Characterization of a projection lens using the extended Nijboer-Zernike approach

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3) IMEC

4) International Sematech

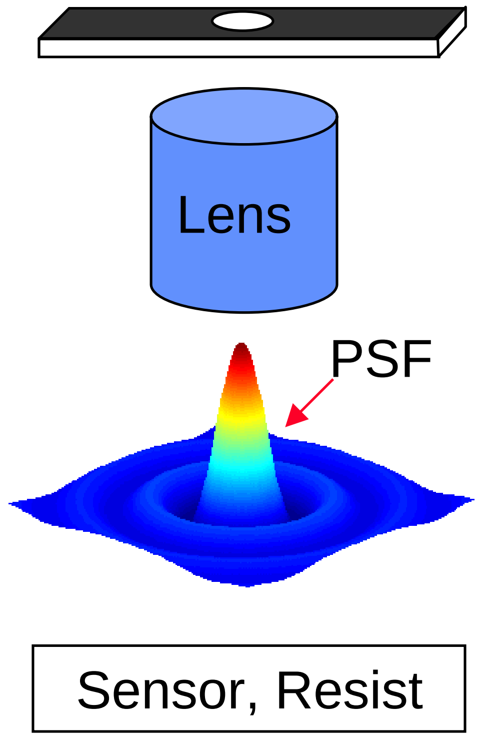
Introduction to lens characterization

- Lens aberrations have an important contribution to CD variation and image misplacement
- Low k_1-imaging requires tight aberration specifications.
- Focal plane deviation, astigmatism, coma and spherical aberration are all adjustable quantities.
- Aberrations may vary in time due machine drift.

The new lens characterization method

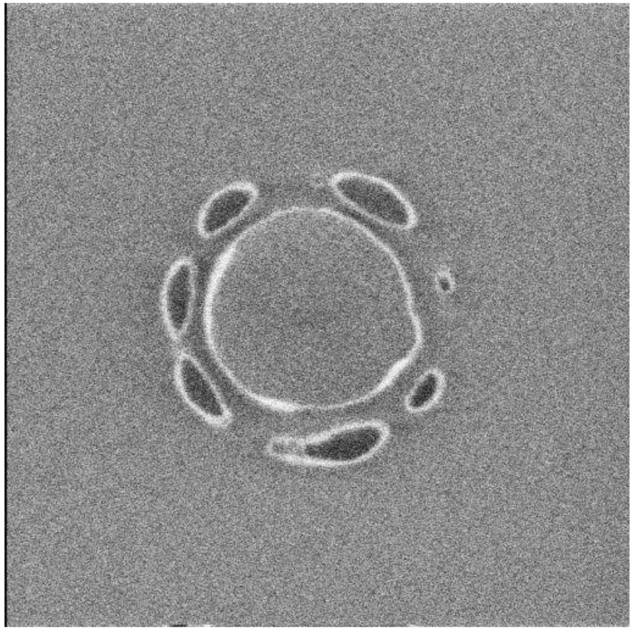
- The new method is based of the observation of the point spread function
- Resolves high and low order aberrations
- Illumination setting independent
- Wavelength independent

Simple binary mask, small hole



The point spread function tells the whole lens story

‘A slice from a point spread function’



- Perfect lens: rotational symmetry, symmetry through focus
- Aberrations: *symmetry is lost*

Interpretation of the experiment

- The experiment is straightforward.
- The problematic part is the interpretation and analysis of the measurement.
- This *inverse problem, getting the Zernike's, is solved* by using a new analytical method: the extended Nijboer-Zernike approach

Outline

- Introduction
- Extended Nijboer-Zernike approach
- Phase retrieval
- First experimental results
    - Microscope
    - Scanner

“Nijboer-Zernike theory of aberrations” (1942)

THE DIFFRACTION THEORY
OF ABERRATIONS

PROEFSCHRIFT

TER VERKRIJGING VAN DEN GRAAD VAN DOCTOR IN DE WIS- EN NATUURKUNDE AAN DE RIJKS-UNIVERSITEIT TE GRONINGEN, OP GEZAG VAN DEN RECTOR MAGNIFICUS Dr. J. M. N. KAPTEYN, HOOGLEERAAR IN DE FACULTEIT DER LETTEREN EN WIJSBEGEERTE, TEGEN DE BEDENKINGEN VAN DE FACULTEIT DER WIS- EN NATUURKUNDE TE VERDEDIGEN OP MAANDAG 1 JUNI 1942, DES NAMIDDAGS OM 4.15 UUR PRECIES

DOOR

BERNARD ROELOF ANDRIES NIJBOER

GEBOREN TE MEPPEL

Airy pattern (1835)

$$U(r) \approx 2\frac{J_1(r)}{r} + 2\sum_{n,m} i^{n+1}\alpha_{nm}\frac{J_{n+1}(r)}{r}\cos m\theta$$

- Best focus, small aberrations
- Defocus included for a few low order terms only

"Extended Nijboer-Zernike theory"
A. Janssen, (2001)

New

$$\boxed{\begin{aligned} U(r,f) &\approx 2V_{00} + 2\sum_{nm} \alpha_{nm} i^{m+1} V_{nm} Cos(m\theta), \\ V_{nm}(r,f) &= \exp(if)\sum_{l=1}^{\infty}(-2if)^{l-1}\sum_{j=0}^{p} \mathrm{v}_{lj}\,\frac{J_{m+l+2j}(r)}{lr^{l}} \end{aligned}}$$

- Good convergence for large defocus and radial values
- Good convergence for high order aberrations
- Nice symmetry and orthogonality properties
- The old theory is a special case of the new theory (*f*=0)

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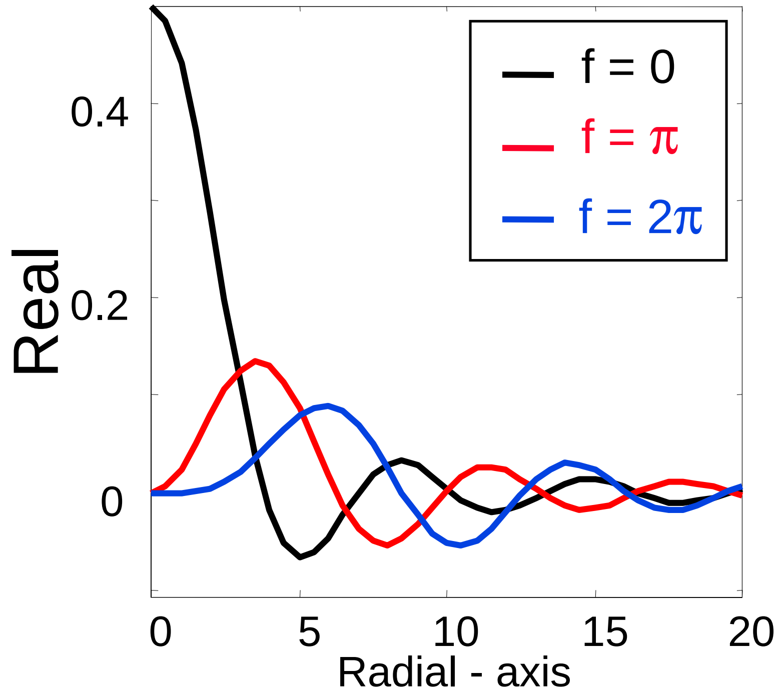
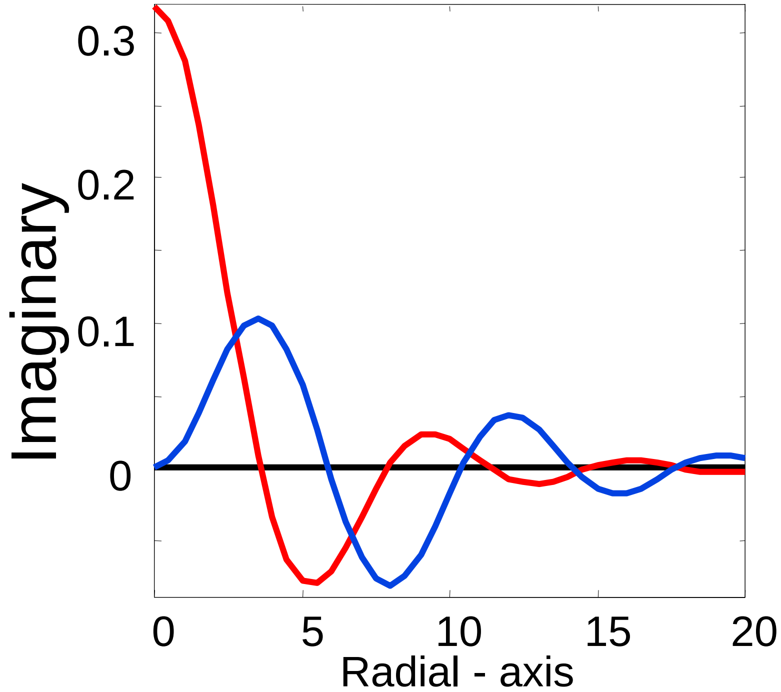
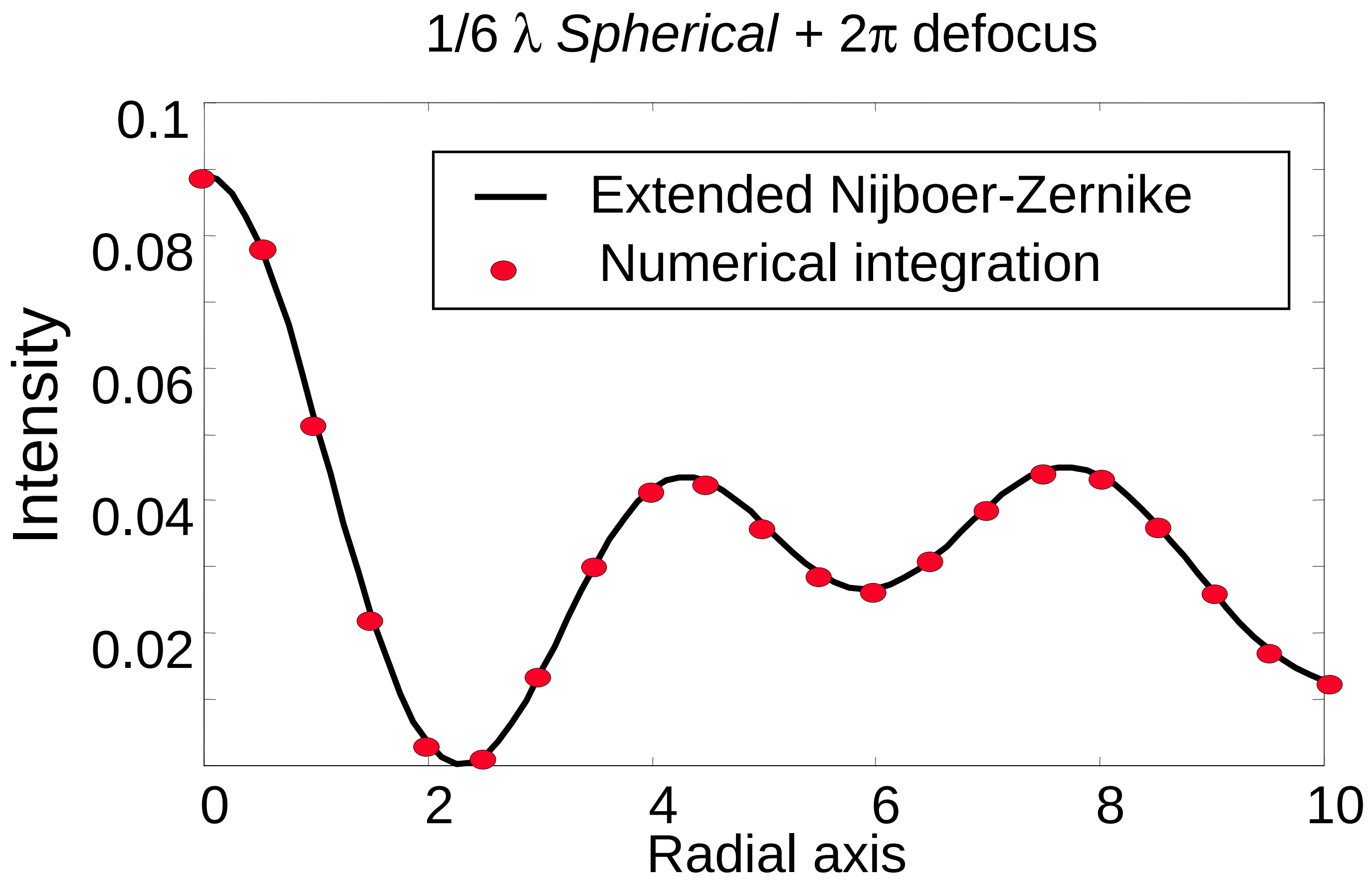
Example: through - focus Airy pattern $V_{00}(r,f)$





- *The complex amplitude* as presented, is linear in α_{nm}.
- The extension to large aberrations exist.

Validation: example



- More info: two publications in *J.O.S.A.* ***A.,*** *May 2002 issue*

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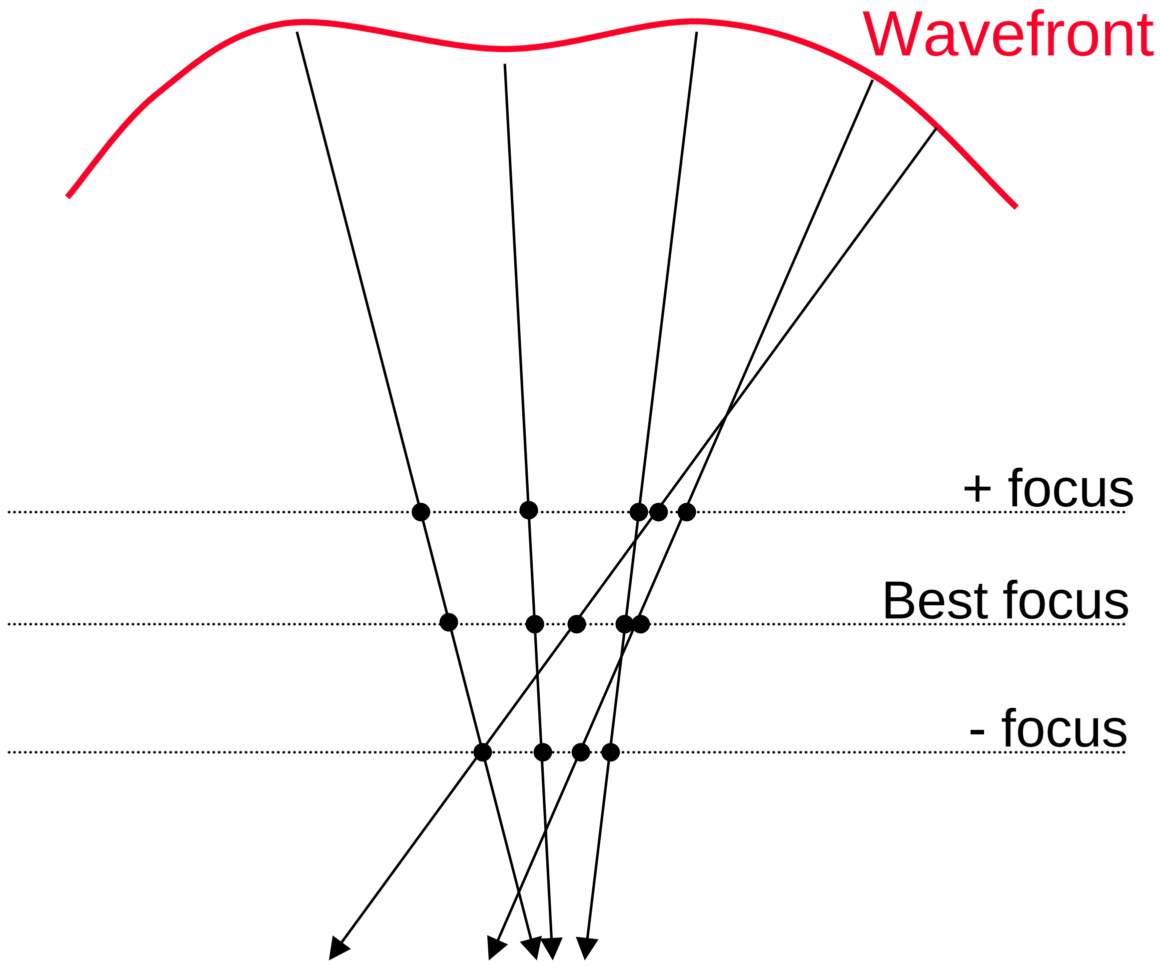
Phase retrieval from intensity ?



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Recipe for phase retrieval

Our approach to determine the lens aberrations is based on the observation of the through-focus point spread function.

$$\text{Observed intensity} = \sum \alpha_{nm} \text{ Basic functions } (V_{nm})$$

- The Zernike coefficients are found on solving a linear system of equations.

Validation phase retrieval

		Input: random aberrations		*Perfect* retrieval
Low order	Position	0.0175		0.0175
	Focus	-0.0187		-0.0187
	Astigmatism	0.0726		0.0726
	Coma	-0.0588	Intensity PSF	-0.0588
	Spherical	0.2183	$\longrightarrow$	0.2183
	Three-point	-0.0136		-0.0136
High order	Astigmatism	0.0114		0.0114
	Coma	0.1067		0.1067
	Spherical	0.0059		0.0059
	⋮	⋮		⋮

- Details in the conference paper.

Applications to a microscope

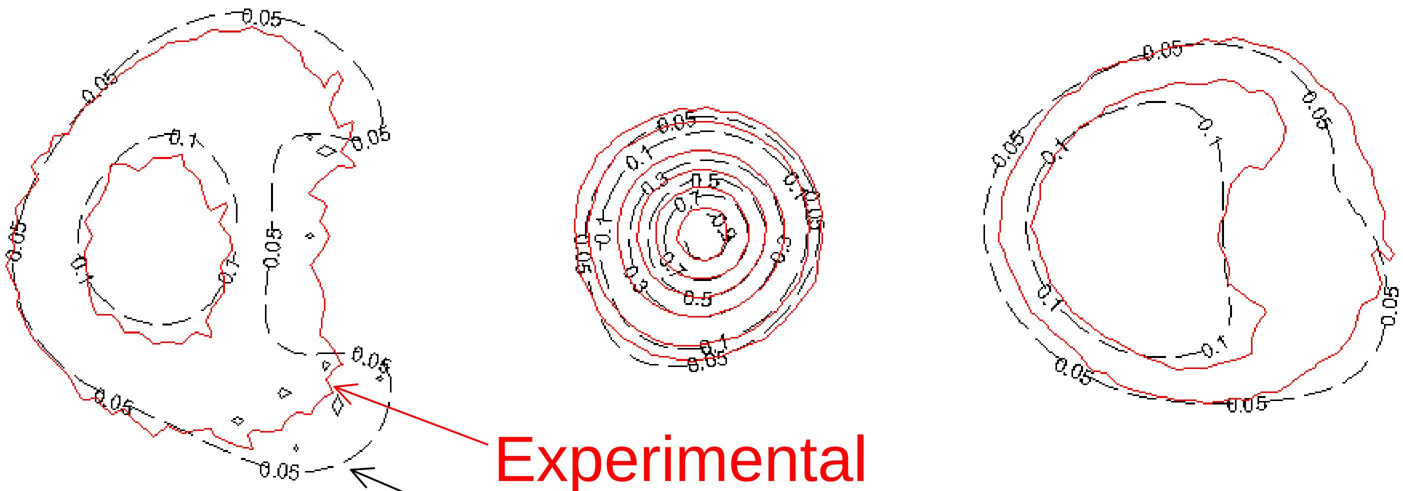
- MSM100, $\lambda = 193$ nm
- Load a reticle, observe aerial image on a CCD camera

Ideal to observe the point spread function of the objective lens

Through-focus aerial image of an isolated hole

(λ=193 nm MSM-100)

- focus | Best focus | + focus

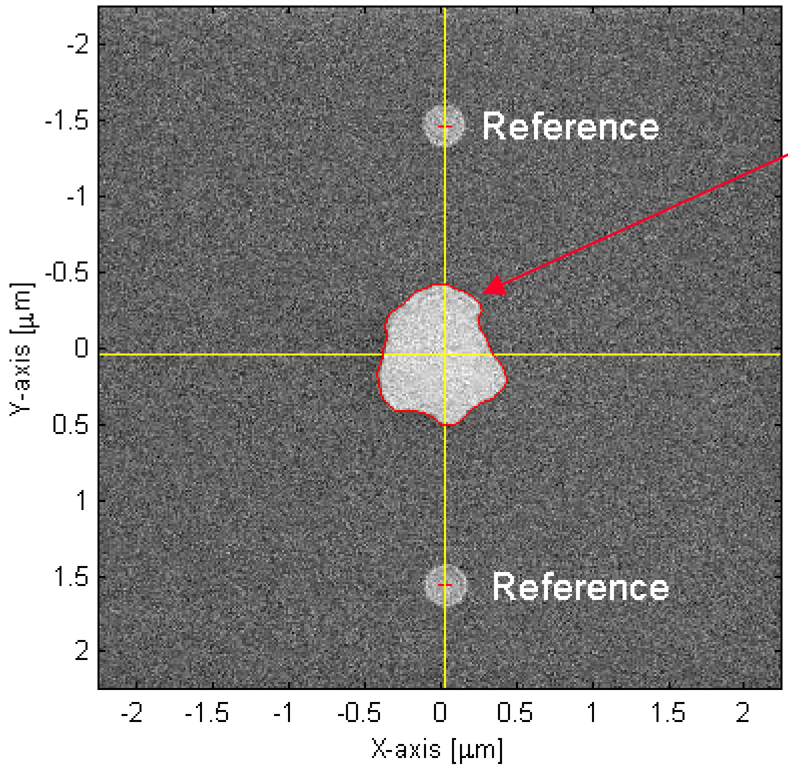


Experimental

Retrieved Zernike coefficients

The dominant term is high order coma

Applications to a scanner

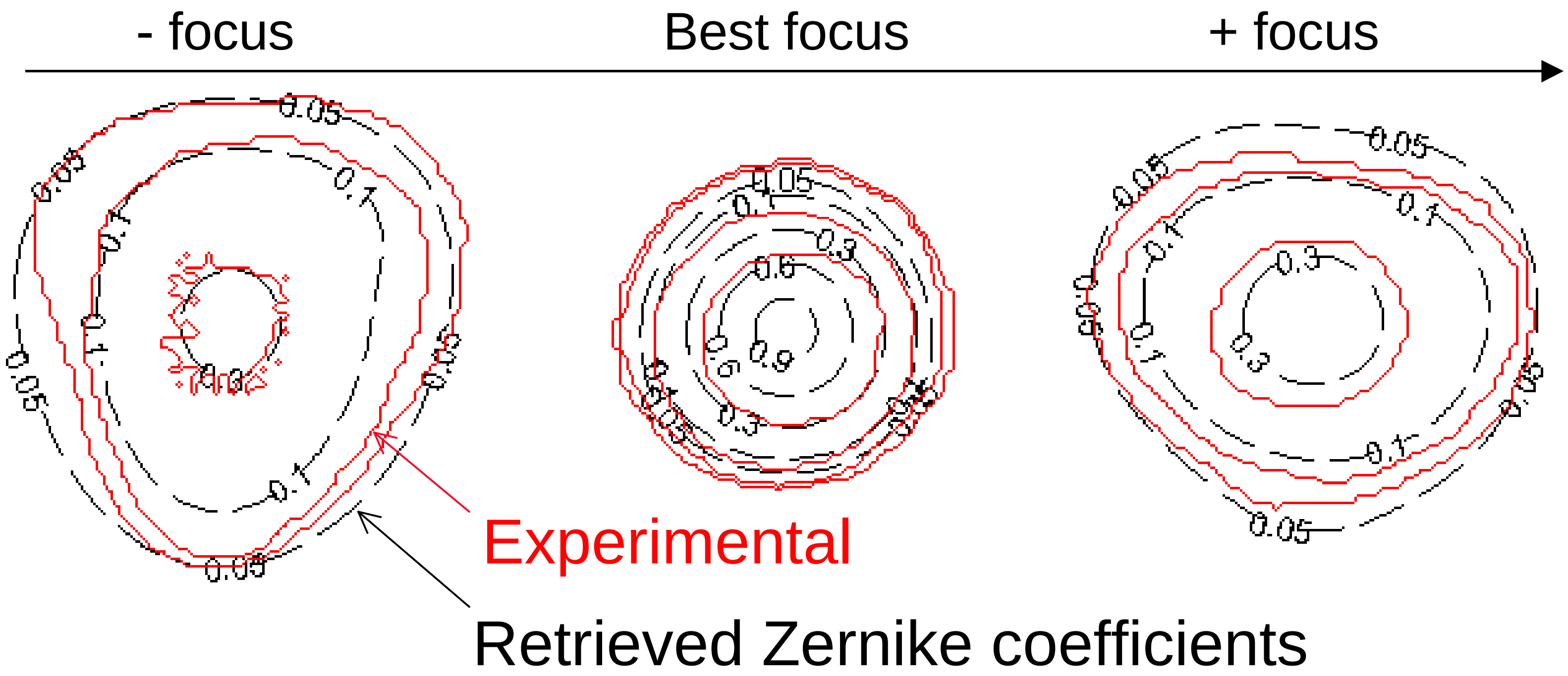


Single contour of the point spread function

FEM: combine contours into a through-focus aerial image

Through-focus aerial image of an isolated hole

(ASML PAS 5500/950, λ=193 nm scanner)



The dominant terms are low order astigmatism and low order three-foil.

Summary

- The proof of principle of a new experimental method to characterize a lens has been given.
- The method is based on the observation of the point spread function.
- 'Getting the Zernikes' is solved analytically: the extended Nijboer-Zernike approach

<u>Applications:</u>

- Projection lenses 193, 157 and 13 nm
- Optical microscopes, such as reticle inspection tools

Acknowledgement

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