Optimization of LaN/B multilayer mirrors for 6.x nm wavelength

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Abstract

In this article we present an overview of the optimization of LaN/B multilayers that enabled the deposition of a multilayer with a normal incidence reflectance of 57.3 % at 6.6 nm wavelength, the highest value reported to date. Two different ways of nitridation of the La layers were investigated: firstly N-ion post treatment of the La layer and secondly reactive magnetron sputtering of La in N_2 atmosphere. Initially the optimization of the multilayers was performed for 50 period test multilayers, followed by the selection of the best process to study the stability of the full stack deposition and the optical performance of the mirrors. The scaling of reflectivity with increasing number of periods for LaN/B multilayer mirrors will also be discussed.

Introduction

The continued demand for the increase of computer power and processor speed requires an increase of the amount and density of electronic components on integrated circuits. This can be achieved by decreasing the size of the features. For the lithographic process this means a continuous requirement to improve the minimal printable feature size, which is determined by the resolution of the optical system. This, in turn, is limited by the well-known Rayleigh criterion [1]: $\Delta \sim \lambda/NA$, where Δ is the minimal printable feature size, *NA* is the numerical aperture of the optical system and λ the working wavelength. Therefore the resolution can be improved, either by reducing the wavelength or increasing the numerical aperture of the projection optics.

Photolithography using an even shorter wavelength of ~6.x nm (the value of x still has to be determined by the industry), has the potential to be a possible successor of the currently introduced EUV lithography using 13.5 nm light. Another advantage of using light with a wavelength of 6.x nm is that a given resolution can be obtained with a smaller NA than required for the 13.5 nm case, resulting in an increase of the depth of focus.

The wavelength of the next generation lithography is referred to as 6.x nm. *X* can be determined only by comparing the reflectivity spectrum to the emission spectrum of the light source. However, the type of light source for this wavelength is still under debate and *x* remains undefined, but the wavelength is likely to be in the range from 6.6 till 7.0 nm. This uncertainty does not pose restrictions on the fundamental research required to develop the multilayers. The value of the period thickness can easily be adjusted to the wavelength of selection later.

We have performed the basic research of the optical coatings, the key element of the optical system for possible 6.x nm lithography. The theoretical reflectivity of La/B based multilayer mirrors is more than 80% at 6.6 nm but the highest achieved reflectivity is still considerably lower. Currently the

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best results are: 58.6% measured at 20 degrees off normal presented by Chkhalo et.al. [2] and in this article we will discuss the reflectivity of 58.5% at 20 degrees off normal and 57.3% [3] at 1.5 degrees off normal angle of incidence. The possible causes of the difference between the measured and theoretical values will be discussed.

Results and discussions

It was shown that La/B multilayer mirrors suffer from high layer intermixing and that nitridation of the La layers is an efficient way to improve the localization of La [3]. In the same paper we have analyzed the structural differences of LaN/B multilayer mirrors in the case when LaN was created by N-ion post treatment of every deposited La layer and when LaN is deposited by reactive magnetron sputtering in N_2 atmosphere. The presented analysis was performed for the already optimized multilayers. Here we will illustrate the process of optimization itself.

A coarse optimization of the deposition was performed, for practical reasons on multilayer stacks of 50 periods only. Because of this low number of periods the absolute reflectance value does not represent the possible maximum achievable, but clearly shows the improvements. The evolution of the reflectivity of these test multilayers is shown in Fig. 1. Finally, the best developed process is applied to deposit full stack multilayers to demonstrate high reflectance.

The multilayer structures were deposited using DC magnetron sputtering of La and B targets using Ar as a sputter gas. The multilayers where La was nitridated by N-ion post treatment are indicated in Fig. 1 as La/N/B, and the multilayers where LaN was deposited using the reactive magnetron sputtering are indicated as La(N_2)/B. The reflectance has been measured at the reflectometry beam line of the Physikalisch Technische Bundesanstalt (PTB, Berlin) at the BESSY II synchrotron radiation source using sigma-polarized soft X-ray radiation[4]. For the process optimization the wavelength of 6.75 nm was selected because it is sufficiently far from the B-K absorption edge at 6.6 nm. Therefore the multilayer reflectivity at this wavelength does not depend on the B chemical state and the influence of multilayer structure modifications on the reflectivity can be identified uniquely.

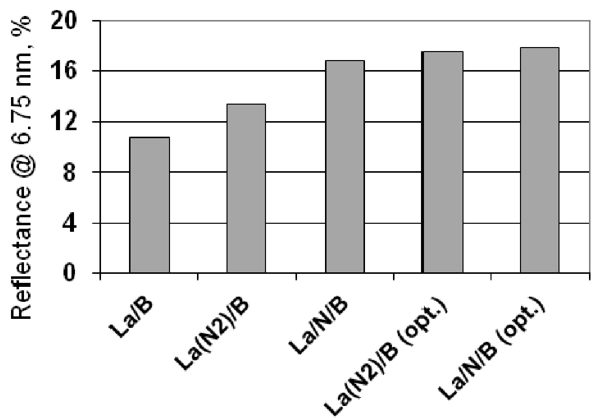

Figure 1. The evolution of the reflectivity of 50 period multilayer coatings for various La-nitridation processes.

According to Fig. 1 the reflectivity of the multilayers depends on the optimization of the selected processes. The reflectivity of multilayers deposited after such a coarse optimization is indicated with the addition (opt.). A pronounced effect of optimization is visible for the reactive magnetron sputtering, indicating the importance of the deposition optimization step. Fig. 1 shows that after the optimization both deposition processes show comparable reflectivity.

For high reflectance, the multilayer should have more than 150 periods[5]. To demonstrate that the results obtained for 50 period multilayers can be extrapolated to a larger number of periods, we deposited and analyzed the reflectance of LaN/B multilayer coatings with increasing number of periods: from 25 till 200. Fig. 2 shows the measured reflectivity maximum together with the model values. Fig. 2 shows that up to 125 periods there is almost no difference between calculated and measured reflectivity values, indicating only a marginal influence of growth evolution or layer to layer deposition instabilities. The measured value for the 150 period multilayer can be taken out from the analysis because of a specific error in this particular coating. For more than 125 periods most likely deposition instabilities influence the reflectivity and should be further investigated.

The measured reflectivity spectra for 175 period multilayers each with different period and measured at 1.5 and 20 degrees off normal incidence are presented in Fig. 3. All these multilayers were produced in the same deposition run, therefore they have similar internal structures and only the period thicknesses are slightly different. Fig. 3 shows that the measured reflectance at 20^{o} off normal incidence is slightly higher than the one at the normal incidence. This is because of a general increase of the reflectance of s-polarized EUV light with an increase of the incidence angle.

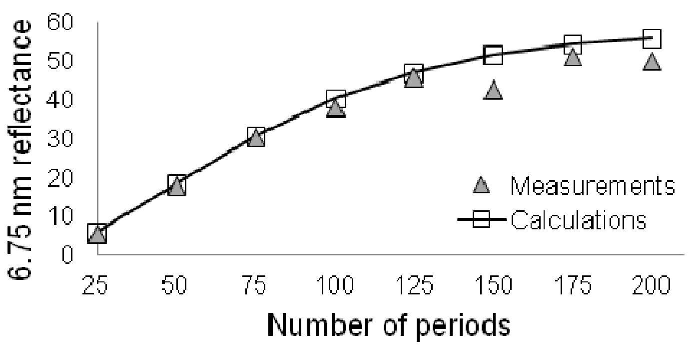

Figure 2 Measured and simulated reflectivity for LaN/B multilayer mirrors depending on the number of periods.

The evolution of the peak reflectance at 6.65 nm of the best systems developed at the FOM Institute DIFFER is presented in Fig. 4. The highest achieved near normal incidence reflectance is 57.3 % at 6.65 nm, which is also the highest value reported in literature to date. As major steps of multilayer development we can indicate the replacement of B_4C with pure boron as the spacer material and the gradual optimization of the nitridation of the La layers. To improve the multilayer performance further, the first step might be to fully optimize the nitridation of La. However, nitridation of the La layer does not improve the interface quality but increases the optical contrast of the layers by preventing La-B interdiffusion. To improve interface roughness, layer smoothening may be required.

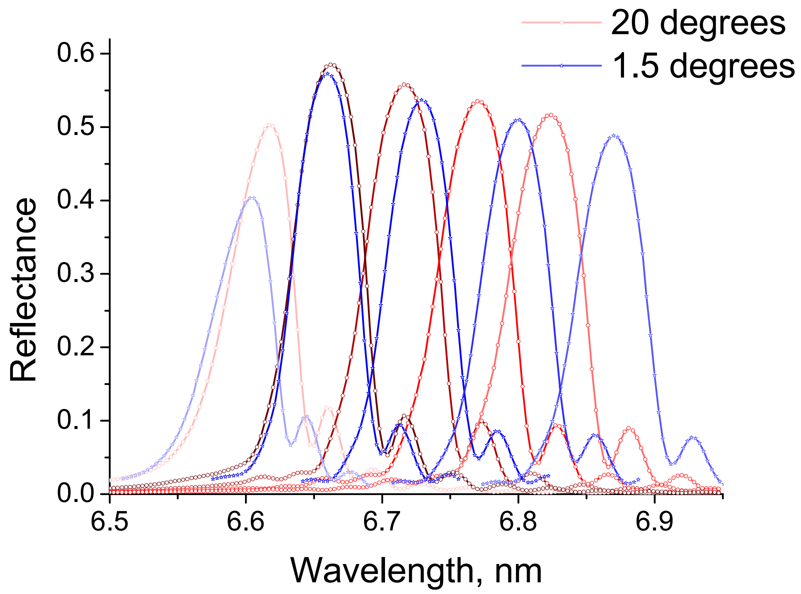

Figure 3 Reflectivity spectra for 175 period LaN/B multilayer mirrors deposited with different periods and measured at 20 and 1.5 degrees off normal incidence.

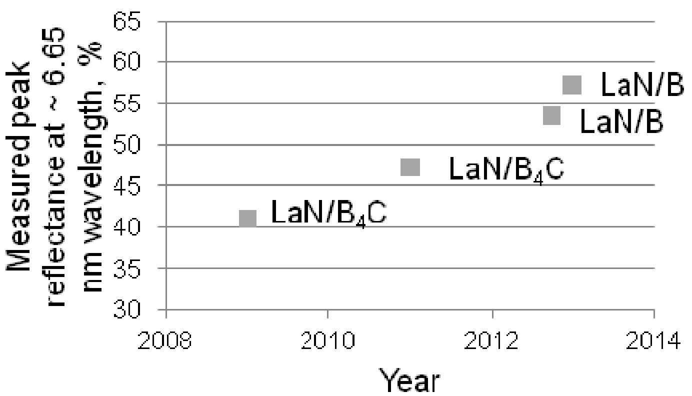

Figure 4 The evolution of 6.6 nm reflectivity development at nSI laboratory at FOM DIFFER.

Conclusions

We have shown that optimization of the multilayer deposition process can be done on multilayers with a limited number of periods, in this case 50. The reflectivity measured from these 50 period multilayers can truthfully be scaled up if the structure of the multilayer mirror is properly reconstructed and if the deposition process is stable enough. The optimization of two processes of nitridation of the La layers, namely reactive magnetron sputtering of La and N-ion post treatment of the La layer, showed that both processes are capable of producing multilayers with comparable high reflectance. The outcome of the optimization enabled the production of a multilayer mirror with 57.3% refelctance at normal incidence and 58.5% at 20 degrees off normal incidence at 6.65 nm wavelength.

Acknowledgements

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