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

Peter Dirksen, Joseph Braat, Peter De Bisschop,
Augustus Janssen, Casper Juffermans,
Alvina Williams

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 to 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

Sensor, Resist
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)

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

- Best focus, small aberrations
- Defocus included for a few low order terms only
“Extended Nijboer-Zernike theory”
A. Janssen, (2001)

\[
U(r, f) \approx 2V_{00} + 2 \sum_{nm} \alpha_{nm} i^{m+1} V_{nm} \cos(m\theta),
\]

\[
V_{nm}(r, f) = \exp(if) \sum_{l=1}^{\infty} (-2if)^{l-1} \sum_{j=0}^{p} v_{lj} \frac{J_{m+l+2j}(r)}{lr^l}
\]

♦ 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 $\alpha_{nm}$.

- The extension to large aberrations exist.
Validation: example

1/6 $\lambda$ Spherical + $2\pi$ defocus

More info: two publications in J.O.S.A. A., May 2002 issue
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Phase retrieval from intensity?

Wavefront

+ focus

Best focus

- focus
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

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<th>High order</th>
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<td>Focus</td>
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Intensity PSF

Perfect retrieval

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

Experimental
Retrieved Zernike coefficients
Applications to a scanner

FEM: combine contours into a through-focus aerial image

Single contour of the point spread function
Through-focus aerial image of an isolated hole 
(ASML PAS 5500/950, $\lambda=193$ nm scanner)

- focus  

Best focus

+ focus

Experimental
Retrieved Zernike coefficients

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
Acknowledgement

The authors wish to thank David van Steenwinckel, Michael Benndorf and Johannes van der Wingerden from Philips Research Leuven for their valuable input and experimental support.