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EUV multilayer optics

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Abstract

According to the optics requirements of an EUVL tool, the accurate deposition of high reflective and laterally graded multilayers on ultraprecise polished substrates can be regarded as one of the major challenges of EUV lithography development today. To meet these requirements, a new dc magnetron sputtering system NESSY and technologies to coat laterally graded EUV multilayers on curved optics were developed. The major characteristics of the deposition tool and results of sputtered multilayer optics are presented in this paper.

Keywords: EUV; EUVL; Mo/Si; Optics; Multilayer mirrors; Broadband; Narrowband; Magnetron sputtering

1. Introduction

The demand to enhance the optical resolution, to structure and observe ever smaller details, has pushed the way towards the EUV and soft X-rays. Induced mainly by the production of more powerful electronic circuits with the aid of projection lithography, optics developments in recent years can be characterized by the use of electromagnetic radiation with smaller wavelength. The good prospects of the EUV and soft X-rays for next generation lithography systems at a wavelength of $\lambda = 13.5$ nm, microscopy in the "water window" ($\lambda = 2.3$–4.4 nm), solar physics ($\lambda = 5$–60 nm), spectroscopy, plasma diagnostics and EUV/soft X-ray laser research have led to considerable progress in the development of different multilayer optics. Since optical systems in the EUV/soft X-ray spectral region consist of several mirror elements a maximum reflectivity of each multilayer is essential for a high throughput of the system. Moreover, most applications of multilayer mirrors in EUVL requires also a long-term and thermal stability, often at elevated temperatures. This requirement is most important in the case of the first mirror of the illumination system close to the EUV source (C1) where a short-time decrease of reflectivity is most probable.

A serious drawback of multilayer coatings for their application in EUV optics is their limited range of reflectivity in the spectral range; the spectral FWHM (full width at half maximum) of typically 0.5 nm covers only a small part of the output of some EUV sources, e.g. the spectrum of a broadband Xe source [1]. In all cases where maximum peak reflectivity is not required, e.g. in EUV metrology, astronomy and microscopy, broadband mirrors provide useful applications.

Whereas the tailoring of the spectral properties of optical components is developed to a high level and widely used for the hard X-ray range, the UV, VIS and IR, it is rarely used by now in the EUV range. However, some papers focus on the use of depth-graded multilayer mirrors in the hard X-ray region [2] and in neutron optics [3]. So-called "supermirrors" with a broadband reflectivity have been developed on the basis of a period thickness variation by a power law [4]. Specially depth-graded multilayer mirrors [5] are used for telescopes, beam collimators, and X-ray scanners [6].

2. Experimental setup

The dc magnetron sputtering system NESSY (Fig. 1) is equipped with four rectangular magnetrons, 600 mm × 125 mm each.

The maximum substrate diameter is about 650 mm. Two ∅ 450 mm substrates or three ∅ 300 mm substrates can be

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Fig. 1. DC magnetron sputtering system NESSY.

coated simultaneously. The target-substrate-distance is variable and allows the installation of moving shutters to realize lateral thickness gradients of the sputtered multilayer.

The system operates with a UHV load lock system (Fig. 2). The base pressure is well below 8×10^{-9} mbar. Special effort was made to construct the cathodes. Different configurations of the magnets were successfully realized in order to assure highest flexibility for different coating materials in terms of homogeneity requirements and target utilization.

The lateral layer thickness distribution was optimized with specially formed shadowing masks fixed close to the cathodes. A homogeneity of ±0.1% on 150 mm and ±0.2% on 300 mm and a reflectivity of $R > 68.5\%$ @ 13.5 nm is routinely achieved with Mo/Si multilayers on both flat and curved substrates.

Fig. 2. Substrate loading.

3. Experimental results

Mo/Si multilayers with different thin film designs were realized. Beside the maximization of the peak reflectivity using a periodic multilayer design, the maximization and minimization of the FWHM were designed and realized using special broadband and narrowband multilayer designs, respectively.

Normal incidence reflection measurements were performed with synchrotron radiation at the PTB Berlin (BESSY II), Germany. All mirrors were measured in the wavelength range 12–15 nm with a wavelength resolution of 0.02 nm and an accuracy of $\Delta R = 0.5\%$. The incident angle of the beam was fixed at 1.5°, the spot had a diameter of about 1.5 mm at the sample surface. Fig. 3 compares the measured reflectance of Mo/Si multilayer mirrors with a periodic, a broadband and a narrowband design.

The main results of the optical characterization of the periodic, the broadband and the narrowband multilayer design are summarized in Table 1.

3.1. Broadband design

A non-periodic design was used to obtain the broadband reflection in the EUV range. The design is based on a stochastic optimization process of all layer thicknesses. A desired spectral reflectivity $R_0(\lambda)$ in the wavelength range between λ_{min} and λ_{max} is used as a so-called "target function". Numerical calculations are used to optimize the design of a multilayer stack by a stochastic variation of each layer thickness to minimize the deviation between

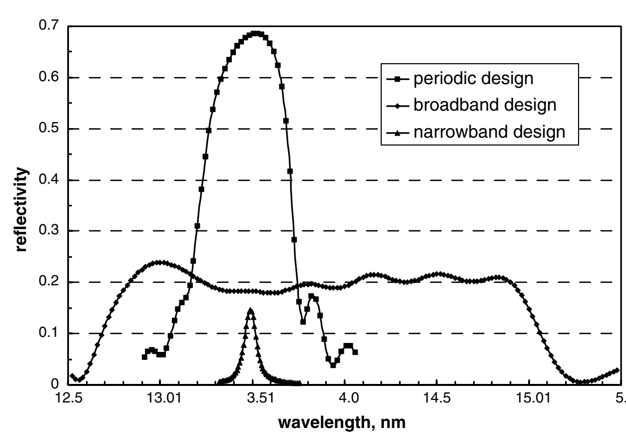

Fig. 3. Measured EUV reflectivity of Mo/Si multilayers.

Table 1
Measured reflectivity, peak wavelength and FWHM of periodic, broadband and narrowband multilayer designs

	Periodic	Broadband	Narrowband
R (%)	68.8	20	14.6
λ (nm)	13.5	13–15	13.5
FWHM (nm)	0.50	2.33	0.077