Lawrence Berkeley National Laboratory
Lawrence Berkeley National Laboratory

Title
In-situ testing of high resolution optical systems via localized wavefront curvature sensing

Permalink
https://escholarship.org/uc/item/6nj6d718

Author
Miyakawa, Ryan

Publication Date
2012-06-01

eScholarship.org Powered by the California Digital Library
University of California

In-situ testing of high resolution optical systems via localized wavefront curvature sensing

Ryan H. Miyakawa, Christopher N. Anderson, Patrick P. Naulleau
Center for X-ray Optics, Lawrence Berkeley National Lab, 1 Cyclotron Rd. Berkeley CA, 94720
rhmiyakawa@lbl.gov

Abstract: We present a new form of optical testing based on measuring localized wavefront curvature. In this method a system of pseudo-sine gratings reveal the partial second derivatives of the wavefront at specific locations, and the wavefront aberrations are reconstructed using a least squares approach.
© 2012 Optical Society of America
OCIS codes: 010.7350, 070.0070

1. Introduction

Many optical systems such as next-generation lithography tools continue to push the boundaries of resolution to keep pace with the semiconductor industry. As the resolution of these systems gets higher, it becomes increasingly difficult to characterize the aberrations in the system. Interferometric techniques based on reference waves such as phase-shifting point diffraction interferometry (PS/PDI) become difficult to realize due to the strict requirements on coherence and reference wave quality. Self-referencing tests such as lateral shearing interferometry (LSI) suffer from tight tolerances on grating and detector tilt [1].

2. Setup

In this paper, we propose a new method of optical testing that is based on measuring the localized curvature at various points across the pupil. A schematic of the experimental setup is shown in Fig. 1.

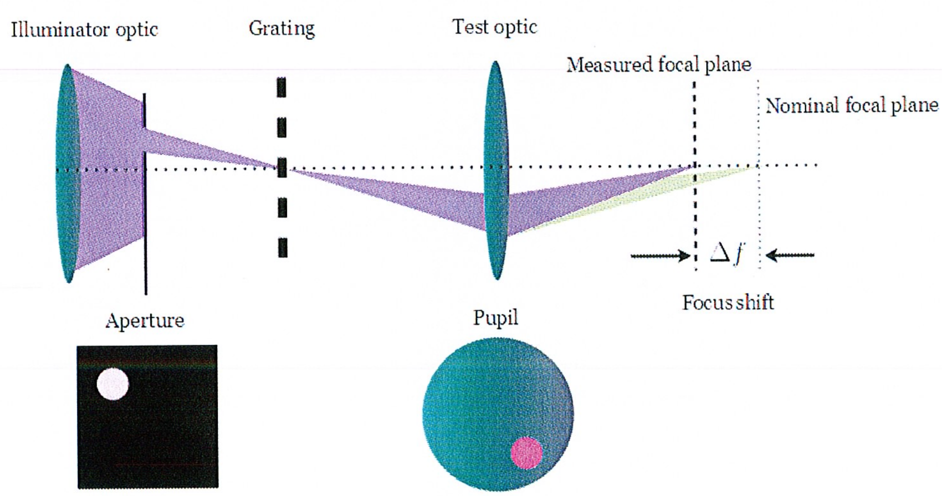

Fig. 1. Schematic of measuring the local curvature of the test optic.

A low-spatial frequency grating is used to send light to a specific point in the pupil. Control of the probe position is governed by an illumination aperture that sets the range of incident spatial frequencies from the illuminator optic.

Aberrations in the test optic cause a departure in the local curvature from that of an ideal optic which manifests as a small focus shift which is measured by a focus sensor in the image plane. The relationship between the wavefront curvature and the measured focus shift is given by:

$$\frac{\partial^2 W}{\partial x^2} \quad \frac{\Delta f \cdot NA^2}{\lambda} \qquad (1)$$

where λ is the illumination wavelength, NA is the numerical aperture of the optic, and x represents the grating axis. The measurement is repeated for the y direction, and the wavefront $W(x,y)$ is reconstructed from its partial second derivatives $[\partial^2 W(x,y)/\partial x^2, \partial^2 W(x,y)/\partial y^2]$ using a least squares approach.

3. Focus sensor

Determining the plane of best focus is performed using an improved grating-on-grating focus monitor. In a typical grating-on-grating focus monitor, a grating is imaged to a pitch-matched conjugate grating which is scanned in various planes through-focus. A diode captures the total integrated intensity through the grating, and the contrast is plotted as a function of grating defocus. The plane of best focus will demonstrate perfect contrast as the gratings are de-phased. A schematic of the focus sensor is shown in Fig. 2a, and the working principle is illustrated in Fig. 2b.

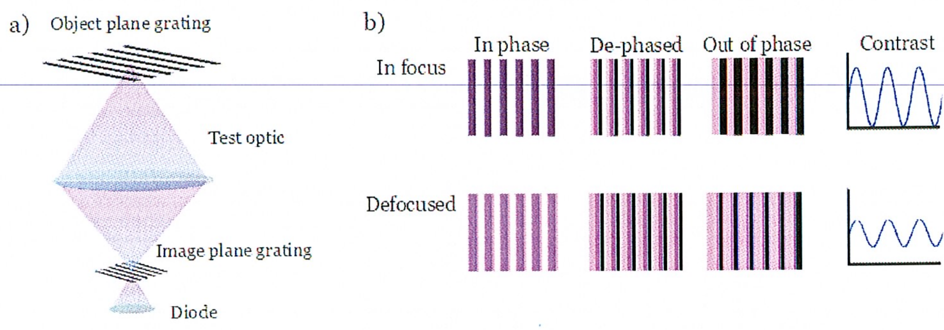

Fig. 2. a) Focus sensor setup, b) Focus sensor working principle: the plane of best focus is given by plane which gives the highest contrast.

To improve the accuracy of the focus monitor, a pseudo-sine grating (PSG) is used in place of a square grating in the image plane. A PSG is binary structure that has a 1-dimensional Fourier transform similar to that of a pure amplitude sine grating. Because PSGs are binary, they can be fabricated using standard lithography for operation at an arbitrary illumination wavelength. An example of two PSG patterns compared with an amplitude sine grating is shown in Fig. 3.

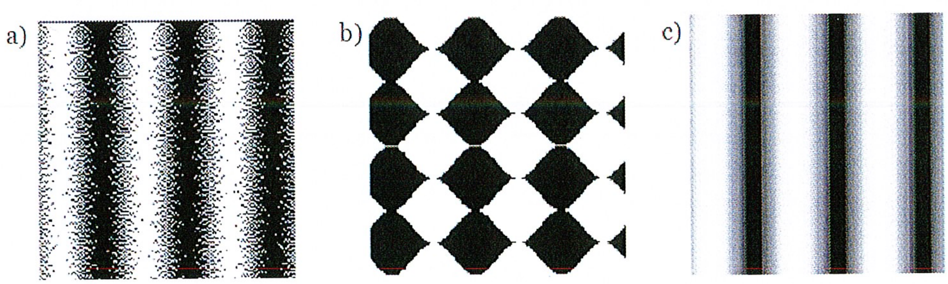

Fig. 3. Each of these three gratings have a similar 1D spectrum. a) Binary PSG #1, b) Binary PSG #2, c) Amplitude sine grating

Since the measured signal is the correlation between the object and image plane gratings, the PSG acts like a transfer function to the image intensity, which serves to zero out the higher order harmonics of the object grating that can otherwise alter the shape of the contrast curve. Since the PSG retains only the ± 1 orders, it ensures that the pupil is probed only in the desired region.

4. Summary

The proposed method of optical testing is versatile, as it does not require resolution-limited spatial filters or complicated interferometric schemes. Since wavefront curvature is measured in a small subsection of the pupil, the object grating and image PSG are relatively easy to manufacture, as their critical dimension will be several times larger than the resolution limit of the optical system. Finally this method scales well to short wavelengths and high numerical apertures, covering regimes relevant to a number of applications such as next generation lithography tools.

References

1. P. P. Naulleau, K. A. Goldberg, et al."Extreme-ultraviolet phase-shifting point-diffraction interferometer: a wave-front metrology tool with subangstrom reference-wave accuracy," Applied Optics **38**, 7252-63 (1999).

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or The Regents of the University of California.

This work was supported by the Director, Office of Science, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.