Damage studies of multilayer optics for XUV FELs

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Multilayer coated optics are used for control of XUV and soft X-ray radiation in many fields of science and technology, and have experienced a considerable boost of technology due to the application in advanced photolithography. A new field is the application in experiments at short wavelength Free Electron Lasers. This includes the XFEL that is under development and FLASH that is already delivering photons to users (both in Hamburg, Germany). The photon flux from these sources is extremely high, and in the case of FLASH, the ~10 fs long XUV pulses can have a power density of 10^{11} W/cm^2 for a 4 mm beam spot on the optics. This is at least 10 orders of magnitude higher than in the case of lithography, and damage or even destruction of the optics can be expected. Moreover, for some application the mirrors have to be placed in the focused beam and the intensity can then reach even 10^{14} W/cm^2. Under such conditions the optical properties of the reflecting elements would be changed already during the pulse. These two effects, permanent damage of the coatings and change of the optical properties of materials under high intensity XUV irradiation, can limit the performance of the multilayer optics.

We report on research on the flux resistivity of several multilayers for a wavelength range in the soft X-ray / XUV part of the spectrum by means of exposures at FLASH. Samples were irradiated at different intensity levels with single or multi shots. The permanent damage of surfaces was investigated by means of phase-contrast microscopy, atomic force microscopy, transmission electron microscopy, Raman spectroscopy and X-ray diffraction. Morphological and structural changes of the material were used for determination of the damage mechanism (atoms desorption, thermal fatigue, melting, ablation etc.). The flux resistivity of different multilayer samples was compared with their optical performance. The results will be used as input for the further development of multilayer coatings for short wavelength FEL optics.

The other operating regime where multilayers can be used is when the multilayer reflects during the pulse, and is possibly damaged shortly after: the range of single shot optics. However, under irradiation with ultra short intense pulses the mirror reflectivity can decrease even within the timeframe of the fs pulse due to the change of the layers' optical properties – namely the real and imaginary part of the refractive index. The responsible physical process is a strong electron gas excitation during the pulse* which depends on the structure of the multilayer and materials used. The phenomenon was studied by means of angular resolved transmission/reflectivity measurements at different intensities.

* S. Haue-Riege et al, PRL 98, 145502 (2007)