

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

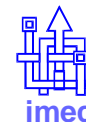
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1) Philips Research

2) Delft University of Technology

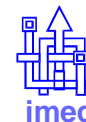
3) IMEC

4) International Sematech



Introduction to lens characterization

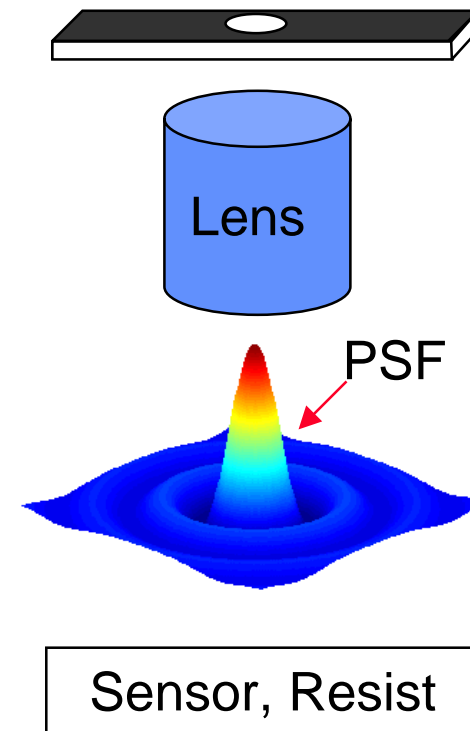
- ◆ Lens aberrations have an important contribution to CD variation and image misplacement
- ◆ Low k_1 -imaging requires tight aberration specifications.
- ◆ Focal plane deviation, astigmatism, coma and spherical aberration are all adjustable quantities.
- ◆ Aberrations may vary in time due machine drift.



The new lens characterization method

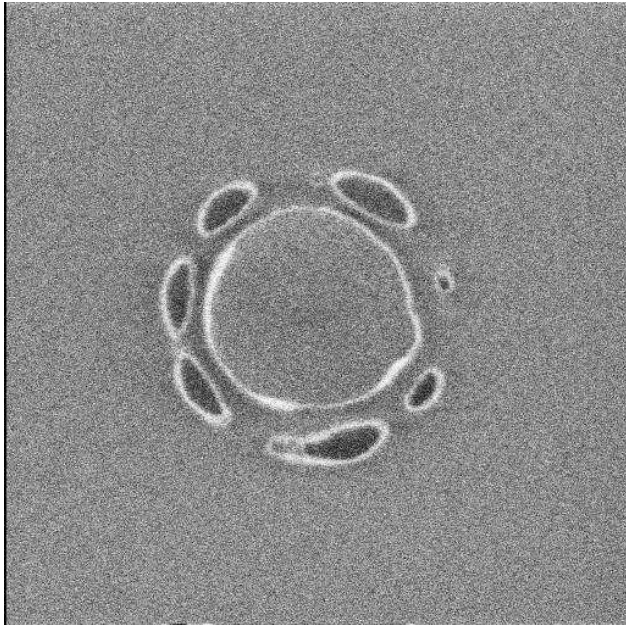
- ◆ The new method is based on the observation of the point spread function
- ◆ Resolves high and low order aberrations
- ◆ Illumination setting independent
- ◆ Wavelength independent

Simple binary mask, small hole



The point spread function tells the whole lens story

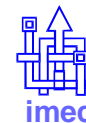
‘A slice from a point spread function’



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

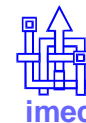
Interpretation of the experiment

- ◆ 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 AANDE 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
GEBBORN TE MEPPTEL

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”

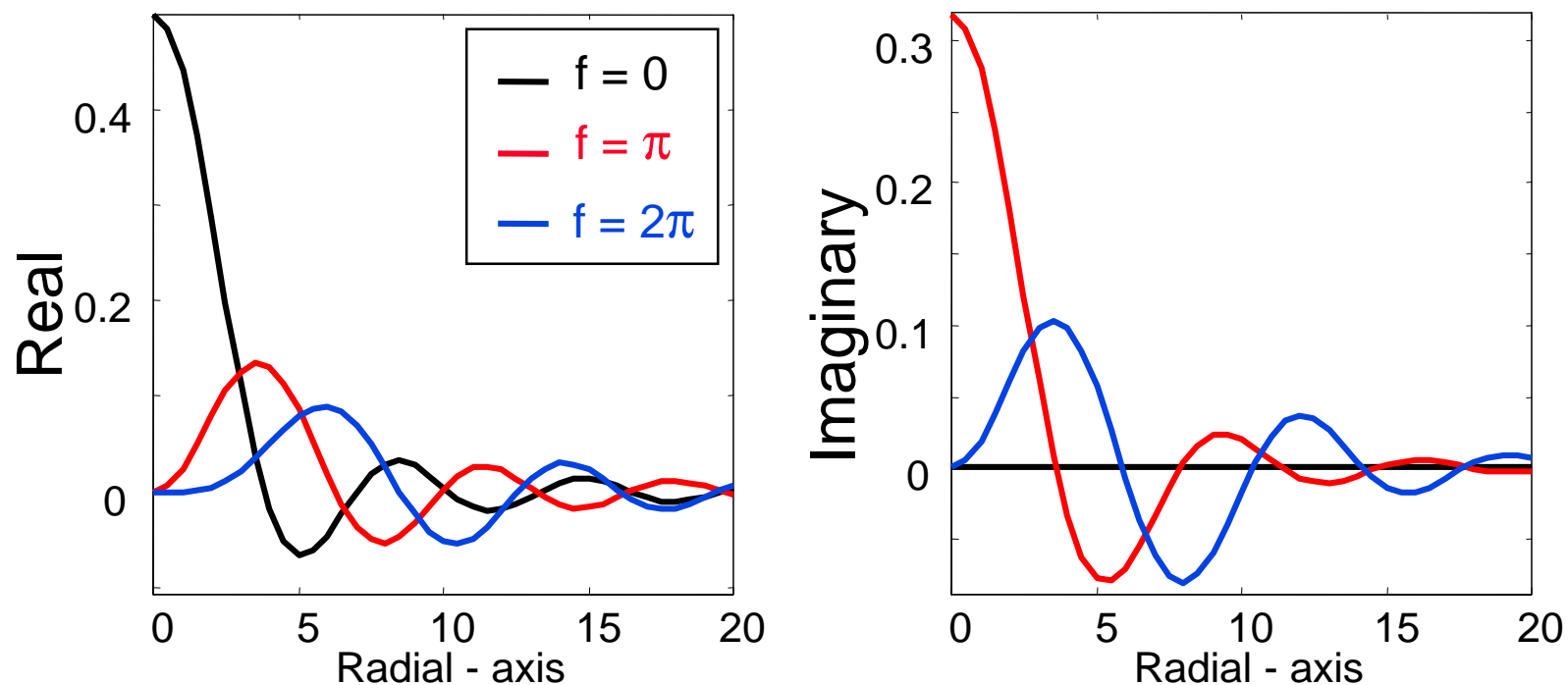
A. Janssen, (2001)

New

$$U(r, f) \approx 2V_{00} + 2 \sum_{nm} \alpha_{nm} i^{m+1} V_{nm} \cos(m\theta),$$
$$V_{nm}(r, f) = \exp(if) \sum_{l=1}^{\infty} (-2if)^{l-1} \sum_{j=0}^p v_{lj} \frac{J_{m+l+2j}(r)}{lr^l}$$

- ◆ 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 ($f=0$)

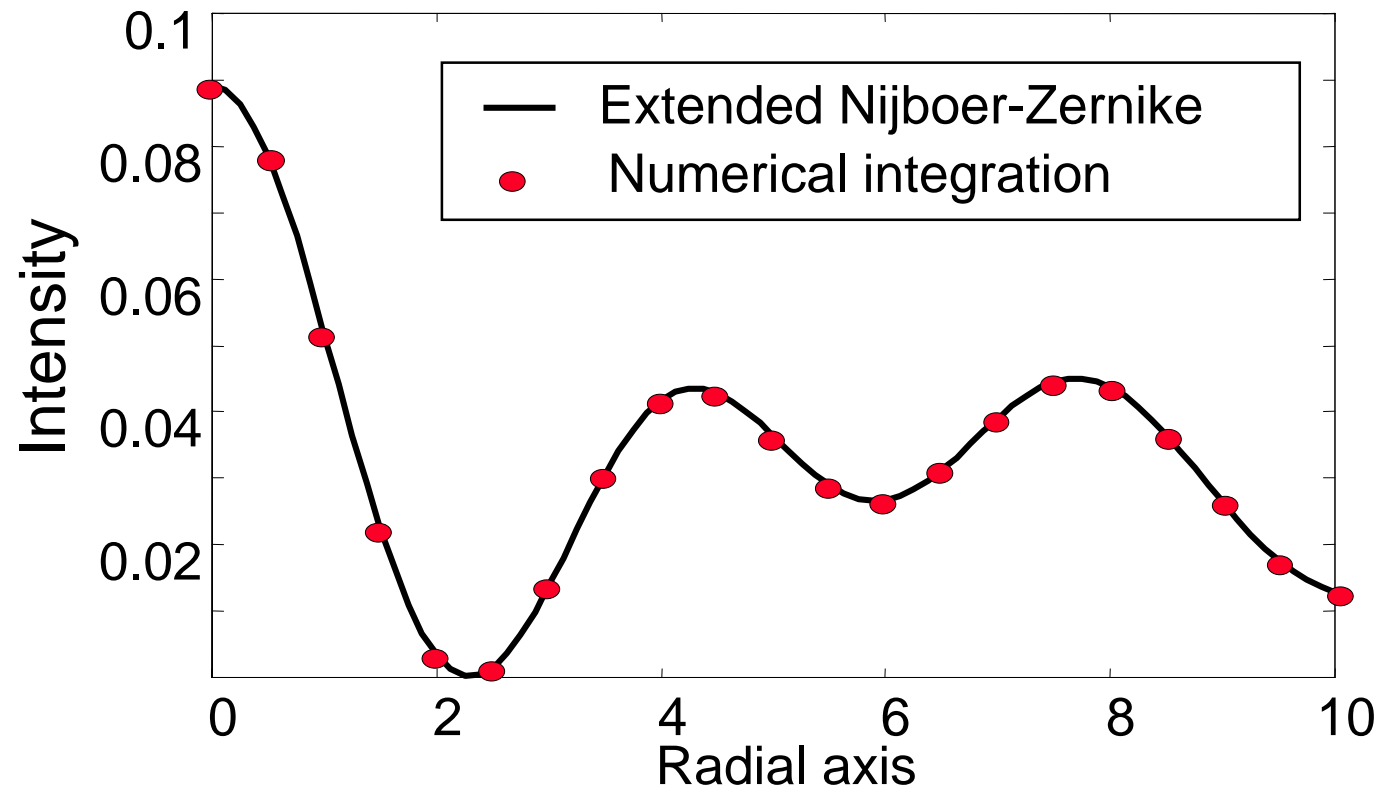
Example : through - focus Airy pattern $V_{00}(r,f)$



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

Validation: example

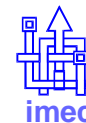
$1/6 \lambda$ Spherical + 2π defocus



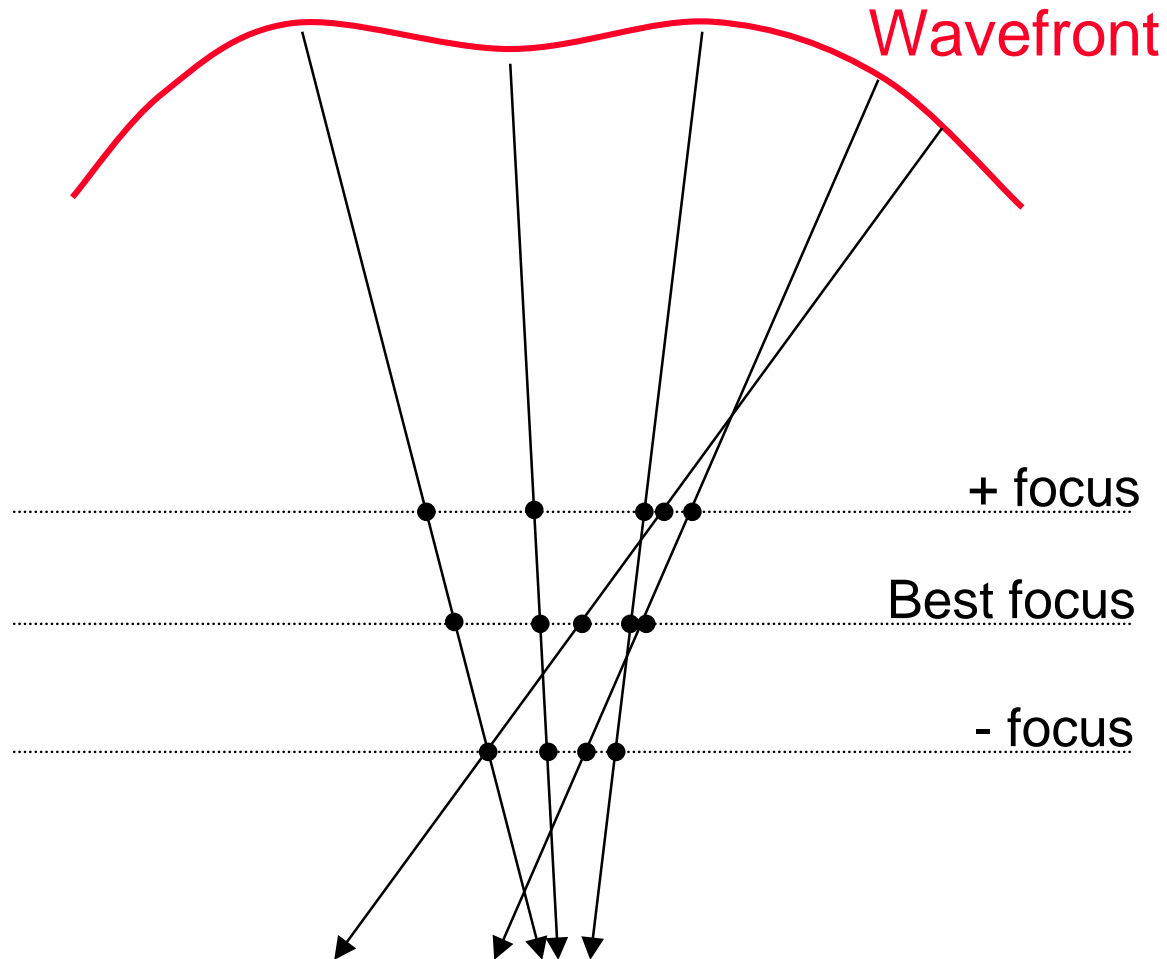
◆ More info: two publications in *J.O.S.A. A.*, May 2002 issue

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Phase retrieval from intensity ?



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

High order ↓ Low order	Position	0.0175	Intensity PSF →	0.0175
	Focus	-0.0187		-0.0187
	Astigmatism	0.0726		0.0726
	Coma	-0.0588		-0.0588
	Spherical	0.2183		0.2183
	Three-point	-0.0136		-0.0136
	Astigmatism	0.0114		0.0114
	Coma	0.1067		0.1067
	Spherical	0.0059		0.0059
	⋮	⋮		⋮

◆ Details in the conference paper.

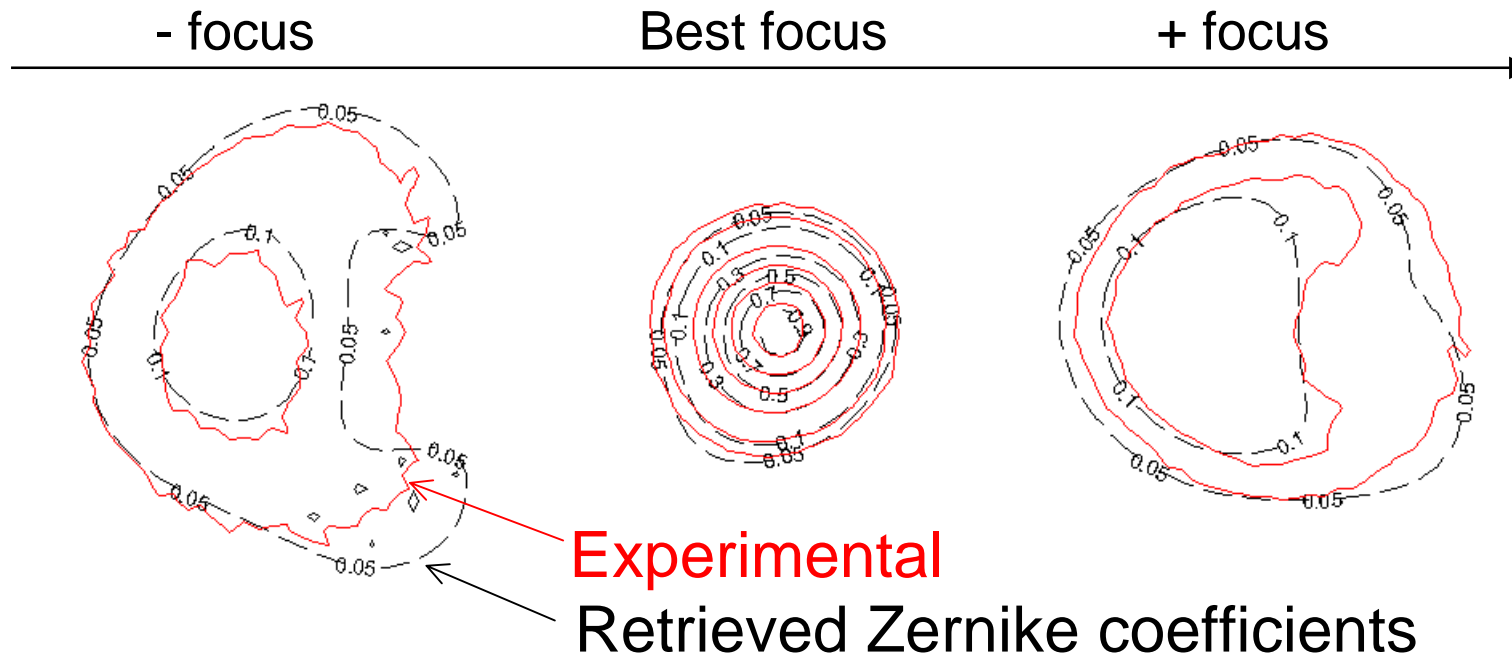
Applications to a microscope

- ◆ 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

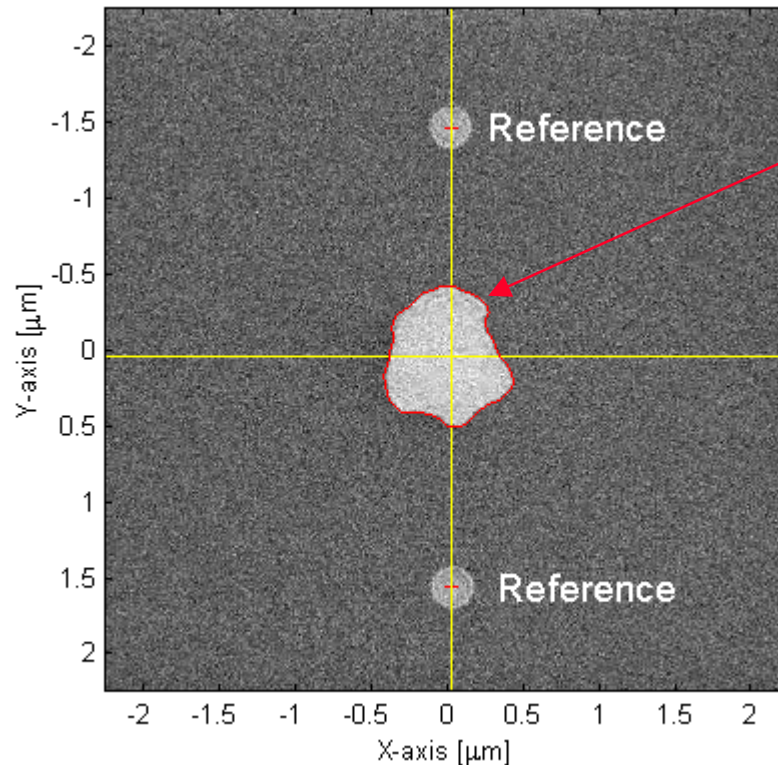
Through-focus aerial image of an isolated hole

($\lambda=193$ nm MSM-100)



The dominant term is high order coma

Applications to a scanner

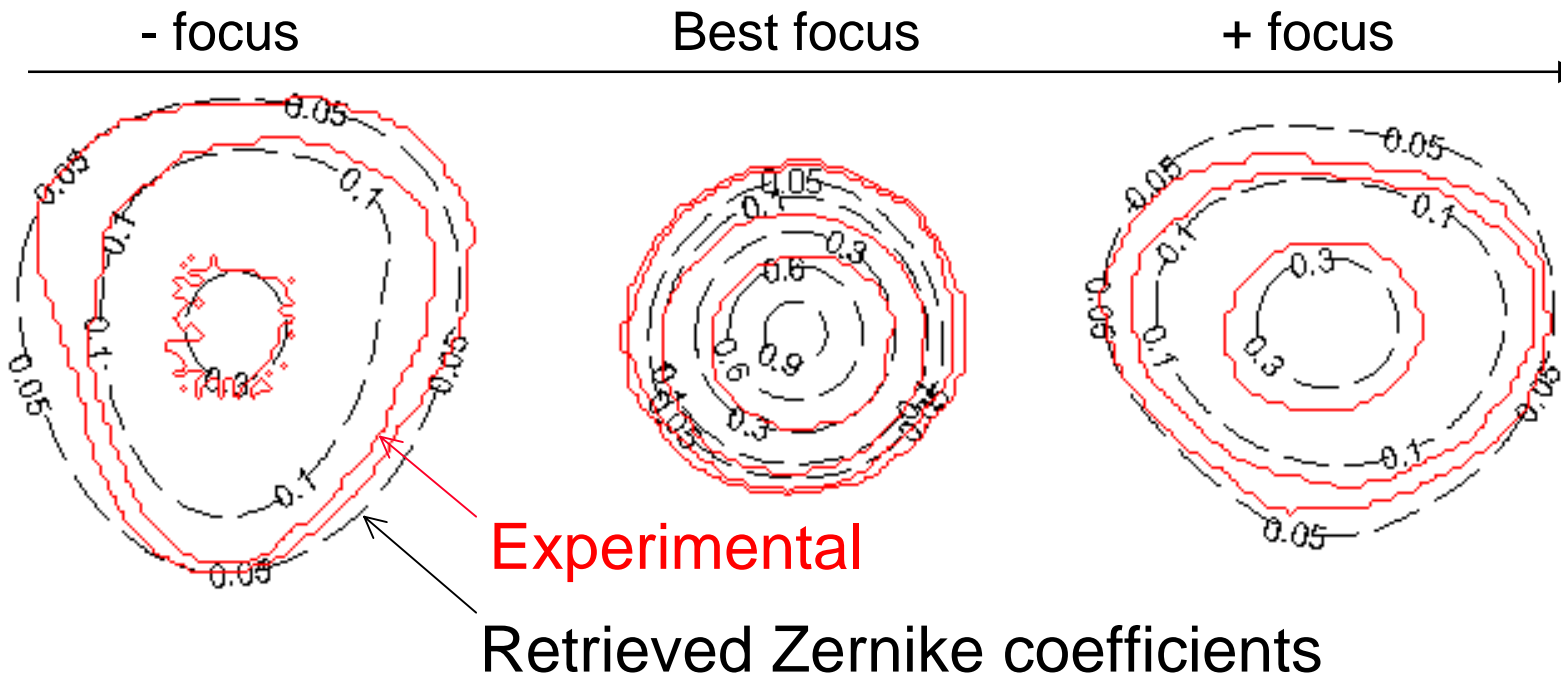


Single contour of the point spread function

FEM: combine contours into a through-focus aerial image

Through-focus aerial image of an isolated hole

(ASML PAS 5500/950, $\lambda=193$ nm scanner)



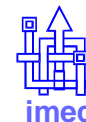
The dominant terms are low order astigmatism and low order three-foil.

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

Applications:

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



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