Smart Multilayer Interactive optics for Lithography at Extreme UV wavelengths (SMILE)

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Project outline

Without doubt, Extreme UV Lithography represents today’s most advanced optical imaging method, operating at the shortest wavelength ever employed for high-resolution and wide field imaging. The technique, being considered indispensable for the fabrication of the next generation of semiconductor circuits, represents a major challenge for optics development in general. Typically, sub-tenth nanometer precision is required for the optics’ accuracy and positioning, while, simultaneously, kilowatt-power level EUV light sources cause tremendous thermal loads on the optics, leading to distortions of the fine imaging process. The obvious, though so far unexplored, solution to this challenge is to add adaptive functionality where it is most effective, namely in the EUV-reflective multilayer coatings. These Bragg-reflecting layers, for which the team holds a world reflectivity record, have enabled the success of early EUV wafer scanners. Yet, they must now be modified to include adaptive figure and spectral functionality to reach the required accuracy and stability. We propose a rigorous new multilayer composition, including piezo- and pyro-electrical materials so that the periodic Bragg structure can be interactively manipulated. Steering such control layers by external electrical or thermal signals will then allow wavefront corrections and localized reflectivity changes. The aim of this project is to achieve an integrated system, where adaptive optics specifically suitable to the EUV are individually manipulated to obtain optimized EUVL system performance. These ‘interactive-EUV’ multilayer optics will need to be grown with layer-thicknesses that have a precision well into the sub-nanometer range, while at the same time having chemical and thermal stability, and atomically sharp optical index profiles. To meet these requirements, fundamental challenges in optics, materials science, and thin-film physics must be resolved. In the SMILE project, the essential elements are uniquely combined to achieve these goals:

- a unique thin film deposition and analysis instrumentation, as well as a proven deposition technology, ideally suited to produce the ultrathin layers from the complex piezo materials while
preserving their adaptive properties,

- a positive assessment of critical adaptive and multilayer control concepts, showing more than adequate dimensional change effects for the proposed adaptive multilayer coatings, including a patent on this adaptive EUV optics,

- a new analysis technique in the form of state-of-the-art EUV interferometry with picometer resolution,

- substantial support from our industrial partner on design, analysis, and system engineering,

- a proven track record of the team in transfer of know-how to industry.

**Reflectance Tuning at Extreme Ultraviolet Wavelengths with Active Multilayer Mirrors**

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**Introduction**

Extreme ultraviolet lithography (EUVL) is the next generation process to satisfy the high demands of the semiconductor industry. At EUV wavelength (13.5 nm) multilayer mirrors are commonly used. Multilayer mirrors are composed of many bilayers (high refractive index and low refractive index) which are designed according to the Bragg law [1]. The Bragg formula defines the interference condition for waves reflected from different layers and relates the layer thickness to the angle of incidence and the wavelength. The thicknesses of the layers are critical for the reflectance so that they are susceptible to environmental changes such as temperature. Here we propose a new active multilayer structure which can be adjusted to compensate for reflectance changes. This multilayer structure makes reflectance tuning with an integrated piezoelectric layer that can change its dimension with external voltage.

**Active multilayer structure**

In the reflectance tuning process, the thickness of the piezoelectric material is of primary interest for the phase difference and for the reflectance tuning range. In order to see the effect of the piezoelectric material thickness on the reflectance let’s define a specific structure as in Fig. 4a) for 13.5 nm which is illuminated at normal incidence. The reflectance, \( R(z) \), is plotted as a function of the piezoelectric layer (BaTiO\(_3\)) thickness, \( z \), in Fig. 4b). Depending on the thickness of the BaTiO\(_3\) layer, the degree of interference changes, so that the total reflectance has maximum and minimum values. In order to have the maximum reflectance tuning range, first we select a minimum acceptable reflectance value (\( R_{\text{min}} \)) and then we find the number of bilayers for upper and lower MLM stacks (\( N_1 \) and \( N_2 \) respectively) that gives the maximum slope above \( R_{\text{min}} \). For example, if we select \( R_{\text{min}} = 60\% \) then
the optimum solution is satisfied with $N_1 = 25$ and $N_2 = 48$. Reflectance tuning range is limited by the mechanical properties of the material. Maximum thickness change (maximum strain, $\epsilon_{\text{max}}$) for BaTiO$_3$ before any plastic deformation is 4.8% [2]. Therefore, if we define the initial thickness of the BaTiO$_3$ layer and the total reflectance as $z_{\text{min}}$ and $R_{\text{min}}$ respectively, then maximum thickness and corresponding reflectance can be written as $z_{\text{max}} = z_{\text{min}}(1 + \epsilon_{\text{max}})$ and $R_{\text{max}}$ respectively where $R_{\text{min}} = R(z_{\text{min}})$ and $R_{\text{max}} = R(z_{\text{max}})$. Using the configuration in the figure, it is possible to change the thickness of the BaTiO$_3$ from $z_{\text{min}} = 2.1$ nm to $z_{\text{max}} = 2.2$ nm resulting in a reflectance tuning range between $R_{\text{min}} = 60.54\%$ and $R_{\text{max}} = 63.82\%$ as shown in Fig. 4b). The reflectance tuning range is 3.28% for this BaTiO$_3$ layer thickness however it is possible to achieve higher reflectance tuning with thicker piezoelectric layer which will be explained in the presentation.

In conclusion an active multilayer mirror structure is described to be used at EUV wavelengths. The structure incorporates a piezoelectric layer into the multilayer mirror that allows reflectance tuning. Using this idea, it is also possible to design structures for different wavelengths ranges and multi-element structures for wavefront correction.

**Bibliography**
