State of the art optics polishing and metrology for EUV lithography mirrors

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Introduction

A team from ASML Optics and Carl Zeiss has worked closely together to solve what was once considered to be a potential showstopper for Extreme Ultra-Violet Lithography (EUVL), achieving an “extreme” optical quality level needed on the imaging optics.

EUV lithography operates using a 13.4 nm wavelength light source. The quality of optics required for the lithography system roughly scales with the light source wavelength so an EUV optical system must be ~14.5X and ~18.5X better than the current generation of tools that operate with a 248-nm source and a 193-nm source tools respectively. In addition to the surface figure error challenges presented by the shorter wavelength, the optical prescription and the spatial period bandwidth for the surface errors significantly increases the fabrication and test difficulty level of EUV optics.

Figure 1
Optical schematic design example for an EUVL projection optic

Figure 2
Impact on lithography for different spatial frequency imperfections in the optical surface

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Typical EUV optical elements are off-axis aspheres, which are generally considered the most difficult type of optic to manufacture. Until the recent introduction of the very high numerical aperture systems, virtually all lithography optical systems used spherical surfaces, which are inherently much easier to manufacture than off-axis aspheres. Even the very high numerical aperture systems have consisted of approximately 80 percent spherical and 20 percent on-axis aspheres.
The heart of the lithography optical train is the projection optic designed by Carl Zeiss. For EUV, this is a 6 mirror optical system with a numerical aperture of 0.25 (Figure 1). EUV photons, at a wavelength of 13.5nm, are absorbed by all materials, therefore, unlike today’s advanced 193nm systems that use transmissive optics, EUV optical systems must be all reflective. To achieve the necessary imaging to support the 32nm node and below, the 6-mirror system preferably uses all off-axis aspheres, and each mirror should have a surface error corrected to better than $\frac{\lambda}{3000}$ where $\lambda$ equals 633nm; i.e. 0.2-nm rms.

Errors on an optical surface consist of “low” order errors, which are usually associated with the aberrations (up to 7th order) that impact an image’s shape, mid-frequency errors that reduce image contrast and high frequency errors that cause light to be lost because it is scattered outside the focal plane. Figure 2 illustrates these different types of surface errors. The range of spatial period errors on the optical surfaces that impact an EUV system is greater than for the 193 nm and 248 nm systems. For a 193 nm system only spatial period errors larger than 0.2 µm have an effect on system performance, while errors with periods as low as 0.01 µm contribute to an EUV system’s performance. The need to correct all these spatial frequencies for EUV mirrors has meant that not only is the polishing of these surfaces a tremendous challenge, but the design and build of metrology to prove the sub-nm mirror performance has also been challenging.

**EUVL Projection Optic design**

The EUV projection optic (PO) contains 6 off-axis aspheric mirrors that in combination create a ring field at the wafer. In the figure 1 design example, these 6 mirrors range in diameter from 160 to 440 mm. Further in this example, each is an off axis asphere, with departure from a sphere of up to 20 microns.

**Technology Leadership**

- EUV optics have been made that support sub 45-nm lithography
- Optics metrology with picometer repeatability is in use at ASML Optics and Carl Zeiss
- State of the art polishing technologies at Carl Zeiss and ASML Optics yield surfaces with < 0.2-nm rms surface
Polishing and quantifying the mirrors

To fabricate the optical surface for each mirror, a series of different polishing techniques and metrology are needed. Both ASML Optics and Carl Zeiss have successfully developed among other technologies, computer controlled polishing and ion beam polishing to achieve the required mirror finish. To monitor and measure the mirror surface over the full range of spatial frequencies, several state of the art metrology systems have been developed by both ASML Optics and Carl Zeiss. These metrology systems include uniquely designed interferometers with picometer reproducibility (see Figure 3, pg. 17), a mid-frequency proprietary interferometer called the sub-aperture surface-height interferometric measuring instrument (SASHIMI), phase-measuring microscopy (PMM) and atomic force microscopy (AFM).

A power-spectral density (PSD) plot is a quantification of the surface error as a function of frequency. A PSD is created by applying a fast Fourier transform to the surface data from each metrology instrument. Ideally the PSD plots from the various metrology instruments overlap to permit seamless stitching of all instrument data into a single composite curve from which the complete surface error values are obtained by numerical integration. Figure 4 is a test example of one finished mirror, and Figure 5 shows the PSD for this mirror, illustrating the successful overlapping metrology measurements that fully qualify the mirror’s performance.

Summary

By combining expertise in optics polishing and in the development of unique metrology equipment, both ASML Optics and Carl Zeiss have worked together to fabricate mirrors for EUV lithography that are state of the art. These mirrors are likely the most critical off-axis aspheres that have ever been made, and it is these extraordinary mirror finishes that will enable sub 45nm imaging on ASML’s EUV Alpha Demo lithography system later in 2005.

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