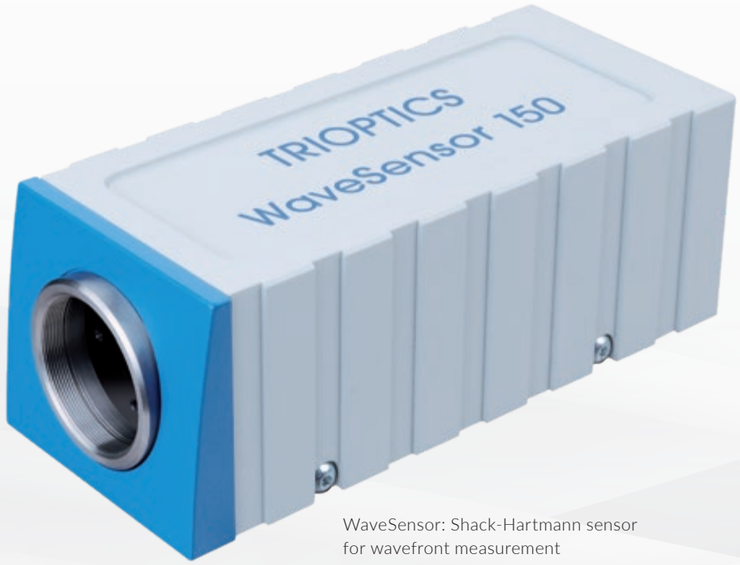
WaveSensor 150

The WaveSensor is the core element of all wavefront measurements at TRIOPTICS. This Shack-Hartmann sensor features an impressive compact and robust design, which means it can be used both individually on an optical bench and integrated in TRIOPTICS wavefront measurement systems.

Depending on the design, the sensor can be used for the measurement and analysis of spherical, aspherical and planar optics in reflection and/or transmission.

Key features of the WaveSensor 150:

- Maximum dynamic range up to 2000 λ, accuracy up to < λ/20 (RMS) and repeatability of λ/200 (RMS)
- Measurement of lenses with diameters up to 14 mm
- Surface topography measurement up to 7° deviation from the sphere (with optional reflex module)
- Compact and robust design
- Flexible wavefront measurement in the laboratory and in production
- Integration into existing laboratory or production facilities
- Communication via CameraLink or IEEE 1394b using the WaveMaster® software



WaveSensor: Shack-Hartmann sensor for wavefront measurement

WaveMaster®

With the systems in the WaveMaster® series, TRIOPTICS offers complete wavefront testing systems which are configured both for typical and also sometimes very specific measuring tasks. This eliminates the need for a conventional optical bench. We coordinate, align and adjust all components. And in combination with the software, many processes can be automated, thus significantly reducing the measuring and testing time.

In addition to systems used for individual measurements of lenses or lens systems in on-axis or off-axis imaging, a system for batch testing during series production is also available.

WaveMaster®	Compact 2	PLAN	Field	UST	PRO 2
Field of application					
Single lens measurement	■	■	■	■	
Series production					■
Measurement scope					
On-axis	■	■	■	■	■
Off-axis			■	■	
Sample					
Planar optics	■	■			■
Spherical & aspherical optics	■		■		■
Wafer					■
Bi-telecentric lenses				■	

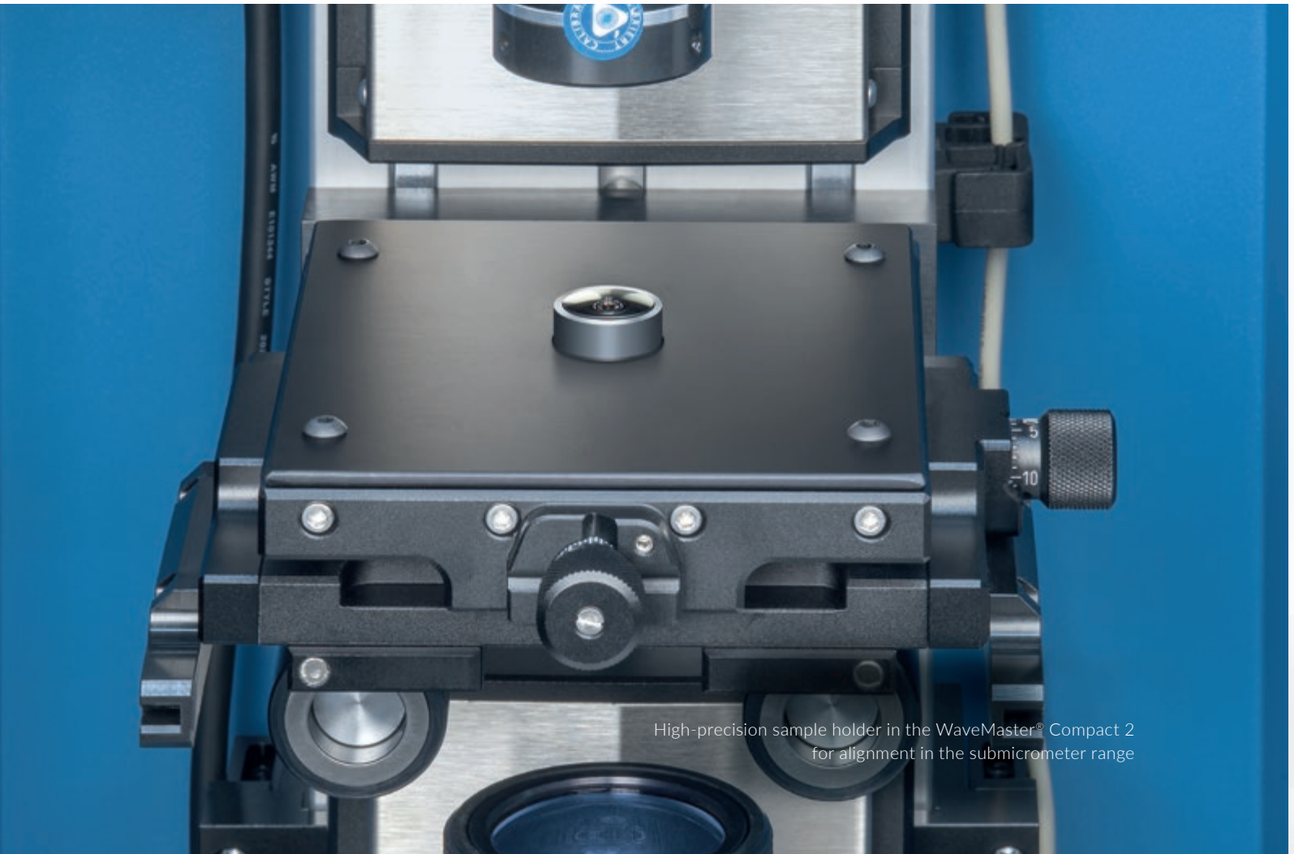
WaveMaster® Compact 2 for the measurement of spherical and aspherical lenses and lens systems in transmission and/or reflection

On-axis wavefront analysis

The WaveMaster® Compact 2 and WaveMaster® PLAN are two precise instruments used for on-axis measurement of the wavefronts of spherical, aspherical and planar optics for quality control and R&D applications. Both instruments are easy to handle and enable quick measurements. They can be flexibly adapted to a wide variety of samples.

Key features

- High measurement accuracy of up to λ/20 (RMS) and a repeatability of λ/200 (RMS) with WaveSensor 150
- Quick measurement speed enables high sample throughput
- Fast and easy adaptation for different sample types due to exchangeable imaging telescopes in a kinematic mount
- High-precision sample holder for alignment in the submicron range
- Only minimum amount of sample alignment necessary when measuring series of samples
- Real time comparison between wavefront data and master lenses or design values
- Vibration-resistant design
- Comprehensive measurement and analysis software



High-precision sample holder in the WaveMaster® Compact 2 for alignment in the submicrometer range

WaveMaster® Compact 2 – measure & test spherical and aspherical lenses

To optimize handling, the WaveMaster® Compact 2 features automatic positioning of the wavefront sensor and the imaging optics in the exit pupil as well as focusing of the point light source. The selection of different microscope lenses allows for different numerical apertures (up to 0.95) and working distances.

The WaveMaster® Compact 2 is available in three different versions, depending on the required measurement method:

WaveMaster® Compact 2	Transmission
WaveMaster® Compact 2 Reflex	Reflection
WaveMaster® Compact 2 Universal	Transmission and Reflection

WaveMaster® Compact 2

WaveMaster® PLAN – measure & test of planar optical elements

The WaveMaster® PLAN features collimated illumination for ultra-easy measurement of plane plates, filters or wedges in transmission.

WaveMaster® PLAN measures planar elements with a Shack-Hartmann sensor

Off-axis wavefront measurement

In particular with wide-angle lenses, high-quality imaging of abaxial objects is key. Here, mere on-axis wavefront measurements are often not sufficient because high field angles are not taken into account. Therefore, TRIOPTICS also offers solutions to cover this application as well:

WaveMaster® Field	Universal wavefront measurements at field angles up to 70°
WaveMaster® UST	Testing system for bi-telecentric lenses

Like the systems for measuring on-axis wavefronts, the WaveSensor 150 also delivers high off-axis measuring accuracy of up to λ/20 (RMS) and a repeatability of λ/200 (RMS). In addition, the off-axis measurement increases the sensitivity with respect to the lens centering, so that the lens positioning to the desired wavefront can be optimized even more precisely.

Off-axis wavefront measurement
with the WaveMaster® Field

WaveMaster® Field

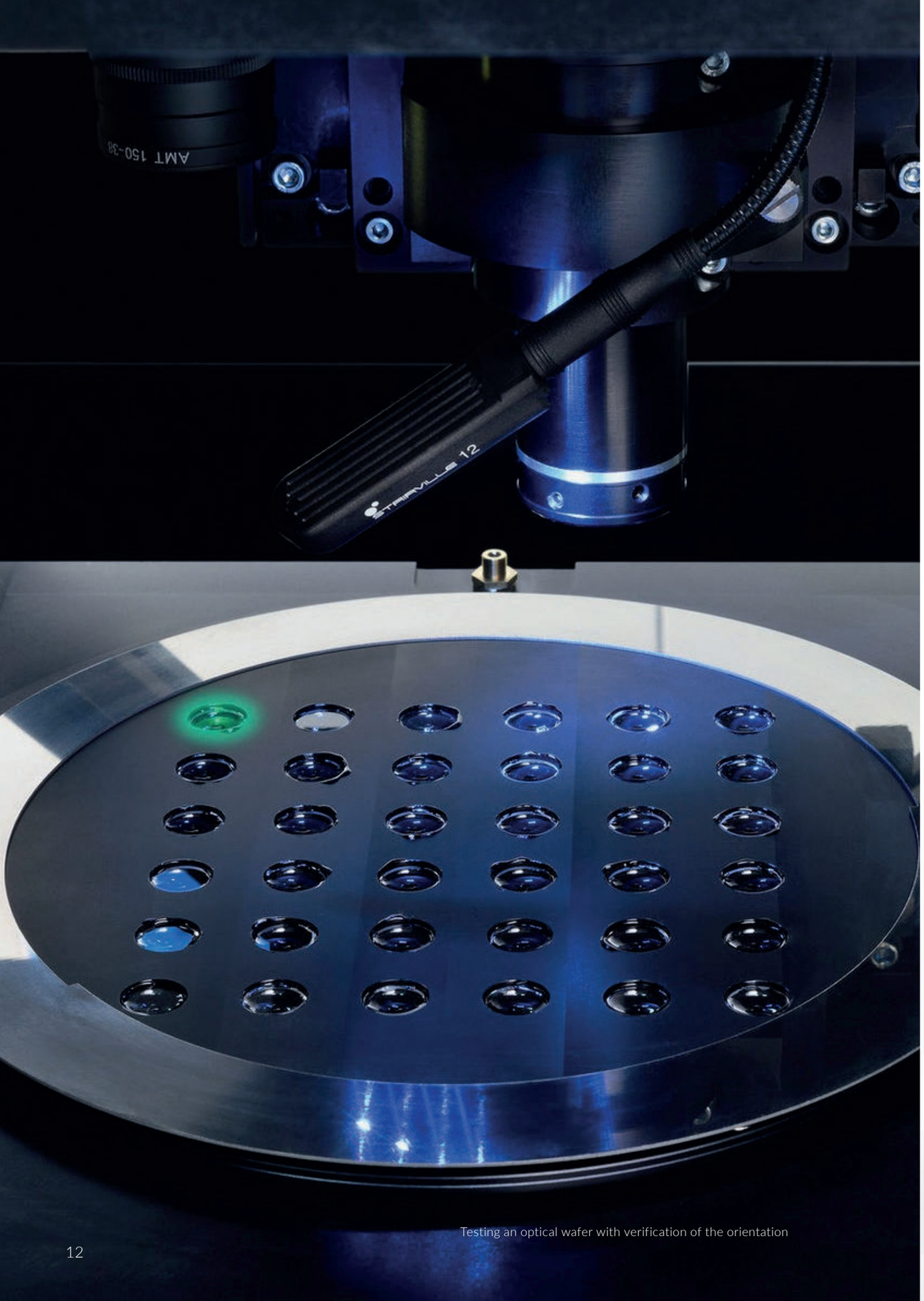
The WaveMaster® Field was explicitly designed for use in research and development. The system enables both the comprehensive measurement of samples across their entire field of view and a subsequent in-depth analysis. Individual incident angles and wavelengths can be flexibly adjusted in just a few steps to simulate changing lighting conditions. Adaptations to different samples can be made just as easily.

Off-axis wavefront measurement
with the WaveMaster® Field

WaveMaster® UST

The WaveMaster® UST is a universal stepper optic tester (UST) for bi-telecentric lenses weighting up to 450 kg. It automatically measures their entire field up to a field size of 70 x 45 mm² on the lens side. The measurement procedure can be performed at multiple wavelengths and various intensities. Preconfigured measuring sequences and a high degree of automation ensure the correct positioning of all axes during the measurement and the wavelength change.

WaveMaster® UST
for testing bi-telecentric lenses



Testing an optical wafer with verification of the orientation

TRIOPTICS
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WaveMaster® PRO 2

Series production testing of lenses and optical wafers

The WaveMaster® PRO 2 sets new standards in the series production testing of lenses and optical wafers – entire batches of lenses can be measured in a fully automatic process. With a typical measurement time of 3 seconds per lens and fast tray or wafer changes, this instrument is designed to meet the requirements for testing in mass production. A comparison of the measurement results and design data yields the pass/fail analysis for each individual lens.

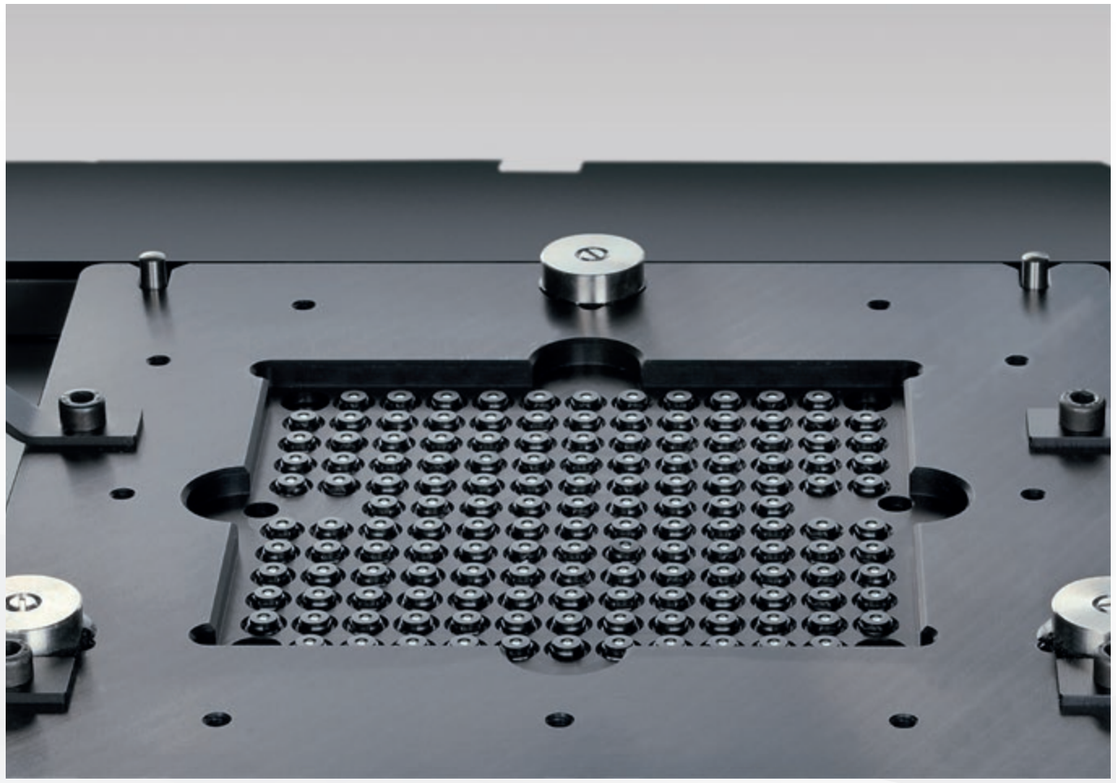
The WaveMaster® PRO 2 is available in three variants. Each model is specifically designed for a certain sample type:

WaveMaster® PRO 2	Small spherical and aspherical lens and lens systems
WaveMaster® PRO 2 PLAN	Planar lenses and afocal lens systems
WaveMaster® PRO 2 Wafer	Optical wafers

WaveMaster® PRO 2 facilitates quality control after series production, including pass/fail analysis

Advantages of the WaveMaster® PRO 2

- Fully automatic measurement of a large number of samples (wafer or preloaded trays)
- Measurement duration: < 3 s (per lens and measuring step)
- User-defined pass/fail analysis
- Absolute or relative wavefront measurement
- High measurement accuracy of up to λ/20 (RMS) and repeatability of λ/200 (RMS) with the WaveSensor 150
- Complete wavefront analysis (PV, RMS, Zernike, PSF, MTF, Strehl)
- Export of all measurement results for each single lens
- Optional: Integrated system for measuring wafer orientation, wafer bow and tilt



Tray for holding single lenses

WaveMaster® Software

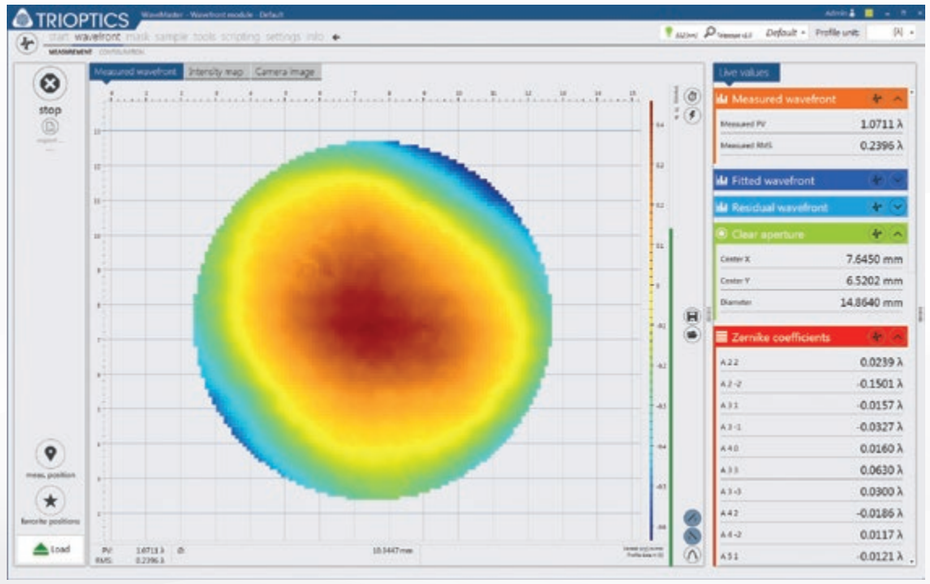
Clearly structured display of measurement results – comprehensive analysis

The WaveMaster® software is clearly structured, easy to use and contains all the functions for aligning, measuring and analyzing samples with the WaveMaster® system.

The software communicates with the Shack-Hartmann sensor and analyzes the measured wavefront in real time. In addition, it controls the WaveMaster® systems, thus providing automated measurement processes.

Advantages of the software

- One software does it all: Data collection, data calculation, calibration, display of data, real-time analysis
- Menu-driven operator guidance
- Simple and intuitive measurement and analysis of wavefronts and surfaces (with reflex module)
- Theoretical data from ZEMAX and Code V or data from master lenses can be loaded and compared in real time during measurements
- Device control



WaveMaster® software displays the measurement results of a single lens test with the Zernike analysis

WaveMaster® Software

To ensure optimal measurement of the samples, the measurement and analysis ranges are set individually. The measurement results can be output in various ways and the quantities derived from them can be displayed:

- 2D or 3D wavefront, interference fringes and phase
- PV and RMS
- Intensity
- Local slopes
- Camera image

If required, wavefront and camera images are averaged. The results are documented by certificates.

Adaptation to production

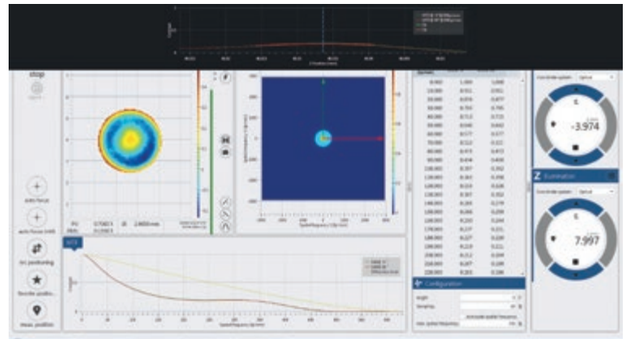
For use in production, the WaveMaster® software in these systems is enhanced with a corresponding additional module which provides a clearly structured display of the test progress for all lenses. Compliance with the pass/fail criterion, which can be freely selected from a wide range of parameters, is displayed in a color-coded form. For better comparability of the larger aberrations, the software corrects the wavefronts for the tilt and defocus Zernike coefficients. Furthermore, user accounts with different access rights can be assigned.

Series measurement of a wafer in production

The basic functions of the WaveMaster® software can be expanded with two analysis modules:

MTF/PSF analysis module

This module enables the real-time calculation and display of 3D/2D MTF and PSF data as well as the Strehl ratio. The measurement results are output as a table and can be exported.

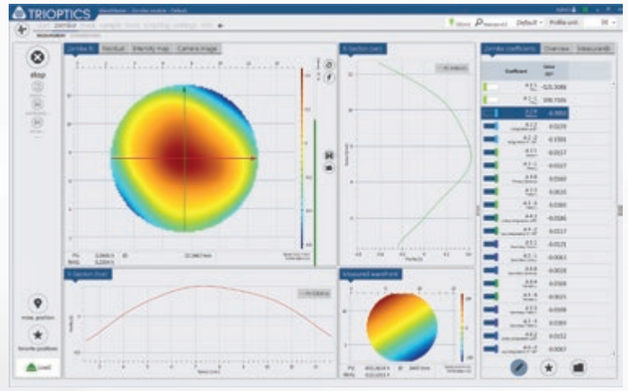


Determining the MTF from the measured PSF using the MTF/PSF analysis module

Zernike analysis module

The Zernike analysis module can be used to conduct an in-depth evaluation of the measurement results. The options include:

- Zernike fit and analysis of wavefront data in real time
- Numerical and graphical display of fit results
- Import of wavefront data from ZEMAX and CODE V for real-time comparison
- Export of wavefront data and analysis results to ASCII and ZEMAX formats
- Display of the temporal curve of the Zernike coefficients



Comprehensive evaluation of aberrations with the Zernike analysis module

Technical Data

WaveSensor	150	150 with reflex module
General		
Sensor range	15 x 15 mm	15 x 15 mm
Wavelength	405 nm ... 1100 nm[1]	405 nm ... 1100 nm[1]
Wavefront accuracy	< λ/20 (RMS)	0.05 µm (RMS)
Wavefront repeatability	< λ/200 (RMS)	0.005 µm (RMS)
Dynamic range	2000 λ	2000 λ
Measurement frequency	up to 12 Hz	up to 12 Hz
Lateral resolution	138 x 138 microlenses	138 x 138 microlenses

WaveMaster®	Compact 2	Compact 2 Reflex	Compact 2 Universal
Research & Development			
Sample diameter	0.5 mm ... 14 mm [2,3]	4.5 mm ... 18 mm [3,5]	Transmission: 0.5 mm ... 14 mm[2,3] Reflection: 4.5 mm ... 14 mm[3,5]
Flange focal length	-30 mm ... +100 mm [4]	-	-30 mm ... +100 mm [4]
Radius of curvature	-	-50 mm ... 30 mm [6]	-50 mm ... 30 mm [6]
Sample holder	Single seat, manual positioning		
Maximum asphericity	-	≤ 7° [7]	≤ 7° [7]

WaveMaster®	PLAN	Field	UST
Research & Development			
Sample diameter	0.5 mm ... 14 mm [2,3]	0.5 mm ... 14 mm [2,3]	up to 1100 mm x 650 mm x 1200 mm
Sample holder	Single seat, manual positioning		Interface for customized lens holders
Maximum sample weight	-	-	450 kg
Maximum distance between object and image plane	-	-	1200 mm
Max. field dimensions image side	-	±20 mm	100 mm x 100 mm
Max. field dimensions object side	-	±70°	70 mm x 45 mm

WaveMaster®	PRO 2	PRO 2 Wafer	PRO 2 PLAN
Production			
Sample diameter	0.5 mm ... 14 mm [2]	0.5 mm ... 14 mm [2]	0.5 mm ... 14 mm [2]
Flange focal length	-12 mm ... +50 mm [4]	-12 mm ... +50 mm [4]	-
Sample holder	Tray	Wafer holder	Tray
Measurement time per lens	< 3 s[8]	< 3 s[8]	< 3 s[8]
Sample throughput per hour	≥ 1200 lens[8]	≥ 1200 lens[8]	≥ 1200 lens[8]
Lens per tray	Max. 148 [8]	-	Max. 148 [8]
Exchange time for tray of lenses	10 s	10 s	10 s
Wafer tray exchange time, incl. alignment	< 2 min	< 2 min	< 2 min
Setup time for new lens design	< 5 min	< 5 min	< 5 min

1 In accordance with customer's specifications
2 Depending on telescope
3 More details upon request
4 Depending on microscope
5 Depending on radius of curvature and illumination lens
6 Depending on sample diameter and illumination lens
7 Local deviations from the best fit sphere
8 Depending on sample

Accessories

All of the WaveMaster® systems feature a flexible design and can thus be adapted to the specific requirements of your application.

Illumination
Light sources with various wavelengths are available. The kinematic mount makes it easy to integrate the different light sources into the instruments.

Sample holders
To ensure optimum positioning of the samples, individual lens seats and especially trays are individually tailored to customer requirements.

Telescopes
For maximum utilization of the dynamic range of the Shack-Hartmann sensor and thus the lateral resolution of the sensor, a set of telescopes is available as an accessory. The optimum magnification of the telescope is determined based on the sample diameter and the dimensions of the wavefront sensor. With the kinematic mount, switching telescopes is very easy.

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93-006-003-EN Version 002

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