EOS AM
2008
TOM 4-1177

Image simulations of extended objects using an algorithm based on the Extended Nijboer-Zernike (ENZ) formalism

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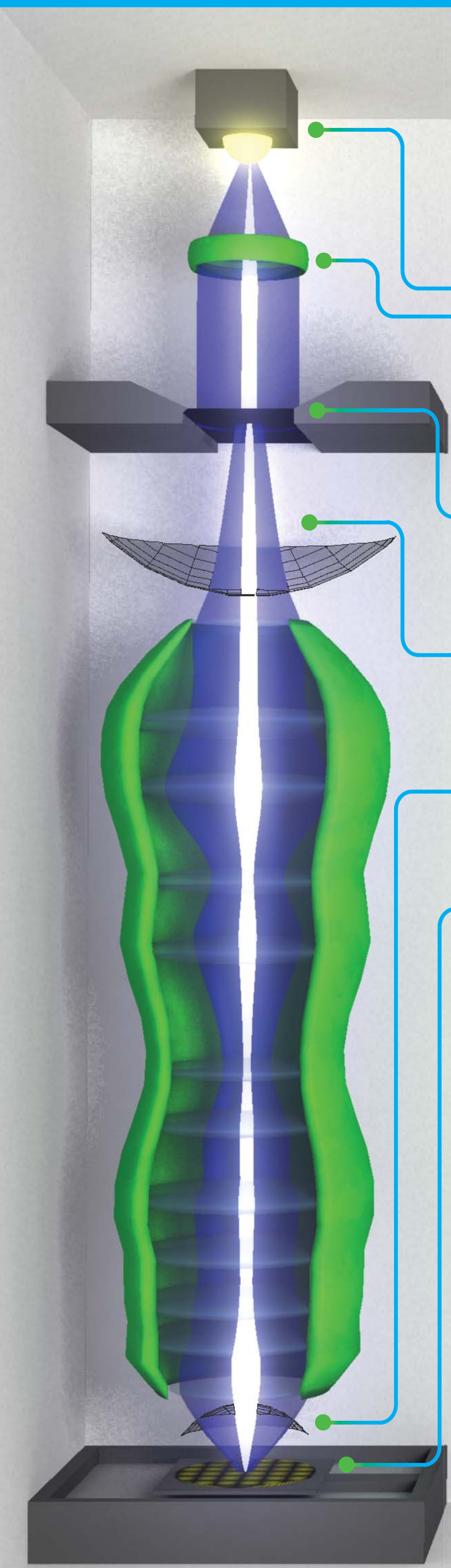

*Artists impression by Olaf Janssen

Introduction:

We present details of a recently developed imaging algorithm based on the Extended Nijboer-Zernike (ENZ) formalism [1][2]. We focus mainly on the imaging part of the algorithm which generates the through-focus images using the Zernike functions that describe the entrance pupil distribution. We show an example illustrating some of the advantages introduced by the ENZ approach.

ENZ imaging scheme:

- Discretize extended source
- Source element generates plane wave through Köhler illumination scheme
- Rigorously compute the near-field at the mask due to plane wave illumination
- Propagate near-field to the entrance pupil and represent it as a Zernike expansion
- Include aberrations and transmission changes and generate Zernike coefficients of exit pupil field
- Construct through-focus image contribution using the Zernike coefficients of the exit pupil and the ENZ basic functions
- Final image is obtained as the incoherent sum of all source element contributions

Convergence & accuracy:

- Convergence considerations on the FDTD tool performing both the near-field and the propagation computations can be found in Refs. [3],[4].
- The convergence of the Zernike expansion in the entrance pupil strongly depends on the object. Large objects with a high degree of periodicity require a large number of Zernike coefficients. Convergence for a double hammerhead structure is shown in Fig. 2A.
- The ENZ basic functions are computed using a well-converging series expansion. These functions are independent of the object and can thus be calculated and stored in advance.

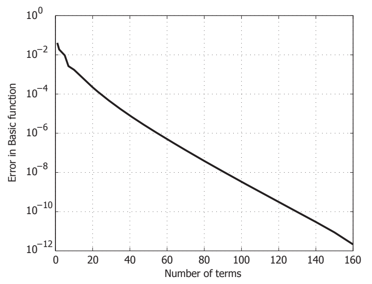

Fig 1. Convergence of the ENZ basic functions.

- As the ENZ basic functions can be computed in advance, the operational accuracy of the method is solely limited by the accuracy of the Zernike expansion in the entrance pupil. This is illustrated by the double hammerhead example presented below.

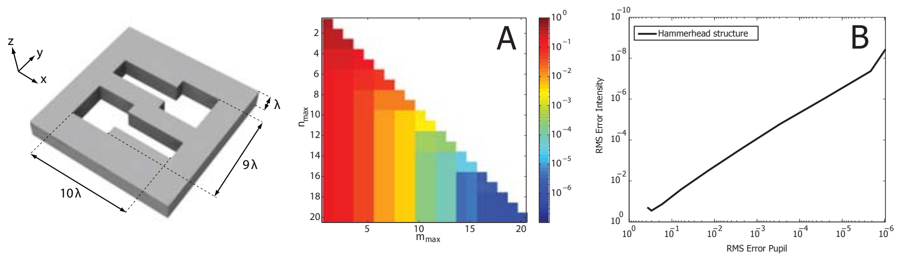

Fig 2. For a double hammerhead structure we show: A) The expansion accuracy (RMS error) in the pupil versus the maximum number of radial and azimuthal Zernike orders (n_{max}, m_{max}) included in the fit. B) The resulting accuracy in the through-focus image.

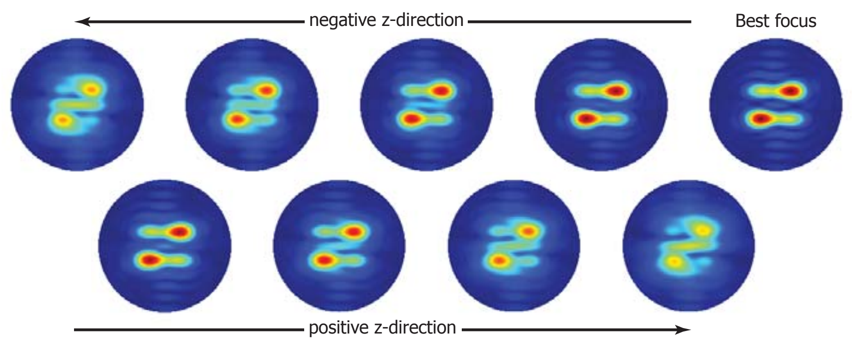

Fig 3. We show the simulated through-focus image behaviour (imaging by an immersion lithographic system, NA = 1.224, λ = 193nm, immersion fluid water, x-pol. normal incidence plane wave illumination) of the hammerhead structure defined in Fig 2. Note that all images are obtained in a single computational run using ENZ basic functions stored in a look-up table.

Conclusions:

Advantages of ENZ-imaging:

- fully rigorous approach
- complete through-focus image behaviour obtained in a single simulation (see Fig. 3)
- speed enhancements possible through precalculation and storage of ENZ basic functions

References:

[1] S. van Haver, et al., SPIE **6924,** 69240U (2008)
[2] ENZ website: http://www.nijboerzernike.nl
[3] O.T.A. Janssen, et al., SPIE **6924,** 692410 (2008)
[4] P. Lalanne, et al., J. Eur. Opt. Soc. Rap. Publ. **2**, 07022 (2007)

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