Digitial Holographic Microscopy (DHM) for overlay metrology

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Our Mission: ARCNL focuses on fundamental physics and chemistry in the context of technologies for nanolithography, primarily for the semiconductor industry

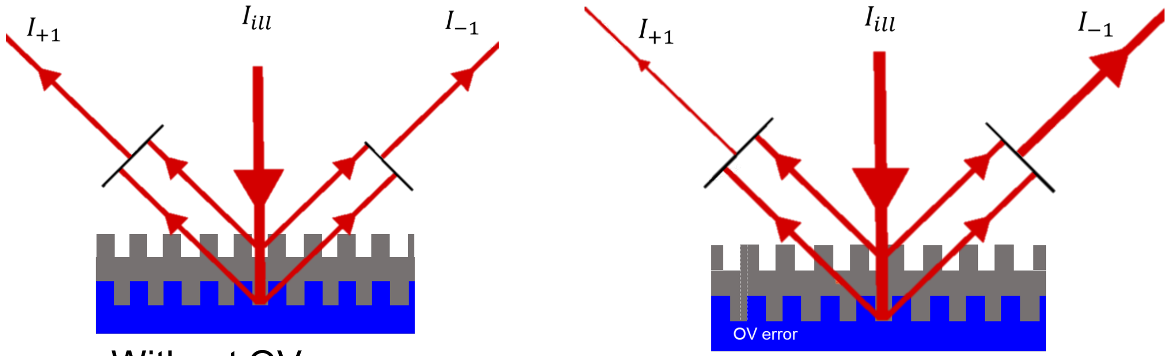
"Computational Imaging" group explores
Digital Holographic Microscopy (DHM) for overlay metrology
https://arcnl.nl/research-groups/computational-imaging

Outline

- **Digital Holographic Microscopy (DHM) for optical overlay metrology**
- Non-isoplanatic aberration correction
- Illumination spot profile correction
- Near infrared wavelength range
- Summary

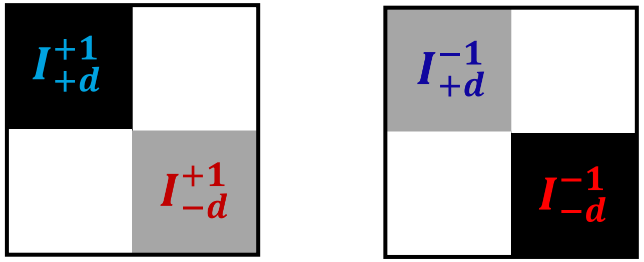
Diffraction-based overlay (DBO) metrology

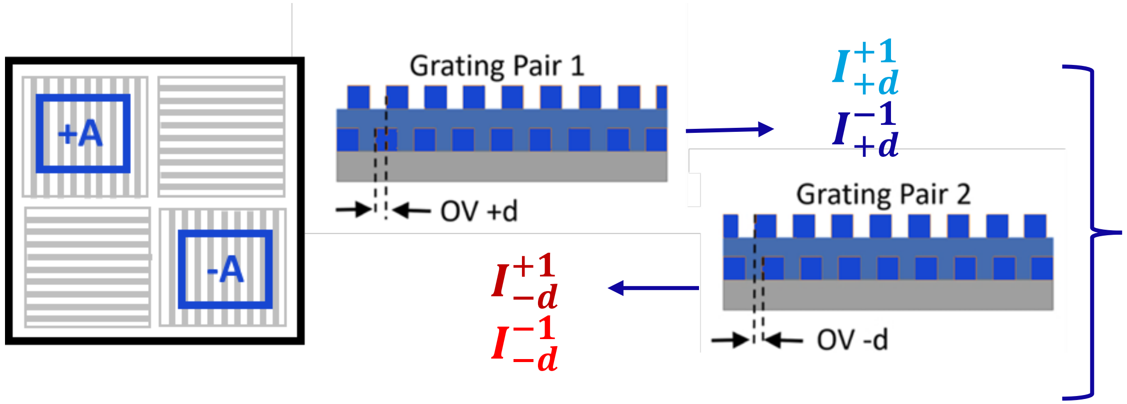
measured ±1st order diffraction intensities



Without OV error   With OV error

+1st order diffraction intensities   -1st order diffraction intensities





Set of 4 intensities yields overlay

$$I^{+1}_{+d} - I^{-1}_{+d} = A_{+d}$$

$$I^{+1}_{-d} - I^{-1}_{-d} = A_{-d}$$

$$\mathrm{OV} = d\left(\frac{A_{+d} + A_{-d}}{A_{+d} - A_{-d}}\right)$$

Why Digital Holographic Microscopy (DHM)

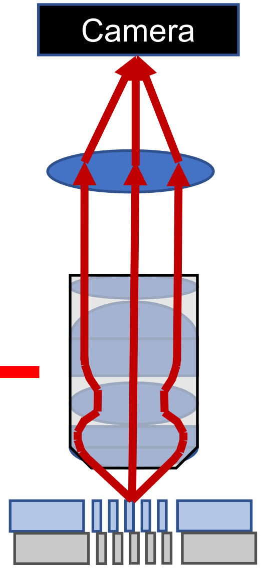
Overlay target characteristics → Imaging requirements

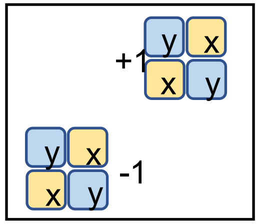
Overlay target characteristics	Imaging requirements
Low diffraction efficiencies	Enough signal-to-noise
Very small size	Good imaging quality/resolution
Various thickness and stack materials	Broad wavelength selection
Influence from surrounding structures	Optical crosstalk suppression

Problem: Stringent requirements for high quality imaging needs bulky, expensive optics

Solution: Computational imaging, solve hardware imperfections with simple optics + software

Regular microscope





Camera image (intensity only)

Simplify complex optics

+

Computational imaging

Why Digital Holographic Microscopy (DHM)

Problem: expensive optics with stringent requirements for high quality imaging
Solution: computational imaging, solve hardware imperfections with software

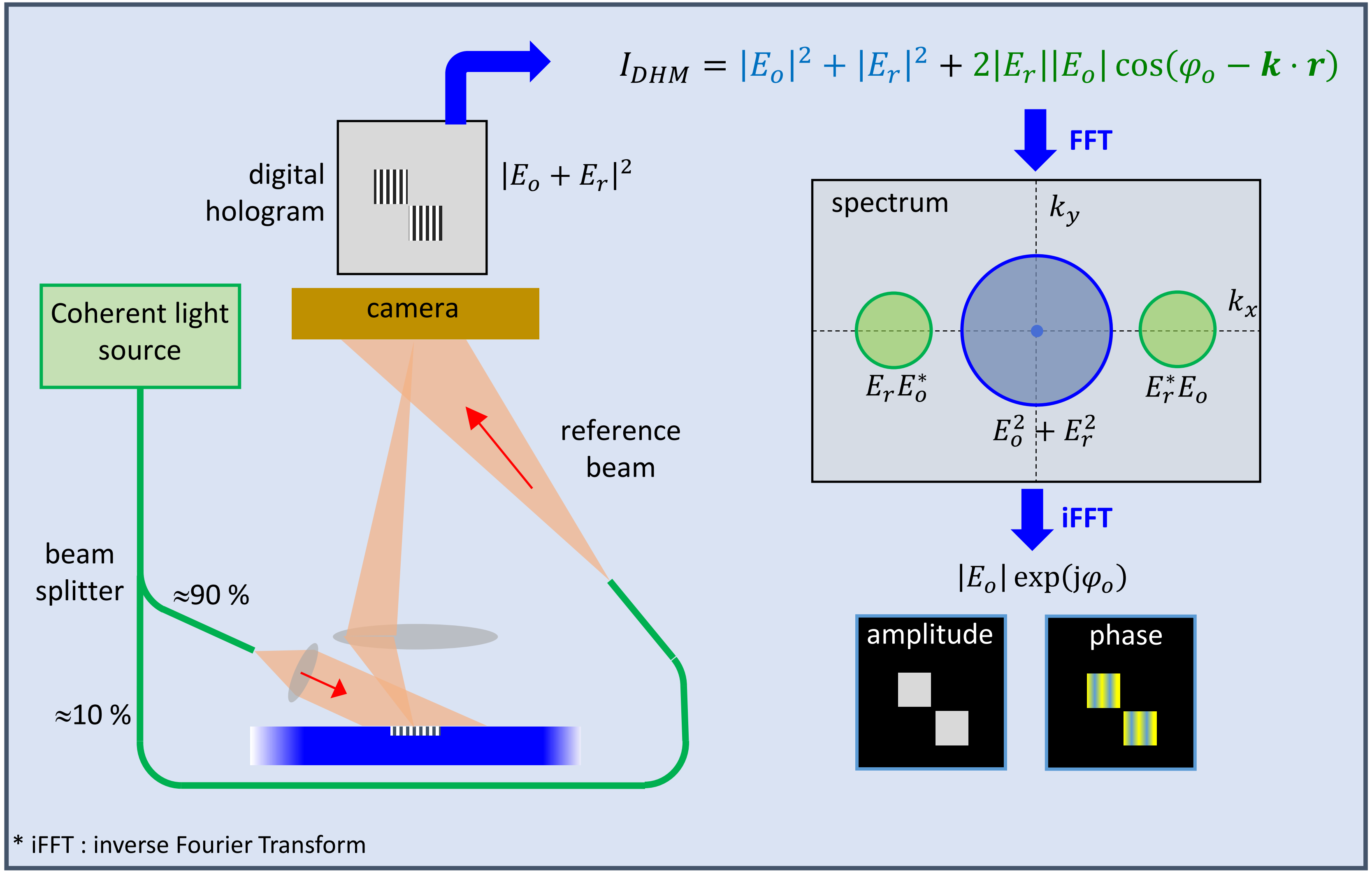
Problem: physics-based image correction requires full-field information
Solution: coherent imaging, measure full complex-valued field

Problem: cameras can only measure amplitude, not phase
Solution: phase retrieval via holography

Our approach: Digital Holographic Microscopy (DHM)

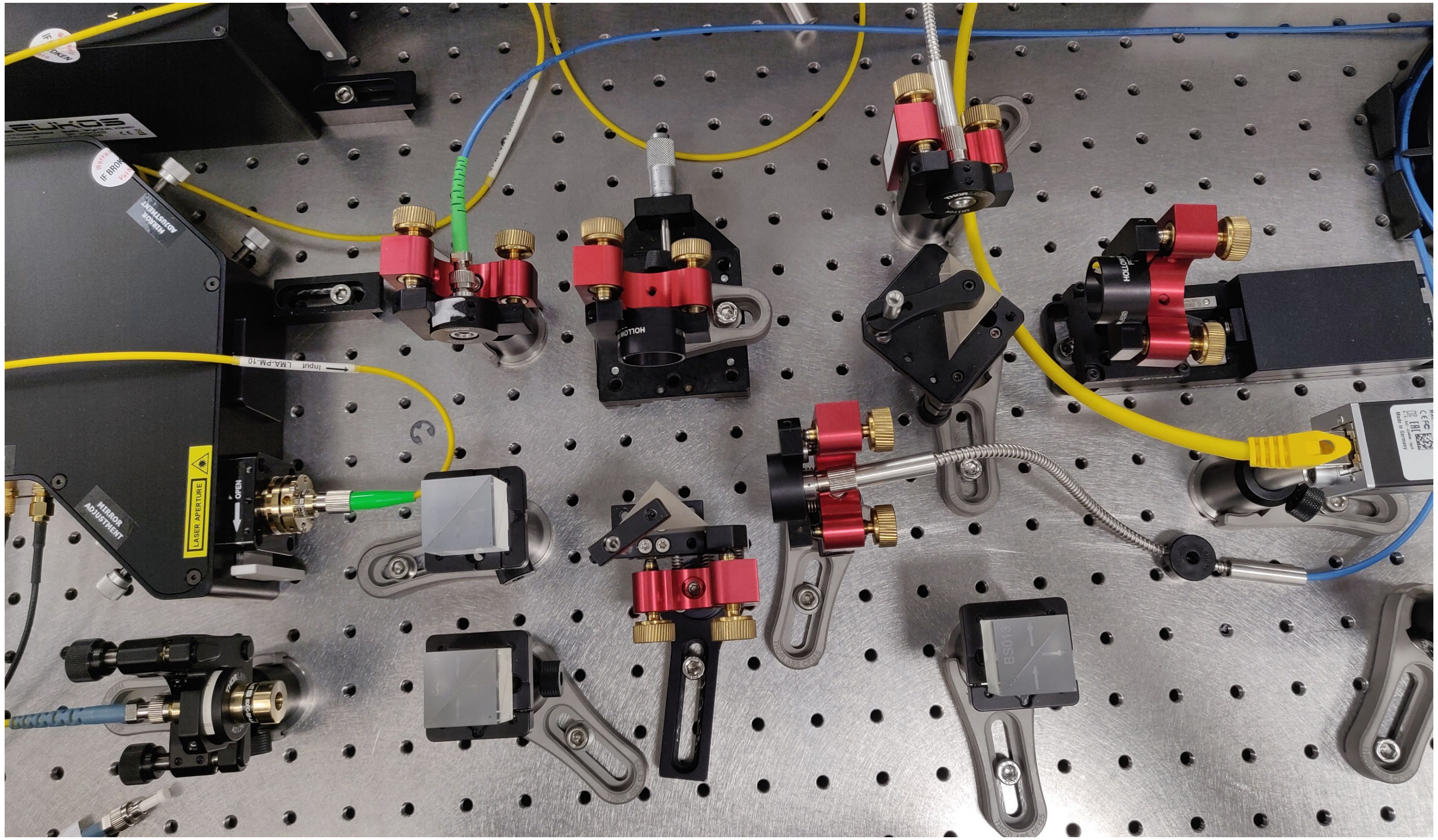
Coherent imaging system

Dark-field Digital Holographic Microscopy concept

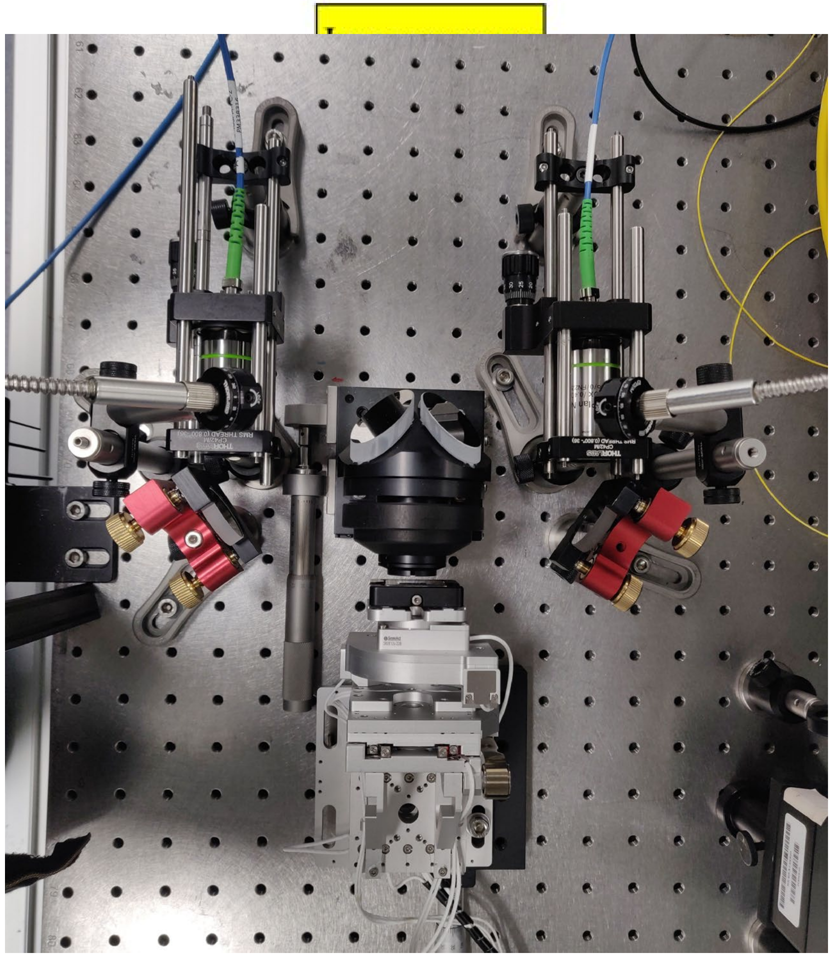


Exp. Implementation on Dark-Field Holographic Microscopy (DHM)

Supercontinuum

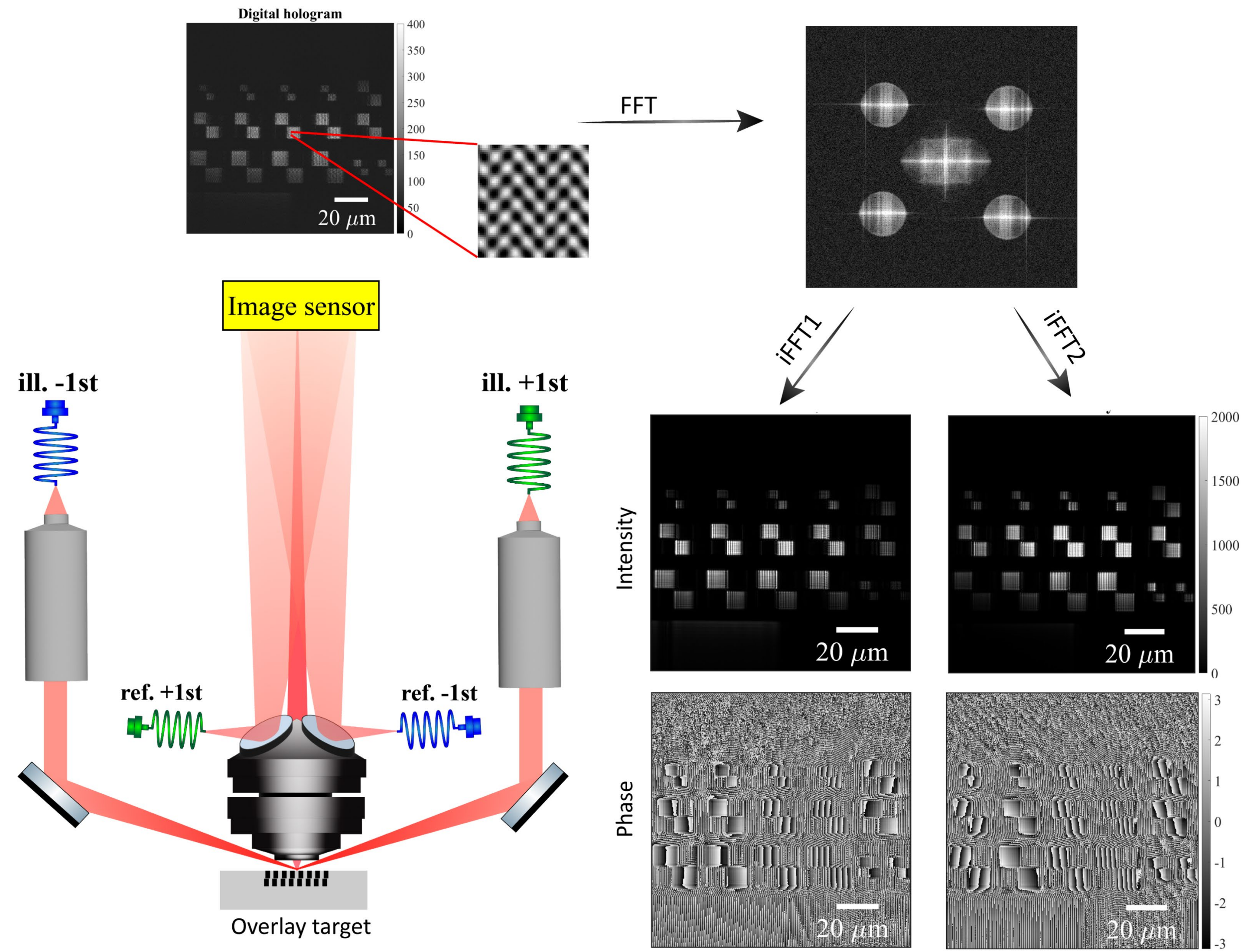


Beam generation



Sensor head

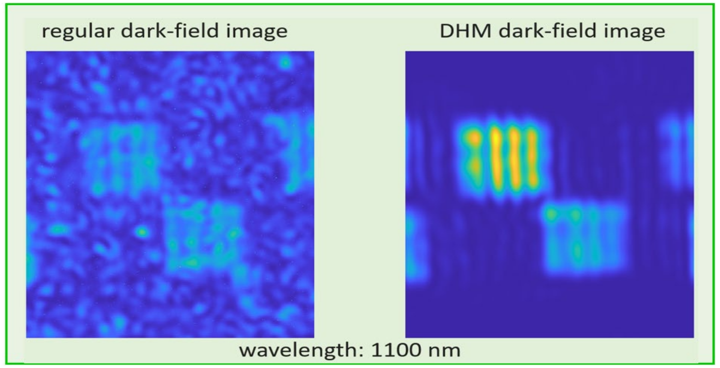
Parallel acquisition of diffraction orders in DHM

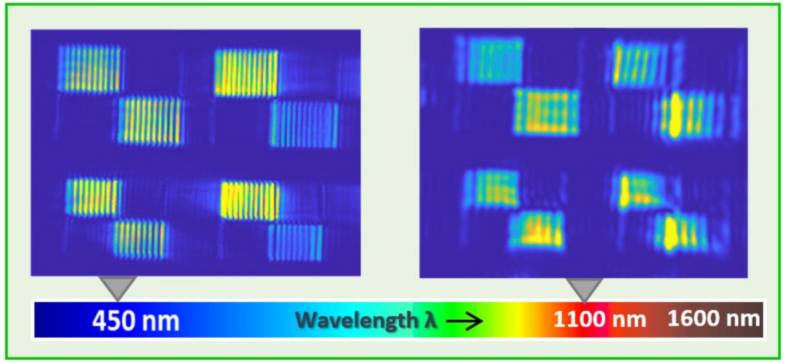


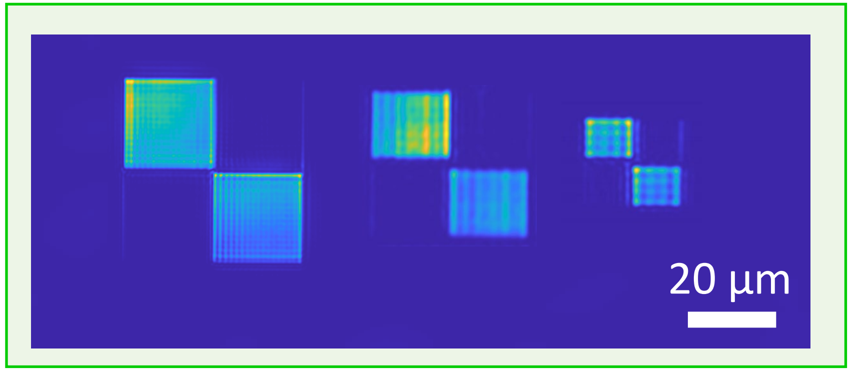
Simultaneous acquisition of both -1 and +1 diffraction orders using full NA of the imaging system.

Both amplitude and phase are retrieved.

Advantages of Digital Holographic microscopy

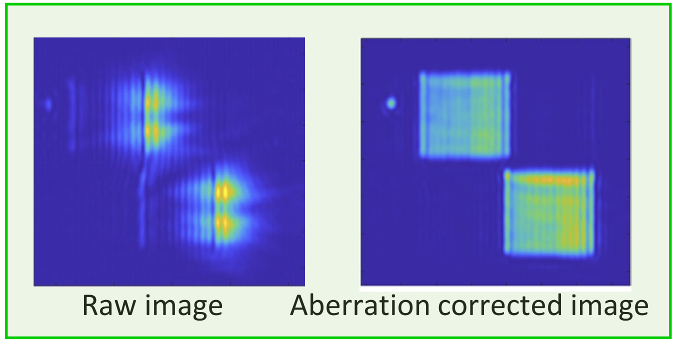


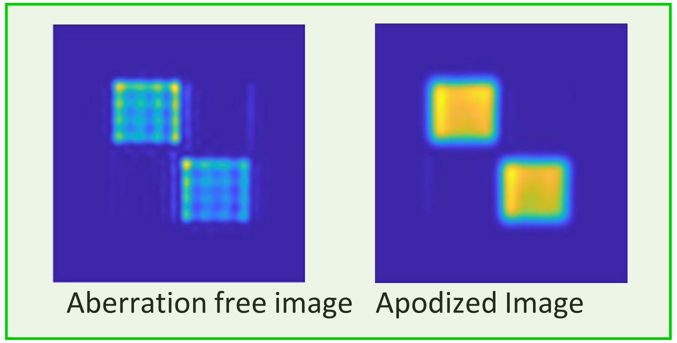




Opportunities offered by DHM

1. Detection of weak targets by stray light suppression and "optical amplification".
2. 400 – 1600 nm wavelength range with a single sensor
3. High imaging quality with high-NA optics
4. Computational aberration correction
5. Image enhancement with flexible pupil apodization





C. Messinis *et al.*, *Optics Express* **28**(25) (2020)
C. Messinis *et al.*, *Optics Express* **29**(23) (2021)
T.T.M. van Schaijk *et al.*, *J. Micro/Nanopattern. Mats. Metro* **21**, (1)(2022)
C. Messinis *et al.*, *Opt. Continuum* **1**(5) (2022)

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Imaging lens – Anteryon NA= 0.8

2-element imaging lens:

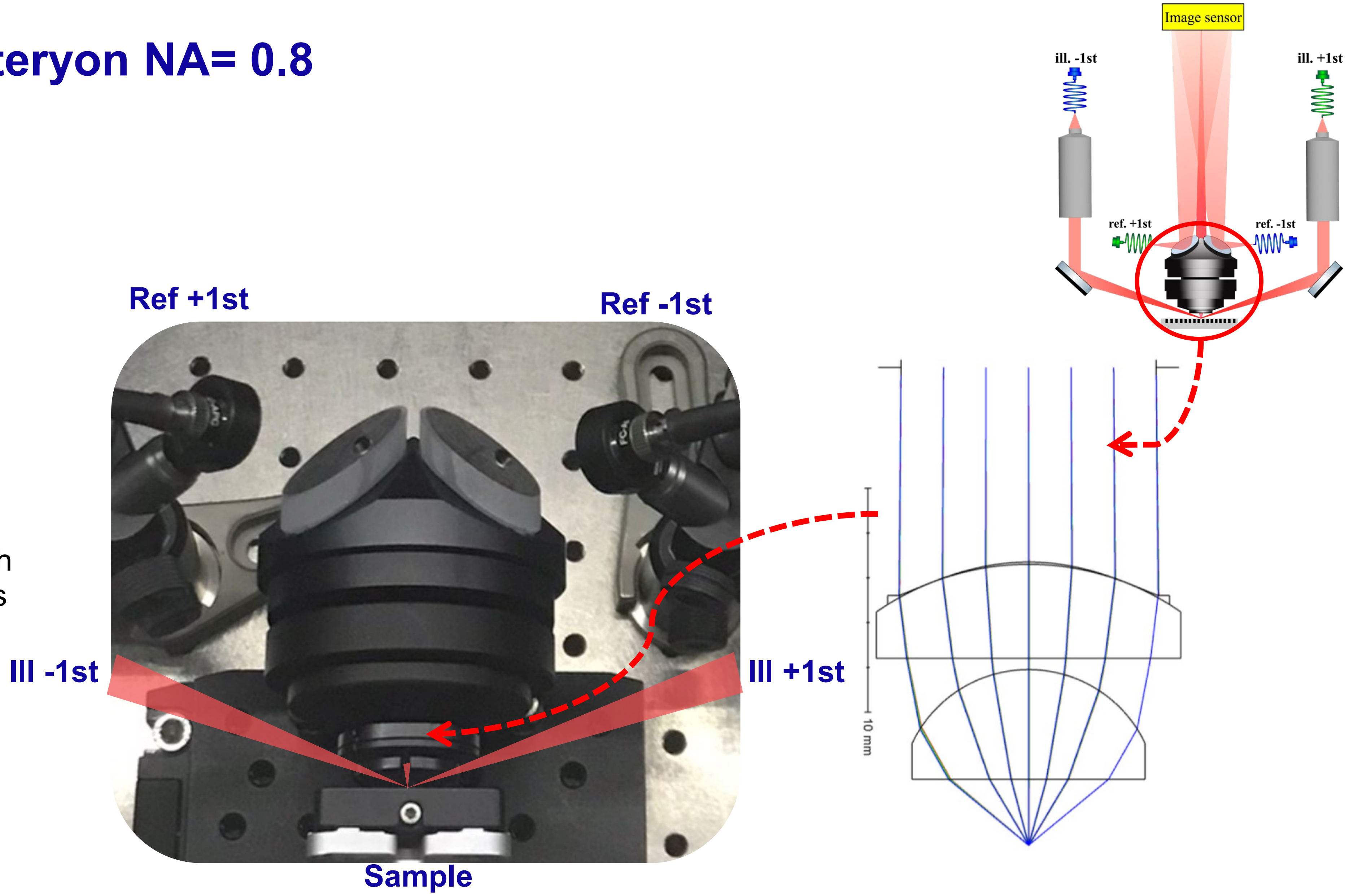
- ➢Compact
- ➢Low-cost
- ➢No AR-coating

NA = 0.8

Drawback:

Aberration levels increase with non-isoplanatic 4d aberrations

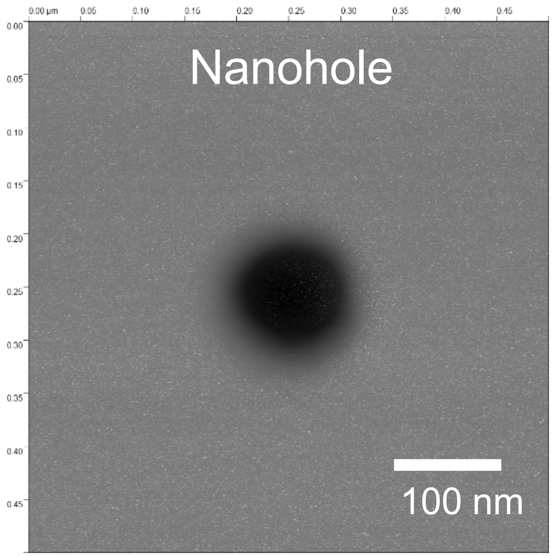
Lens optimized to only have aberrations that are easily computationally correctable



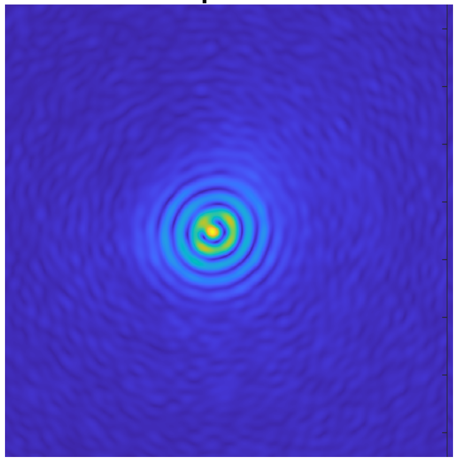
Top view

Computational aberration correction

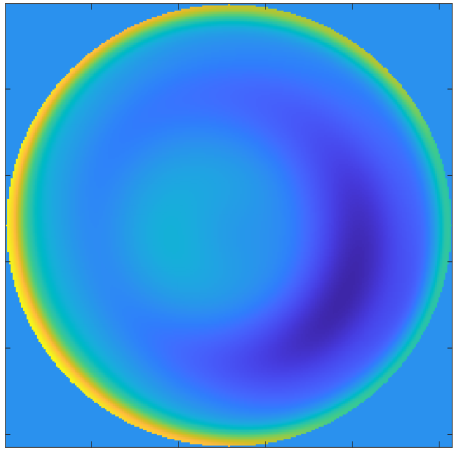
Calibration



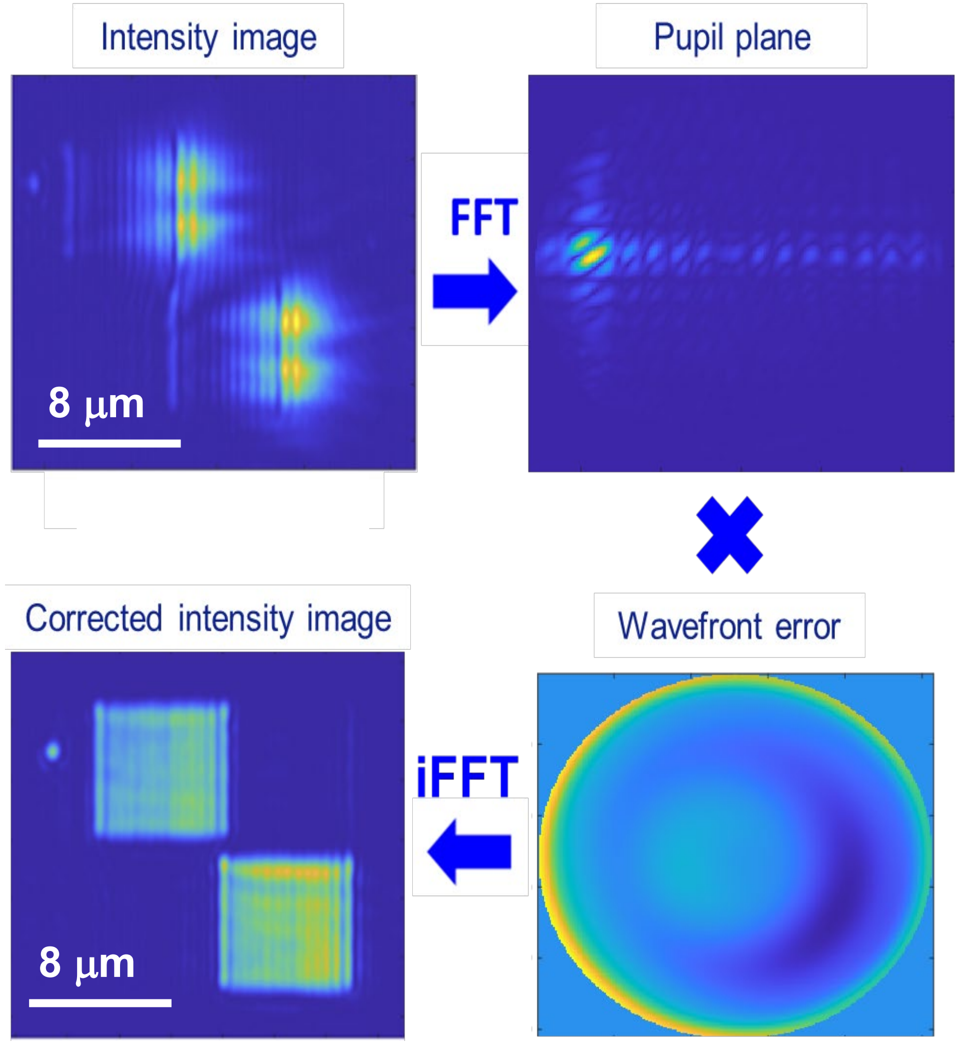
Amplitude



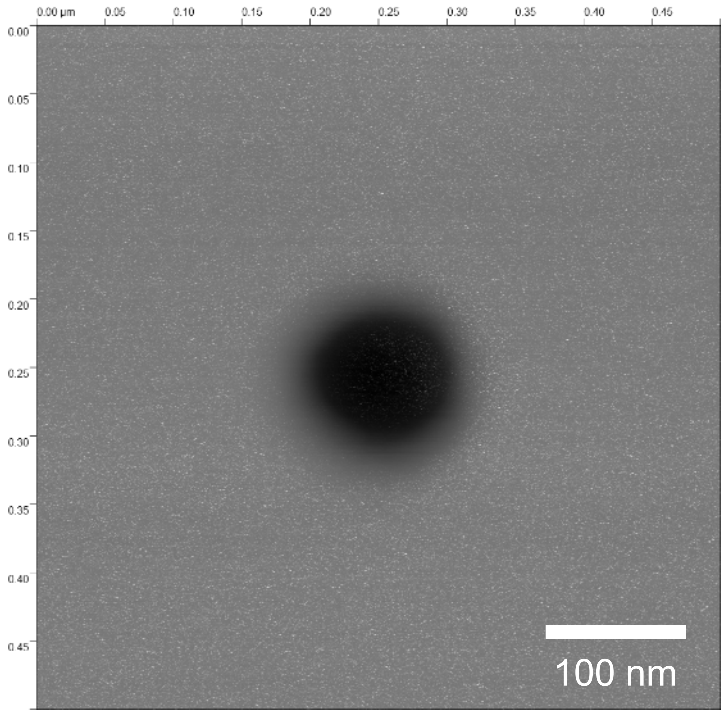
Phase

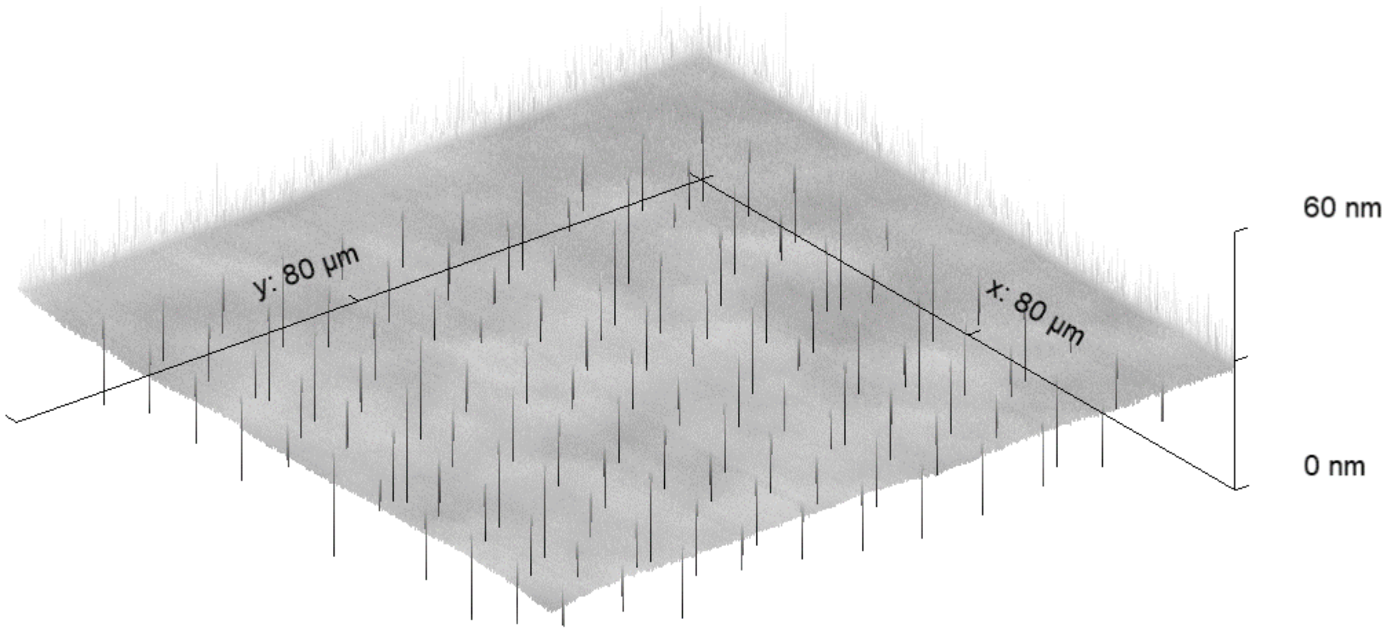


Correction



4D-PSF Calibration via 2D-array of Nanoholes

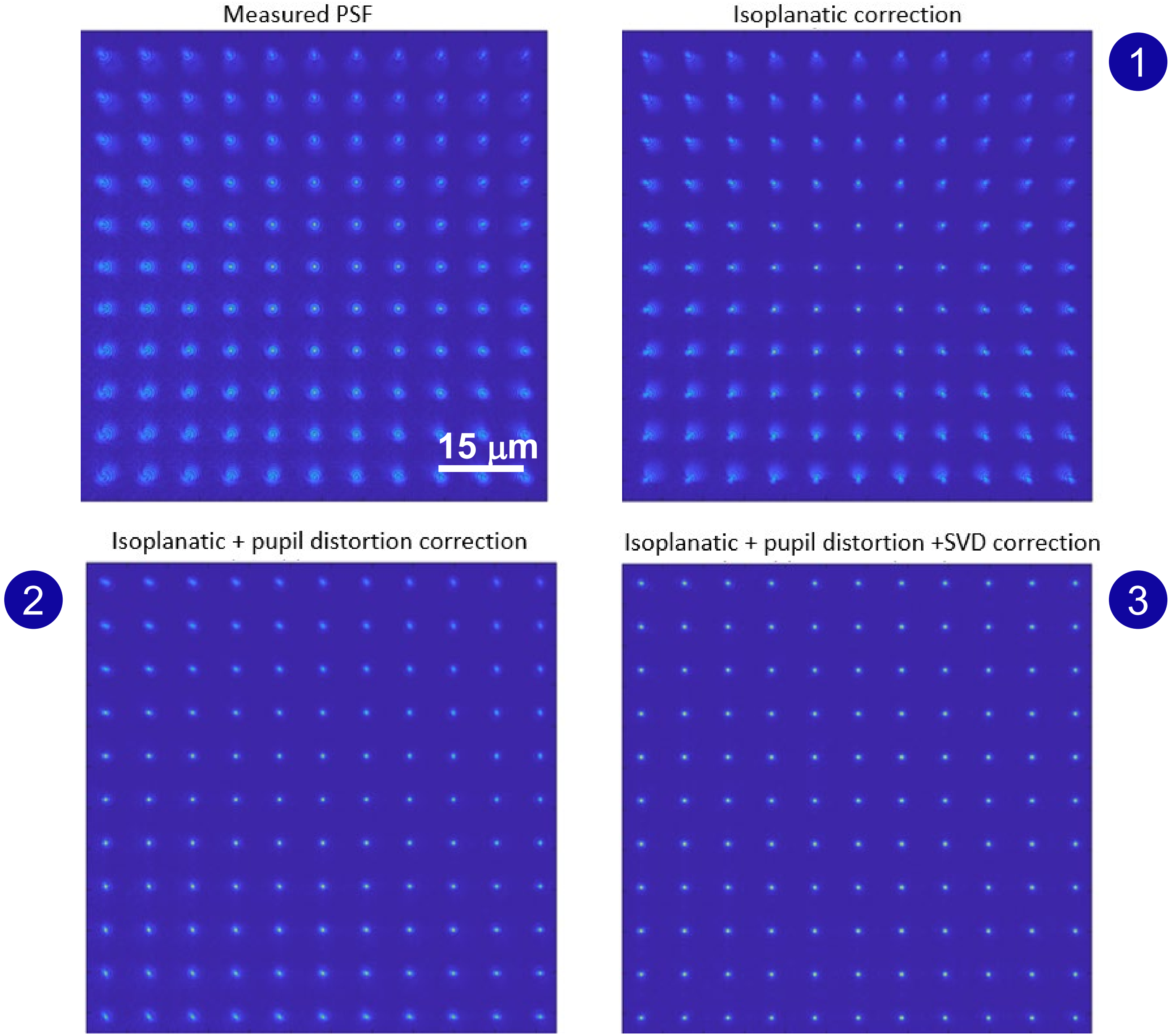




- Nanoholes acts as δ-functions

- Nanoholes probe the spatial variation of the 4D-PSFs as measured directly via the sideband of the hologram.

Aberration calibration + correction 3 step approach

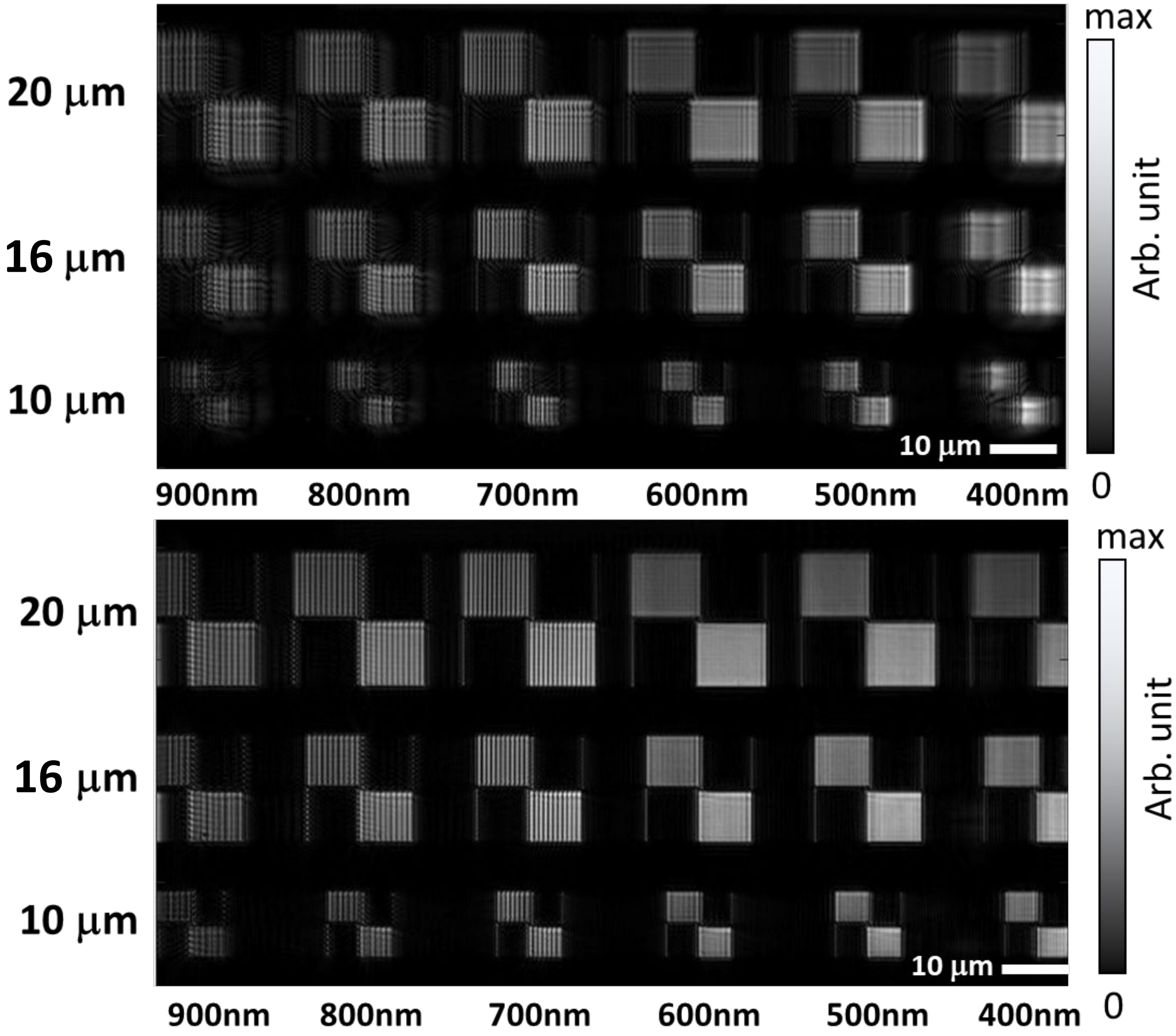


Aberration correction

7x7 nanohole calibration grid

OV target with various sizes and pitches

Wavelength: 532nm



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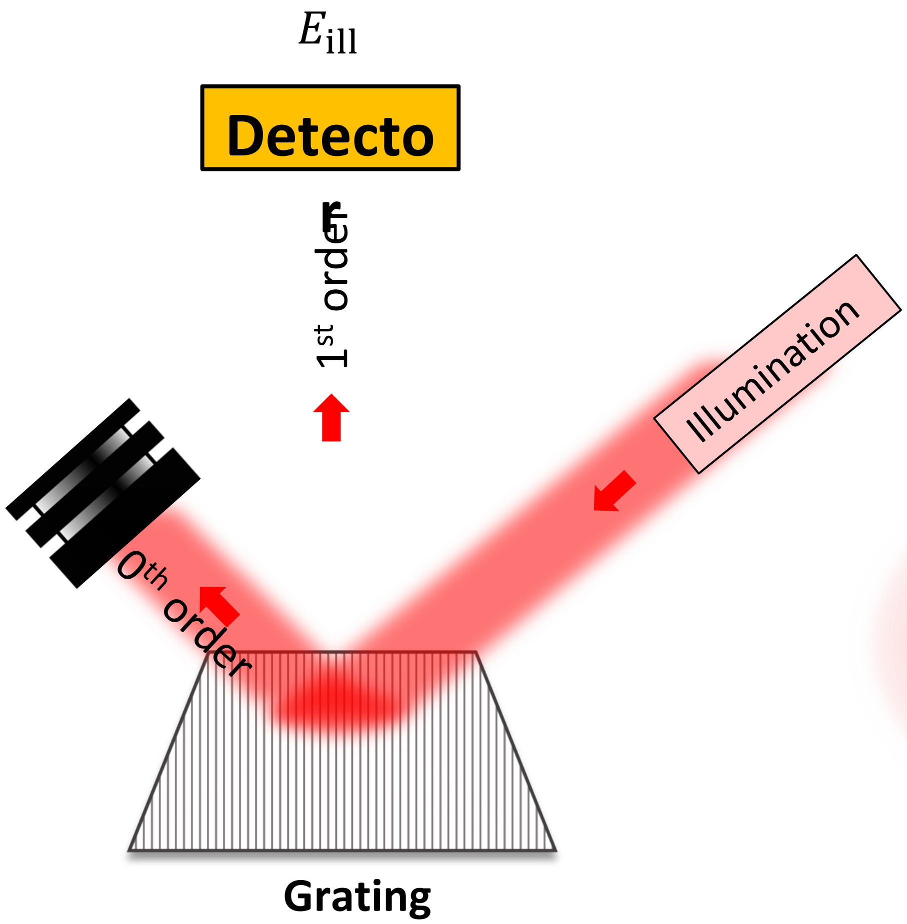
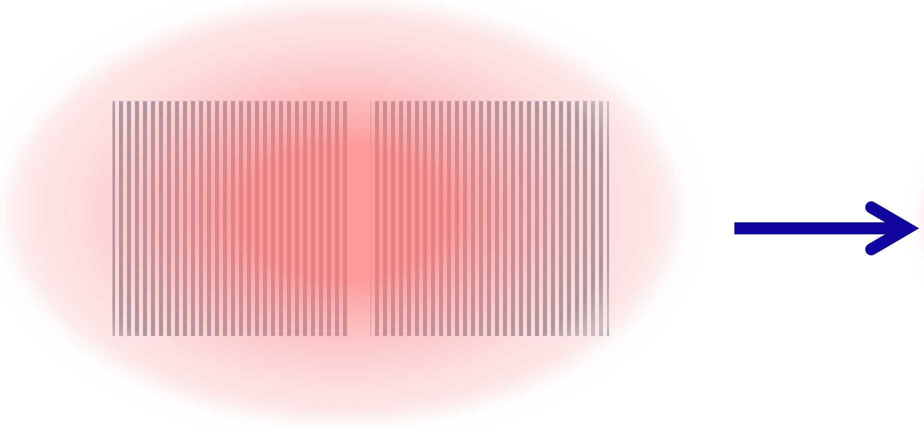
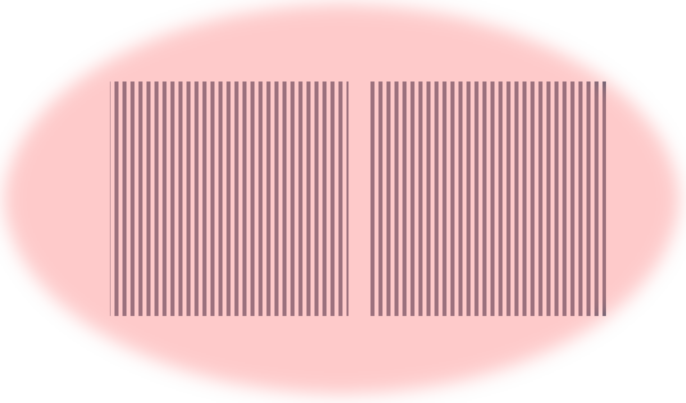
Dark-field illumination beam calibration



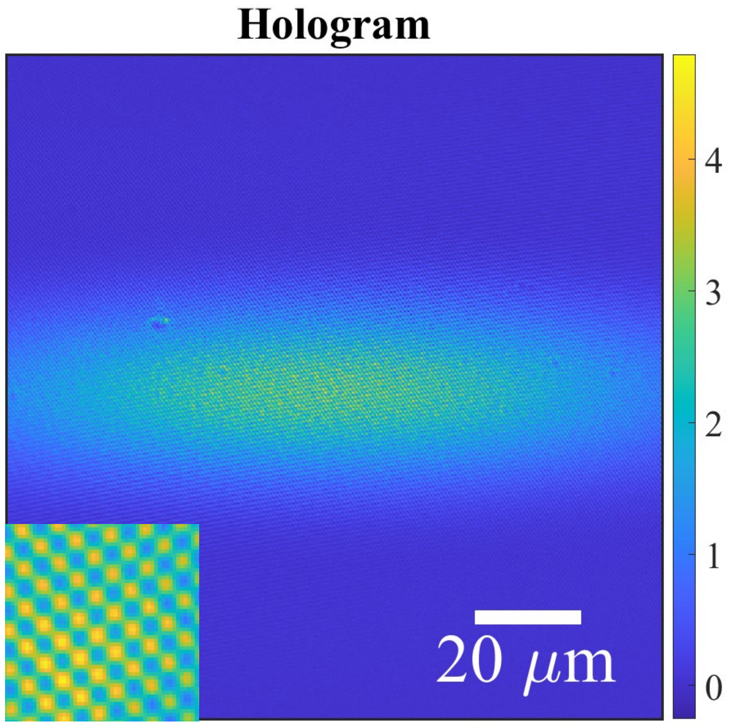


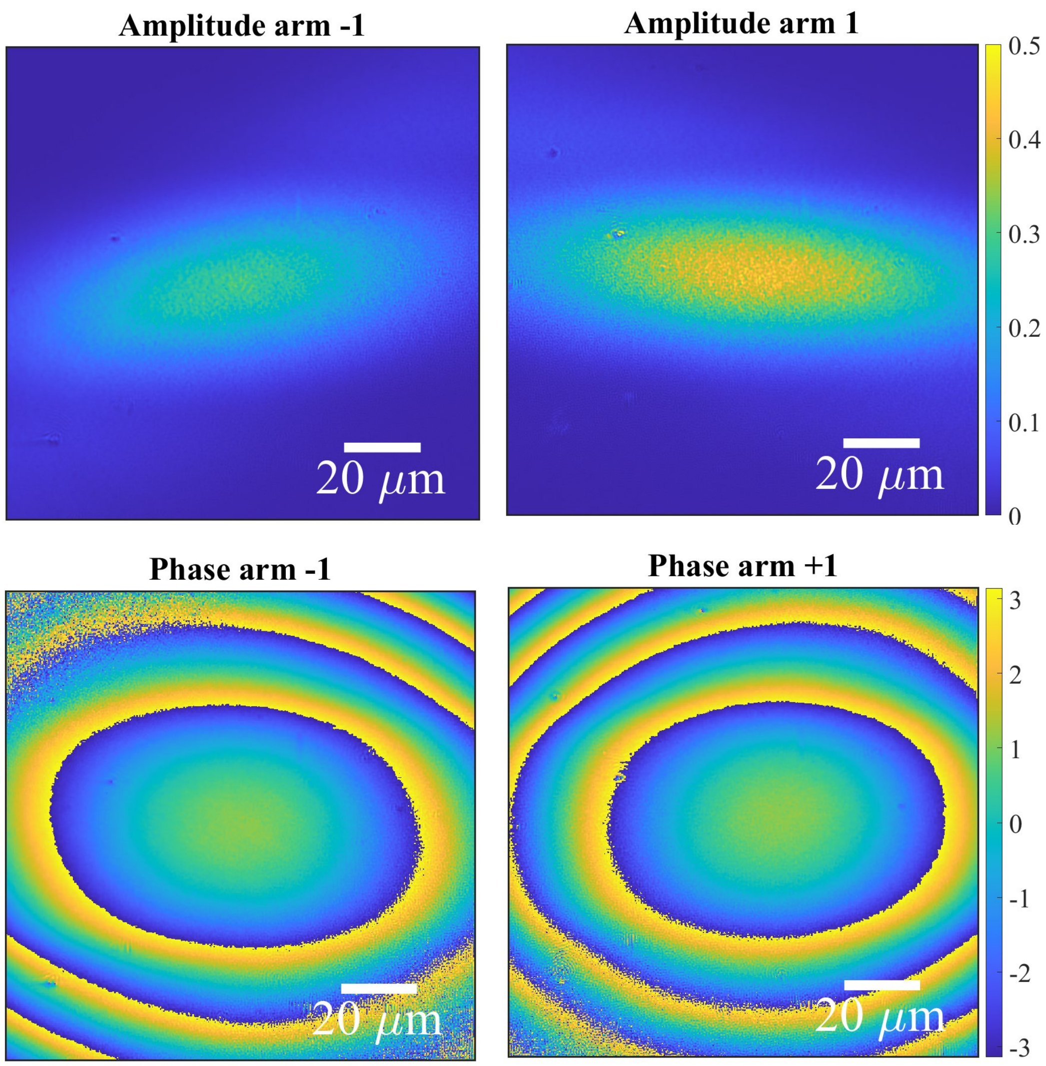
Gaussian beam profile



Corrected homogeneous beam profile

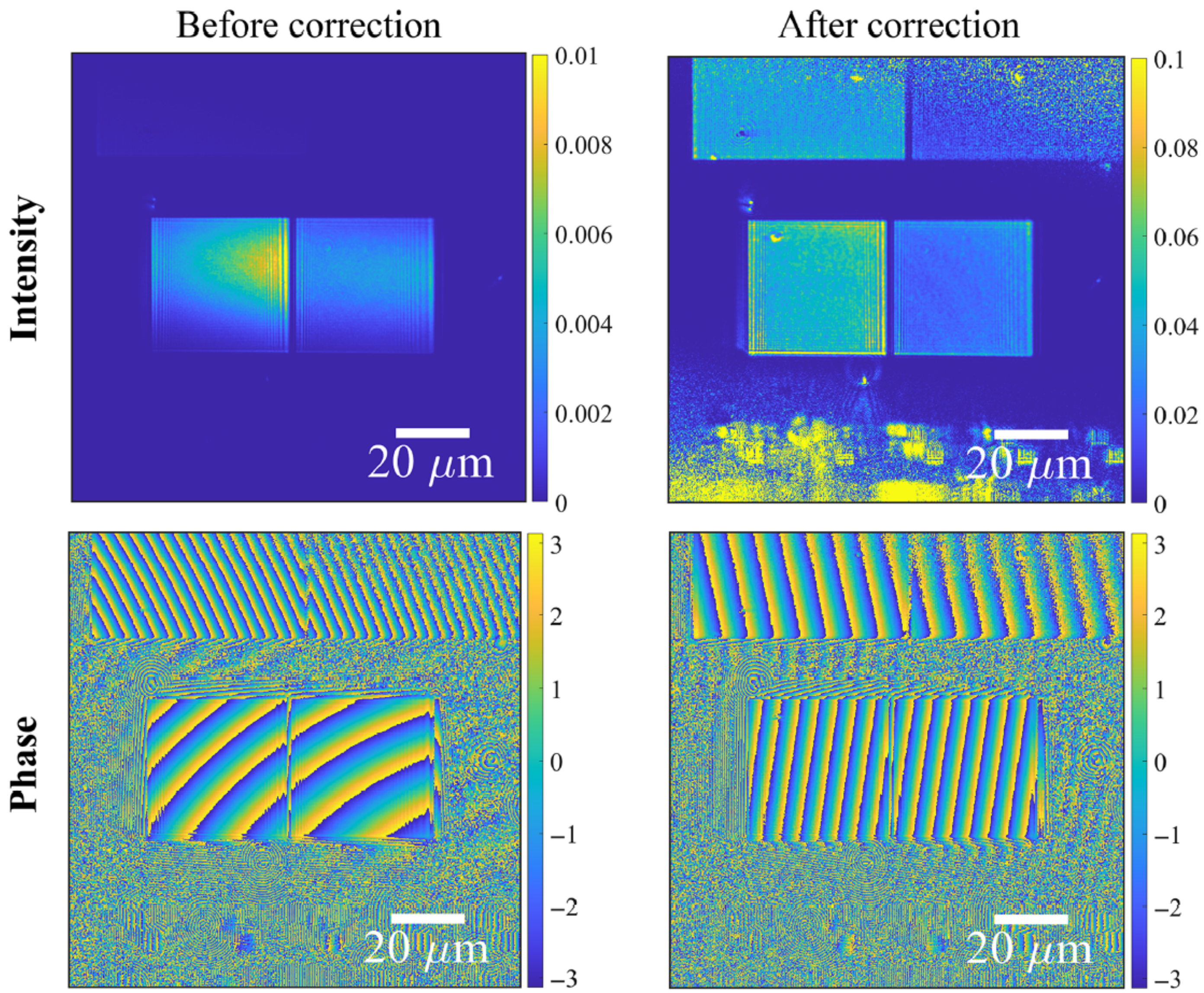
Illumination spot measurement



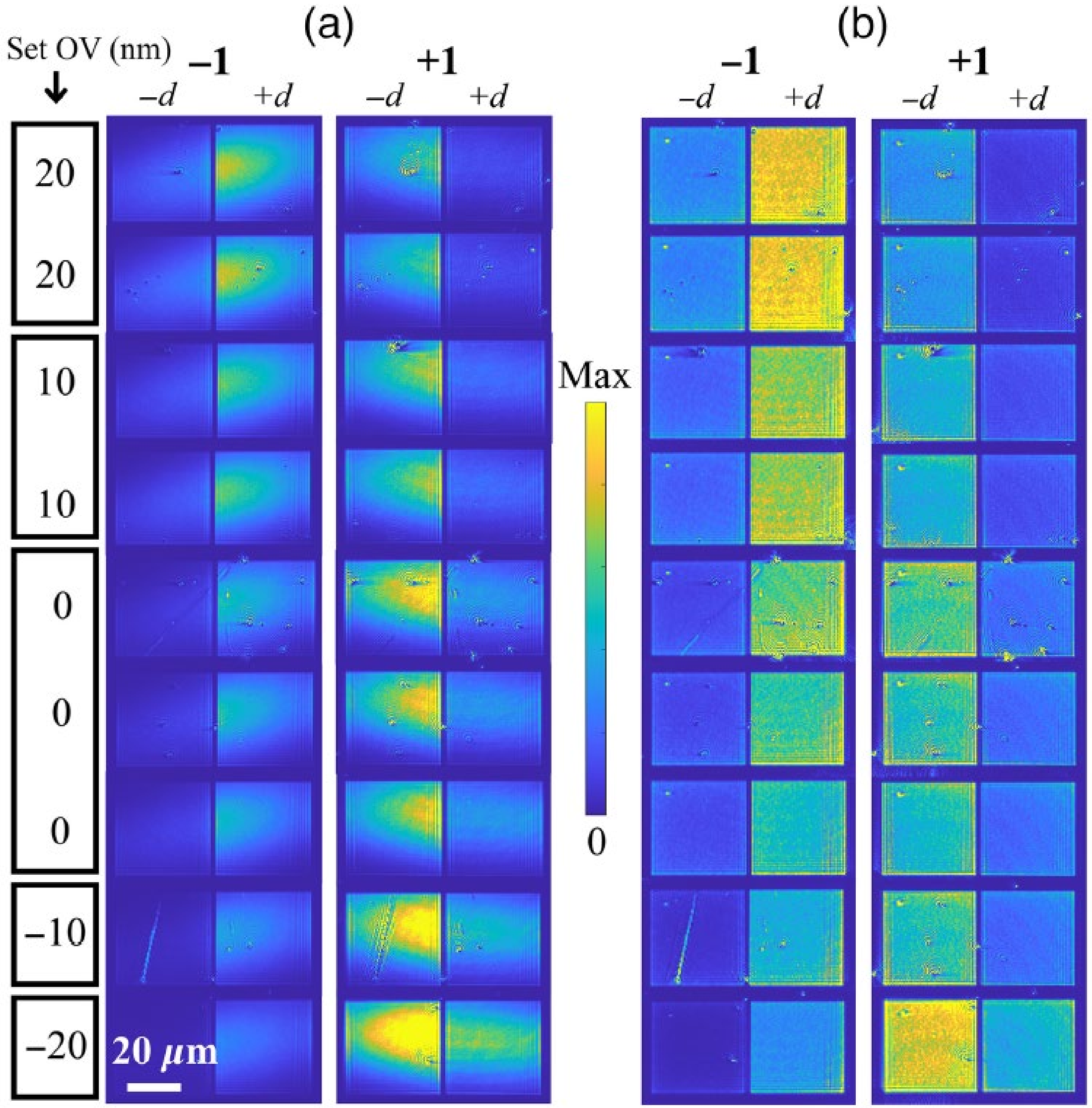


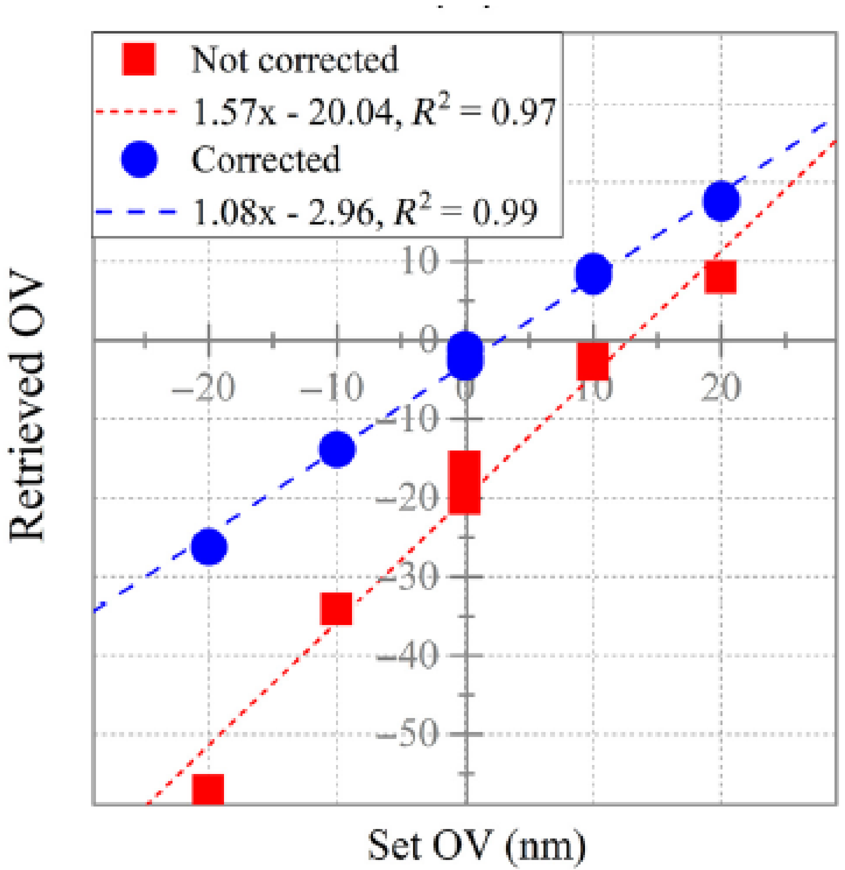
Large grating to calibration spot profile

Illumination spot correction



Illumination spot correction





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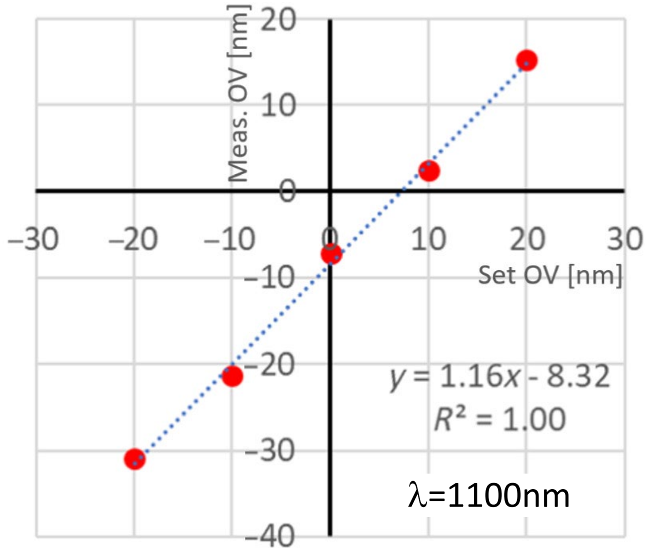
Near infrared wavelength range

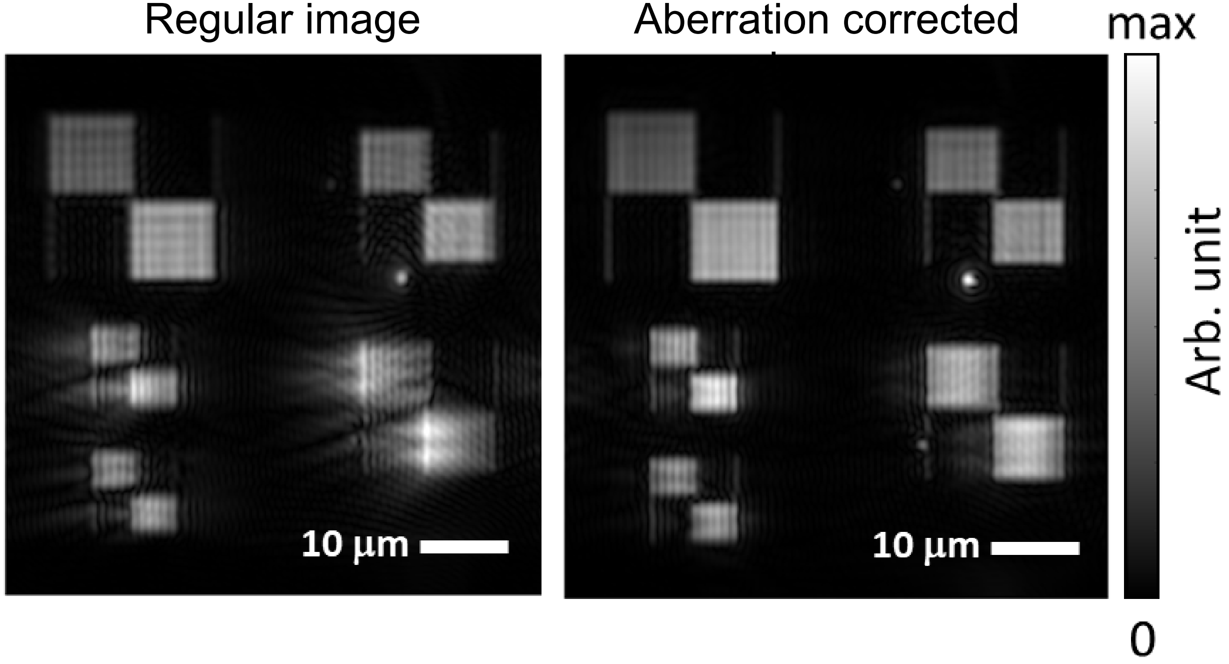
- Cover VIS to NIR wavelength regime in one image sensor
- Longer wavelengths for thicker stacks
- Image through bonded Si wafer
- Opaque materials



Wavelength: 1300 nm

Regular image

Aberration corrected



Summary

- Dark-field digital holographic microscopy using simple optics is a potential tool for semiconductor metrology.
- Using the retrieved phase information system imperfections can be corrected computationally.
- Capable of imaging over a large wavelength range 400 - 1600 nm

Thanks you!

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- Arie den Boef
- Johannes de Boer
- Marc Noordam
- Bartjan Spaanderman
- Stefan Witte

Thank you for your attention.