Aerial image simulations using measured EUV wave front data

Marcel Dierichs

The ETS experimental EUV optical column provides experimental lens performance data that you can use for aerial image simulation-based investigations. (ETS stands for Engineering Test Stand -- the first full-field EUV scanner built by the EUV consortium LLC.) Compared with current systems, the performance of the EUV optical column is relatively unknown, because of the difference in concept (refractive versus reflective optics) and a significantly shorter wavelength. This concept requires drastically improved polishing techniques to reach the necessary surface quality needed for imaging.

This poster shows the results of aerial image simulations using the Projection Optics Box 1 (POB1) pupil phase data of the ETS. Our goal is to verify that with the data known, no significant imaging problems occur. Otherwise, we would need to improve the design and/or the specifications.

Figure 1 shows an illustration of the ETS with the positions and coarse dimensions of the POB mirrors.

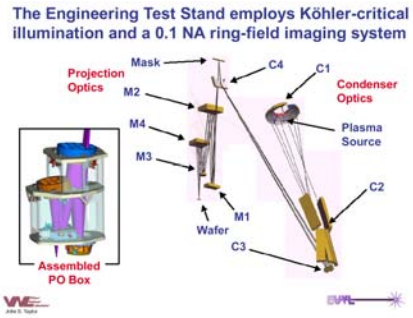


Figure 1. Illustration of the ETS optical column[1].

The ETS is the only source of the EUV machine data available presently. For optimum imaging performance, the surface roughness of each mirror has to be as small as possible. The common way to show this is in the Power Spectral Density (PSD) plot (figure 2). Three different surface measurements that cover different parts of the spectral frequency range make up the PSD. Figure 3 shows the results for all mirrors of the first part of the PSD, i.e. the interferometric data. In this figure, you can see clearly the orange-peel effect, we expect, caused by the polishing of the surfaces. Figure 4 shows the interferogram of the assembled POB and the residual after the correction of all aberrations up to Z36. The latter yields the phase map we use in the simulations.

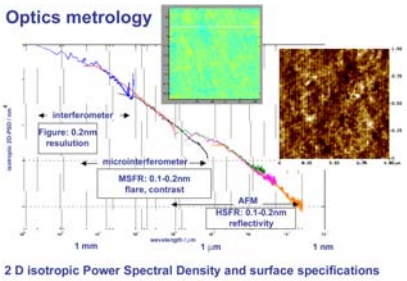


Figure 2. PSD for a real mirror as measured by Zeiss[2].

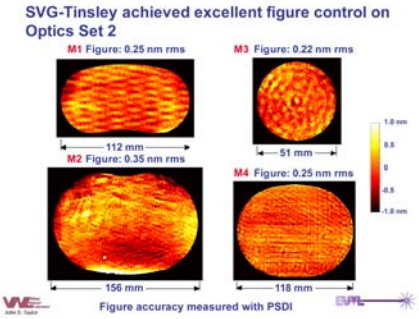
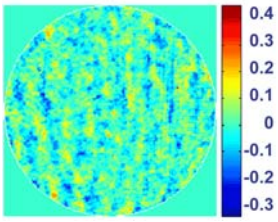


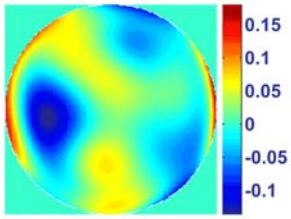
Figure 3. Interferometric data for each ETS mirror[1].

Ideally corrected



+

Z1-Z36



=

ETS POB2, center

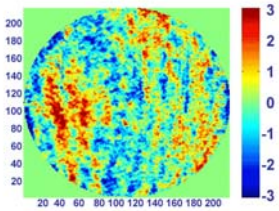


Figure 4. Subtraction of the aberrations from the ETS interferogram of the assembled POB.

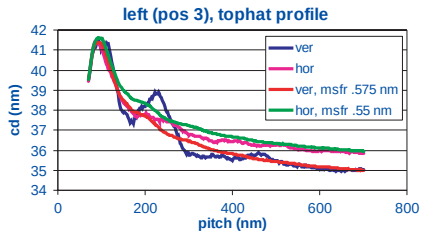
We scale the ETS data to a 0.25-NA system to get results for 30-nm dense lines and simulate the illuminator using a top-hat profile with a sigma of 0.5. In addition to the phase data, the simulation uses the incorporated long-range flare as a fractal type of log slope, having an MSFR of 0.25 nm rms.

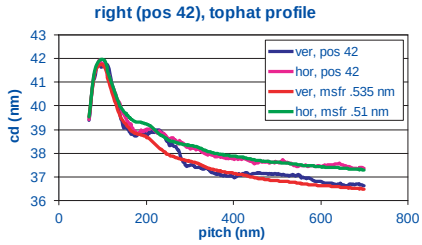
For a projection-pupil with the phase data, and for the PSD with an added MSFR, the simulations include pitch linearity for three positions in the ETS slit (figure 5). We manipulate the results shown, in terms of MSFR, to achieve the same iso-CD for the specific slit position and orientation. In both cases, the simulation corrects all aberrations up to Z36, and the pitch linearity is for bright field lines.

You can see clearly the bump in the pitch linearity for the vertical lines where use is made of the measured data. By matching the corresponding diffraction structure to the fine structure of the measured and corrected data, you can get an explanation of the bump. Because the fine structure is in one direction only, the effect is visible for only one orientation.

A second effect is the difference in MSFR for horizontal and vertical lines. The values found also change across the slit. This means that the amount of background flare is strongly dependent on orientation and slit position, which results in significant CD-uniformity effects. This is quite different compared with the results from the commonly used isotropic PSD.

Acknowledgements: The author wishes to thank the following persons for supplying the various data, and for discussions; Hans vd Laan, Uwe Mickan, Mark Eurlings, Anton v Dijsseldonk, Koen v Ingen-Schenau, Marco Moers, and Armand Koolen of ASML; Wolfgang Singer, Martin Lowisch, Martin Antoni, and Joachim Wietzorrek of CZO-SMT; John Bjorkholm of Intel; and Henry Chapman of LLNL.





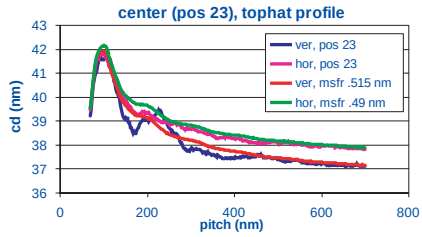


Figure 5. Pitch linearity for three different positions in the ETS POB.

In addition to the pitch linearity, we did simulations on a 50-nm elbow (figure 6). If you subtract the aerial image calculated with an analytical isotropic PSD only from the aerial image calculated using the measured wave front, you can see clearly the ghosted image that the spatial frequency of the orange-peel effect causes (figure 7).

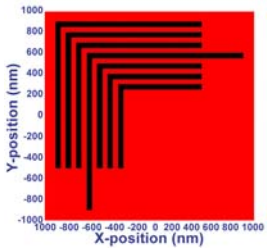


Figure 6. 50-nm elbow structure

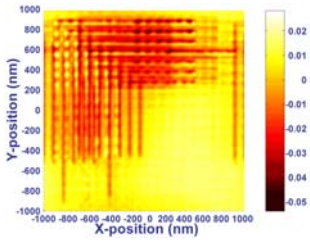


Figure 7. Ghost image caused by the orange-peel effect

Conclusions:

The effects of the orange-peel effect on ETS mirrors:
- Orange-peel effect on the surface of the mirrors causes significant CD and H-V effects at one position, and also through the slit as a function of pitch linearity.
- Orange-peel effect also causes a ghosted image, which you can see in the elbow structure. The effect of this on CD still has to be calculated.

References:
1. J S Taylor, D Sweeney, R Hudyma, "Optical system issues in EUV Lithography," International Sematech, August 14, 2001
2. U Dinger, Zeiss SMT AG