High reflectance multilayers for EUVL HVM-projection optics

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ABSTRACT

Reported is a summary of multilayer deposition results by FOM on three elements of the projection optics of the ASML Extreme UV Lithography HVM tools [1]. The coating process used is e-beam evaporation in combination with low-energy ion-beam smoothening. The reflectance of the coatings, which are covered with a special protective capping layer, is typically around 68%, with a maximum value of 69.6% and a non-correctable figure error added by the full multilayer stack of better than 35 picometer. The results are compared to the earlier coatings of the EUVL Process Development Tool [2].

Keywords: Mo/Si multilayers, EUV Lithography

1. INTRODUCTION

The two ASML Process Development Tools, also named Alpha Demo Tools and situated at IMEC, Leuven, Belgium, and at the College of Nanoscale Science and Engineering of the University at Albany, New York, USA have demonstrated the feasibility of the lithographic process with 13.5 nm light. The multilayer coatings in these tools have a typical reflectance of 65% resulting in a high throughput of the optical system. Since the coating of the optics for these Process Development Tools, an enormous progress has been made both in the field of multilayer technology as in the field of substrate manufacturing. Multilayer reflectance of over 70% has been demonstrated [3] while substrates can now

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Extreme Ultraviolet (EUV) Lithography, edited by Bruno M. La Fontaine, Proc. of SPIE Vol. 7636, 76362T · © 2010 SPIE · CCC code: 0277-786X/10/$18 · doi: 10.1117/12.846566

be polished down to a high spatial frequency roughness of well below 0.1 nm rms [4]. The challenge is to deposit the multilayers on the real substrates of such optics and achieve the same high reflectance that is obtained on super polished 1” lab substrates while simultaneously controlling the lateral multilayer profile. This should be met both in terms of the matching of the wavelength and the local angle of incidence as well as the total film thickness of the multilayer stack.

At FOM, the deposition on three out of the six elements of the HVM tools was performed. At present almost all optics have been coated successfully. In this paper we discuss the performance of the coatings of characteristic elements of the projection optics.

2. EXPERIMENTAL

The Mo/Si multilayer films were deposited in the FOM multilayer deposition facility by means of e-beam deposition and additional ion beam polishing [5,6,7] in an ultra high vacuum system (base pressure during deposition typically 5×10^{-8} mbar). Growth and polishing of the Mo and Si layers was controlled by in-situ reflectometry using a small, built-in soft X-ray source. The roughness of the layers is reduced by medium-energy Kr-ion treatment. Furthermore, masking was applied to modify the deposition flux to meet the required lateral coating profile. The substrates were produced by Carl Zeiss SMT AG and were mounted in specially designed substrate holders that enable reproducible mounting and positioning in the deposition facility. To meet the tight specifications of the coating period, a mounting reproducibility of better than 25 μm has been realized. The EUV reflectance at near-normal incidence around 13.5 nm has been measured at the Physikalisch Technische Bundesanstalt (PTB) [8] at the BESSY storage ring in Berlin, and at the in house reflectometry set-up [9] at Carl Zeiss SMT AG. The wavelength of maximum reflectance, λ_{max}, was used to determine the local film thickness.

3. PROJECTION OPTICS

The task of the projection optics is to produce a demagnified image of the reticle on the resist coated wafer. The required resolution can only be achieved if the accuracy of the surface figure of the multilayer-coated optics is in the sub nanometer regime. In other words, the coating induced added figure error has to be minimized to that dimensional range, a very challenging task in coating technology.

There are two major effects the coating can have on the surface figure. The first effect is the coating induced stress, which will result in an unacceptable deformation of the mirror if it exceeds a tensile or a compressive value of typically below 100 MPa. The value of multilayer induced stress can for instance be reduced to almost zero by using stress mitigation techniques[10]. The second effect is the figure error that the coating itself might add to the substrate. The coating has a total thickness of almost 0.5 μm, which by itself will change the surface figure. If the coating profile would be ideal, this change in figure could be accounted for when figuring the substrate, but in practise there will be a low frequency or a long range and a high frequency or short-range deviation of the ideal coating thickness. Low frequency variations can to a certain extend be compensated by alignment of the mirrors, like relative height and tilt of the mirror plane, through the lower order Zernike polynomial corrections. The remaining short-range deviations of the ideal profile add up in the residue and form the so-called non-correctable added figure error, which should be below 100 picometer.

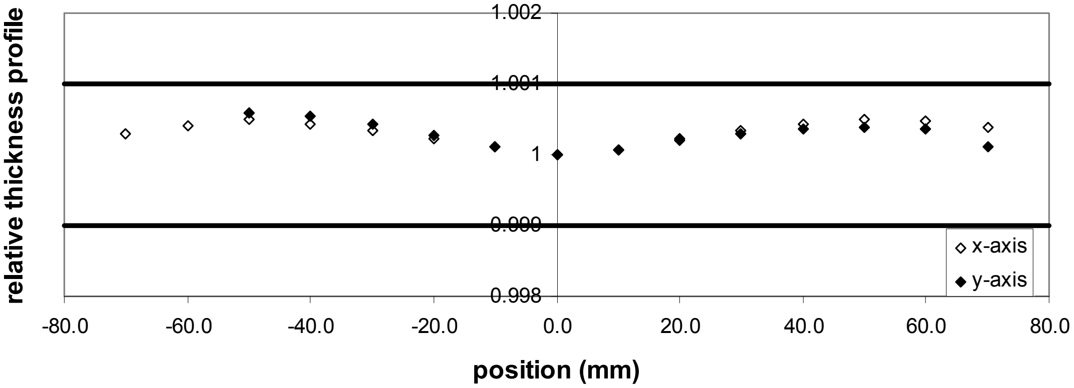

Figure 1. Relative thickness profile of the coating on a projection optics element, measured in two perpendicular directions. The deviation from the desired profile is well within the error budget (solid lines).

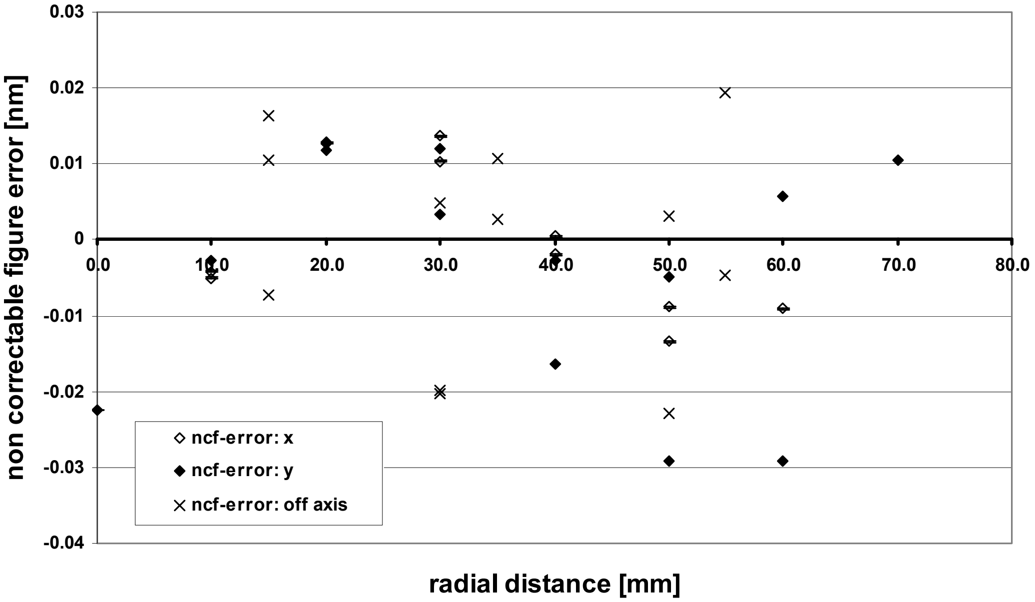

Figure 2. Non correctable added figure error determined in two perpendicular directions. The rms value amounts to 35 pm, i.e. well within the 100 pm error budget.

As a typical example of an optical element representative for the projection optics, we discuss the coating of a concave element. The active optical surface has a diameter of typically 140 mm and the optical design requires a flat multilayer d-spacing profile, both in terms of reflection and wavefront properties. Figure 1 shows the relative thickness profile obtained, determined in two perpendicular directions where both curves nicely coincide, demonstrating the required rotation symmetry of the coating profile. The small deviation from the desired perfectly flat profile is well within the specified error budget of ± 0.1%, represented by the solid lines in figure 1.

The added figure error can best be determined by calculating the multilayer period Λ and thus the total film thickness from the determination of the wavelength of maximum reflectance of the reflectivity curves measured at points distributed over the entire surface. As mentioned before, the coating profile can be corrected through lower order Zernike polynomial corrections. The alignment-adjusted design period Λ is given by:

$$\Lambda_{adjust}(r) = \Lambda_{design}(r) + a + b_{x,y}\ r + c\ r^2 + d\ r^4 , \qquad \text{Eq. 1}$$

with r being the radial distance, $\Lambda_{design}(r)$ the designed period and $\Lambda_{adjust}(r)$ the alignment-adjusted design period. Taking the difference between the measured and alignment-adjusted design period $\Lambda_{adjust}(r)$, the non-correctable added figure error can be calculated. The distribution of this figure error is shown in figure 2 and amounts to an rms value of 35 picometer only, which is three times better than specified.

As described above, the coating profile can affect the imaging properties of the optics, the throughput of the optical system, and therefore the effectiveness of the tool (in terms of number of wafers exposed per hour) is determined by the reflectance of the mirrors as well as by the matching of the periodicity to the operating wavelength of the tools. The latter has to be accurate within ± 0.1%, which is well met. Obviously, the reflectance has to be as high as possible.

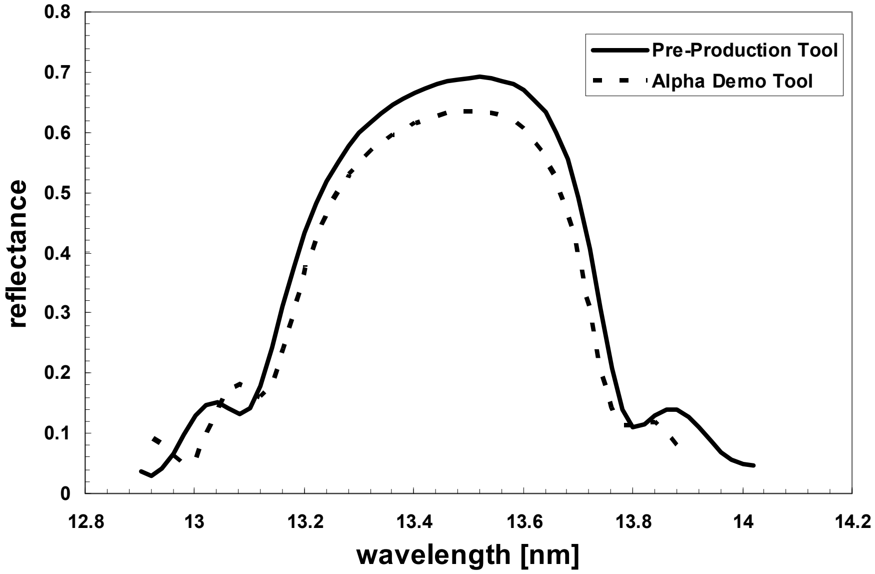

Figure 3. The reflectance of a projection optics element (black curve), measured at the local angle of incidence; the dotted curve represents the reflectance of the optic in the Process Development Tool (Alpha Demo Tool).

Figure 3 shows the reflectance of one of the mirrors, measured at the angle of incidence at which it will be used in the tool. The peak value of 69.6% is almost as high as obtained on super polished laboratory samples.

The achieved improvement in the reflectance of the mirrors has a huge impact on the throughput of this series of EUVL optics which increases by more than 50% with respect to the throughput obtained in the process development tools.

4. CONCLUSIONS

The above discussed examples of the performance of multilayer coatings on EUVL projection optics clearly shows that it is possible to meet the tight specifications of EUV optics by simultaneously achieving a peak reflectance and a well-controlled lateral coating profile. The realized reflectivity is directly comparable to what can be obtained on small test samples, resulting in an optical throughput of the system that enables the production of tools for high volume manufacturing. The specified lateral coating profiles are well met: on the projection optics we demonstrated that the most critical issue, the non-correctable added figure error, can be a factor of three better than required. The overall reflectance of the coatings that are capped with a special protective layer is 68% with peak values of 69.6%.

ACKNOWLEDGEMENTS

This work is part of the research programme of the 'Stichting voor Fundamenteel Onderzoek der Materie (FOM)' within the framework of the Industrial Partnership Programs XMO and CP3E that are carried out in close cooperation with Carl Zeiss SMT AG, Oberkochen (Germany). The reflectance measurements shown in figure 3 have been performed at the Radiometer Laboratory of the Physikalisch Technische Bundesanstalt (PTB) in Berlin (Germany).

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