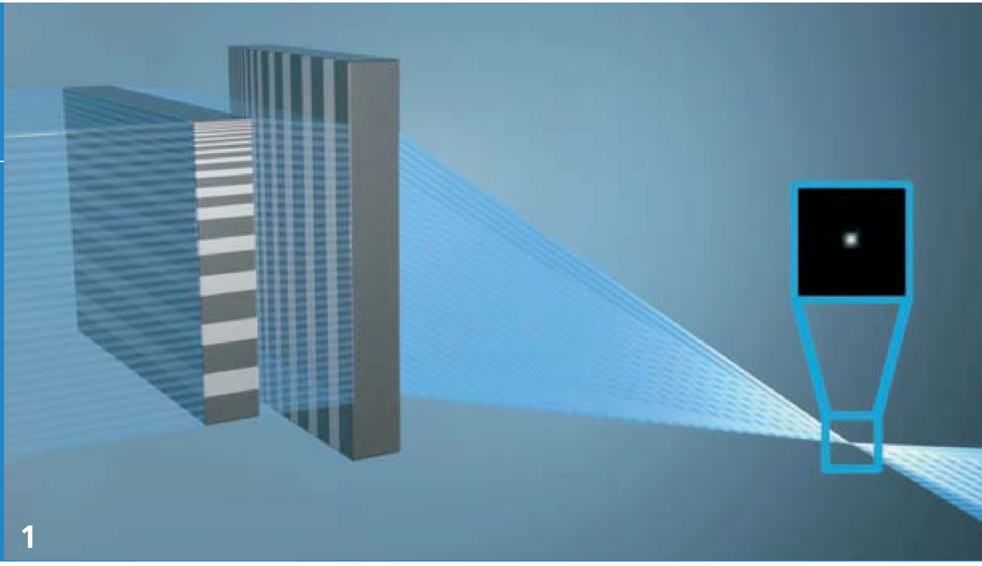

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MULTILAYER LAUE LENSES FOR HIGH-RESOLUTION MATERIAL CHARACTERIZATION

THE TASK

Material characterization with hard X-rays promises very high lateral resolutions with simultaneously high penetration capability. With regard to coherence, parallelism and intensity of X-rays, synchrotron radiation sources offer excellent conditions. The spatial resolution accessible by using these sources is primarily limited by the available optical components. By using two multilayer Laue lenses (MLL) in accordance with the schematic diagram in Figure 1, point foci in the order of 10 nm have already been realized.

The objective of ongoing research at Fraunhofer IWS is to qualify MLL for use in laboratory applications and thereby improve the lateral resolution of diffractometry, fluorescence analysis, and reflectometry of currently about 20 µm down to the submicron range. The radiation properties of synchrotron radiation sources and laboratory equipment significantly differ, which must be considered in the design of a laboratory experiment. Here, beam sizes in the range of 1 µm appear to be realistic.

OUR SOLUTION

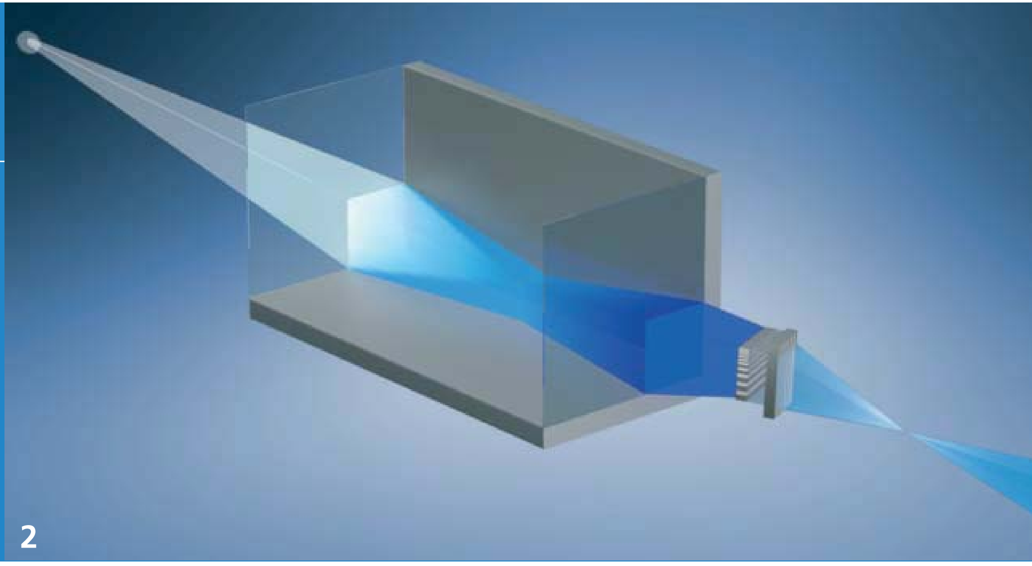
In order to maximize the portion of usable radiation, it is necessary to fabricate lenses with a large aperture. In the case of MLL this requires thick coatings. Due to residual stresses, large coating thicknesses can lead to strong bending and possibly to damage of the layer during the manufacturing process.

In order to investigate the implications connected with the transition from synchrotron to laboratory sources, a program based on the "Beam Propagation Method" was developed at the Fraunhofer IWS. The model calculations show that depending on the actual beam path and the MLL design, the significant influence factors on the anticipated focus magnification can be determined. Figure 2 schematically depicts the setup used for the model calculations. An optical mirror system ensures a pre-focusing of the radiation coming from the source onto the MLL.

At Fraunhofer IWS Dresden, strong internal stresses in MLL are reduced through a special multilayer coating design consisting of four individual layers per period. In addition to an absorber and spacer material with reversed internal stresses, a separating barrier layer is introduced at the interface (Fig. 3). With appropriate thickness ratios of the three involved materials, this material system is nearly stress-free and thereby allows the fabrication of layer systems of more than 100 µm.

RESULTS

First experiments were performed with the material system shown in Figure 3, which had a thickness of about 65 µm. For the suggested setup, calculations showed that a pre-focusing mirror with a short focal length and therefore a markedly curved wavefront is a disadvantage for the geometric separation of orders behind the MLL. The results of a configuration with a mirror with a moderate focal length of 28 cm appear useful when the MLL is placed about 3.5 cm away from the focus. With ideal beam properties for the given lens configuration, this design results in a focus size of around 40 nm. Radiation from a copper X-ray tube with a Ni absorber is dominated by $K_{\alpha 1}$ and $K_{\alpha 2}$ spectral lines. When these two lines are taken into



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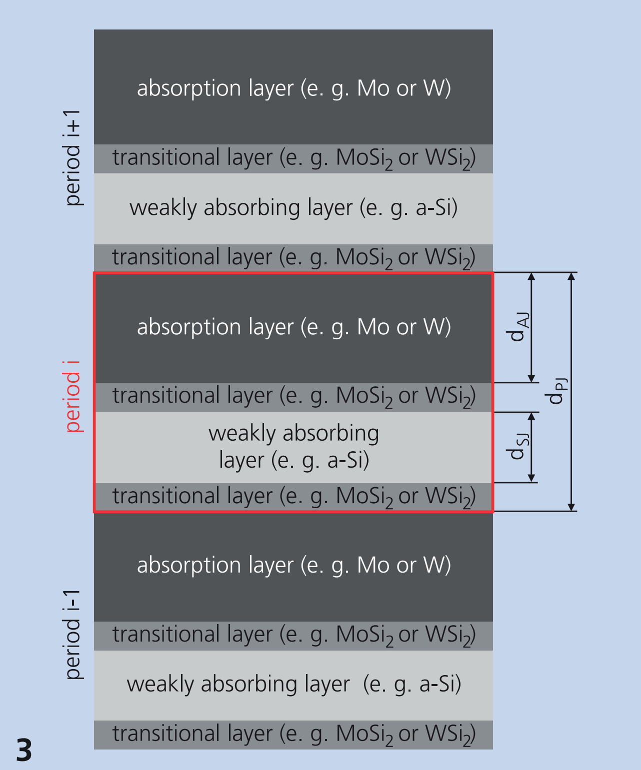
account, the calculations yield essentially two separate foci whose distance is approximately 25 µm in the propagation direction and 150 µm perpendicular to it.

In the case of coherence lengths that are smaller than the aperture of the lens, only the relevant part of the lens contributes to form the focus size, which is thereby increased; however, it does not lead to any appreciable reduction of the flux in the focus. Thus a focus size of 400 nm arises for a lens of with a size of 100 µm and a coherence length of 10 µm, according to the above mentioned example, while a coherence length of 1 µm yields a focus size of around 4 µm.

Multilayer system of four separate layers per period



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Calculations to estimate the influence of the divergence of the incoming beam show for a typical value of 0.02 ° a focus shift of up to 5 µm perpendicular to the propagation direction. This results in a corresponding enlargement of the focus of the MLL. A lower angular divergence at the entrance of the lens is achieved when a narrow-band mirror is used. This simultaneously leads to an increase of the coherence length. Further improvements can also be achieved when MLL are produced with better angular selectivity, i. e. when they are made with adjusted lamella thicknesses.

Overall, the modeling results show that through the use of MLL and optimized optics, it is possible to achieve focus sizes of 1 µm even for laboratory sources. The lateral resolution capability of diffractometry, fluorescence analysis and reflectometry can therefore be extremely improved.

1 *Crossed MLL for the pinpoint focusing*

2 *Schematic depiction of the MLL laboratory setup that was used for model calculations*

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