DLC/Si multilayer mirrors for EUV radiation

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ABSTRACT

In this paper, a new type of spectral filter mirrors for extreme ultraviolet radiation based on DLC/Si multilayer coatings is presented (DLC - diamond-like carbon). The coating is nearly transparent for infrared radiation (IR) of λ = 10.6 nm but highly reflective at λ = 13.5 nm (EUV). We deposited DLC/Si multilayers by ion beam sputter deposition with 40 and 60 periods exhibiting maximum EUV reflectances of about R_{max} = 43 % and R_{max} = 50 %, respectively. Combining IR antireflective and EUV reflective coatings, first prototype mirrors have been fabricated with an EUV reflectance of about 42.5 % and an IR reflectance of about 4.4 % at the same time.

Investigations on the thermal behavior of the multilayer stack and the cleaning properties for tin contaminated mirror surfaces have been carried out. Excellent stabilities of EUV peak position and reflectance values have been found using annealing temperatures of up to 700 °C. Furthermore, several cycles of Sn etching under H_2 reactive conditions have been applied to the mirrors without significant changes of the filter performance.

Keywords: EUV optics, spectral purity filters, multilayer mirrors, ion beam deposition, ion beam polishing, surface roughness, smoothing layer

1. INTRODUCTION

Future high power EUV tools in next generation lithography systems will be operated with CO_2 laser pulse plasma (LPP) sources. Some kilowatts of laser pulse power at 10.6 µm wavelength are partially converted into EUV radiation but also into more than 95 % out-of-band energy. Recently it has been shown, that for the most powerful EUV sources for lithography a stable in-band EUV burst power of about 100 W and an average power of 25 W at the intermediate focus can be achieved [1]. This EUV power output can be obtained by irradiating molten tin droplets by an intense pulsed CO_2 laser with an output power of more than 10 kW at the wavelength of 10.6 µm. According to the semiconductor roadmap [2] this EUV power output for next generation sources has to be doubled during the next years, requiring CO_2 lasers with 20 kW photon energy and more [3]. In these LPP based EUV sources tin droplets are irradiated by a focused laser beam and plasma is generated that emits EUV radiation. The conversion efficiency of the LPP process into a 2 % bandwidth around the 13.5 nm central wavelength for EUVL is about 3 %. Thus the process also emits a high amount of energy especially in the DUV and in the infrared region. In particular the 10.6 µm incident radiation can be scattered and reflected from the source volume. This unwanted out-of-band radiation has to be filtered out of the optical path in order to avoid deterioration of the optics and the mask and exposure of the IR sensitive resists.

State-of-the-art EUV mirrors consist of metal/non-metal multilayer systems (e. g. Mo/Si) with maximum reflectance values of about 65-70 %. Due to the metal layers in the coating, these mirrors are also excellent reflectors for infrared radiation (R > 90 %). Hence additional spectral filters have to be introduced into the optical path. Various filter designs have been proposed for suppression of DUV and IR radiation, including thin foil filters [4], grid-type filters [5] and reflective grating-like optics [6]. For the suppression of DUV radiation, an efficient way is the addition of specific capping layers on top of standard Mo/Si multilayers. With properly adjusted layer designs the total DUV reflection of the

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mirrors can be significantly reduced [7]. However, IR antireflection coatings on top of EUV multilayer mirrors can not be used, because of the fact that the required thickness of the capping layers would result in unacceptable EUV losses.

In the new approach an EUV reflective, but IR transparent multilayer is combined with an infrared antireflection coating below the multilayer (fig. 1). This new type of spectral purity filter could be applied in the vicinity of the source plasma (e. g. on collector mirrors) because the heating infrared radiation will pass the coating and can be cooled away effectively behind the mirror (if the substrate is IR transparent) or in the mirror substrate itself. Thermal stability of the coating as well as chemical persistency of the mirror in the source plasma environment are crucial issues for such a system. First results of fabricated prototype mirrors are shown in this paper. Both optical characterizations and investigations on the thermal and chemical behavior of the layer stacks are presented.

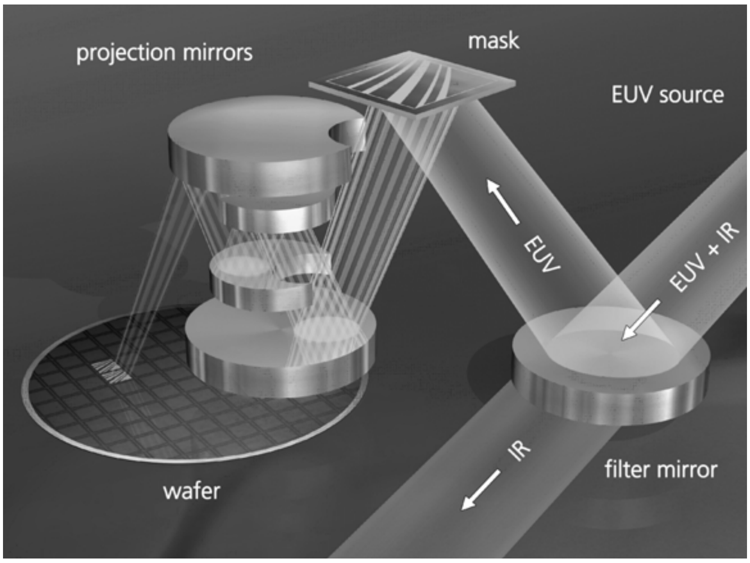

Figure 1. Sketch of a potential beam path in an EUV lithography system. The IR transparent filter mirror can be introduced close to the EUV plasma source, e. g. as collector mirror or first illumination mirror.

2. MODEL CONSIDERATIONS

In order to replace the metal layers in conventional EUV mirrors with IR transparent materials, carbon turned out to be a promising alternative. To achieve a reasonable optical contrast for the EUV reflection particularly the diamond-like state (DLC – diamond-like carbon) with densities > 2.5 $\mathrm{gcm^{-3}}$ and higher content of sp3-bondings is favorable. Additionally, DLC layers have a better optical transparency in the infrared range in comparison to graphite layers [8].

Carbon based multilayer mirrors for X-ray optical applications have already been investigated earlier [9, 10]. It has been shown that carbon densities of up to 2.7 $\mathrm{gcm^{-3}}$ can be achieved using ion beam sputter deposition. At the same time, surface and multilayer interface microroughnesses between 0.15 and 0.20 nm (measured by AFM) have been obtained with these coatings. These facts indicate that DLC/Si multilayers should be a very promising option for EUV mirror coatings with only minor IR reflection and absorption.

State-of-the-art laser optics for high power IR applications are coated with IR antireflection layers of some 100 nm to several µm thickness (depending on wavelength and spectral demands). Typical materials are e. g. ThF_4 or ZnSe. A major question we had to answer was how to keep the surface roughness below 0.5 nm, which is necessary for a good EUV reflecting multilayer on top. Typical IR antireflection coatings exhibit surface roughnesses of several nanometers which is not acceptable for the desired application. We found the deposition of a thin silicon smoothing layer (IR transparent as well) as a very suitable solution of the problem. The smoothing can be done by means of ion beam deposition and ion beam etching as well [11]. Figure 2 shows the principal layout of the proposed stack of an IR transparent EUV multilayer mirror.

In figure 3 theoretical IMD [12] calculations of the spectral behavior of some (EUV) multilayer systems are shown. The good EUV reflectance value at 13.5 nm (up to 73 %) and the very high IR reflectance (> 90 %) of a standard Mo/Si multilayer with 50 periods can be seen. In contrast, the proposed DLC/Si multilayer exhibits about 45 % EUV reflectance (for a 40-fold stack). With an appropriate ThF_4 antireflection layer an IR reflectance at 10.6 µm as low as 4 % can be achieved. In this case the whole stack acts as an effective IR antireflection system. Furthermore, the specific spectral response of the stack in the infrared range can be adapted to special requests by the design of the ThF_4 antireflection layer(s).

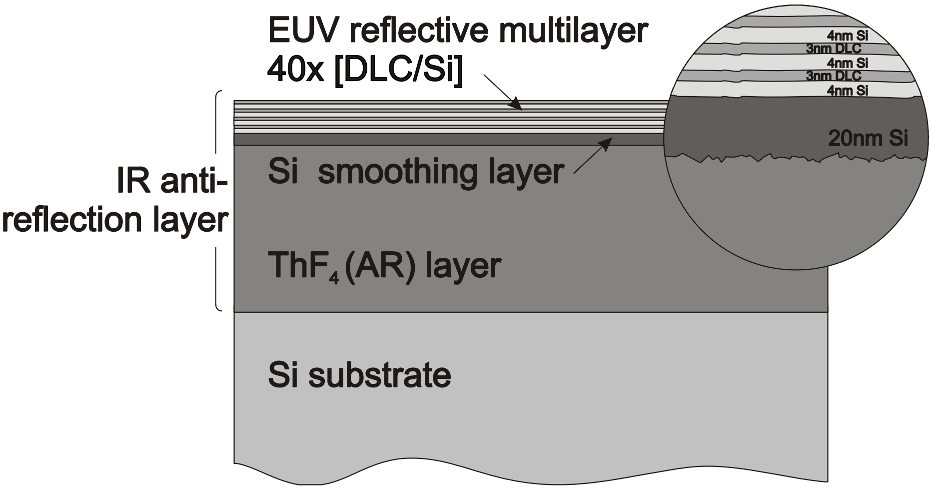

Figure 2. Scheme of an IR antireflection EUV mirror based on a 40x[DLC/Si] multilayer, a Si smoothing layer and a ThF_4 bottom layer.

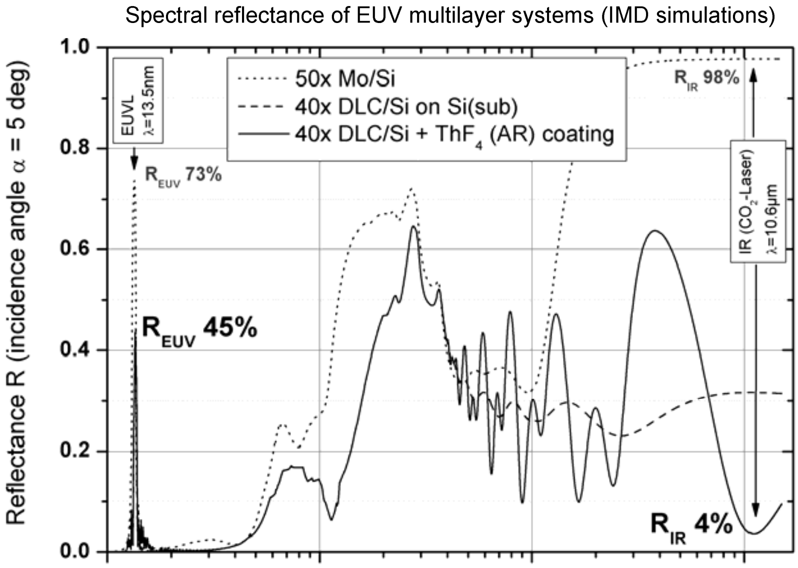

Figure 3. IMD [12] simulations of the spectral response of different EUV multilayer mirror systems from the EUV to the IR range.

3. METHODOLOGY

3.1 Deposition Technology

In order to deposit the proposed IR transparent EUV multilayer mirror three processing steps have to be carried out: 1) deposition of the IR antireflection layer (in this paper ThF_4) on an adequate substrate (e. g. silicon), 2) smoothing of the ThF_4 to achieve a sufficient roughness for the EUV multilayer and 3) deposition of the DLC/Si multilayer itself.

The ThF_4 IR antireflection coatings used in our experiments have been supplied by a commercial vendor. The technology used for the fabrication of the coatings is based on an evaporation process and is a well known standard process for coatings of high power CO_2 laser optics.

Steps 2) and 3) of the mentioned processing chain were performed using the dual ion beam sputter deposition (DIBSD) system “IonSys 1600”, built by Roth&Rau MicroSystems. As main parts, the machine contains two linear ECR ion sources with grid lengths of 400 mm. Both sources can be operated at ion energies between 50 and 2000 eV. The first ion source is used for sputtering of the coating material(s), which are arranged on a rotatable target holder for up to 6 different materials. The second ion source is directed onto the substrate surface. Depending on the operating conditions, esp. the kinetic energy of the ions, this source can be used for growth assistance, smoothing, etching or pre-cleaning of the substrate or the growing film. Substrates with dimensions of up to 500 mm x 200 mm are arranged face-down and can be linearly moved across differently shaped slits. Further details of the ion beam machine can be found elsewhere [10].

For the smoothing of the ThF_4 antireflection layer (step 2) it turned out, that best results can be achieved by deposition of a thin silicon smoothing layer. This is done in an alternating process of deposition and re-etching of Si material. During the deposition phase one can assist the growth of the silicon with a low energy assistance beam (50 eV, Ar). This provides some additional energy for surface diffusion, resulting in smoother films. Re-etching of the deposited silicon is done by high energy bombardment (approx. 1000 eV, Ar) by the secondary ion source at near normal incidence (10 - 20 °). The smoothing effect is determined by the particle energy used, but also by the substrate temperature, which increases during the process. To reduce the initial ThF_4 surface roughness of 1..2 nm rms (HSFR, measured by AFM) down to the desired range < 0.5 nm it was necessary to repeat deposition and re-etching steps 5-10 times, with approx. 100 nm deposited (and re-etched) Si thickness.

Deposition of the DLC/Si multilayer (step 3) is done in the standard IBSD arrangement, where only the primary ion source is used. We applied various ion energies (800…1200 eV) and sputtering gases (Ar and Kr) in order to find the optimum conditions for high-reflection multilayer coatings.

Figure 4 shows the different operating modes of the DIBSD machine during processing the prototype mirrors.

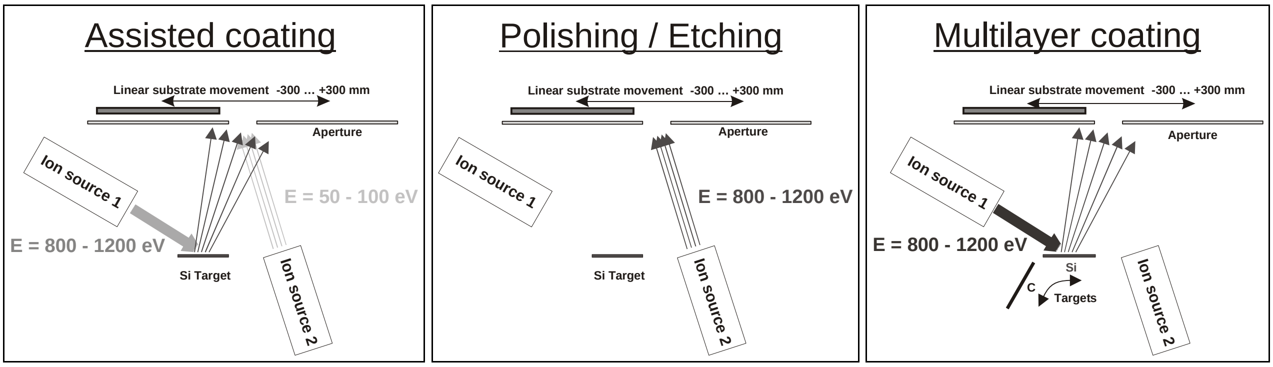

Figure 4. Operating modes of the DIBSD machine during the processing steps of the prototype mirrors.

Left: Assisted coating of the Si smoothing layer, Middle: Re-etching of the Si layer, Right: Deposition of the DLC/Si multilayer.

The ranges of the used ion energies are shown for the different processes. The Si-coating and re-etching steps (left and middle) are repeated several times prior to the multilayer deposition.

3.2 Characterization

Surface quality during processing, stack regularity, final optical performance in the IR and EUV range and the changes of the optical behavior after heat treatment and Sn contamination have been analyzed.

The surface topography has been characterized by atomic force microscopy (AFM) operated in tapping mode in an air environment. The AFM measurements have been performed with different scan length between 1 x 1 µm² and 10 x 10 µm². From the height profiles, the rms surface roughness σ_r and the 2-dimensional power spectral density (PSD) function have been calculated using standard formulas (see e. g. [13]).

Layer thickness, density, interface and surface roughness have been measured by X-ray reflectometry (XRR). From the XRR patterns conclusions about the composition and regularity of the DLC/Si multilayer stack have also been drawn. The measurements have been performed using two laboratory XRR devices, each having different angular resolutions δ of approximately 0.006 and 0.01 deg.

EUV reflectance measurements were performed at the EUV reflectometry beamline at PTB Berlin. Typically the reflectance values were measured at a fixed incidence angle of 5 deg and wavelength scans from approx. 12.5 to 14.4 nm have been carried out. The accuracy (standard deviation) of these measurements is about σ_λ = 0.06 pm for the wavelength and σ_R < 0.06 % (absolute) for the reflectance [14].

The optical behavior of the coatings in the infrared range has been characterized by FTIR spectrometry using a silver mirror with 98 % reflectance as a reference. In this paper only the reflectance values for 10.6 µm wavelength are discussed. More details and FTIR spectra can be found in [15].

4. RESULTS AND DISCUSSION

4.1 Smoothing of ThF_4 antireflection layers

Depending on the optical demands in the IR range, esp. the reflectance suppression needed at 10.6 µm, and the refractive indices of the corresponding materials, the thickness of the ThF_4 antireflection layers have to be in the range of 600..700 nm. All samples we got from our industrial supplier had an initial surface roughness of about 1.4 - 2.0 nm rms (HSFR, measured by AFM). A typical 1 x 1 µm² AFM image is shown in fig. 5 (left). With the geometrical and energetic conditions in the “IonSys 1600” we are currently not able to smooth the ThF_4 surface directly by ion bombardment. Therefore we decided to introduce a thin silicon smoothing layer. This material is IR transparent (as used in the DLC/Si multilayer) and it is known that certain spatial frequencies of the surface roughness of a silicon layer can be effectively smoothed by ion beam treatment [11].

In order to keep the influence of this additional layer on the infrared optical properties as low as possible the thickness has to be less than a few 10 nm. Because of the fact that a sufficient smoothing effect by IBSD can only be obtained after deposition of a certain film thickness (in the range of some 100 nm), we had to perform an alternating deposition and re-etching procedure, adding and removing almost the same amount of material of about 100 nm for each step.

Figure 5 (middle) shows the surface topography after 5 cycles of deposition and re-etching. The roughness of this surface state was about 0.21 nm (for 1 x 1 µm² AFM) which is sufficiently low for the following EUV multilayer deposition. The thickness of the remaining silicon smoothing layer was about 20 nm. The right graph of figure 5 shows the PSD functions of these AFM measurements and one of a super-polished silicon substrate for comparison. For spatial frequencies > 2-3 μm^{-1} a significant reduction of the initial ThF_4-induced roughness is achieved. Lower frequencies are obviously difficult to smooth with the procedure we used.

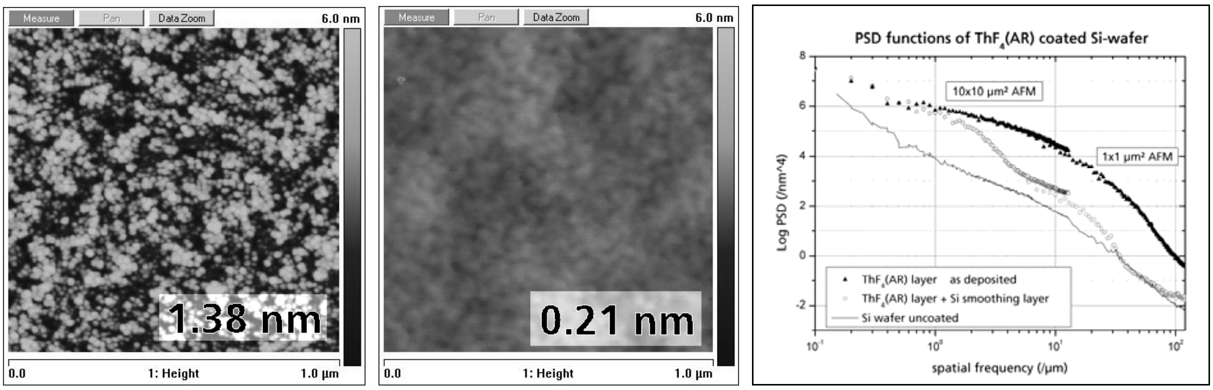

Figure 5: AFM images of the surface topography of the initial ThF_4 coating (left) and of the surface of the final silicon smoothing layer (middle). Inserted values represent the rms roughnesses σ_r calculated from each image. Right: PSD functions derived from the AFM images before (solid triangles) and after (open circles) smoothing of ThF_4 coating. The bottom curve (line) shows a super-polished Si substrate for comparison ($\sigma_r < 0.1$ nm rms)

4.2 Deposition of the DLC/Si multilayer

In order to evaluate the possibilities of the IBSD technique, first samples of 40, 60 and 80-fold DLC/Si multilayers have been deposited on super-polished silicon wafers. It is known, that ion type and ion energy have a strong influence on the diamond-like behavior of the DLC layers, e. g. the carbon density can vary from 2.3 g/cm³ for 800 eV Krypton up to 2.7 g/cm³ for 1200 eV Argon ions, respectively [9]. On the other hand high kinetic energies of the particles can cause stronger interdiffusion and chemical reactions at the interfaces implicating decreased optical contrast of the layers.

As a result of the EUVR characterizations we found that ion energies of about 1200 eV are the optimum for the deposition process (fig. 6). EUV reflectance values of about 50 % for the 60-fold as well as for the 80-fold multilayer stacks have been measured (0.35 nm FWHM for 60x). Interestingly, the ion type (Ar / Kr) seems to be of low importance since the EUVR values were very similar for both cases. For the 40-fold stack the maximum EUV reflectance was about 43 % (0.40 nm FWHM).

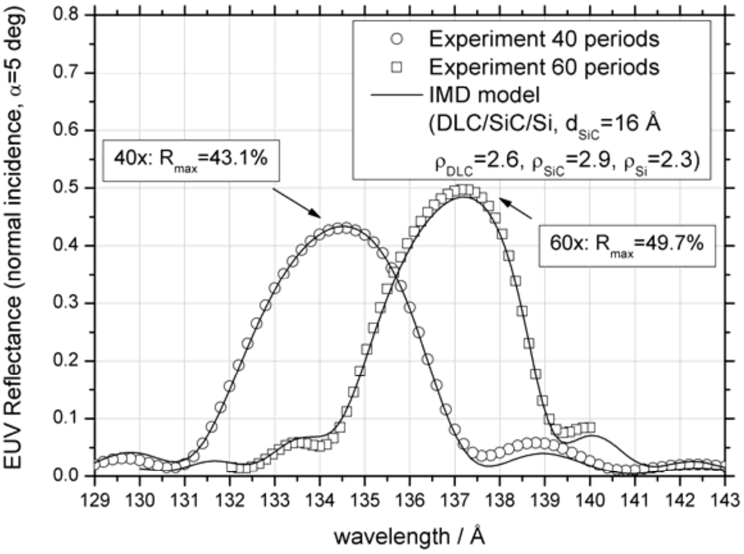

Figure 6: Simulated (lines) and measured (dots) EUVR spectra of 40x and 60x DLC/Si multilayers on super-polished Si substrates. The IMD simulations fit very well when assuming a 3-layer model DLC/SiC/Si (see fig. 7).

The maximum EUVR reflectance values we found are somewhat lower than expected for the simple 2-layer multilayer stack model, assuming the known densities und optical constants of Si and DLC. This behavior can be caused by various factors: 1) less density contrast due to deposition issues, 2) higher roughness of the interfaces, 3) stronger interdiffusion / compound formation at the interfaces. To explain the experimental data and evaluate the composition of the multilayer stack we also performed XRR measurements at samples with various thicknesses and Γ values (Γ = ratio of DLC layer thickness to multilayer period thickness). A typical XRR pattern for a 60-fold DLC/Si multilayer is shown in fig. 7. Numerous Bragg reflection orders can be seen up to very high glancing angles (theta) with a smooth background signal in between. This pattern indicates a very regular stack with outstanding smooth interfaces.

On the other hand the intensities of the Bragg reflections and their decay to higher orders can not be explained (simulated) by a simple 2-layer model (even with maximum density contrast and sharp interfaces). In addition the suppression of the 4th and 6th reflection orders in the middle of the theta range (fig. 7), caused by interferences with other interface reflections within one period, is inconsistent with this model. From the XRR behavior we concluded that the above mentioned possible reasons 1) (low contrast) and 2) (high roughness) for low EUV reflectance can be excluded. To explain the experimental results we tried to introduce a 3-layer model, containing a SiC phase at one (or both) interface(s). Using tabulated values of IMD the SiC phase should exhibit higher density (2.9 gcm^{-3}) but also higher absorption in the EUV region. As written in the legend of figures 6 and 7 this 3-layer model with SiC at the DLC-on-Si interfaces shows a very good agreement to both the measurements in the X-ray and in the EUV range. Furthermore, neither the simulations with additional SiC layers at both interfaces nor at the opposite interface (Si-on-DLC) fit the experimental data as well as this 3-layer model. The SiC thickness of about 16 Å is constant for various gamma ratios and varies somewhat (some Å) with variations of the ion energy used for the deposition.

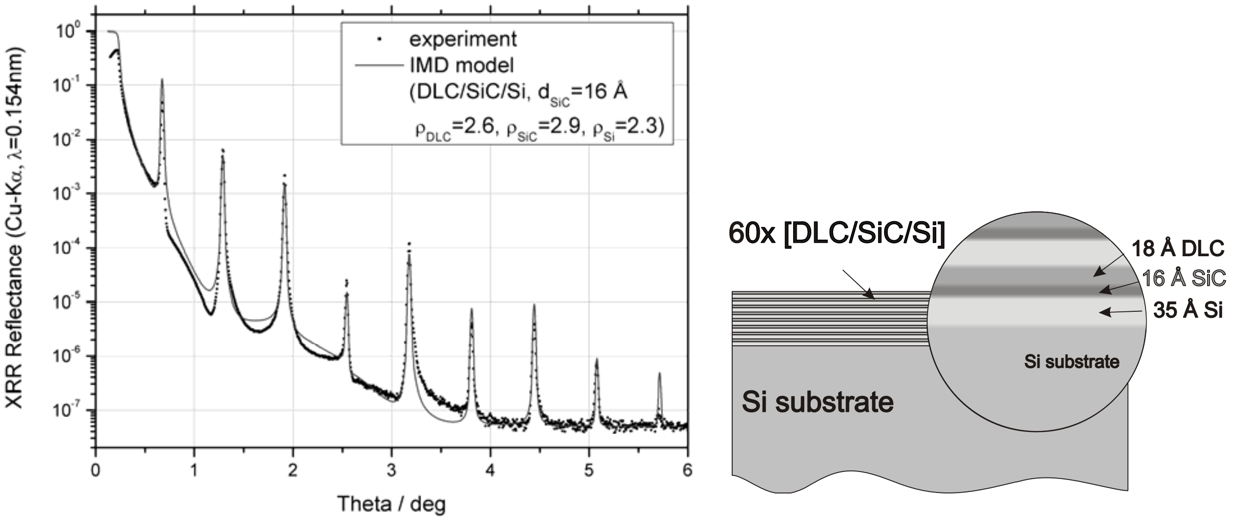

Figure 7: Simulated (line) and measured (dots) XRR spectra of a 60x[DLC/Si] multilayer on a super-polished Si substrate. The IMD simulation fits very well, if a 3-layer model DLC/SiC/Si is used (depicted right).

4.3 Optical characterization of prototype filter mirrors

After the investigations of the optimum experimental conditions for ThF_4 smoothing and DLC/Si multilayer deposition, prototype mirrors with 600 nm ThF_4 antireflection layer, 20 nm Si smoothing layer and a 40-fold DLC/Si EUV reflection multilayer have been fabricated.

In Figure 8 the results of EUV and IR reflectance measurements are shown in comparison to other multilayer systems. In the EUV reflectance pattern (Fig. 8 left) especially the comparison to the measurements of the same stack without the

ThF_4 bottom layer is interesting. Due to the (slightly) increased roughness because of the ThF_4 antireflection layer a reflectance loss of about 1 % (total) is observed for the 40-fold prototype mirror.

The measured IR reflectance values at 10.6 µm (fig. 8 right) demonstrate the antireflection properties of the prototype filter mirror very well: only 4.4 % reflectance have been found, whereas about 33 % has been measured at a pure silicon substrate as well as at a DLC/Si multilayer without an appropriate ThF_4 antireflection layer. Just for demonstration, also a standard 50-fold Mo/Si multilayer was measured and shows – as expected – almost 90 % IR reflectance.

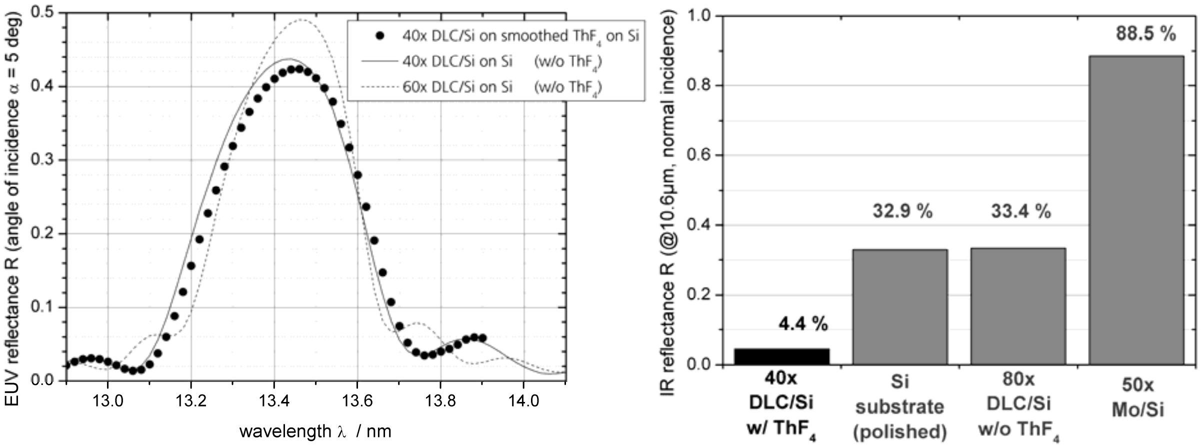

Figure 8. Left: EUVR spectra of a 40x DLC/Si-ML deposited on a smoothed ThF_4 AR coating (dots) in comparison to 40x (solid line) and 60x MLs (dashed line) without ThF_4.

Right: Measured infrared reflectance (@ 10.6 µm, normal incidence) of the DLC/Si mirror with IR-AR design (dark), of 80x DLC/Si without ThF_4 (AR) layer, of a plain Si substrate and of a conventional Mo/Si mirror (grey).

4.4 Thermal Stability

Because of the hot and aggressive environment in the vicinity of an EUV plasma source, thermal and chemical stability of the components and their optical properties are key issues for their integration into an EUV illumination system. Especially for the collector mirror, which is the closest part next to the hot plasma, temperature stable multilayers and chemical robust surface coatings are essential. For example the typical temperature of the mirror surface of a collector shell in recent HVM lithography tools is around 400 °C [16].

We characterized the EUV and IR properties of the produced DLC/Si prototype mirrors with and without the ThF_4 AR layer. Numerous annealing cycles under inert Argon gas atmosphere were carried out with temperatures up to 700 °C.

The stability of the multilayers without ThF_4 layer is quite good: up to 600 °C a more or less linear shift of the peak position (up to 1 % or 0.15 nm at 600 °C) can be seen in the EUV spectra (fig. 9). The maximum reflectance value is almost constant up to 350 °C and drops above this temperature by 3 % from 49.5 % down to 46.5 % for a 60-fold multilayer. This behavior can be explained by two simultaneous processes which we have also proven by XRR measurements. First, and continuing with increasing temperature, a relaxation of the DLC layers happens, which are in the as-deposited state under strong compressive stress. This relaxation is connected with an increase of the layer thickness in the order of about 0.1 % per 100 °C. Note, that the diamond-like behavior (resp. the density) of the DLC layers should be nearly unaffected by this small change. Above 350 °C the second process starts: a growth of the SiC interlayer between DLC and silicon. In the range from 350 °C up to 600 °C the SiC layer thickness increases by approx. 0.4 nm (1.6 up to 2.0 nm). Because of the strong EUV absorption of SiC, the SiC layer formation is connected with a drop of the maximum EUV reflectance at these temperatures.

We found similar temperature behavior for the 40-fold multilayer on silicon up to 600 °C. For the 700 °C step a strong decrease in the thickness and a loss in EUV reflectance of more than 19 % has been observed. This can be explained by a enhanced formation of SiC (hence densification of the multilayer). For the full prototype mirror (40x DLC/Si on ThF_4 on silicon) we found similar thermal behavior only up to 300 °C (see the summary in table 1). Above this temperature we observed strong delamination and degradation of the coatings. The reason for this unexpected failure of the coating is a re-crystallization of the monoclinic ThF_4 phase in the AR layer. Figure 10 shows AFM images of uncoated ThF_4 surfaces in the initial state and after 600 °C/1h annealing. A huge increase in roughness has been observed. The XRD pattern changes from a nanocrystalline shape to the complex multi-peak pattern of the ThF_4 phase (with some peaks belonging to a $ThOF_2$ surface oxide). The adhesion of a DLC/Si multilayer on top of this strongly altering surface structure is obviously not sufficient. Anyway, the final roughness of the ThF_4 layer is far above the limit for an acceptable EUV multilayer mirror. Therefore for applications above 300 °C another material instead of ThF_4 as IR antireflection layer should be used.

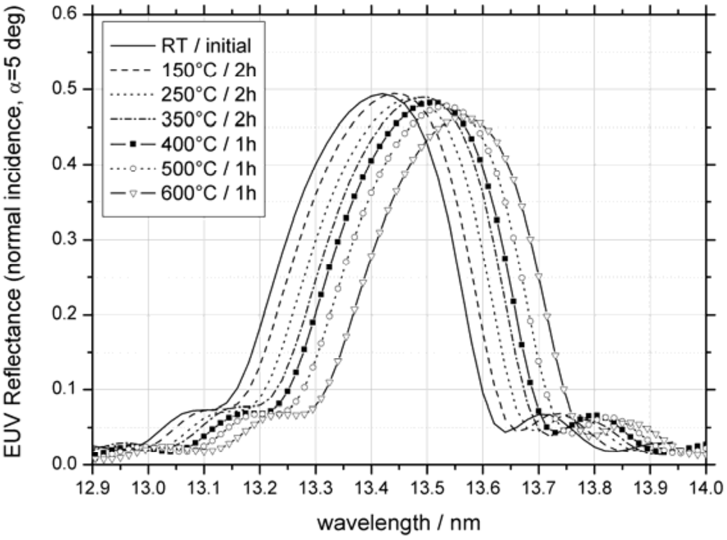

Figure 9: EUVR spectra of a 60-fold DLC/Si multilayer on a super-polished Si-wafer after an annealing cycle with temperatures up to 600 °C. A continuous peakshift of up to 1 % (@ 600 °C) and an EUV reflectance loss of about 3 % (@ 600 °C) are visible.

Table 1. Results of the EUV characterization of annealed DLC/Si mirrors. Temperature, change in maximum EUV reflectance and change in EUV peak position are noted (in % with resp. to the initial values) for a 60-fold and a 40-fold DLC/Si multilayer without ThF_4 and a 40-fold DLC/Si ML with ThF_4 (prototype mirror).

60x [DLC/Si]			**40x [DLC/Si]**			**40x [DLC/Si] on ThF_4**		
Temp. °C	**Δ(R_{MAX}) %**	**Δ(Peakpos) %**	**Temp. °C**	**Δ(R_{MAX}) %**	**Δ(Peakpos) %**	**Temp. °C**	**Δ(R_{MAX}) %**	**Δ(Peakpos) %**
RT / initial	(49.4 %)	-	RT / initial	(43.0 %)	-	RT / initial	(41.6 %)	-
150°C / 2h	0	+0.2	100°C / 1h	-0.7	+0.2	100°C / 1h	-0.4	-0.0
250°C / 2h	-0.5	+0.4	200°C / 1h	-0.4	+0.1	200°C / 1h	-0.6	+0.3
350°C / 2h	0	+0.6	300°C / 1h	-0.9	+0.4	250°C / 1h	-0.7	+0.5
400°C / 1h	-1.2	+0.7	400°C / 1h	-0.9	+0.5	300°C / 1h	(-2.9)	+0.5
500°C / 1h	-1.6	+0.9	500°C / 1h	-1.8	+0.7			
600°C / 1h	-3.2	+1.1	600°C / 1h	-3.0	+0.9			
			700°C / 1h	-19.3	-2.7			

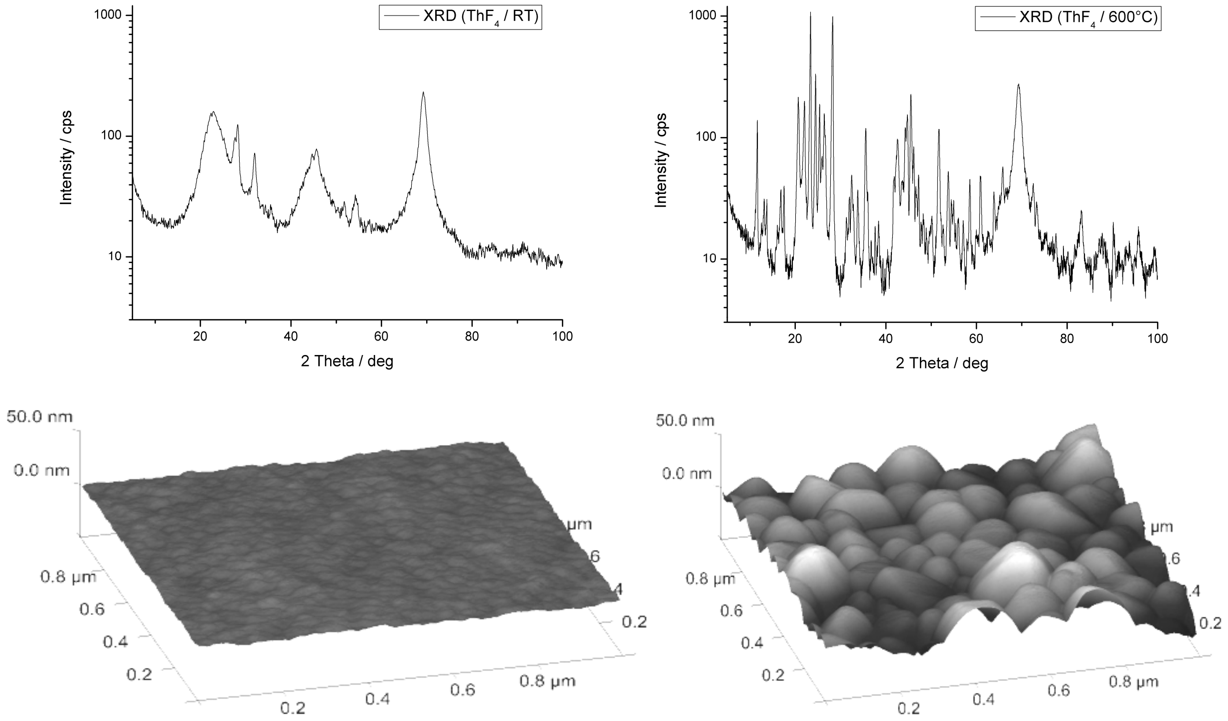

Figure 10: AFM images (bottom) of the surface topography of ThF_4 coatings at RT (left, similar up 300°C) and after 600°C/1h annealing (right). Above the AFM images the corresponding XRD patterns are shown. A clear indication of crystal growth can be seen. Most of the peaks on the right XRD pattern can be related to the monoclinic ThF_4 phase.

4.5 Chemical Stability

Similar to the experiments on thermal stability a set of prototype mirrors (40x DLC/Si on ThF_4 on silicon) was contaminated with a thin Tin layer (some nm Sn thickness, evaporation technique) and EUV characterized before and after cleaning steps. This contamination is similar to an end-of-life state of real EUV optics near the Tin plasma in a LPP EUV source. Typically these contaminated mirrors can be exposed to a H^* radical atmosphere to etch the covering metal contamination layer away. Chemical stability of the remaining (if possible the original) multilayer surface is important for a recovery procedure of a collector mirror.

Table 2 summarizes the Sn thicknesses (estimated by XRF) and the corresponding EUVR values obtained after various cleaning steps (resp. H^* exposure time). For a 6.1 nm thick Sn contamination layer a reduction of the reflectance of more than 25% (absolute) has been found. Already after 20 s H^* exposure no Sn contamination was detectable. Also the maximum reflectance was fully recovered (within the measurement accuracy). Even after 300 s H^* exposure all 40 periods of the DLC/Si multilayer were detected by high-resolution XRR. However, in this case a slight decrease of the EUV reflectance of about 1 % has been measured. A possible explanation is an etching induced roughening or degradation of the top-most DLC layer. In summary, the DLC/Si system exhibits a remarkable chemical stability and seems to be able to withstand numerous recovery cycles after Sn contamination.

Table 2: Results of the EUV characterization of Sn contaminated and H^* etched DLC/Si mirrors.

40x [DLC/Si] on ThF_4 on silicon			
H^* etching time sec	**Sn thickness (XRF) nm**	**R_{MAX} %**	**Peakshift %**
Before Sn dep.	-	(41.6)	-
0	6.1	-25.9	-0.1
10	4.6	-6.0	0.0
20	<0.02	-0.2	0.0
50	<0.02	-0.3	-0.1
300	<0.02	-1.2	+0.2

5. CONCLUSIONS

A new spectral purity filter system for EUV reflection mirrors based on DLC/Si multilayers is proposed. Due to the IR transparency of DLC/Si the multilayer can be introduced as a top coating in conventional IR antireflection systems, such as ThF_4 or ZnSe. Key issues of the fabrication process are: 1) the smoothing of the (standard) IR antireflection layer (e. g. ThF_4), which is done by deposition of an additional 20 nm thick Si smoothing layer, and 2) the deposition of the DLC/Si multilayer itself. Smoothing and multilayer deposition using ion beam etching (IBE) and ion beam sputter deposition (IBSD) have been successfully demonstrated. DLC/Si multilayers with up to 50 % reflectance at 13.5 nm (EUV) have been deposited.

Smoothing of the ThF_4 IR antireflection layer reduces the microroughness (HSFR) from an initial value of about 1.4 nm rms down to about 0.2 nm. Prototype IR filtering DLC/Si mirrors were produced with $R_{EUV} \approx 42.5$ % and $R_{IR} \approx 4.4$ % at the same time.

DLC/Si multilayers exhibit very good thermal stability. A slight peak shift of about 0.1 % per 100 °C (CTW50) can be related to a relaxation of the compressively stressed DLC layers, almost not connected with losses of the sp^3 content (diamond-like behavior). Above 350 °C a thickness increase of the SiC interlayers is observed, resulting in a reduction of EUV reflectance. For 700 °C we found an enhanced SiC formation connected with a thickness reduction and a substantial loss of EUV reflectance. The full filter stack (with ThF_4 AR layer) is limited to about 300°C due to the recrystallization behavior of ThF_4 starting at this temperature. Therefore, for future IR filtering systems an alternative IR antireflection layer material should be introduced, replacing ThF_4 used for this investigation.

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