New multilayer coatings for EUV optics

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Fig. 1:
The magnetron sputtering system Kenotec MRC 903.

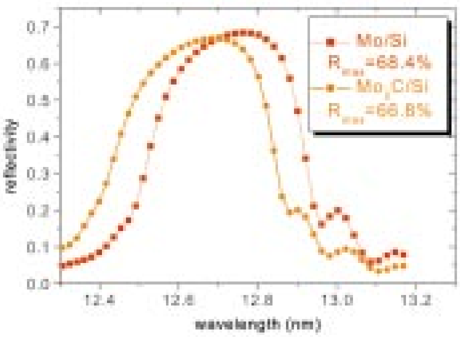

Fig. 2:
Measured EUV reflectivities of a Mo/Si multilayer mirror and a Mo_2C/Si multilayer mirror at normal incidence.

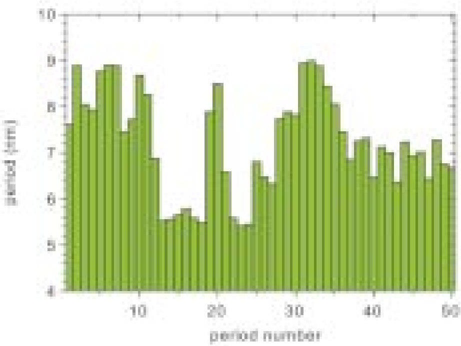

Fig. 3:
Period thickness distribution of a stochastic broadband multilayer mirror designed for high reflectivity up to 20° angle of incidence.

The good perspectives of extreme ultraviolet (EUV) radiation with a wavelength of approximately 13 nm to be applied in next generation lithography systems has led to a great progress in the development of plasma sources and optics for this spectral range recently. Since it is not possible to use lenses at these short wavelengths because of the strong absorption, optical systems must be entirely made up of mirrors. Actual designs for future EUV projection lithography tools contain 9 mirrors, i.e. the overall reflectivity of the system is given by R^9. Therefore, the task to optimize the throughput in future EUV Lithography systems has initiated big efforts to maximize the reflectivity of EUV multilayer mirrors. Using an industrial magnetron sputtering system (Fig. 1), we improved the reflectivity of Mo/Si multilayer mirrors to R = 68.4% by a successive optimization of all deposition parameters and the multilayer design. Simultaneously, the reflectivity of Mo_2C/Si multilayer mirrors was improved to R = 66.8% (Fig. 2). The Mo_2C/Si material combination excels in its thermal stability and therefore it is particularly suited to be used in applications with high thermal load, e.g. in the vicinity of a plasma source.

A serious drawback of multilayer coatings for their application in EUV optics is their limited range of reflectivity in the spectral and angular range. Firstly, the spectral FWHM of only 0.5 nm covers only a small part of the output of an EUV plasma source, and secondly, the fact that the reflectivity decreases significantly at angles of incidence of more than 9° causes big problems to use multilayer coatings on curved substrates. One solution of this problem is the fabrication of graded multilayer mirrors, i.e. coatings with a well defined lateral thickness distribution. However, such graded multilayer mirrors can be fabricated only in highly specialized and expensive coating machines and are actually limited to axially symmetric optics.

Apart from this, we designed and deposited broadband multilayer mirrors on the basis of a specific depth variation of the period. In all cases where maximum peak reflectivity is not required, e.g. in EUV metrology, astronomy and microscopy, broadband mirrors provide a useful alternative that is more easy to deposit than graded multilayers.

The lower reflectivity of broadband mirrors may be compensated by the use of large apertures that are possible due to the broad angular range of reflectivity.

The design of a broadband multilayer mirror for a broad angular range is shown in Fig. 3. The thicknesses of both the Mo layers and the Si layers vary over the whole multilayer stack. Using a thin film design program, the thicknesses in the multilayer have been optimized to fit the simulated reflectivity to a value of more than 30% in the angle of incidence range from 0° to 20°. Additionally, a more simple design with 3 different stacks (Fig. 4) was developed to meet the same requirement. The reflectivity of both mirrors was measured at the reflectometer of the Physikalisch-Technische Bundesanstalt at the synchrotron BESSYII in Berlin. The results in Fig. 5 show that both designs perform well and show a reflectivity of more than 30% up to an angle of incidence of 20°. The stochastic multilayer design is better suited to accomplish a constant reflectivity over a broad range due to its larger number of degrees of freedom, whereas the 3 stacks design is more easy to fabricate because only 3 sets of deposition parameters must be optimized and controlled.

The second task we focused on was to design and deposit a mirror that reflects EUV radiation in the whole wavelength range from 13 nm to 15 nm. The motivation for this development was the fact that some plasma sources that are developed by now in parallel to EUV optics show an emission spectrum that is much broader than the FWHM of a multilayer mirror, e.g. the emission of a Xenon gas plasma source. An optimum use of the output of a plasma source can be reached with special designed mirrors that are well adapted to the output of the source. The combination of such a broad plasma source with a broadband multilayer mirror outperforms a standard multilayer mirror concerning the integral reflectivity. With a stochastic design comparable to that in Fig. 3 a reflectivity of more than 15% was achieved for wavelengths from 13 nm to 15.15 nm (Fig. 6). Thus, the spectral bandwidth was increased by more than 4 times in comparison to a standard multilayer mirror. For comparison Fig. 6 also shows the normalized emission spectrum of a Xe plasma source developed at Fraunhofer ILT Aachen to demonstrate the good adaptation of the mirror reflectivity to the EUV emission of the source.

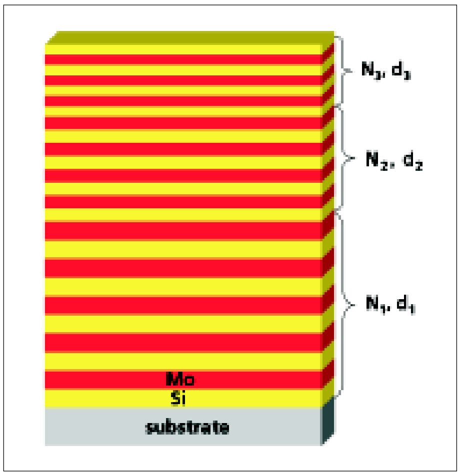

Fig. 4:
Schematic design of a broadband EUV multilayer mirror containing three different stacks: As well the number of periods as the period decrease from the bottom to the top stack of the multilayer.

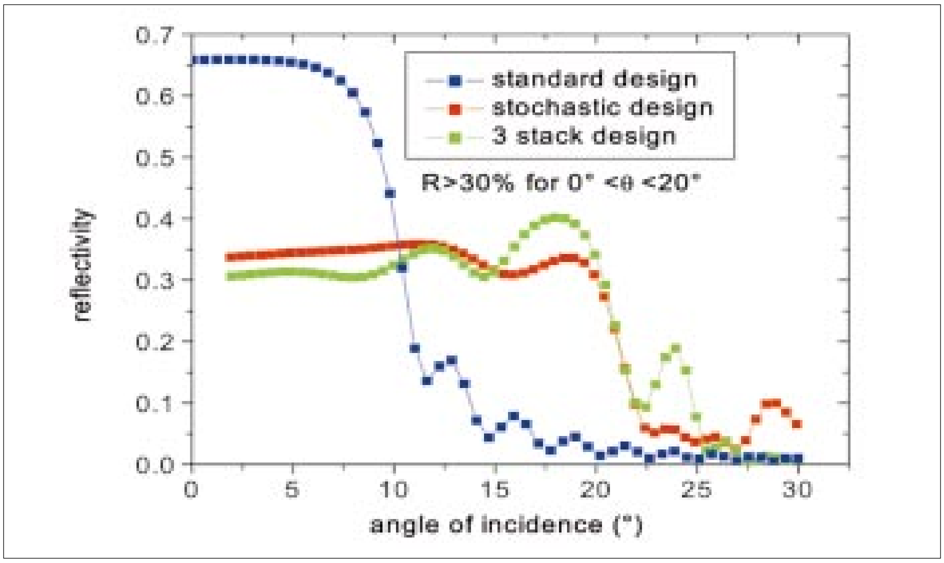

Fig. 5:
Measured EUV reflectivity of two different broadband mirrors in comparison to a standard multilayer mirror.

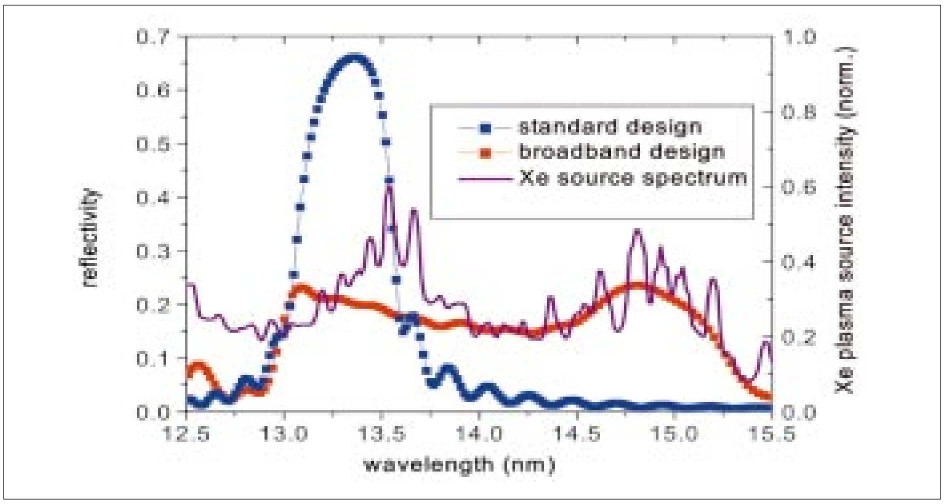

Fig. 6:
Measured EUV reflectivity of a broadband mirror designed for the wavelength range from 13 nm to 15 nm in comparison to a standard multilayer mirror. For comparison the normalized intensity of a Xe plasma source is shown (source: Fraunhofer Institut ILT Aachen).