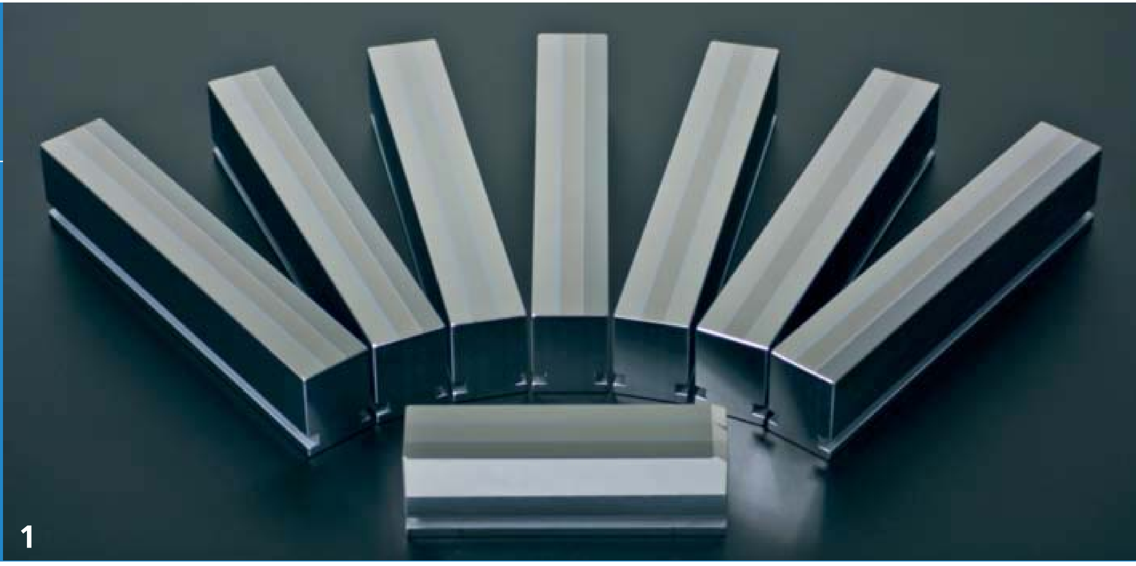


1

HIGH-PRECISION MULTILAYER OPTICS FOR THE X-RAY FREE-ELECTRON LASER (XFEL)

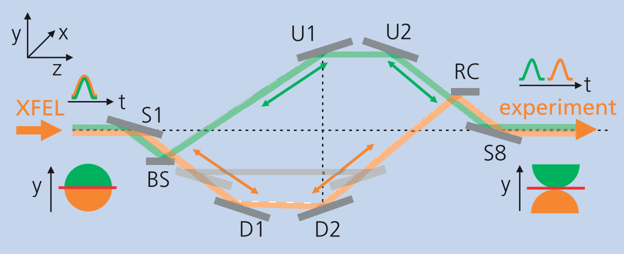
THE TASK

For experiments with femtosecond time resolution at the currently under construction European X-Ray Free-Electron Laser in Hamburg (European XFEL), mirror optics of the highest precision and thermal stability are needed. A split and delay Unit (SDU) which is used for these experiments is made up of eight flat individual mirrors, which split the extremely powerful XFEL X-ray into two beam paths of variable length and then superimposes the two partial beams for the experiment with time delay (Fig. 2).

The challenge with an X-ray SDU (Ephoton > 5 keV) is that the angles of reflection of the mirrors are very small. This requires very large SDU dimensions of up to several meters in order to achieve sufficient time delays [1]. The multilayer optics necessary for reflection angles of 1…5 ° have the peculiarity that for each photon energy, a particular angle of reflection must be precisely adjusted. Furthermore, for the energy range of interest here (5…20 keV), the best reflectivities are achieved with different materials. That means that the coatings of the individual mirrors must fit perfectly with one another to get exactly the same reflection angle or double angles for the beam splitter (BS) and the recombination mirror (RC).

In addition to the high thermal stability required by the intense XFEL radiation, precision requirements of the coating process of > 99.9 percent (that corresponds to an allowed thickness error of a single period from 2…5 pm) arise. Several material combinations must also be deposited next to each other on the mirror.

Schematic illustration of the Split and Delay Unit – SDU at the European X-Ray Free-Electron Laser (European XFEL)



2

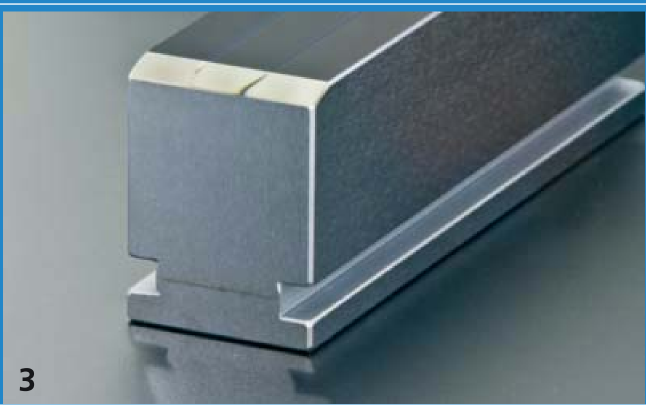
OUR SOLUTION

All of the XFEL's SDU mirrors are subdivided into three surface areas onto which the material systems Mo/B_4C, Ni/B_4C and W/B_4C are deposited with different individual layer thicknesses and numbers of periods for a particular energy range.

One of these 3 zones exhibits a peculiarity: here, so-called "two color experiments" are planned, i. e. each beam path carries different photon energies for the time delayed superposition (basic energy and the 3rd harmonic wave). The mirrors S1 and S8 therefore have special multilayer stacks, which enable the simultaneous reflection of both energies for a fixed angle of incidence [2].

[1] Roling, S. et al.: Proc. of SPIE Vol. 9210, 92100B (2014)

[2] Roling, S. et al.: Opt. Lett. 39, 2782 (2014)



3

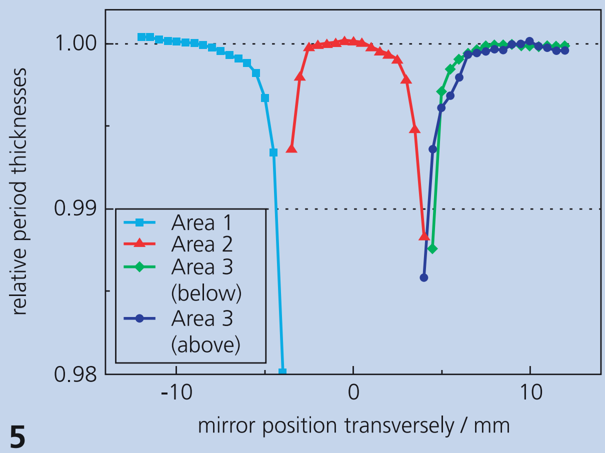
RESULTS

The SDU mirrors shown in Figure 1 have a length of 190 mm and a width of 30 mm. The beam splitter mirror depicted in the foreground is 120 mm long and possesses a partially beveled "splitter edge" (pictured at right). It is arranged directly in the middle of the XFEL beam path.

With shadowing masks, 3 multilayer stacks were applied on each of the SDU mirrors by means of ion beam or magnetron sputtering techniques. The period thicknesses of the individual stacks were in the range of 1.6 to 5.0 nm. Figure 4 shows the reflectogram of the coatings of the beam splitter mirrors. The full widths at half maximum of the reflection peaks of the first order were in the range of only 0.02…0.03 °, which simultaneously defines the homogeneity requirements of both the period thickness lengthwise and crosswise in each coating zone and also between the 8 mirrors (approximately ±0.1…0.2 percent).

In Figure 5, the homogeneity profiles of the period thicknesses of the three coating zones of a SDU mirror are depicted for the transverse direction (respectively normalized to the average period thickness of the zone). It is evident that the work areas meet the requirement for an area of approximately 5…8 mm in length. In between are areas of approximately 3…4 mm width, which must remain unused. The measured deviations of the reflection peak locations of the eight SDU mirrors amount to a maximum of 0.005 ° among each other, which guarantees that they will work in the delay configuration setup according to Figure 2.

Homogeneity measurement of the period thicknesses of the three coating zones of a SDU mirror in transverse direction



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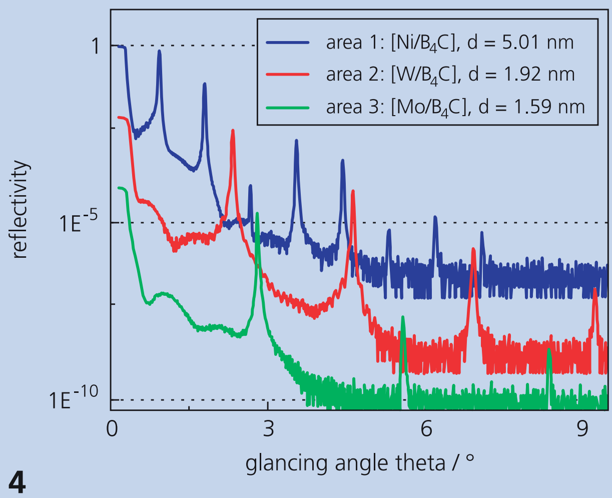
Reflectograms of the three coating zones of the beam splitter (XRR-measurements with Cu-Kα-radiation)



4

1 Eight SDU mirrors for the European XFEL

3 Detail view of the beam splitter edge of the "BS" mirror

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