Extended Nijboer-Zernike (ENZ) based imaging into an image region containing a layered configuration

S. van Haver, J.J.M. Braat, A.J.E.M. Janssen, S.F. Pereira

Delft University of Technology, Department of Imaging Science and Technology,
Optics Research Group, Lorentzweg 1, 2628 CJ Delft, The Netherlands
email: s.vanhaver@tudelft.nl

Summary

We report on recent developments of the Extended Nijboer-Zernike (ENZ) imaging formalism that enables image formation into a layered stack. It will be shown that light reflection effects in the layered stack can be incorporated in the image formation using a complex transmission function based on Fresnel coefficients.

Introduction

The Extended Nijboer-Zernike (ENZ) theory provides a semi-analytic solution to the Debye diffraction integral [1, 2]. It has been originally developed to enable quality assessments of advanced optical systems by means of through focus intensity measurements [3-5]. More recently the ENZ-theory has also been applied to imaging of extended objects [6,7]. The ENZ-formalism has great potential in this field as its semi-analytic nature ensures high accuracy and good performance. Up until now, ENZ-based image formation was only possible in a uniform image region. Here we will report on recent developments that enable the use of the ENZ-formalism for image formation in a region with several layers of different media perpendicular to the optical axis. Such a configuration is, for example, encountered in optical lithography, where image formation takes place in a photoresist layer that can be part of a more general multilayer deposited on top of the silicon wafer.

Discussion

In Fig. 1 a schematic representation of imaging into a multilayered region is shown. The most important difference compared to imaging in a uniform region is that we have to deal with light reflections on the interfaces between the layers. Traditionally, image formation in a multilayer is done by computing the Fresnel coefficients of the layered stack after which the plane wave expansion of the field in the exit pupil is sequentially propagated through all layers using the Fresnel coefficients as weighting factors. One of the disadvantages of this approach is that, in order to obtain the field in the final layer, the field in all preceding layers should be evaluated first.

On the other hand, the ENZ-based approach features a solution to the Debye diffraction integral that relates the field in the exit pupil to any point in a uniform image space. The field in image space is obtained using the Zernike expansion coefficients of the exit pupil times some basic functions that follow from ENZ-theory. We found that it is possible to preserve this appealing approach when a layered configuration is introduced. The field in a given layer is again constructed using basic ENZ-functions, but instead of simply using the Zernike expansion of the exit pupil to obtain the expansion coefficients, one should use the exit pupil expansion times a complex transmission function. This transmission function accounts for the changes in the field components introduced by the multilayer for a particular layer and is again based on the Fresnel coefficients of the layered stack.

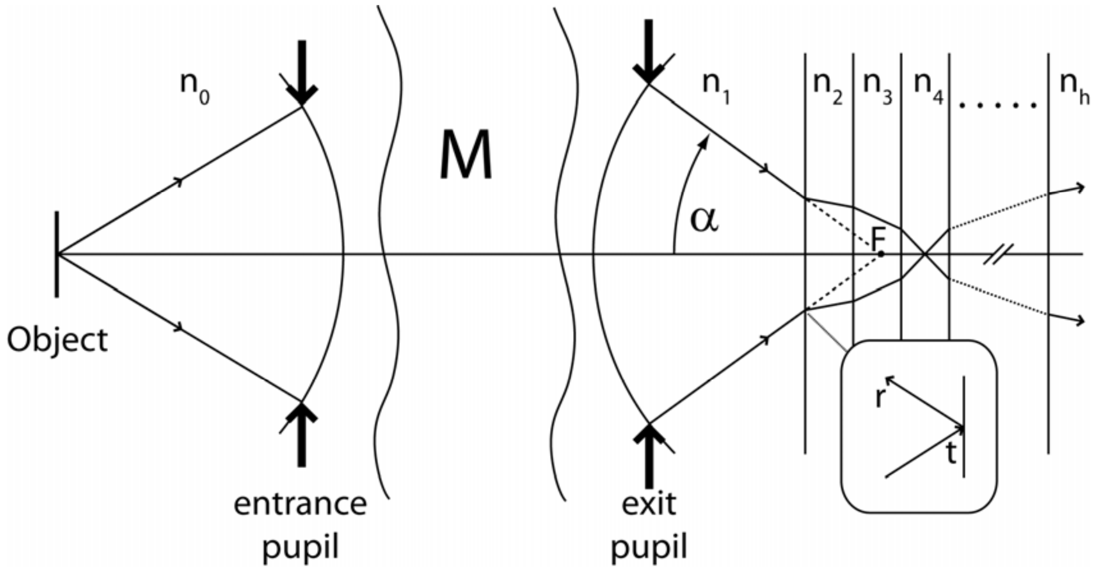

Fig 1: Schematic representation of imaging into a multilayered configuration.

Altogether, it turns out that the total vector field in a single uniform layer of the stack (both forward and backward propagating contributions) is completely defined by eight sets of expansion coefficients and their accompanying ENZ basic functions. This is true for every layer and as a result the field in any layer can be obtained without evaluation of the fields in the layers preceding it.

Conclusion

We report on further enhancements of the ENZ-based imaging method to include image formation in a region containing a layered configuration. It is possible to relate the field in a layered image space directly to the field in the entrance pupil originating from an object. A main advantage of this is that the field in any layer can be obtained without having to evaluate all preceding layers. With this latest addition to the ENZ-toolbox we have concluded the development of a versatile and very accurate imaging method that represents a complete alternative to conventional Fourier based imaging algorithms.

References

[1] A.J.E.M. Janssen, J. Opt. Soc. Am. A **19** (2002), pp. 849-857.
[2] J.J.M. Braat, P. Dirksen, A.J.E.M. Janssen, J. Opt. Soc. Am. A **19** (2002), pp. 858-870.
[3] C. van der Avoort, J.J.M. Braat, P. Dirksen, A.J.E.M. Janssen, J. Mod. Opt. **51** (2004), pp. 687-703.
[4] J. J. M. Braat, P. Dirksen, A.J.E.M. Janssen, A.S. van de Nes, S. van Haver, J. Opt. Soc. Am. A. **22** (2005), pp. 2635-2650.
[5] S. van Haver, J.J.M. Braat, P. Dirksen, A.J.E.M. Janssen, J. Eur. Opt. Soc. Rap. Pub. **1**, 06004, 2006.
[6] S. van Haver, O.T.A. Janssen, A.J.E.M. Janssen, J.J.M. Braat, H.P. Urbach, S.F. Pereira, Proc. SPIE **6924**, San Jose, February 2008, pp. 1-8.
[7] S. van Haver, J.J.M. Braat, A.J.E.M. Janssen, O.T.A. Janssen, S.F. Pereira, “Vectorial aerial-image computations of three-dimensional objects based on the Extended Nijboer-Zernike theory,” submitted to: J. Opt. Soc. Am. A, Dec 2009.