

# LumiTop Series

Spectrally enhanced imaging colorimeter for advanced display testing



We bring quality to light.



#### Product highlights

- ▲ 2D measurements with unprecedented accuracy due to high-end reference spectroradiometer
- ▲ All-in-one display testing solution saves space and time
- ▲ Fastest measurement times for highest throughput
- ▲ Efficient audit concept: no golden samples required
- ▲ Easy integration in production lines

◀ LumiTop 4000 with 29 mm objective lens and CAS140D.

# 01 \\ LumiTop – Solutions for comprehensive display testing

## Designed for display production testing

Instrument Systems engineered the LumiTop imaging colorimeters specifically for inline display testing. As the industry's fastest, most reliable and most accurate imaging colorimeter, LumiTop has become the reference for high-performance display testing.

The unique combination of a high-resolution camera, a fast photometer and an extremely accurate spectroradiometer of our CAS series renders the LumiTop system an exceptionally powerful tool for display quality assurance in 24/7 operation and solves even the most demanding optical testing challenges under the constraints of production takt times and in harsh conditions.

LumiTop systems are easy to integrate into production lines and not only offer unparalleled performance, but also save cost, space and time. They are industry

proven by a huge installation base and come with first class global service, auditing and support and include the comprehensive LumiSuite software package for all your testing needs. For all test requirements in display production, our LumiTop series offers solutions that are perfectly tailored to customer specific QA/QC tasks.

## Display quality control and technological research

Designed as measurement device for production testing, the LumiTop systems also excel in the laboratory. Thanks to the spectroradiometric reference measurement, they feature laboratory test specifications and are often used as reference equipment. The scope of test applications can even be extended: Since the camera comes as modular accessory, the system can be complemented by the accessory optics Top 150 or Top 200 in order to increase sensitivity and variability of the spectroradiometric measurement (DTS 140 series).

For both systems, LumiTop and DTS, the spectroradiometer can as well be operated with Spec Win Pro Software, an extremely comprehensive software allowing a multitude of spectra analyses.

## All DUT technologies and sizes

The LumiTop family covers the whole range of display technologies and DUT sizes, from smart phones, tablets and TVs to micro-displays,  $\mu$ LED-wafers and AR/VR near-eye displays.

As a result, LumiTop systems help to enable and support our customers to manufacture perfect true color displays at consistently high quality across globally distributed production sites and labs.

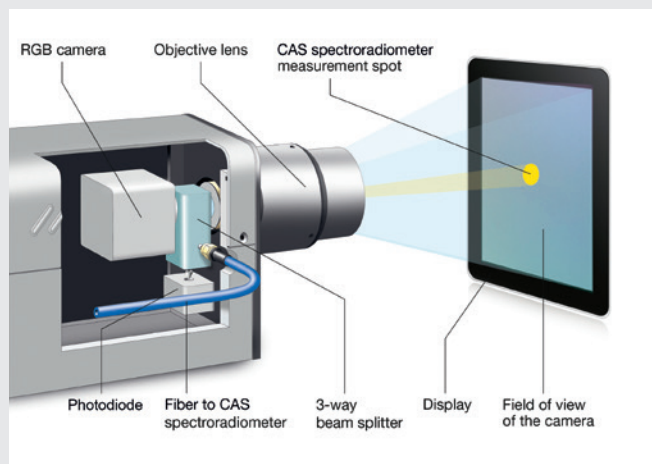
# 02 \\ LumiTop technology and customization

Central to the LumiTop technology is the speed and resolution of a high-performance camera and the unsurpassed accuracy of a fast high-end array-spectroradiometer, acting as a live reference. Simultaneous acquisition of the reference spectrum and the camera image of the entire display lay the foundation for outstanding optical quality tests in demanding takt times and uncompromising accuracy, traceability and 24/7 production performance.

## Customized for lab and production demands

The diverse demands of production and labs are met by LumiTops various options for customization. There is a choice of high dynamic and low-noise RGB-cameras, cooled CCD sensors with 6 MP and fast CMOS sensors with 12 MP and even 150 MP for ultra high resolution. An optional pixel shifter in the LumiTop X150 for up to 600 MP per color

channel enables sub-pixel resolution of entire 4k high definition displays. Sensors with up to 81 dB dynamic range provide a huge measurement range for low and high luminance applications. A variable all-electronic attenuation mode allows higher luminance measurements without additional neutral density filters. Optionally, such filters can be used to even extend the measurement range to extremely bright light sources.



Patented design concept of the LumiTop 2700/4000.

**Quick take**

For speed and resolution, a high-resolution camera is the preferred option, because display pixels can be measured parallel in a single shot. For absolute color, however, spectroradiometry is the most accurate method. Consequently, the two techniques must be combined.

A variety of industry grade objective lenses allow to build a system that fits customer-specific measurement needs, ranging from micro-displays, watches, phones and tablets to TVs and from  $\mu$ LED to wafer-testing and near-eye displays in AR/VR devices.

For many testing schemes in production, timing is of critical importance. Therefore, Instrument Systems introduced a hardware trigger to LumiTop 4000, providing input and multiple output triggers for perfect timing and synchronization,

especially important for OLED testing and other modulated light sources. To complement the imaging camera with a perfectly fitting spectrometer, several choices from our CAS spectroradiometer portfolio are available and complete the LumiTop system. LumiTop 2700 and 4000 were designed without moving parts to maximize speed, reliability and accuracy. LumiTop X150 is optimized for the highest possible resolution and single pixel metrology of high definition displays also featuring exceptional low luminance sensitivity.

## Auditing and Service

An efficient auditing process, the robust design and highly accurate calibration of the LumiTop systems guarantee exceptional long-term stability and accuracy.

Our coordinated auditing, calibration and service strategy improves testing limits even more and reduces factory downtimes. Reliability and accuracy arise from a mix of excellent hardware, dedicated calibration, live referencing and traceable auditing.

Our auditing light sources are very accurately defined light sources traceable to national metrology institutes (NMIs). Regular audit of LumiTop measurement instruments against those light sources guarantees absolute measurement accuracy at any time and at any

production site throughout the supply chain. This assures the same high display quality of the product no matter where and when it is produced. Moreover, our auditing tools are optimized for quick inline instrument checks that minimize factory downtimes. Local partners

and service subsidiaries ensure swift response and provide rapid recalibration, instrument repair, and technical support. Auditing and service is the key to high yields and cost efficient display production testing.

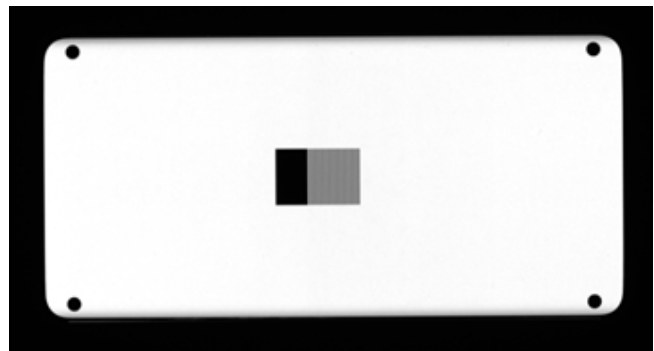
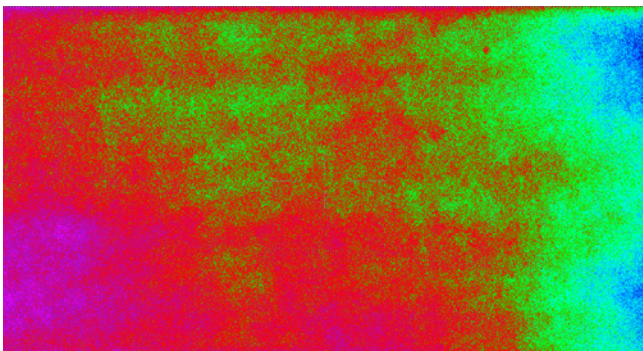
## 03 \\ Flat panel display testing

LumiTop systems provide testing solutions for a wide range of display sizes, geometries and technologies to ensure superior display quality. Advanced solutions comprise dedicated testing of e.g. display edges and large displays.

Instrument Systems' LumiSuite software comprises an extensive set of standard and advanced display tests, including luminance and color uniformity, defect detection and chromaticity (see below). vvhvh

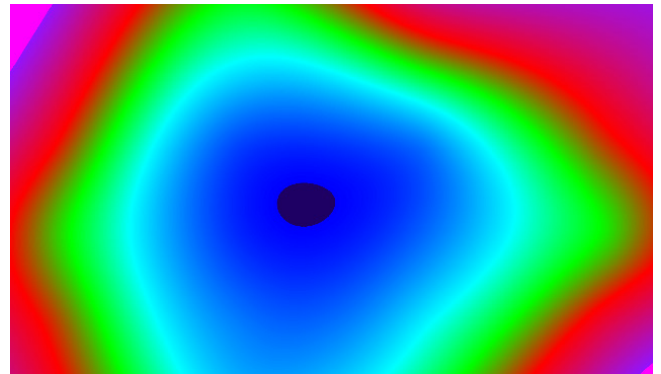
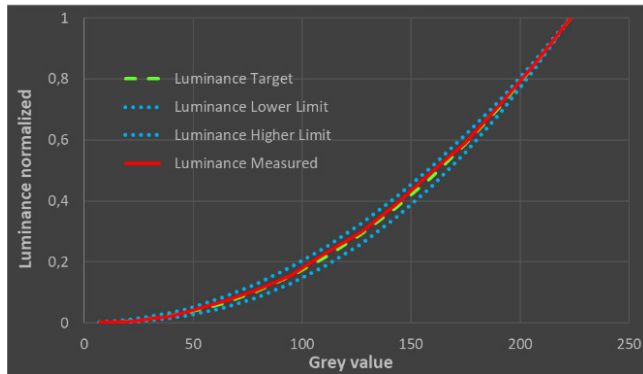
The consequent design for speed and accuracy makes the LumiTop system the perfect test station for quality control in mass production of smart phones, tablets and other flat panel display devices.

### Flat panel display test applications



▲ **Uniformity** of color and luminance is essential for any display and assures a correct representation of an image. Non-uniform displays can distort image content and may lead to an unsatisfactory visual experience or even a wrong interpretation of the image.

▲ The **Mura** effect generally refers to a non-uniform display that is caused by imperfections and variations in the displays light sources. These effects can manifest themselves as darker or lighter, low-contrast areas, or individual image points, lines or blobs that simply deviate from the general image impression. These effects are particularly noticeable in dark images and low-light ambient conditions. Instrument Systems provides testing for different forms of Mura, including the DFF standard Black Mura test of the automotive OEM workgroup.



▲ **Gamma** correction is important to adapt the displays luminance curve to the non-linear (intensity) perception of the human eye. Instrument Systems' LumiTop provides customizable gamma tests, enabling even fast one shot gamma measurements.

▲ For **full display inspection** of large TV screens in production lines Instrument Systems offers the LumiTop equipped with a wide angle lens. It provides angular distortion corrected  $L_v/x/y$  values for the entire display, using an optional **Multi-Point Correction** tool.



▲ **OLED** and other modulated light sources can produce visible artefacts due to a mismatch of exposure time and refresh rate. Using the fast, integrated photometer to determine the exact modulation frequency, LumiTop easily synchronizes the camera measurement to avoid such artefacts. Furthermore, the integrated hardware trigger also allows synchronization to external driver logic enabling precision timing of the measurement for perfectly reproducible test conditions.

▲ **High Luminance Mode** of LumiTop 4000 is an advanced setting for exposure timing enabling measurements of high luminance displays. It extends the measurement range of the camera electronically to higher luminance without the need of neutral density filters.



# 04 \ \ Augmented and virtual reality (AR/VR) testing

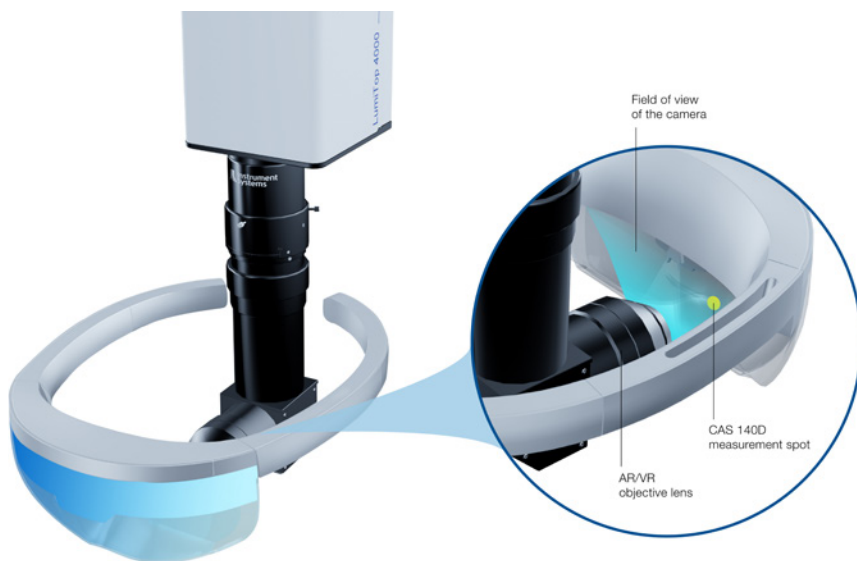


## LumiTop AR/VR brings speed and absolute photometric accuracy to near-eye displays!

Instrument Systems AR/VR lens for LumiTop imaging colorimeters is specifically designed for production

testing of near-eye displays (NEDs) in virtual and augmented reality headsets. The optical design mimics the human eye and measures color and luminance exactly as seen by the user. A large field of view, various pupil sizes and adjustable

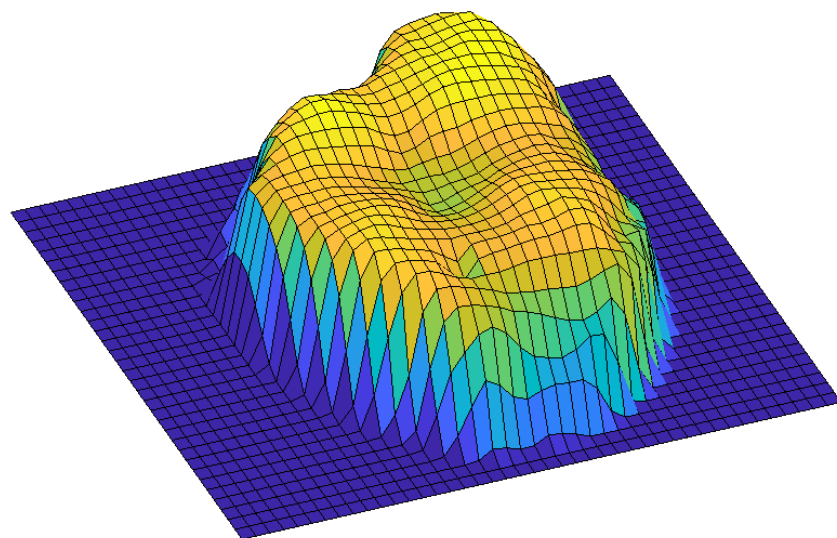
focus distance enable a wide range of testing applications. A unique periscope design facilitates easy access to the NED.



## LumiTop with AR/VR lens

- ▲ LumiTop accuracy and speed
- ▲ >120° FoV
- ▲ Adjustable focus 0.3 m – ∞
- ▲ Various pupil sizes
- ▲ Space for “2-eyes” measurement

The periscope design enables an optimal measurement position also under the tight spatial constraints of fully assembled head mounted devices. Even parallel operation of two LumiTops is possible to measure both NEDs simultaneously.



▲ Contrast across the near-eye display of an AR head mounted device.

## User experience of true colors and luminance

- ▲ High resolution camera to avoid Moiré effects
- ▲ Optimized lens design to measure what the human eye sees
- ▲ Fast photometer and trigger for synchronization and control of modulated light sources

LumiTop with AR/VR lens delivers highly reproducible, traceable and accurate color and luminance measurements to provide the best displays for augmented and virtual reality.

# 05 \\ LED wafer and array testing

LED-based light sources have largely superseded conventional light sources. Due to their technical advantages, they have given rise to many new exciting applications. In particular, upcoming  $\mu$ LED technologies are expected to drive displays in head-mounted devices for augmented and virtual reality applications and other mobile devices. Each LED in the millions of pixels on a wafer is a single light source with individual variations in color and luminance. To assure the highest quality under the constraints

of economical production takt times, fast and accurate optical testing has to be provided for every LED on the wafer posing new challenges to LED and  $\mu$ LED production testing.



LumiTop 4000, 29mm and 100 mm, optionally with periscope.

## 2D testing of $\mu$ LED wafers

With millions and millions of LEDs on a single wafer, standard sequential testing of each  $\mu$ LED with an integrating sphere is not practical anymore. A massively parallelized 2D testing process for defects and spectral properties is the key to an economical production. The LumiTop concept has been extended to innovative wafer testing by using a dedicated macro lens and a specifically optimized calibration

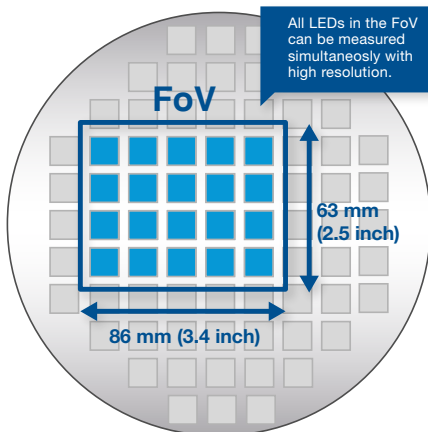
for narrow bandwidth  $\mu$ LEDs. A hardware trigger for synchronization ensures reproducible measurements of time dependent light sources and speeds up measurement times.

- ▲ Fast 2D testing of  $\mu$ LED wafers and arrays
- ▲ Defect detection
- ▲ Optimized color calibration
- ▲ High luminance options
- ▲ Trigger for synchronization

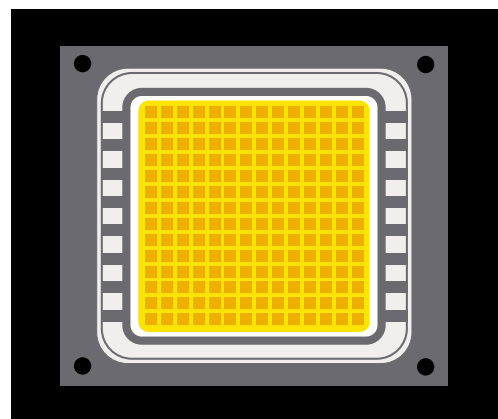
## Automotive $\mu$ LED array testing: Adaptive headlights

Adaptive headlights in cars are becoming bright, high resolution LED-projectors. For safety reasons and quality control these light sources need to be tested rigorously to meet automotive specifications.

LumiTop provides the accuracy and customization to provide testing solutions also for very bright  $\mu$ LED arrays.



Wafer Testing: FoV customizable according to  $\mu$ LED size.



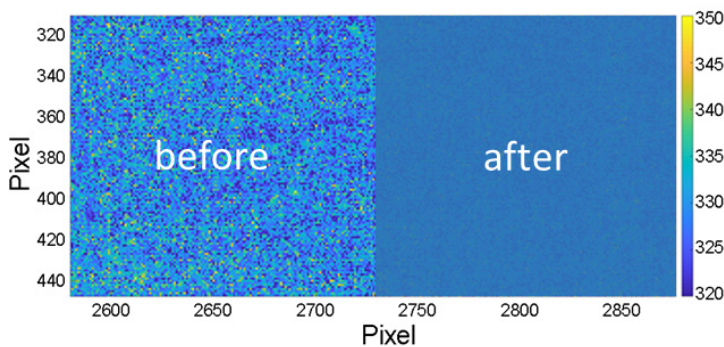
Schematic  $\mu$ LED array for adaptive automotive front lighting systems.

# 06 \\ Pixel metrology

With the advent of  $\mu$ LEDs each of the millions of pixels on a display is an individual light source with individual variations in color and luminance. To produce high-quality uniform displays, these variations must be tested, corrected, and kept below visual noticeability. To assure the highest quality under economical takt time constraints, fast and accurate optical testing has to be provided for every pixel on the entire display. The LumiTop X150 system from

Instrument Systems provides ultra-high-resolution images of displays, where each DUT pixel is oversampled sufficiently by many camera sensor pixels to derive accurate color and luminance values. As a result, a well-resolved image of all display pixels becomes rapidly available. A Single Pixel Evaluation (SPE) process derives pixel maps of the DUT with values of luminance and color for each display pixel. The pixel maps contain all relevant data of the display and

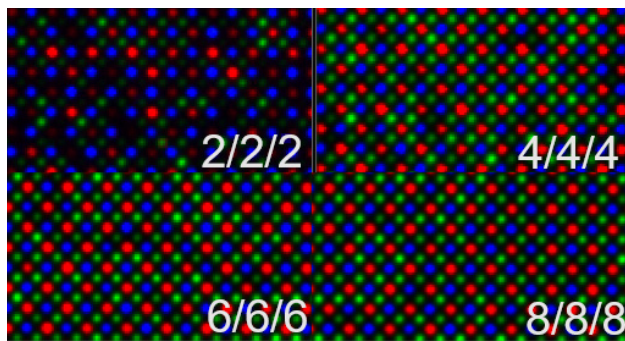
act as a source for all desired quality parameters. Our SPE algorithms are optimized for fast and accurate pixel data to fulfil demanding production requirements and enable pixel demura in luminance and color. The pixel map characterizes the display completely. Calibration and demura for luminance and color can be performed on pixel level even at low luminance for superior display quality testing. See details in the figure on the upper left.



Pixel map before and after pixel demura.

## LumiTop X150 – demura

- ▲ Maps of pixel resolved luminance and color
- ▲ Defect Detection in luminance and color
- ▲ User defined pass/fail criteria
- ▲ Enables pixel resolved correction (demura)



Details of a high resolution image of an OLED smart phone display at different low luminance grey levels.

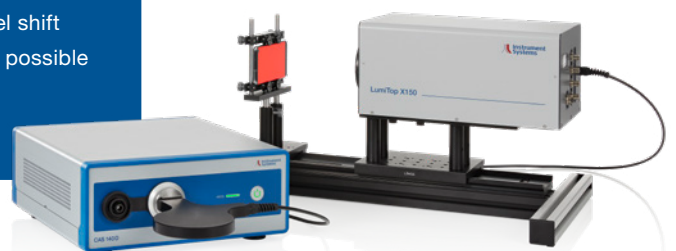
## LumiTop X150 – low luminance

- ▲ Low luminance analysis
- ▲ Enables calibration at low luminances
- ▲ Enables Gamma correction for wide luminance range

LumiTop X150 comprises a 151 MP RGB camera sensor, the highly accurate CAS 140D spectroradiometer and a fast photometer for flicker measurements. An optional pixel shifter renders demosaicing unnecessary and enhances resolution to 150 MP per color channel and beyond, depending on the number of pixel shifts.

### LumiTop X150

- ▲ True 150 MP resolution per color channel using 2x2 pixel shift
- ▲ Even higher resolution possible with 4x4 pixel shifting
- ▲ Various lens options





# 07 \ Automotive

Displays are becoming more and more prevalent in the automotive cabin and must serve a variety of functions flawlessly in a challenging environment. Specialized analysis to measure effects such as Black Mura must be conducted according to established standards; this enables meaningful comparison between supplier and manufacturer. The automotive OEM software features of the LumiSuite

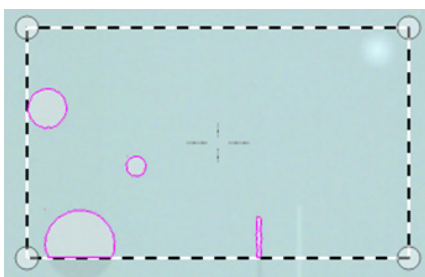
contain tools specially developed for the evaluation of automotive displays and conforming to the standards of the DFF automotive OEM working group. These features include Black Mura, detection of numerous pixel defects including dot or line defects, and Gamma measurement, and include built-in pass/fail criteria in the SDK to minimize setup time and effort.



# 08 \ LumiSuite Software

LumiSuite is the comprehensive software suite for all your production inspection tests, laboratory measurements and analysis needs. It comes with support for all of Instrument Systems' imaging light measurement devices including the whole LumiTop family. It is available with an intuitive graphical user interface (GUI) and a software development kit (SDK). The visual workflow of the GUI guides you seamlessly through all measurement and data analysis steps. Help is always at your hand by hovering the mouse over buttons and icons.

Advanced, multi-step inspection tests can easily be put together using the recipe feature. Recipes can be saved, modified and even transferred to the SDK for automatic in-line use. All your work and data is neatly stored in projects.



LumiSuite Analysis: Defect Detection.

LumiSuite provides a comprehensive tool box of predefined tests, pre-processing tools and analyses for display testing in production and lab. Standard quality assurance tests and defect detection include among other:

- ▲ Spotmeter analysis (luminance & chromaticity)
- ▲ Line profiles
- ▲ Histogramm and statistics
- ▲ Uniformity
- ▲ Point, line, area mura
- ▲ Pixel defect detection
- ▲ Integral object analysis

Optional advanced tests include Black Mura, Single Pixel Evaluation and Multi-Point Correction.

LumiSuite additionally supports:

- ▲ Hardware trigger
- ▲ Flicker and luminance modulation measurement
- ▲ Multiple user defined dark current calibrations
- ▲ Correction of angular dependencies
- ▲ Synchronization to modulated light sources (e.g. OLED)

These features enable sophisticated and fast measurement schemes for challenging samples based on  $\mu$ LED, LED and OLED technologies.



# 09 \\ Technical specifications

## LumiTop 2700 / LumiTop 4000

	LumiTop 2700		LumiTop 4000			
<b>Measurement quantities</b>						
2D	Luminance, color					
Spot	Spectrum, luminance, color, flicker					
<b>General specifications</b>						
Operating system	Windows 7/10 (64 bit)					
Dimensions (l x w x h) <sup>1)</sup>	274 mm x 192 mm x 112 mm		286 mm x 190 mm x 121 mm			
Weight <sup>2)</sup>	3.7 kg		4.1 kg			
Power supply	12 V		24 V			
Operating temperature range	15 – 35 °C					
<b>Camera specifications</b>						
Effective resolution (h x v)	2750 x 2200 (6.1 megapixels, CCD)		4096 x 3000 pixels (12 megapixels, CMOS)			
Pixel size	4.54 µm x 4.54 µm		3.45 µm x 3.45 µm			
Dynamic range	61 dB		70 dB			
AD converter	12 bit					
Size sensor	1" (16.0 mm diagonal)		1.1" (17.52 mm diagonal)			
Interface camera	Gigabit Ethernet		Gigabit Ethernet, M12 12-Pin Female			
Measurement range 2D <sup>3) 4)</sup>	L = 0.005 cd/m <sup>2</sup> - 5,000 cd/m <sup>2</sup>		L = 0.02 cd/m <sup>2</sup> – 270,000 cd/m <sup>2</sup>			
<b>Accuracy and precision</b>	<b>Luminance</b>	<b>Color</b>	<b>Luminance</b>	<b>Color</b>		
Accuracy of camera (rel. to CAS) <sup>5)</sup>	±0.4 %	±0.0015	±0.4 %	±0.002		
Instrumental precision camera <sup>6)</sup>	±0.03 %	±0.0001	±0.03 %	±0.0001		
Camera uniformity (RNU) <sup>7)</sup>	±0.35 %	±0.0013	±0.35 %	±0.0013		
<b>Measurement time<sup>8)</sup></b>						
Measurement time hybrid mode	0.5 s		0.7 s			
Measurement time camera only	0.5 s		0.7 s			
<b>CAS specifications</b>						
	<b>CAS 140D</b>		<b>CAS 140CT</b>		<b>CAS 120</b>	
Interface CAS	USB, PCIe, Gigabit Ethernet		USB, PCIe		USB	
Measurement range CAS <sup>9) 9)</sup>	L = 0.003 cd/m <sup>2</sup> – 4 x 10 <sup>7</sup> cd/m <sup>2</sup>		L = 0.015 cd/m <sup>2</sup> – 6 x 10 <sup>7</sup> cd/m <sup>2</sup>		L = 0.10 cd/m <sup>2</sup> – 1.5 x 10 <sup>8</sup> cd/m <sup>2</sup>	
<b>Accuracy and precision</b>	<b>Luminance</b>	<b>Color</b>	<b>Luminance</b>	<b>Color</b>	<b>Luminance</b>	<b>Color</b>
Accuracy of CAS	±3.0 % <sup>10)</sup>	±0.0015 <sup>11)</sup>	±3.5 % <sup>10)</sup>	±0.0015 <sup>11)</sup>	±4.0 % <sup>10)</sup>	±0.002 <sup>11)</sup>
Instrumental precision CAS <sup>6)</sup>	±0.1 %	±0.0001	±0.1 %	±0.0001	±0.1 %	±0.0002
Polarization sensitivity <sup>12)</sup>	±2.0 %	±0.002	±2.0 %	±0.002	±2.0 %	±0.002
<b>Flicker specifications</b>						
Flicker range	5 cd/m <sup>2</sup> – ca. 600 cd/m <sup>2</sup>					
Flicker accuracy <sup>13)</sup>	±1 dB					
Flicker instrumental precision <sup>13) 14)</sup>	±0.02 dB					

Spot size and field of view at selected working distances for 29 mm lens (f/2.8)							
Working distance <sup>15)</sup> [mm]	385	400	500	700	800	1000	1200
Spot size [mm]	11.0	11.5	14.9	21.7	25.1	31.9	38.6
<b>LumiTop 2700</b>							
Field of view [mm]	138 x 110	144 x 115	187 x 149	271 x 217	313 x 251	398 x 319	482 x 387
Field of view diagonal [in]	7.0	7.3	9.4	13.7	15.8	20.1	24.3
<b>LumiTop 4000</b>							
Field of view [mm]	156 x 114	163 x 119	211 x 155	307 x 225	355 x 260	450 x 330	546 x 400
Field of view diagonal [in]	7.6	8.0	10.3	15.0	17.3	22.0	26.6

<sup>1)</sup> Inclusive lens and fiber exit.

<sup>2)</sup> Without CAS, with mode mixer.

<sup>3)</sup> External neutral density filters on the lens (OD 0.3/0.6/0.9) are available for increasing the upper measurement limit or measuring modulated light sources.

<sup>4)</sup> Lower measurement limit based on a signal to noise ratio of 10:1 for maximum exposure time (60 seconds LumiTop 2700 / 10 seconds LumiTop 4000). Upper measurement limit based on a signal level < 80 % for a white (non-modulated) LED light source using for minimum exposure time (1 ms LumiTop 2700 / 27  $\mu$ s LumiTop 4000).

<sup>5)</sup> Typical value for maximum deviation over the FOV relative to the CAS spot; calculated for an image with 16 pixels (LumiTop 2700) / 21 pixels (LumiTop 4000) cropped at each edge and 10 by 10 pixels (LumiTop 2700) / 13 by 13 pixels (LumiTop 4000) binning (34 averages) immediately after calibration with reference used for flat-field correction.

<sup>6)</sup>  $2\sigma$  of repeated measurements of one instrument ( $L \approx 100$  cd/m<sup>2</sup>, autoexposure).

<sup>7)</sup> RNU (response non-uniformity) is defined as 99.7 % percentile of the deviation of the mean image value; calculated for an image with 16 pixels (LumiTop 2700) / 21 pixels (LumiTop 4000) cropped at each edge and 10 by 10 pixels (LumiTop 2700) / 13 by 13 pixels (LumiTop 4000) binning (34 averages) immediately after calibration with reference used for flat-field correction.

2700) / 13 by 13 pixels (LumiTop 4000) binning (34 averages) immediately after calibration with reference used for flat-field correction.

<sup>8)</sup> Time between beginning of two subsequent measurements using the SDK; determined with a camera exposure time of 20 ms and CAS exposure time of 200 ms for a white LED ( $L \approx 500$  cd/m<sup>2</sup>). Depends mainly on PC processing capability.

<sup>9)</sup> Lower measurement limit based on a signal to noise ratio of 10:1 for maximum exposure times 65 s for CAS 140D and CAS 140CT, 20 s for CAS 120. Upper measurement limit based on a signal level < 80 % for a white (non-modulated) LED light source using a CAS internal optical density filter OD4 and minimum exposure time (10 ms CAS 140CT / 4 ms CAS 140D and CAS 120). Values valid for CAS 140CT, CAS 120 with 100  $\mu$ m and CAS 140D with 250  $\mu$ m slit width.

<sup>10)</sup> Immediately after calibration relative to calibration standard.

<sup>11)</sup> Immediately after calibration.

<sup>12)</sup> Maximum deviation from average of repeated CAS measurements with a linear polarized light source and varying polarization angle.

<sup>13)</sup>  $L \approx 150$  cd/m<sup>2</sup>, 30 Hz, 10 % sine wave.

<sup>14)</sup>  $2\sigma$  of repeated measurements of one instrument.

<sup>15)</sup> Distance between DUT and front plate of LumiTop.

## LumiTop 4000 with macro lens

LumiTop 4000 with macro lens		
<b>Measurement quantities</b>		
2D	Luminance, color	
Spot	Spectrum, luminance, color, flicker	
<b>General specifications</b>		
Operating system	Windows 7/10 (64 bit)	
Dimensions (l x w x h) <sup>1)</sup>	334.4 mm x 190 mm x 121 mm	
Weight <sup>2)</sup>	4.5 kg	
Power supply	24 V	
Operating temperature range	15 – 35 °C	
Lens	100 mm (macro)	
<b>Camera specifications</b>		
Effective resolution (h x v)	4096 x 3000 pixels (12 megapixels, CMOS)	
Pixel size	3.45 $\mu$ m x 3.45 $\mu$ m	
AD converter	12 bit	
Size CMOS sensor	1.1" (17.52 mm diagonal)	
Interface camera	Gigabit Ethernet, M12 12-Pin Female	
Measurement range 2D <sup>3) 4)</sup>	$L = 0.06$ cd/m <sup>2</sup> – $0.8 \times 10^6$ cd/m <sup>2</sup>	
<b>Accuracy and precision</b>	<b>Luminance</b>	<b>Color</b>
Accuracy of camera (rel. to CAS) <sup>5)</sup>	$\pm 0.4$ %	$\pm 0.002$
Instrumental precision camera <sup>6)</sup>	$\pm 0.03$ %	$\pm 0.0001$
Camera uniformity (RNU) <sup>7)</sup>	$\pm 0.35$ %	$\pm 0.0013$
<b>Measurement time <sup>8)</sup></b>		
Measurement time hybrid mode	0.7 s	
Measurement time camera only	0.7 s	

LumiTop 4000 with macro lens				
CAS specifications	CAS 140D		CAS 140CT	
Interface CAS	USB, PCIe, Gigabit Ethernet		USB, PCIe	
Measurement range CAS <sup>3) 9)</sup>	L = 0.009 cd/m <sup>2</sup> – 1.2 x 10 <sup>8</sup> cd/m <sup>2</sup>		L = 0.045 cd/m <sup>2</sup> – 1.8 x 10 <sup>8</sup> cd/m <sup>2</sup>	
Accuracy and precision	Luminance	Color	Luminance	Color
Accuracy of CAS	±3.0 % <sup>10)</sup>	±0.0015 <sup>11)</sup>	±3.5 % <sup>10)</sup>	±0.0015 <sup>11)</sup>
Instrumental precision CAS <sup>6)</sup>	±0.1 %	±0.0001	±0.1 %	±0.0001
Polarization sensitivity <sup>12)</sup>	±2.0 %	±0.002	±2.0 %	±0.002

CAS specifications	CAS 120	
Interface CAS	USB	
Measurement range CAS <sup>3) 9)</sup>	L = 0.30 cd/m <sup>2</sup> – 4.5 x 10 <sup>8</sup> cd/m <sup>2</sup>	
Accuracy and precision	Luminance	Color
Accuracy of CAS	±4.0 % <sup>10)</sup>	±0.002 <sup>11)</sup>
Instrumental precision CAS <sup>6)</sup>	±0.1 %	±0.0002
Polarization sensitivity <sup>12)</sup>	±2.0 %	±0.002

Flicker specifications	
Flicker range	5 cd/m <sup>2</sup> – 1800 cd/m <sup>2</sup>
Flicker accuracy <sup>13)</sup>	±1 dB
Flicker instrumental precision <sup>13) 14)</sup>	±0.02 dB

Spot size and field of view at selected working distances for 100 mm lens (f/2.8)			
Working distance <sup>15)</sup> [mm]	257	400	550
Spot size [mm]	1.0	2.8	4.4
Field of view [mm]	14.4 x 10.5	40.2 x 29.5	61.6 x 45.1
Field of view diagonal [in]	0.7	2.0	3.0

- <sup>1)</sup> Inclusive lens, fiber exit, and back plate connector. At shortest working distance for the 100 mm lens.
- <sup>2)</sup> Without CAS, with mode mixer.
- <sup>3)</sup> External neutral density filters on the lens up to OD 3 are available for increasing the upper measurement limit or measuring modulated light sources.
- <sup>4)</sup> Lower measurement limit based on a signal to noise ratio of 10:1 for 10 seconds exposure time. Upper measurement limit based on a signal level < 80 % for a white (non-modulated) LED light source using an exposure time of 27  $\mu$ s.
- <sup>5)</sup> Typical value for maximum deviation over the FOV relative to the CAS spot; calculated for an image with 21 pixels cropped at each edge and 13 by 13 pixel binning (34 averages) immediately after calibration with reference used for flat-field correction.
- <sup>6)</sup> 2 $\sigma$  of repeated measurements of one instrument (L  $\approx$  100 cd/m<sup>2</sup>, autoexposure).
- <sup>7)</sup> RNU (response non-uniformity) is defined as 99.7 % percentile of the deviation of the mean image value; calculated for an image with 21 pixels cropped at each edge and 13 by 13 pixel binning (34 averages) immediately after calibration with reference used for flat-field correction.

- <sup>8)</sup> Time between beginning of two subsequent measurements using the SDK; Determined with a camera exposure time of 10 ms and CAS exposure time of 200 ms for a white LED (L  $\approx$  500 cd/m<sup>2</sup>). Depends on PC processing capability.
- <sup>9)</sup> Lower measurement limit based on a signal to noise ratio of 10:1 for maximum exposure times 65 s for CAS 140D and CAS 140CT, 20 s for CAS 120 and 1 s for CAS 100. Upper measurement limit based on a signal level < 80 % for a white (non-modulated) LED light source using a CAS internal optical density filter OD4 and minimum exposure time (10 ms CAS 140CT / 4 ms CAS 140D, CAS 100 and CAS 120). Values valid for CAS 140CT, CAS 100, CAS120 with 100  $\mu$ m and CAS 140D with 250  $\mu$ m slit width.
- <sup>10)</sup> Immediately after calibration relative to calibration standard.
- <sup>11)</sup> Immediately after calibration.
- <sup>12)</sup> Maximum deviation from average of repeated CAS measurements with a linear polarized light source and varying polarization angle.
- <sup>13)</sup> L  $\approx$  150 cd/m<sup>2</sup>, 30Hz, 10% sine wave.
- <sup>14)</sup> 2 $\sigma$  of repeated measurements of one instrument.
- <sup>15)</sup> Distance between DUT and front plate of LumiTop 4000.

## LumiTop X150

LumiTop X150	
Measurement quantities	
2D	Luminance, color
Spot	Spectrum, luminance, color, flicker
General specifications	
Operating system	Windows 7/10 (64 bit)
Dimensions (l x w x h) <sup>1)</sup>	365 mm x 230 mm x 160 mm



<b>LumiTop X150</b>	
<b>General specifications</b>	
Weight <sup>2)</sup>	10.4 kg
Power supply	24 V
Operating temperature range	15 – 35 °C

<b>Camera specifications</b>	
Effective resolution (h x v)	14,192 x 10,640 (151 megapixels, CMOS)
Pixel size	3.76 µm x 3.76 µm
Dynamic range	80.8 dB
AD converter	14 bit
Size sensor	2.6" (66.8 mm diagonal)
Interface camera	Gigabit Ethernet, M12 12-Pin Female, Quad CoaXPress (4 x 6.25 Gbit/s)
Measurement range 2D <sup>3)</sup> 4)	L = 0.003 cd/m <sup>2</sup> – 50,000 cd/m <sup>2</sup>

<b>Accuracy and precision</b>	<b>Luminance</b>		<b>Color</b>	
Accuracy of camera (rel. to CAS) <sup>5)</sup>	±0.2 %		±0.001	
Instrumental precision camera <sup>6)</sup>	±0.04 %		±0.0002	
Camera uniformity (RNU) <sup>7)</sup>	±0.015 %		±0.0006	
<b>Measurement time<sup>8)</sup></b>	<b>Single image</b>	<b>Region of interest</b>	<b>2x2 image</b>	<b>Region of interest</b>
Measurement time hybrid mode	3.5 s	1.9 s	8.3 s	5.5 s
Measurement time camera only	3.2 s	1.1 s	7.5 s	4.7 s

<b>CAS specifications</b>	<b>CAS 140D</b>			
Interface CAS	USB, PCIe, Gigabit Ethernet			
Measurement range CAS <sup>3)</sup> 9)	L = 0.0004 cd/m <sup>2</sup> – 5 x 10 <sup>6</sup> cd/m <sup>2</sup> (250 µm slit size)			
	L = 0.0013 cd/m <sup>2</sup> – 1.2 x 10 <sup>7</sup> cd/m <sup>2</sup> (100 µm slit size)			
<b>Accuracy and precision</b>	<b>Luminance</b>		<b>Color</b>	
Accuracy of CAS	±3.0 % <sup>10)</sup>		±0.0015 <sup>11)</sup>	
Instrumental precision CAS <sup>6)</sup>	±0.1 %		±0.0002	
Polarization sensitivity <sup>12)</sup>	±2.0 %		±0.002	

<b>Available lenses</b>					
<b>Number</b>	<b>Focal length</b>	<b>FOV size</b>	<b>FOV diagonal</b>	<b>CAS spot diagonal</b>	<b>Working distance <sup>13)</sup></b>
1	104 mm f/4	max. 193 mm x 145 mm	9.5"	11.6 mm	~ 400 mm
		min. 137 mm x 103 mm	6.7"	8.2 mm	~ 300 mm
2	92 mm f/3.3	max. 331 mm x 248 mm	16.3"	19.9 mm	~ 560 mm
		min. 226 mm x 170 mm	11.1"	13.6 mm	~ 380 mm

<sup>1)</sup> Not including external fiber and mode mixer.

<sup>2)</sup> Without CAS, with mode mixer.

<sup>3)</sup> Contact us for extended measurement range options.

<sup>4)</sup> Lower measurement limit based on a signal to noise ratio of 10:1 for maximum exposure time (60 s). Upper measurement limit based on a defocused measurement with signal level < 80 % of a white (non-modulated) LED light source at minimum exposure time (80 µs).

<sup>5)</sup> Typical value for maximum deviation over the FOV relative to the CAS spot; calculated for an image with 72 pixels cropped at each edge and 12 by 12 pixels binning (34 averages) immediately after calibration with reference used for flat-field correction.

<sup>6)</sup> 2σ of repeated measurements of one instrument (L ≈ 100 cd/m<sup>2</sup>, autoexposure, 3h warm up time).

<sup>7)</sup> RNU (response non-uniformity) is defined as 99.7 % percentile of the deviation of the mean image value; calculated for an image with 72 pixels cropped at each edge and 12 by 12 pixels binning (34 averages) immediately after calibration with reference used for flat-field correction.

<sup>8)</sup> Time between beginning of two subsequent measurements using the SDK; determined with a camera exposure time of 20 ms and CAS exposure time of 200 ms for a white LED (L ≈ 500 cd/m<sup>2</sup>). Depends mainly on PC processing capability. Single image refers to a one shot 151 MP demosaiced RGB image. 2x2 image refers to a 2x2 pixel shifted image with 151 MP resolution per color channel and is only available with optional pixel shifter hardware.

ROI-Region of Interest refers to an image size filling only 50% of the camera sensor in each dimension.

<sup>9)</sup> Lower measurement limit based on a signal to noise ratio of 10:1 for maximum exposure times 65 s for CAS 140D. Upper measurement limit based on a signal level

< 80 % for a white (non-modulated) LED light source using a CAS internal optical density filter OD4 and minimum exposure time 4 ms (CAS 140D).

<sup>10)</sup> Immediately after calibration relative to calibration standard.

<sup>11)</sup> Immediately after calibration.

<sup>12)</sup> Maximum deviation from average of repeated CAS measurements with a linear polarized light source and varying polarization angle.

<sup>13)</sup> Distance between DUT and front plate of LumiTop.

## LumiTop 2700 with wide angle lens

LumiTop 2700 - Wide angle lens		
<b>Measurement quantities</b>		
2D	Luminance, color	
Spot	Spectrum, luminance, color, flicker	
<b>Camera specifications</b>		
Effective resolution (h x v)	~ 2750 x 2200 pixels (6.1 megapixels)	
Pixel size	4.54 $\mu\text{m}$ x 4.54 $\mu\text{m}$	
AD converter	12 bit	
Size CCD sensor	1" (16 mm diagonal)	
<b>General specifications</b>		
Interface CAS	USB, PCIe	
Interface camera	Gigabit Ethernet	
Operating system	Windows 7 / 10 (64 bit)	
Dimensions (l x w x h) <sup>1)</sup>	339 mm x 194 mm x 112 mm	
Weight <sup>2)</sup>	3.7 kg	
Power supply	12 V	
Operating temperature range	15 – 35 °C	
<b>Measurement range <sup>3)</sup></b>		
Measurement range CAS <sup>4)</sup>	L = 0.008 cd/m <sup>2</sup> – 50 x 10 <sup>6</sup> cd/m <sup>2</sup>	
Measurement range 2D <sup>5)</sup>	L = 0.0025 cd/m <sup>2</sup> – 3,000 cd/m <sup>2</sup>	
<b>Accuracy and precision</b>	<b>Luminance</b>	<b>Color</b>
Accuracy of CAS	$\pm 3.5\%$ <sup>6)</sup>	$\pm 0.0015$ <sup>7)</sup>
Accuracy of camera (rel. to CAS) <sup>8)</sup>	$\pm 0.6\%$	$\pm 0.0025$
Instrumental precision CAS <sup>9)</sup>	$\pm 0.1\%$	$\pm 0.0001$
Instrumental precision camera <sup>8)</sup>	$\pm 0.03\%$	$\pm 0.0001$
Polarization sensitivity <sup>10)</sup>	$\pm 2\%$	$\pm 0.0004$
Camera uniformity (RNU) <sup>11)</sup>	$\pm 1\%$	$\pm 0.0020$
<b>Measurement time <sup>12)</sup></b>		
Measurement time hybrid mode	0.5 s	
Measurement time camera only	0.5 s	
<b>Flicker</b>		
Flicker range	20 cd/m <sup>2</sup> – ca. 600 cd/m <sup>2</sup>	
Flicker accuracy <sup>13)</sup>	$\pm 1\text{dB}$	
Flicker instrumental precision <sup>13) 14)</sup>	$\pm 0.02\text{dB}$	
<b>Lens 11 mm</b>		
Aperture	f/2.8	

LumiTop 2700 - Wide angle lens							
Spot size and field of view at selected working distances							
Working distance <sup>15)</sup> [mm]	1100	1200	1300	1400	1500	1600	1700
Spot size [mm]	82.9	91.6	100.3	109.2	118.2	127.2	136.3
Field of view [mm]	1036 x 830	1144 x 916	1254 x 1004	1364 x 1093	1476 x 1182	1590 x 1273	1703 x 1364
Field of view diagonal [in]	52.2	57.7	63.2	68.8	74.5	80.2	85.9

<sup>1)</sup> Inclusive lens and fiber exit.

<sup>2)</sup> Without CAS, with mode mixer.

<sup>3)</sup> External neutral density filters on the lens (OD 0.3/0.6/0.9) are available for increasing the upper measurement limit or measuring modulated light sources.

<sup>4)</sup> Lower measurement limit based on a signal to noise ratio of 10:1 for 65 s exposure time. Upper measurement limit based on a signal level < 80 % for a white (non-modulated) LED light source using an optical density filter OD4 and an exposure time of 10 ms.

<sup>5)</sup> Lower measurement limit based on a signal to noise ratio of 10:1 for 60 seconds exposure time. Upper measurement limit based on a signal level < 80 % for a white (non-modulated) LED light source using an exposure time of 1 ms.

<sup>6)</sup> Immediately after calibration relative to calibration standard.

<sup>7)</sup> Immediately after calibration.

<sup>8)</sup> Typical value for maximum deviation over the FOV relative to the CAS spot; calculated for an image with 16 pixels cropped at each edge and 10 by 10 pixel binning (34 averages) immediately after calibration with reference used for flat-field correction.

<sup>9)</sup>  $2\sigma$  of repeated measurements of one instrument ( $L \approx 100 \text{ cd/m}^2$ , autoexposure).

<sup>10)</sup> Maximum deviation from average of repeated CAS measurements with a linear polarized light source and varying polarization angle.

<sup>11)</sup> RNU (response non-uniformity) is defined as 99.7 % percentile of the deviation of the mean image value; calculated for an image with 16 pixels cropped at each edge and 10 by 10 pixel binning (34 averages) immediately after calibration with reference used for flat-field correction.

<sup>12)</sup> Time between beginning of two subsequent measurements using the SDK; determined with a camera exposure time of 20 ms and CAS exposure time of 200 ms for a white LED ( $L \approx 500 \text{ cd/m}^2$ ). Depends on PC processing capability.

<sup>13)</sup>  $L \approx 150 \text{ cd/m}^2$ , 30Hz, 10% sine wave.

<sup>14)</sup>  $2\sigma$  of repeated measurements of one instrument.

<sup>15)</sup> Distance between DUT and front plate of LumiTop

## LumiTop AR/VR (preliminary)

LumiTop AR/VR	
Camera specifications	
Measurement range 2D	$L = 0.01 \text{ cd/m}^2 - 1800 \text{ cd/m}^2$
Measurement range CAS	$L = 0.003 \text{ cd/m}^2 - 2 \times 10^6 \text{ cd/m}^2$
Angular resolution	> 30 Pixel/° (full FoV)
Lens specifications	
Field of View (FoV)	120°
Adjustable focus distance	0.3 m – ∞
Entrance pupil	~1 – 3.6 mm
MTF @ 50 LP/mm	> 50 %
Lateral chromatic aberrations	~1 Pixel
Calibration specifications	
Luminance accuracy	± 3%
Color accuracy (CAS 140D)	± 0.0015 Traceability to PTB (= very low device-to-device deviations in distributed production environment )

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