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The phase control company

Quadriwave Lateral Shearing Interferometry for optical metasurfaces metrology

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Summary

- ✓ Introduction to Optical Metasurfaces
- ✓ Challenge that is faced
- ✓ Introduction Quadriwave Lateral Shearing Interferometry
- ✓ Use Case : Optical Metrology on a Metalens
- ✓ Other Examples
- ✓ Conclusion and Perspectives

Optical Metasurfaces

Metasurface are composed of subwavelength nanostructured element engineered to control the optical properties.

a) Effective Refractive Index Metasurface b) Pancharatnam-Berry Metasurface

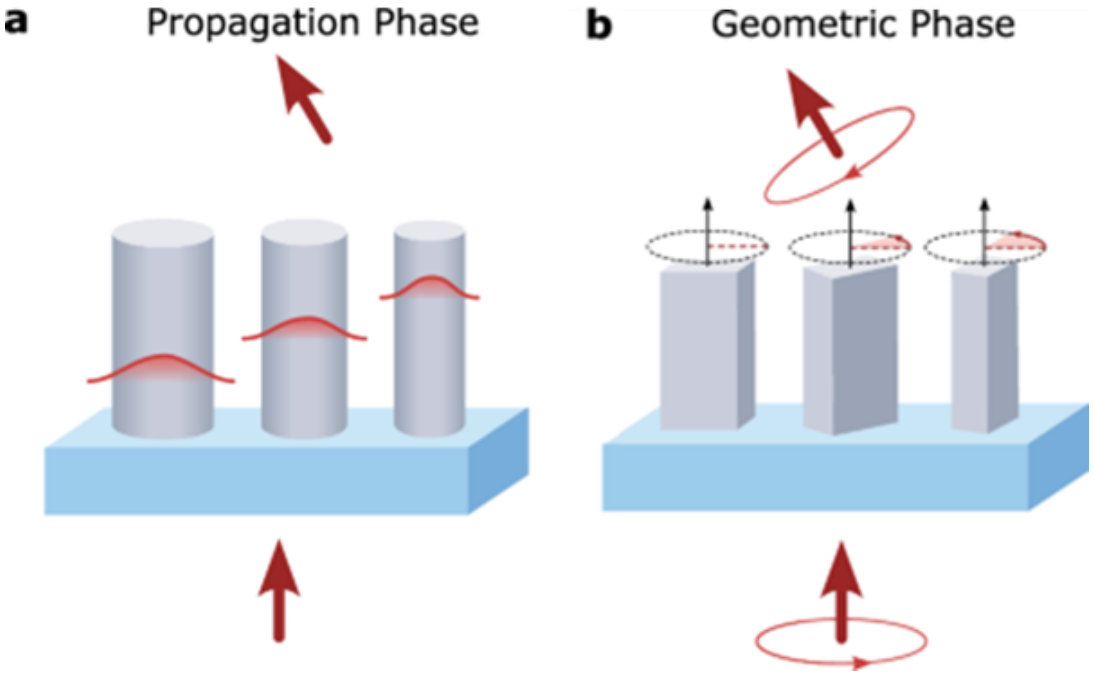

Fig : Schematic representation of the three mechanisms used to control phase propagation in dielectric metasurfaces.
Source : Kossowski et al., 2025, Metrology of metasurfaces: optical properties

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The Challenge

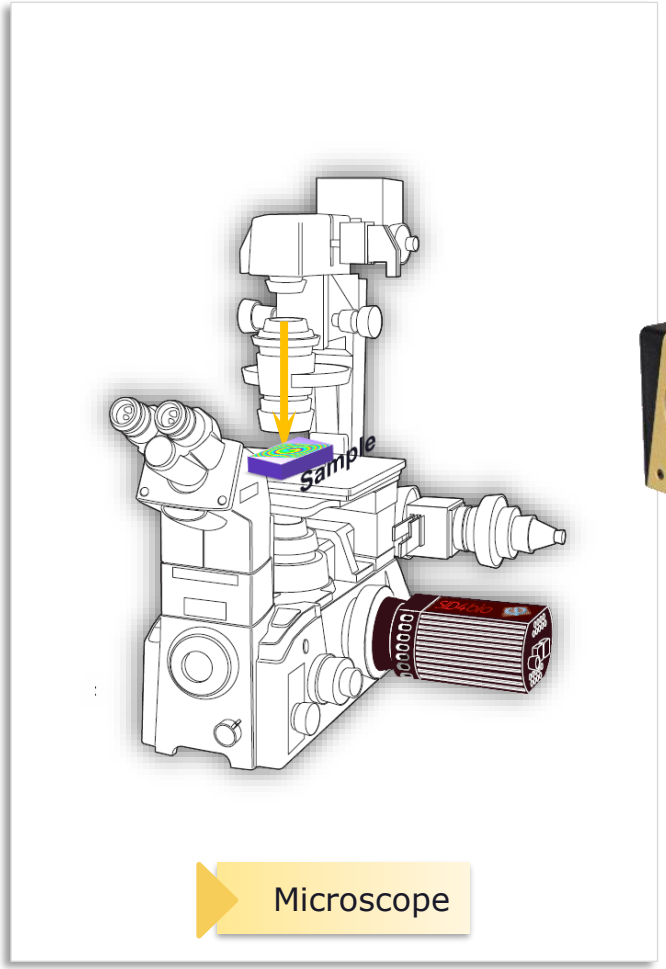
Ensure that the produce metasurface relate to the design

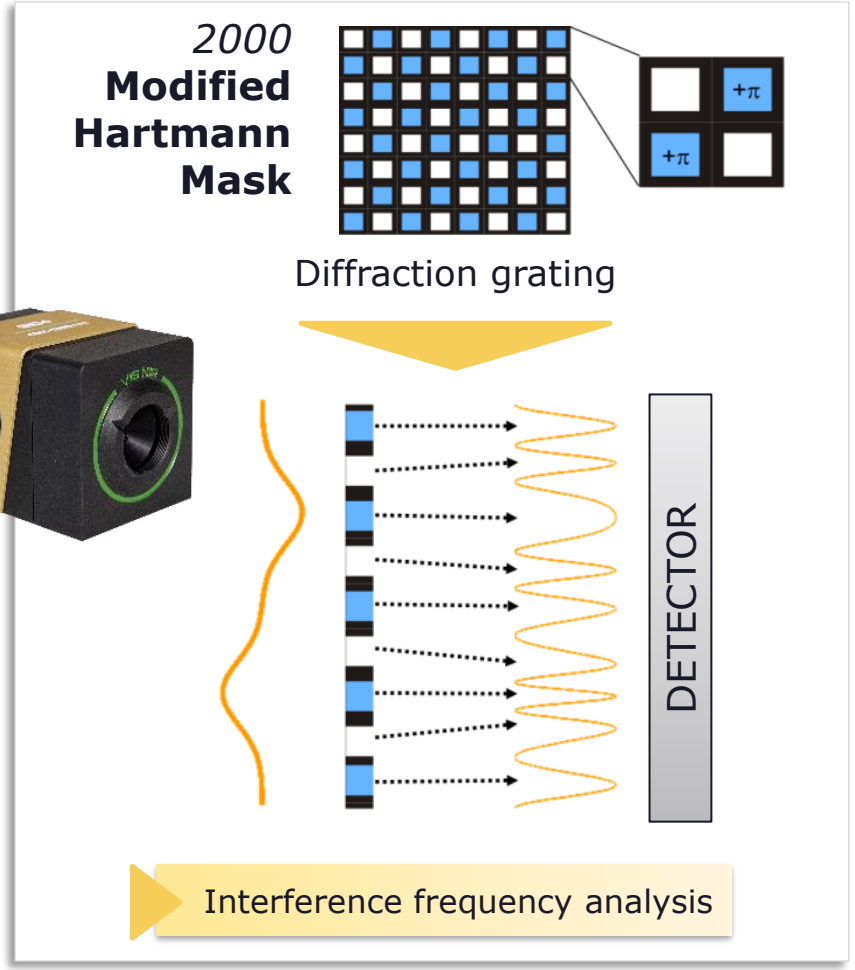
How to proceed? Verify the performance and use the feedback to retroact

How to characterize? Measure the wavefront once shaped by the metasurface

What do you need? One solution that is robust and high-resolution but that is also easy and quick to be use

Quadriwave lateral shearing interferometry





- Four replicas are generated by the diffraction grating and create an interferogram on the sensor
- The phase is encoded in the interference fringe deformation
- Phase image and intensity image are computed in real-time and displayed on the user screen

Many advantages:

- Fully achromatic
- Higher resolution
- Larger dynamic range
- High NA beam compatible
- Independent to Polarization

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Metalens characterization: Sample and Setup

On microscope

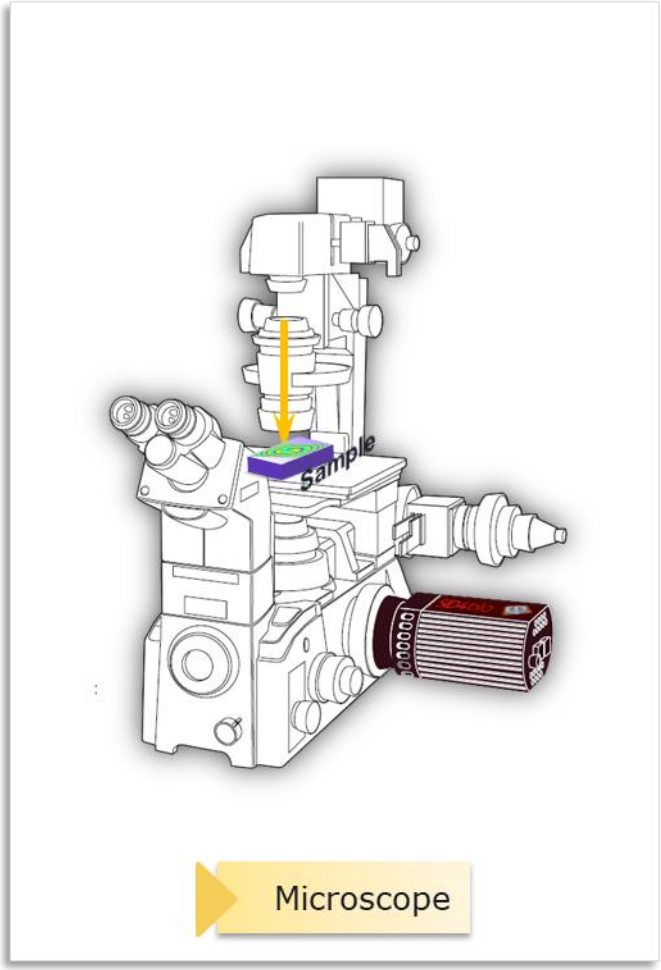
40x

625nm

ERI Metalens

Negative Defocus

Spherical Aberration



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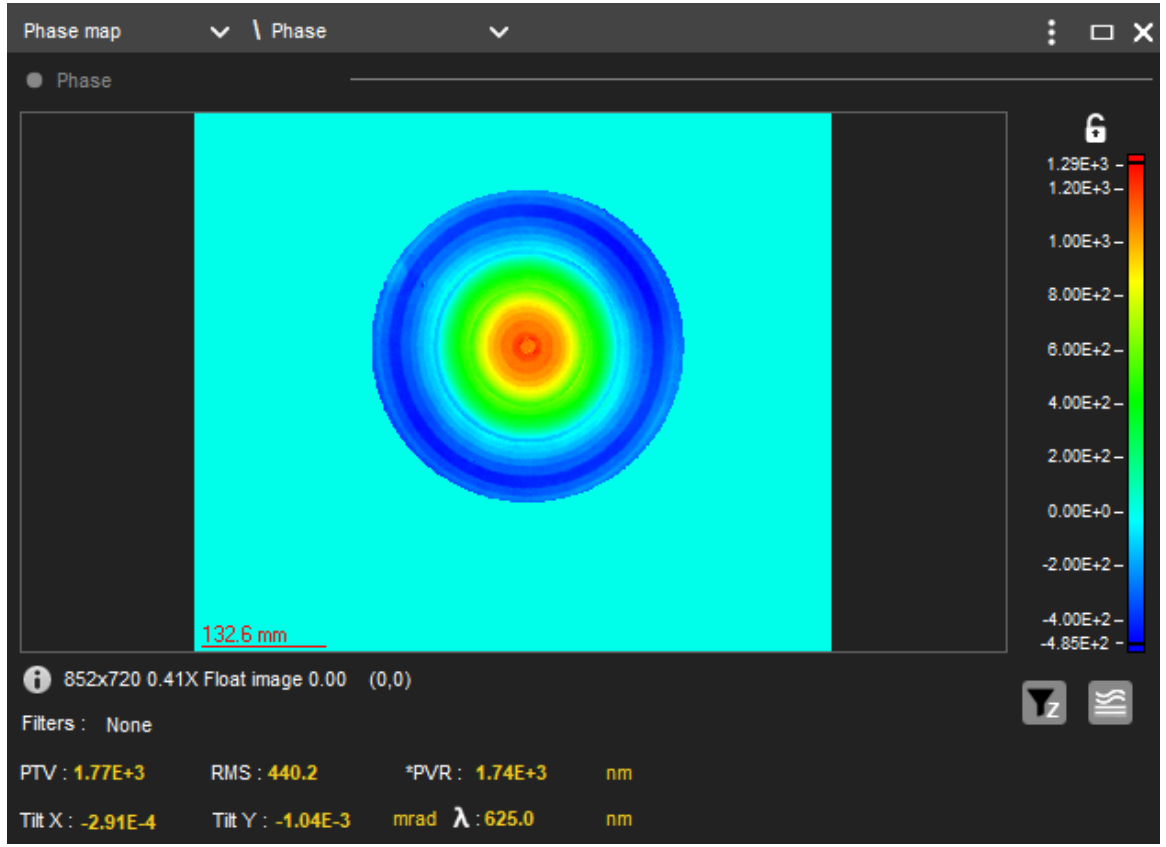
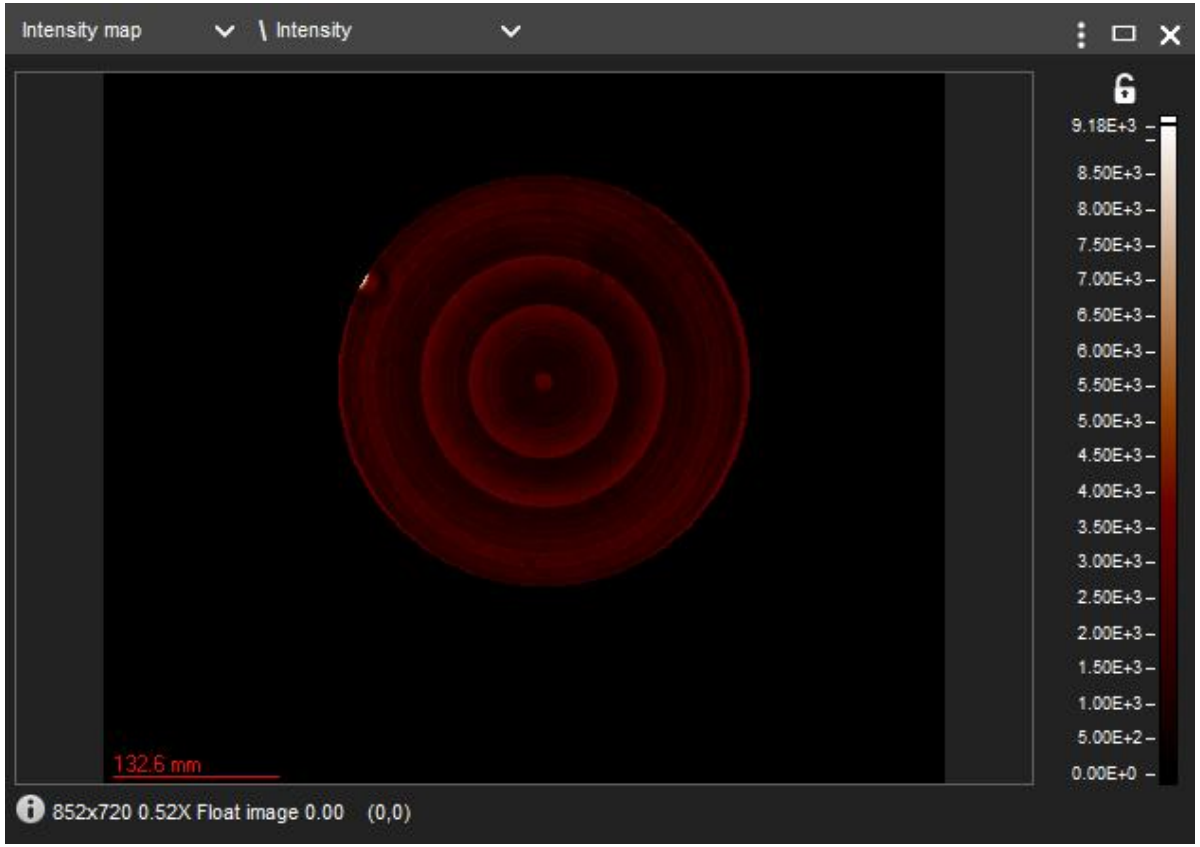
Metalens characterization: wavefront aberrations





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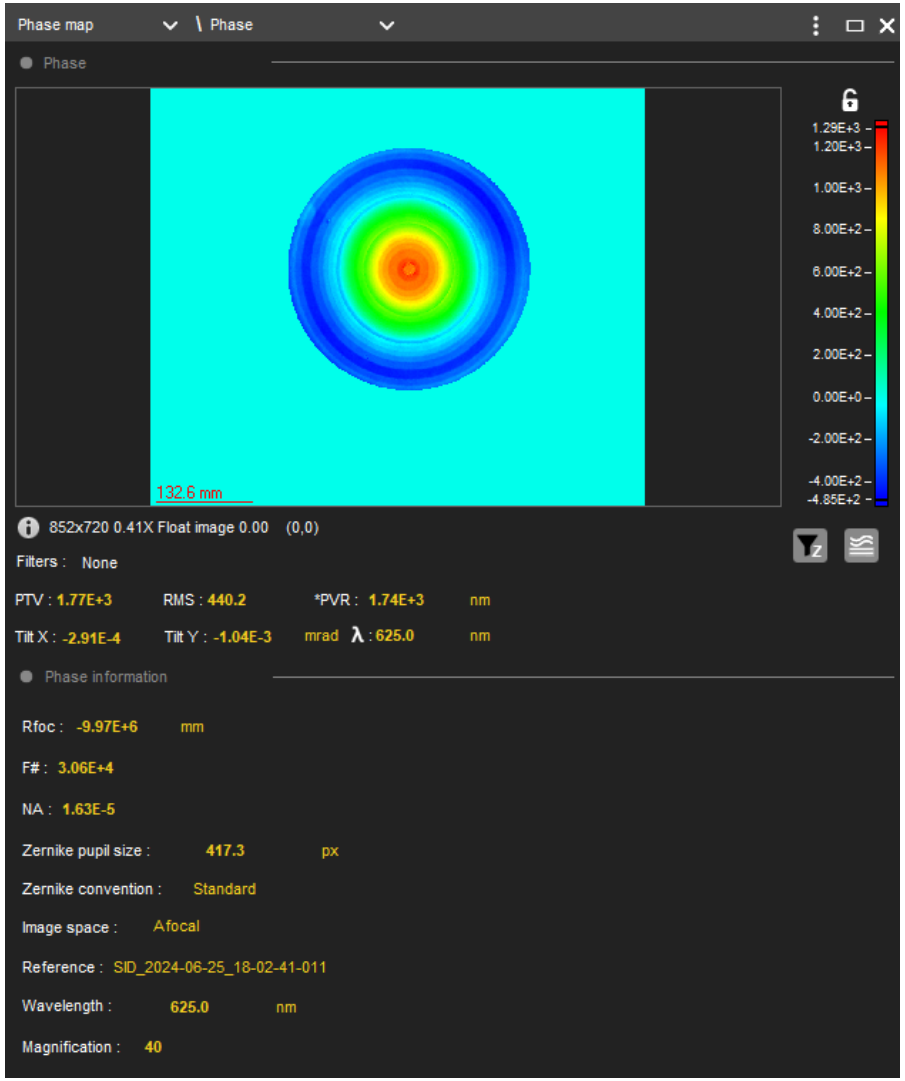
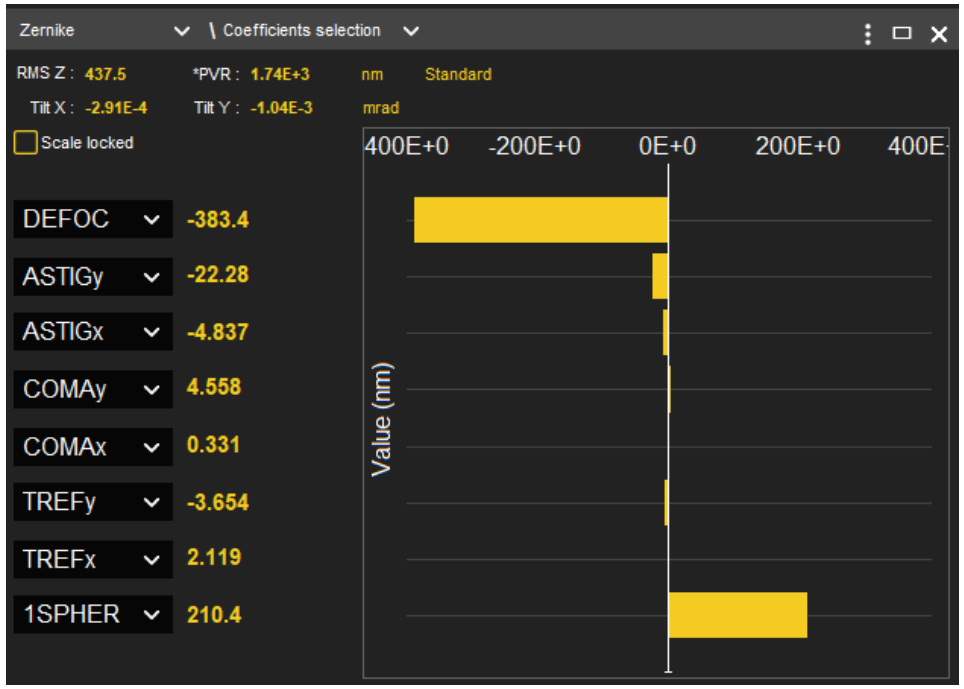
Metalens characterization: wavefront aberrations





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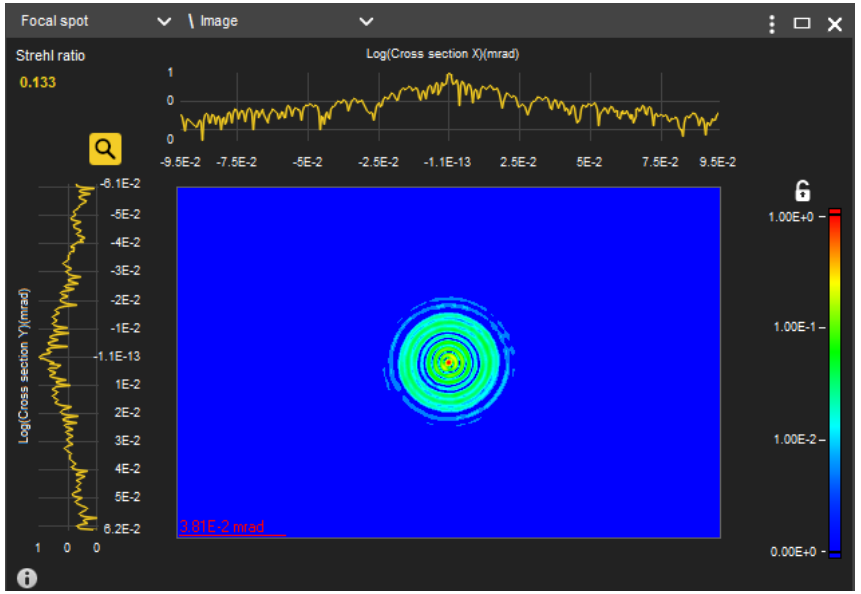
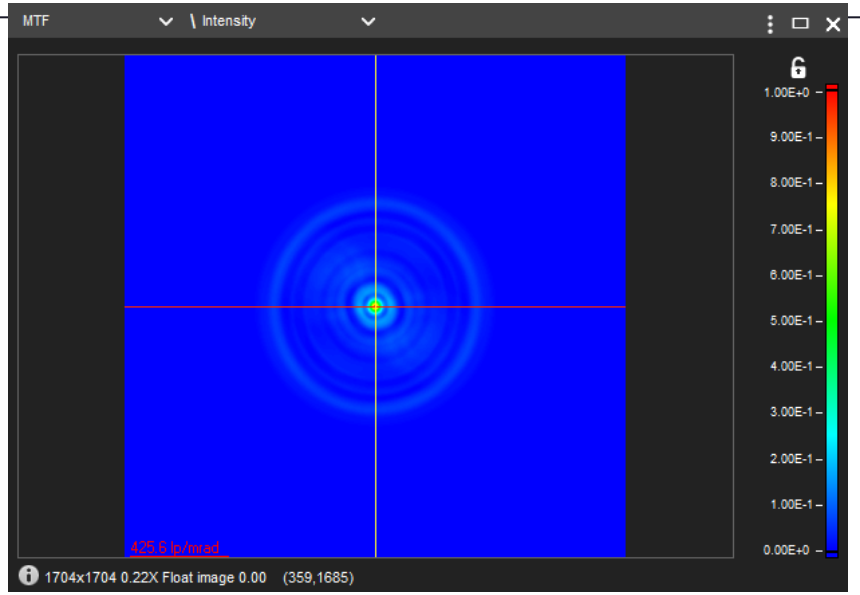
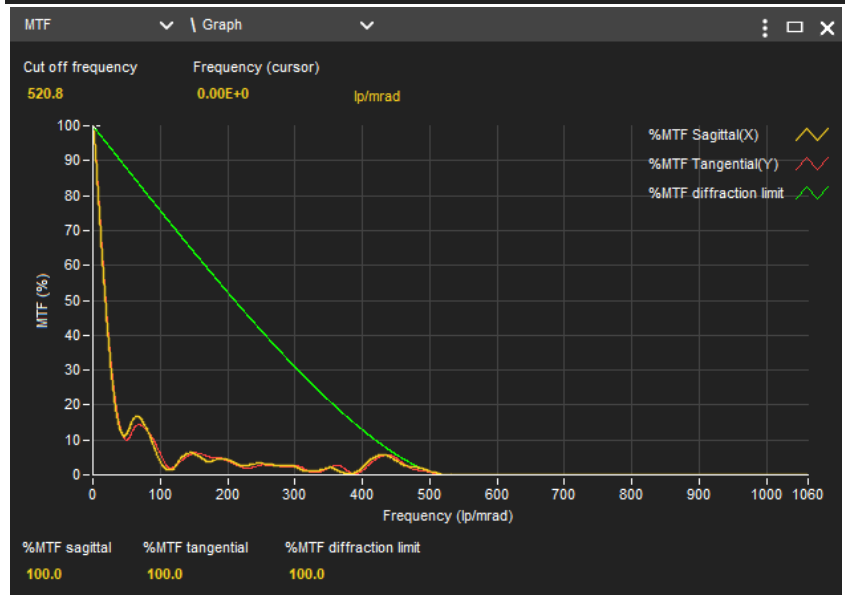
Metalens characterization: MTF

PSF







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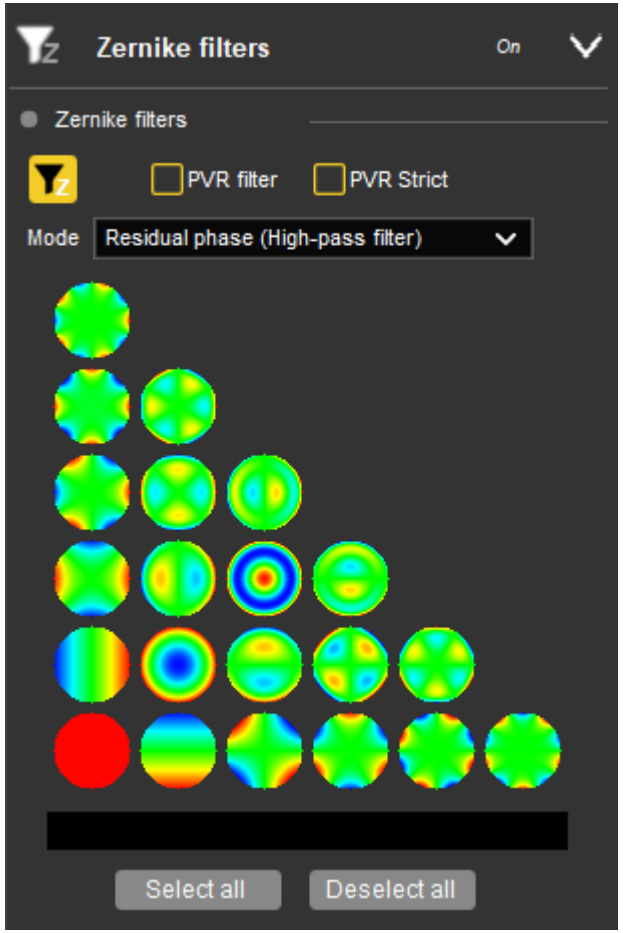
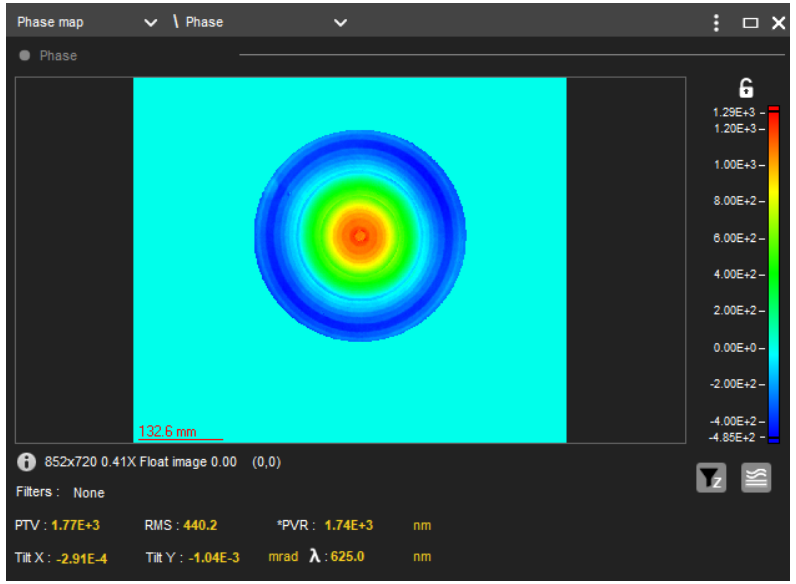
Metalens characterization: beyond the defocus





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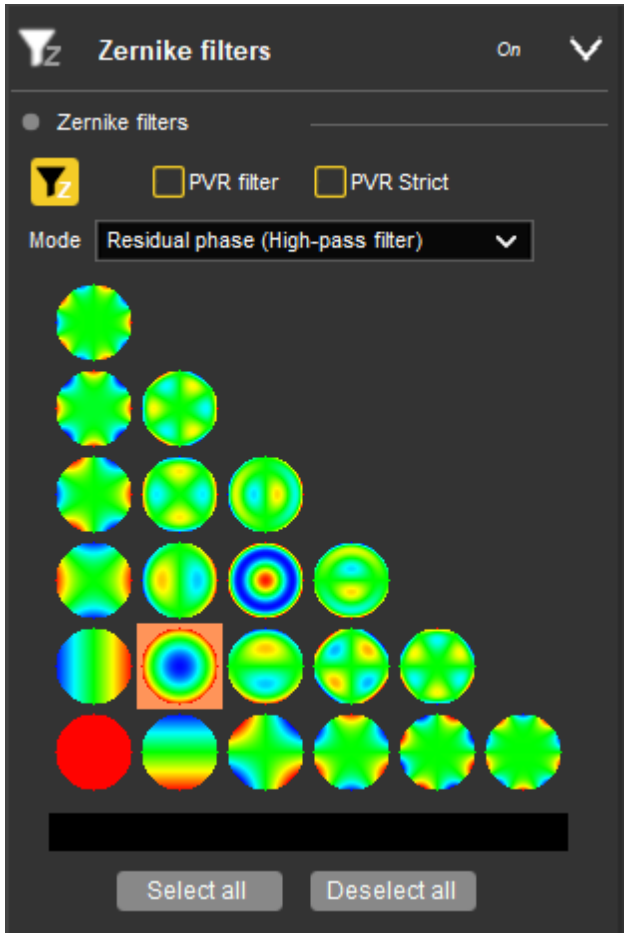
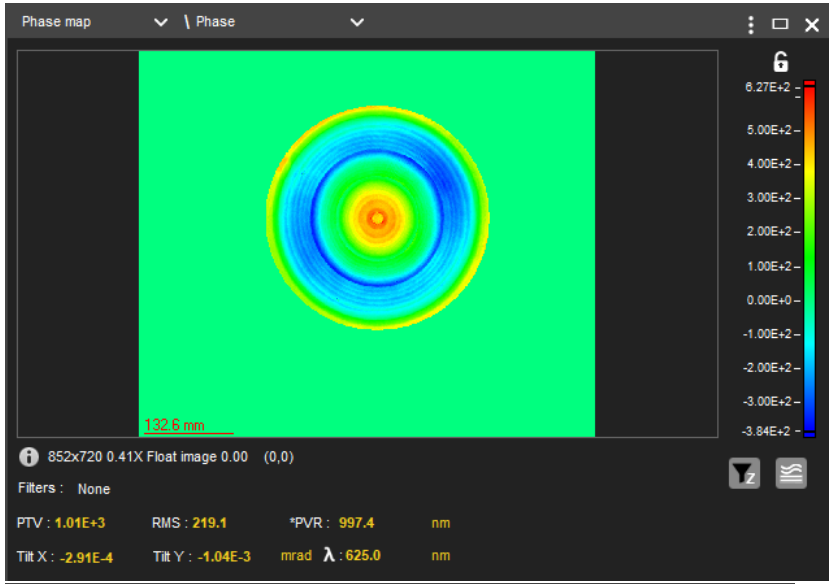
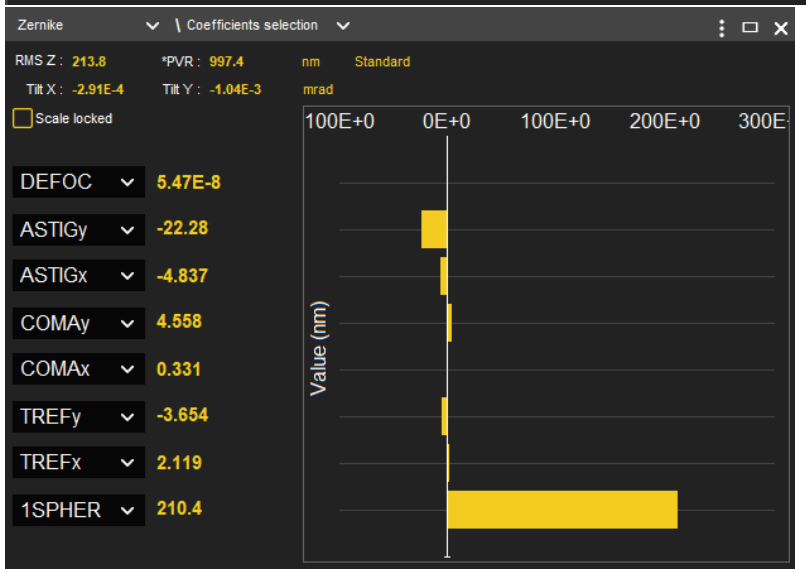
Metalens characterization: beyond the defocus







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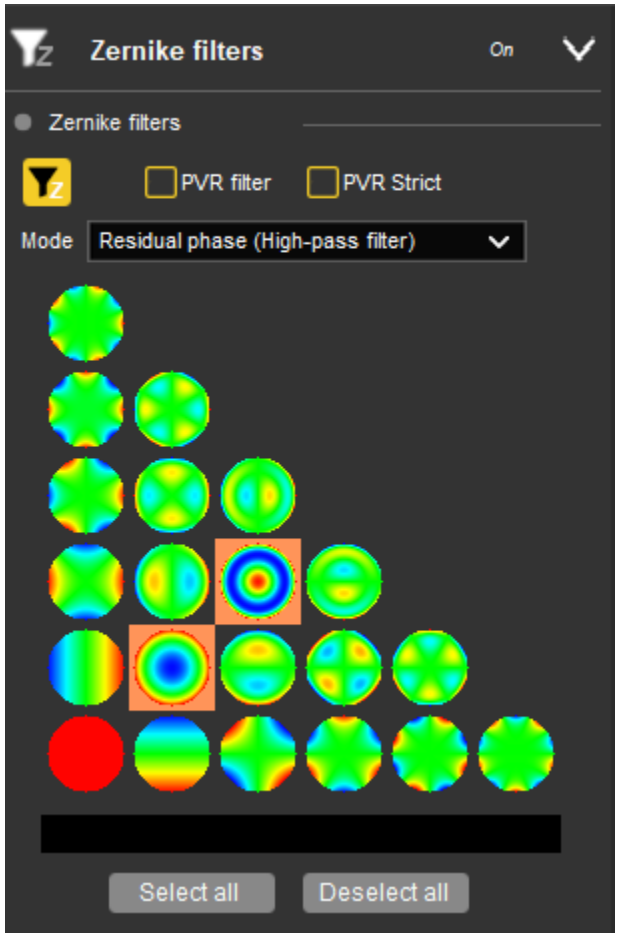
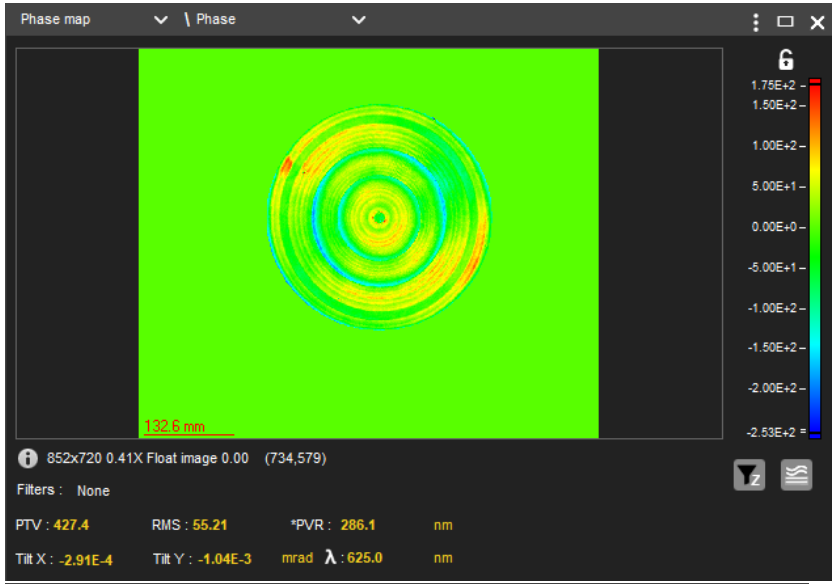
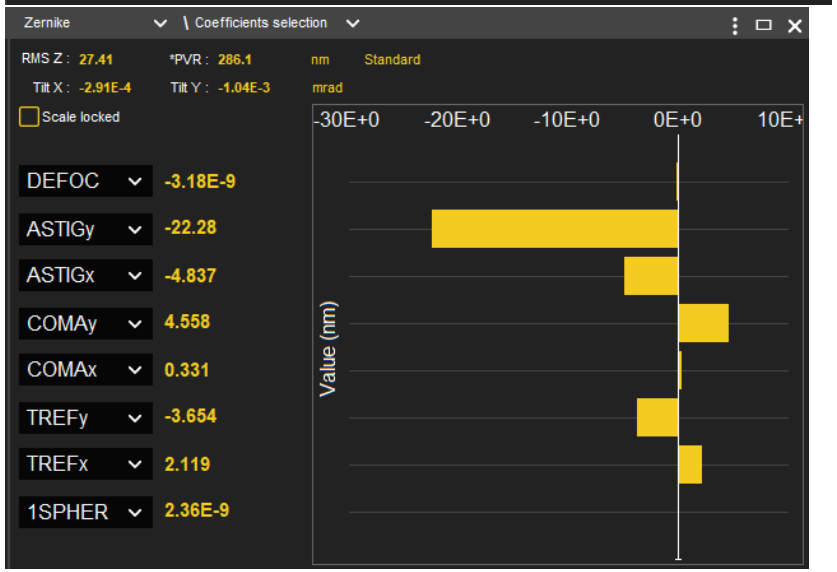
Metalens characterization: behind the defocus







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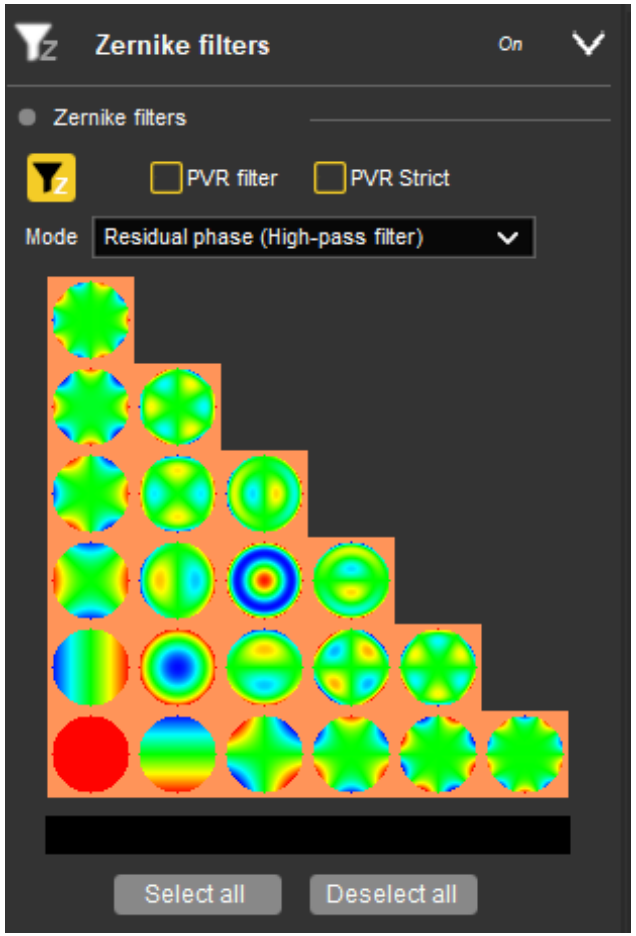
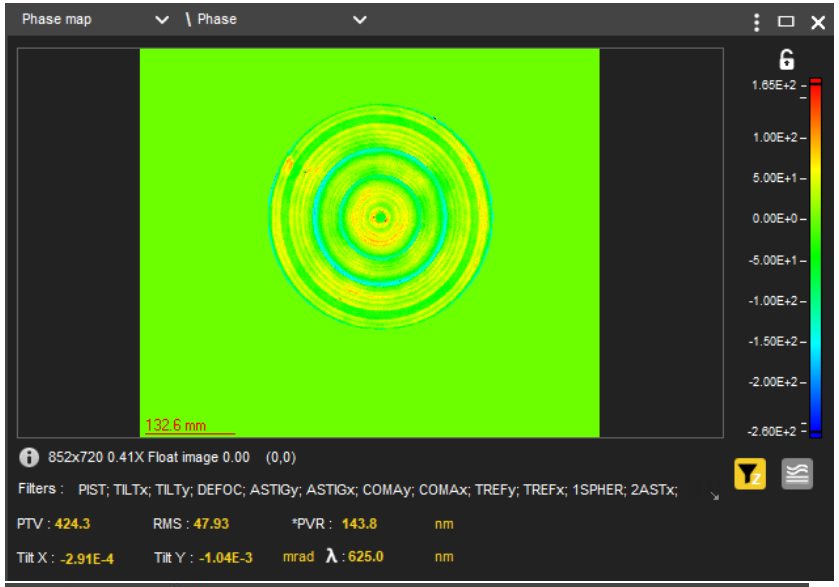
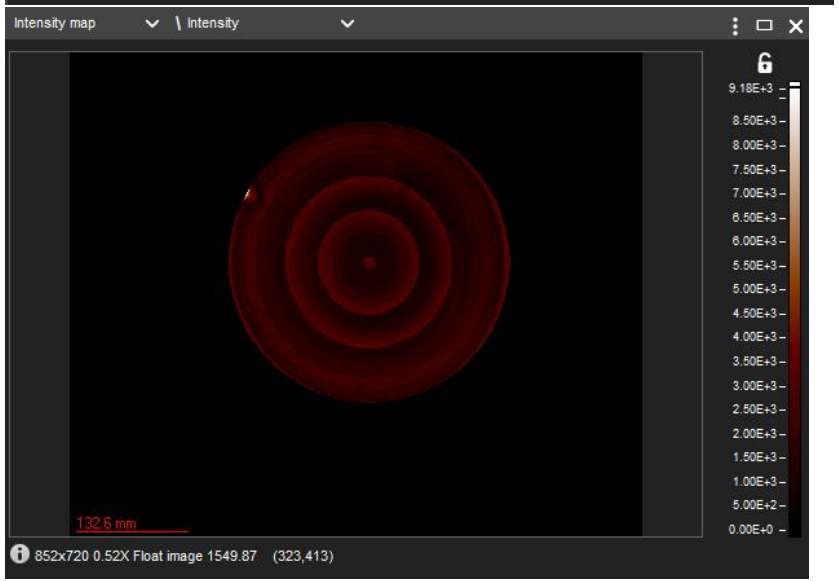
Metalens characterization: Defect







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Other Example

- ✓ PB Metalens
- ✓ Vortex
- ✓ Beam Deflector

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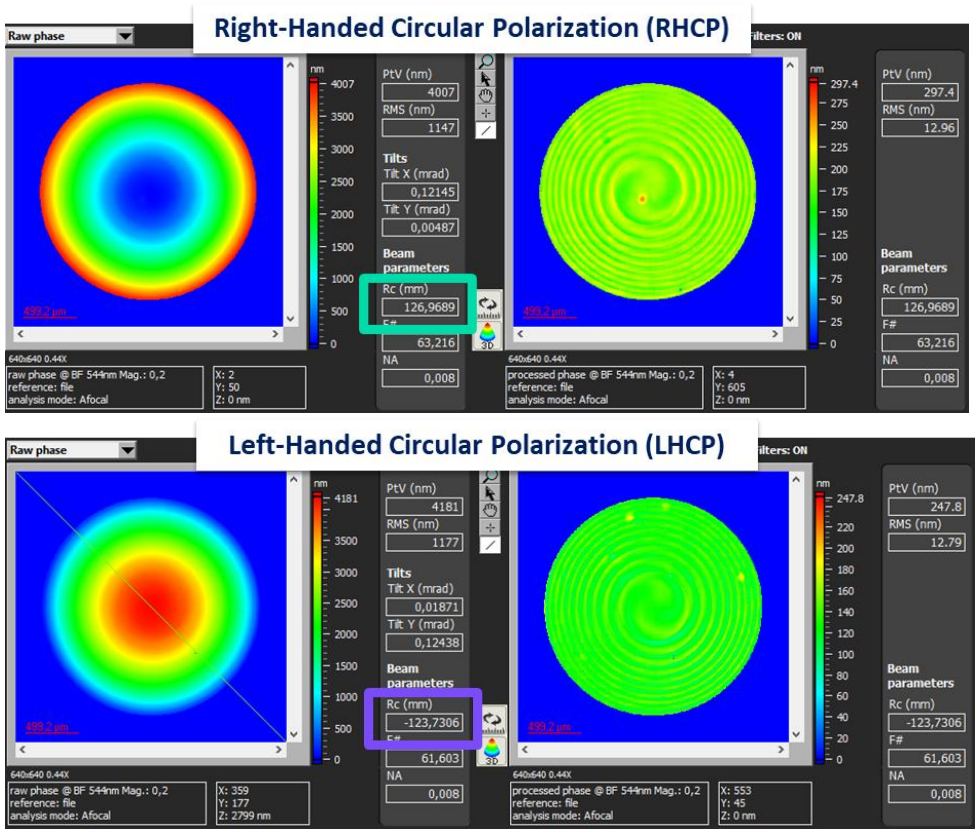
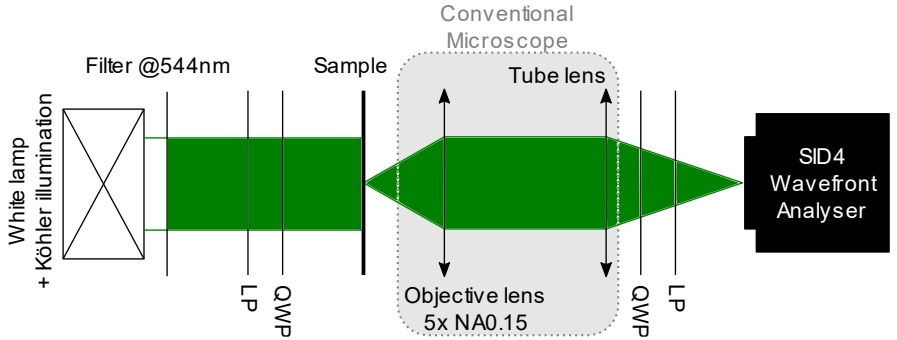
Optical function – Polarization Independant

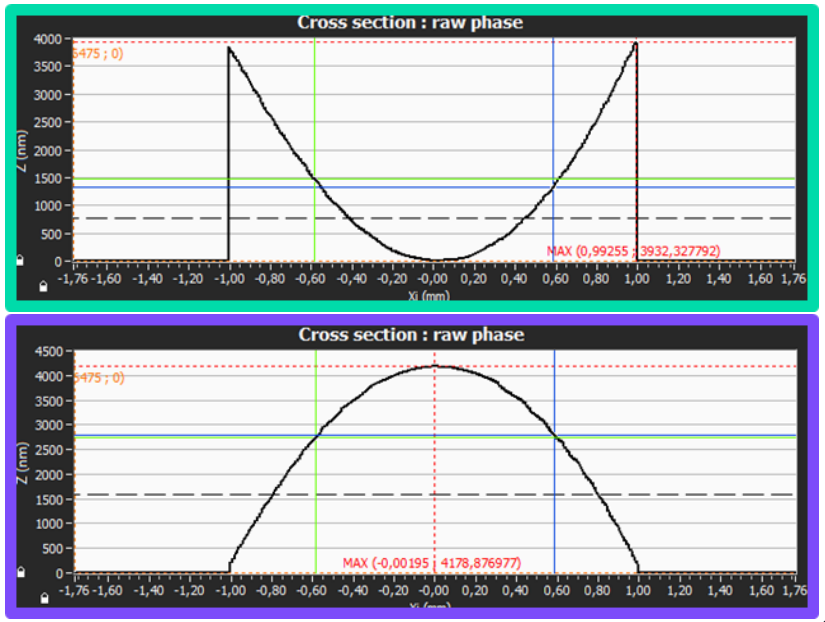
PB metalens: focal length is polarization dependent

QWLSI measurement is polarization independent





Wavefront curvature sign is inverted as polarization direction is rotated



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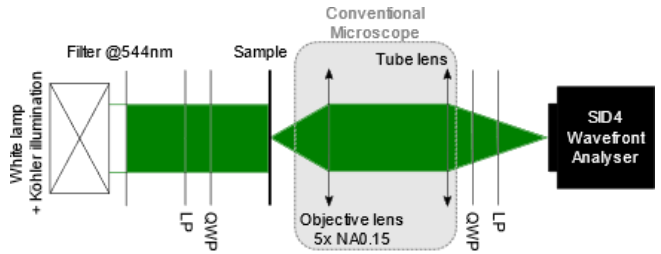
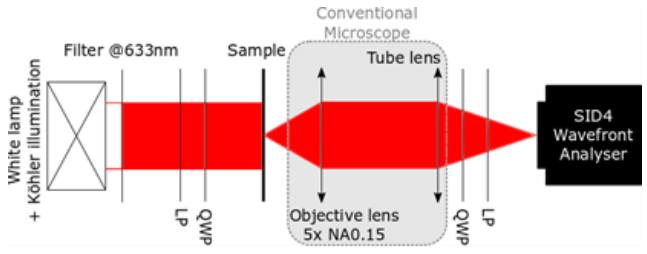
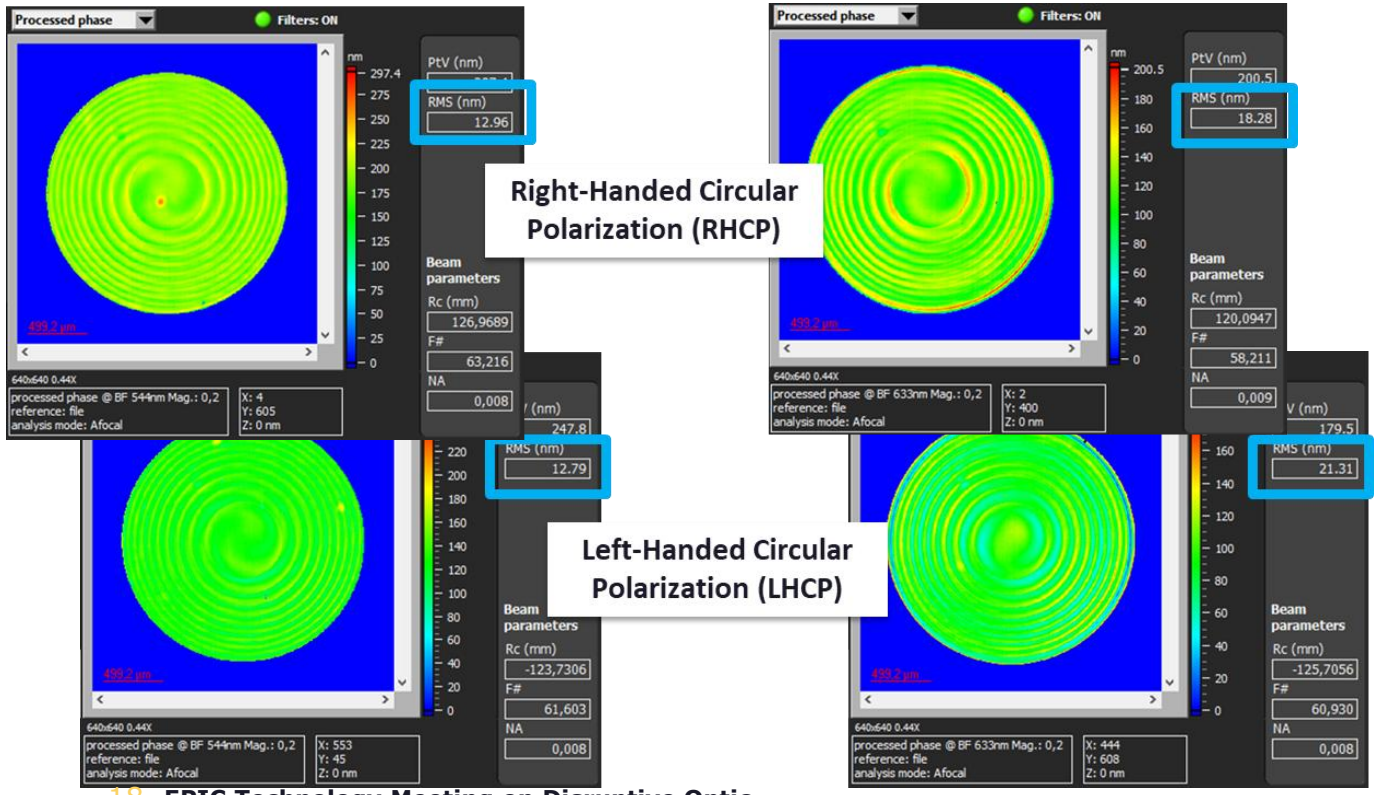
Optical function – Achromaticity





544 nm

633 nm



QWLSI is an achromatic technology

- PB metasurface optimized design wavelength is 544nm
- Measurements can be done at any wavelength in the spectral sensitivity range of the sensor
- Lower residual high frequency wavefront aberrations are obtained when the measurement is done at the design wavelength (544nm)
- Detect design defects that are wavelength dependent

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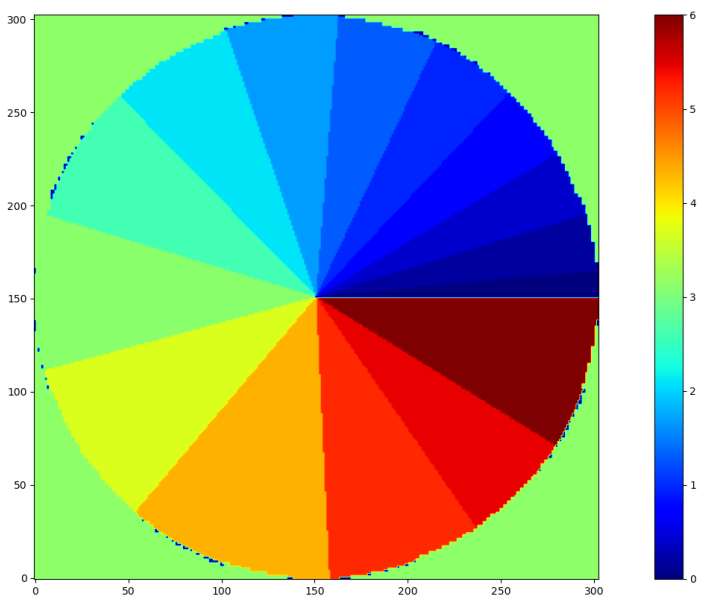
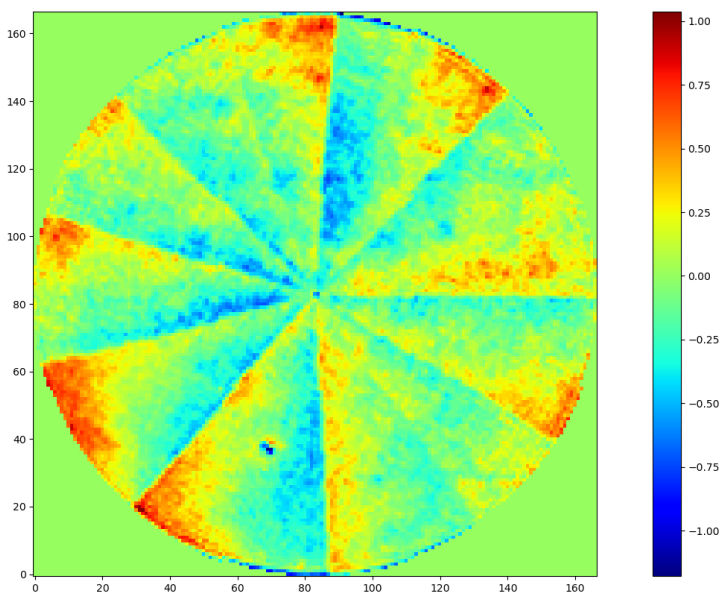
QWLSI for vortex

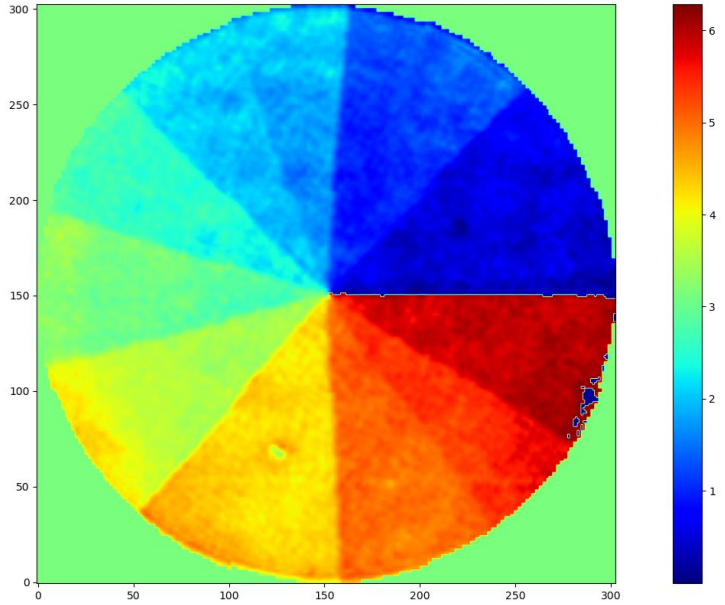
Design



Wavefront measured



Post processed Wavefront



- ✓ We can observe parts of the metasurface which was not perfectly manufactured
- ✓ We can reconstruct the phase between 0 and 2pi

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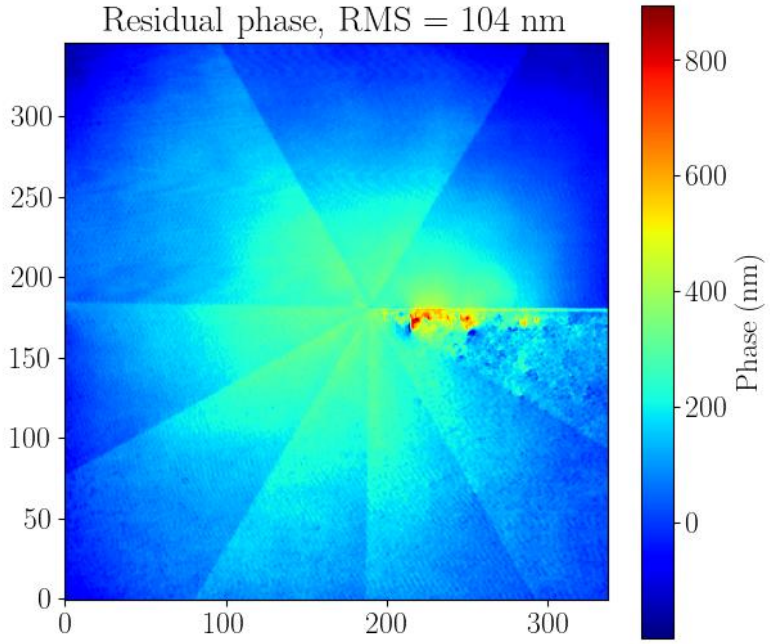
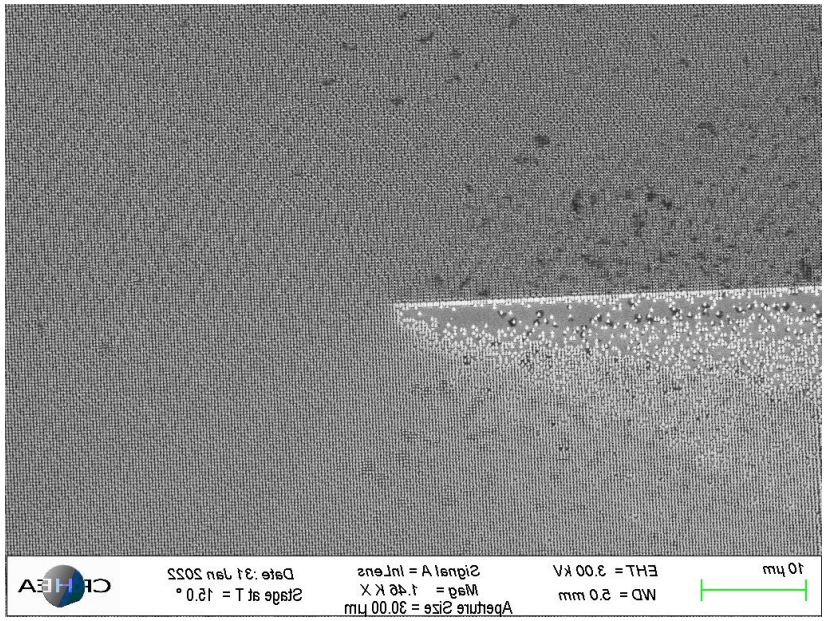
Wavefront measurement for fab feedback





- ✓ We can observe parts of the metasurface which was not perfectly manufactured
- ✓ Good correlation with SEM characterization, but in a much shorter time (~minutes)
- ✓ Pillar discretization is clearly visible on the residual

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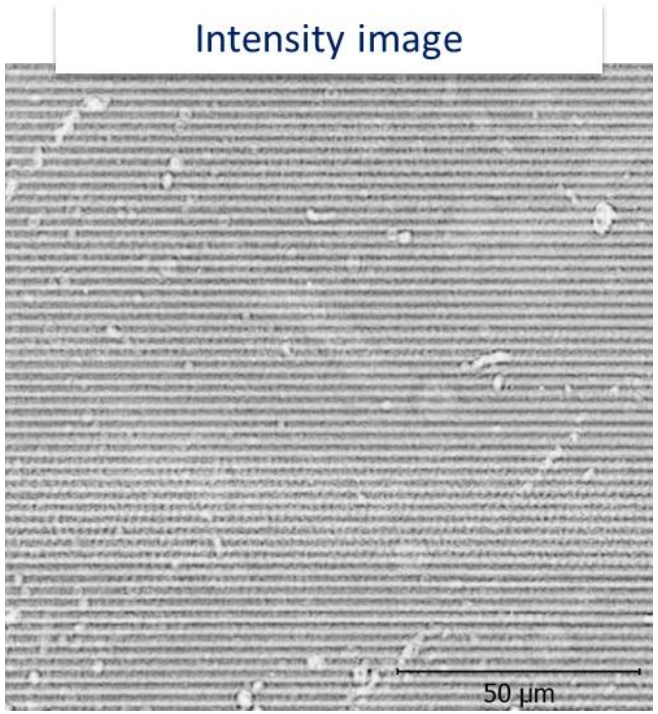
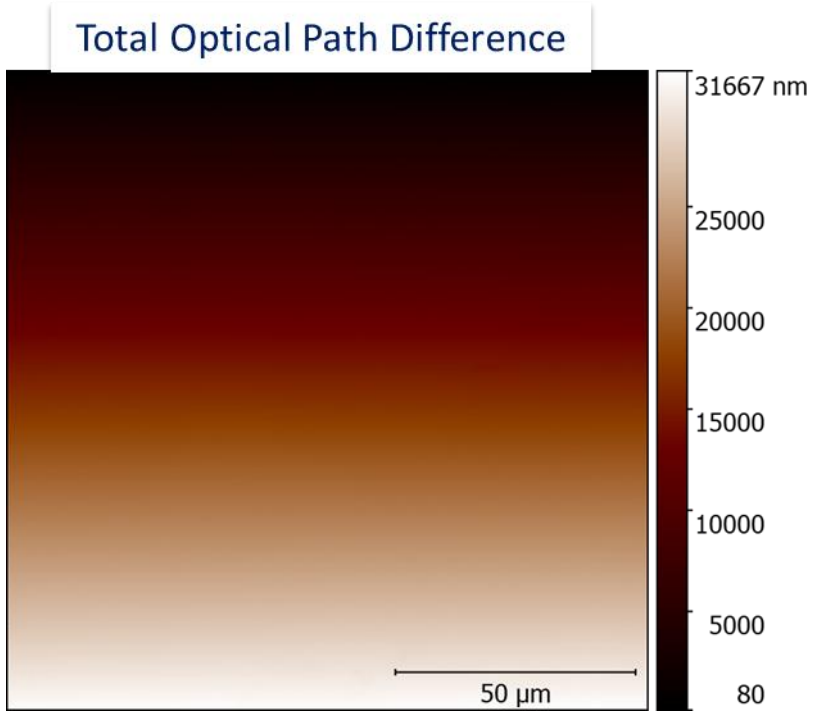
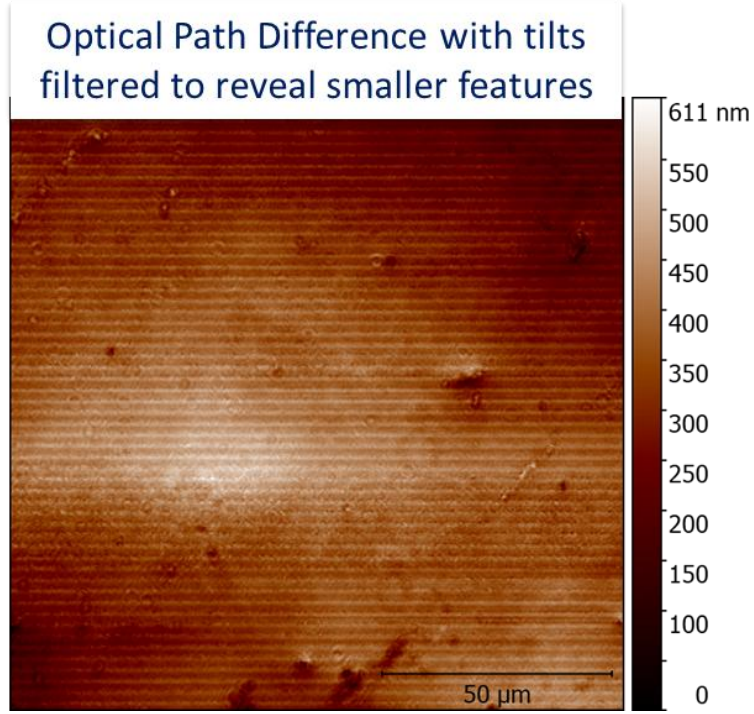
QWLSI for Beam Deflector

PB metasurface beam deflector: 15deg linear phase gradient







Images courtesy of CRHEA

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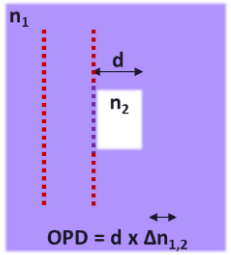
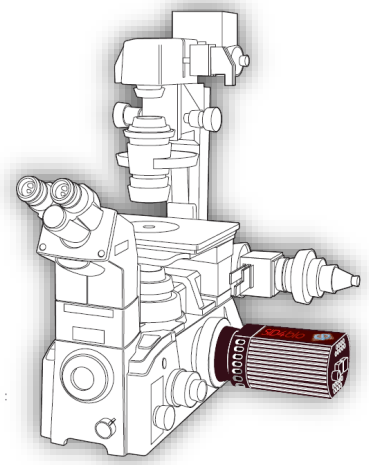
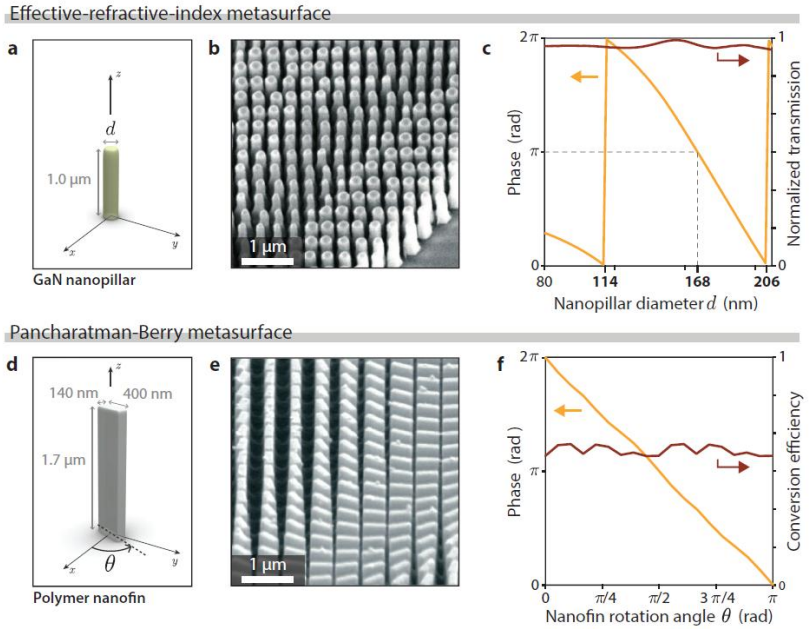
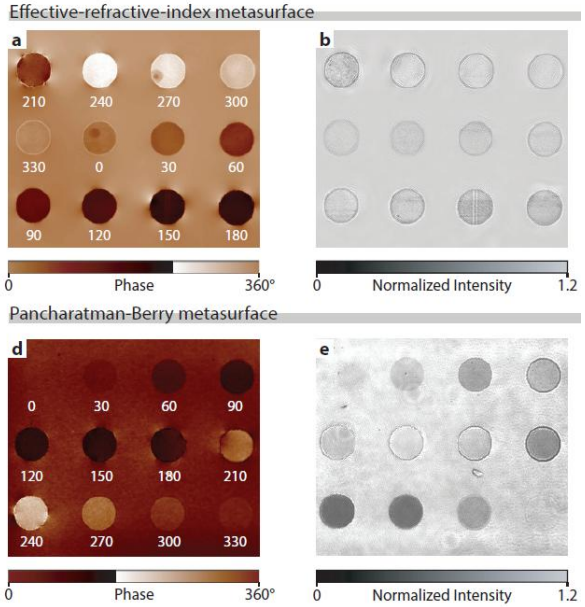
Process Control

QWLSI can be used as a **Quantitative Phase Imaging** technique to measure the optical path difference generated by the sample in the object plane









- Phase-piston metasurfaces (ERI and PB) varying gradually by 30 deg steps (from 0 to 360 deg) imaged within one field of view
- Intensity images can also be retrieved simultaneously

Images courtesy of CRHEA

Metasurface optical characterization using quadriwave lateral shearing interferometry
S. Khadir *et al*, CNRS CRHEA
arXiv:2008.11369v1

Conclusion and prospects

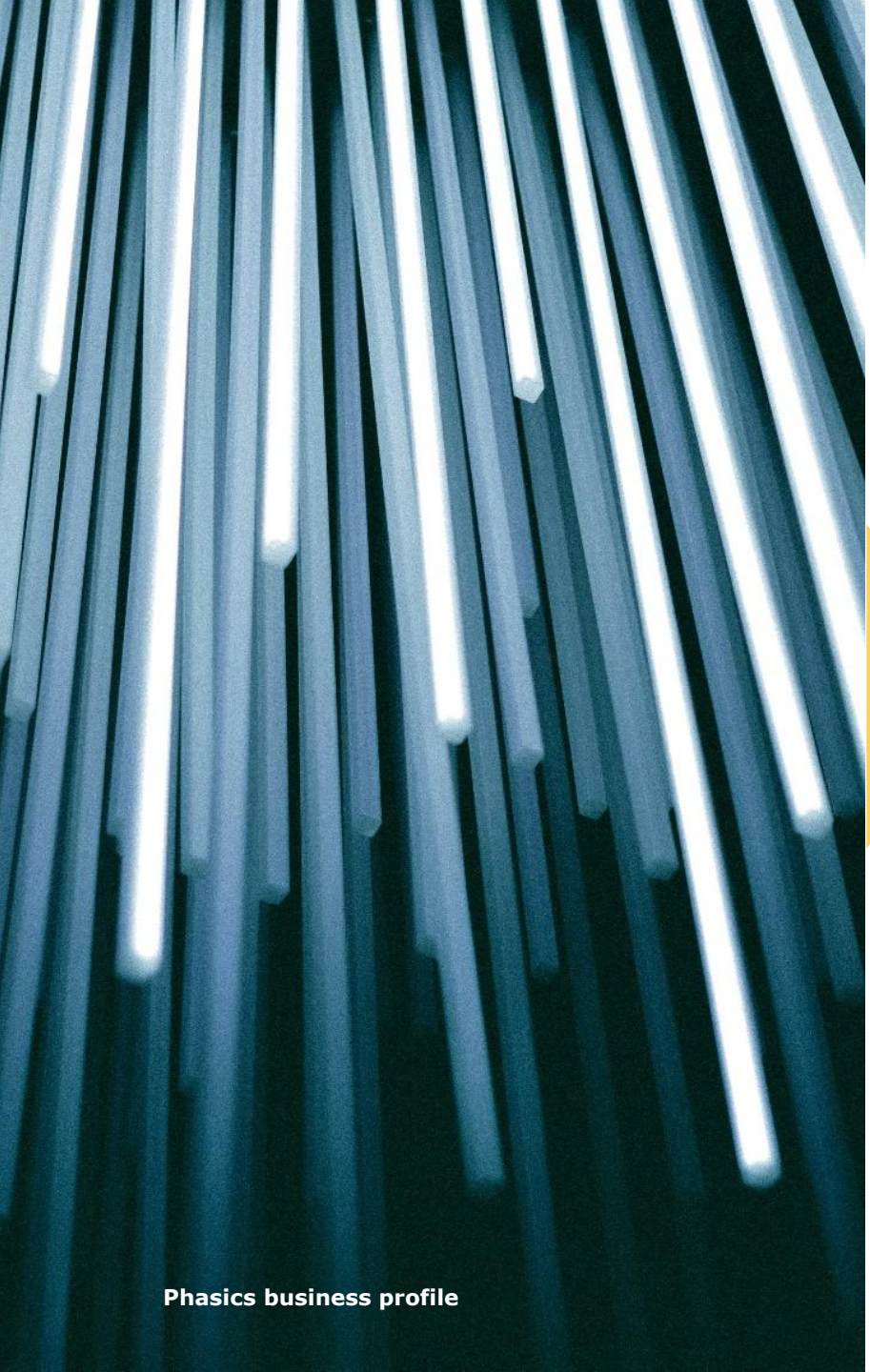
We use a wave front sensor, based on Quadriwave Lateral Shearing Interferometry (QLSI), to characterize the optical transmittance of metasurfaces

We validated its use with

- ✓ Metalenses
- ✓ Deflectors
- ✓ Pistons
- ✓ Vortices

Such characterization is useful to :

- ✓ Validate optical functions and quality, like for standard optics
- ✓ Detect and understand manufacturing error without the need to use more time-consuming solution, providing a huge gain in processing time.



ANNEXE