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Plug-in MLL optics with long working distances for X-ray Nanodiffraction experiments

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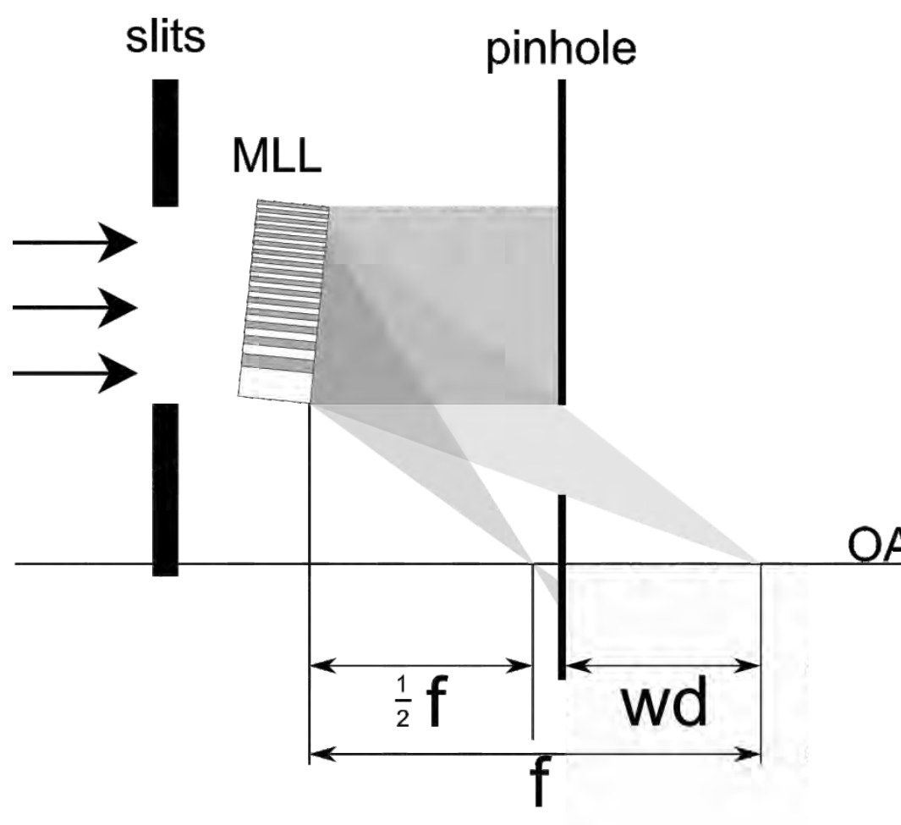
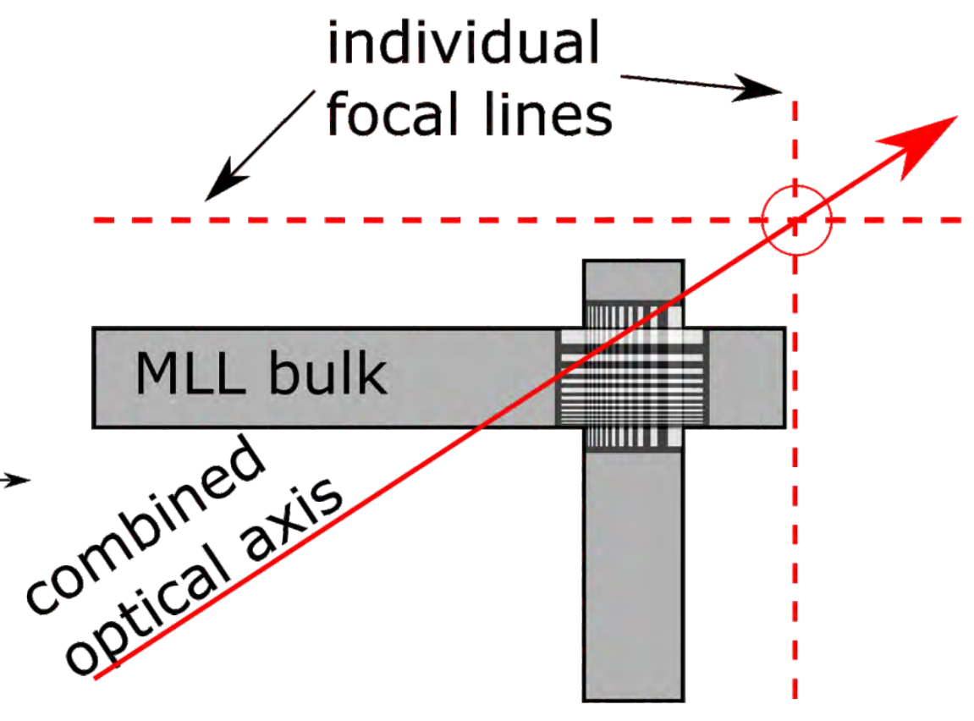
MLLs for high resolution X-Ray Nanoprobes

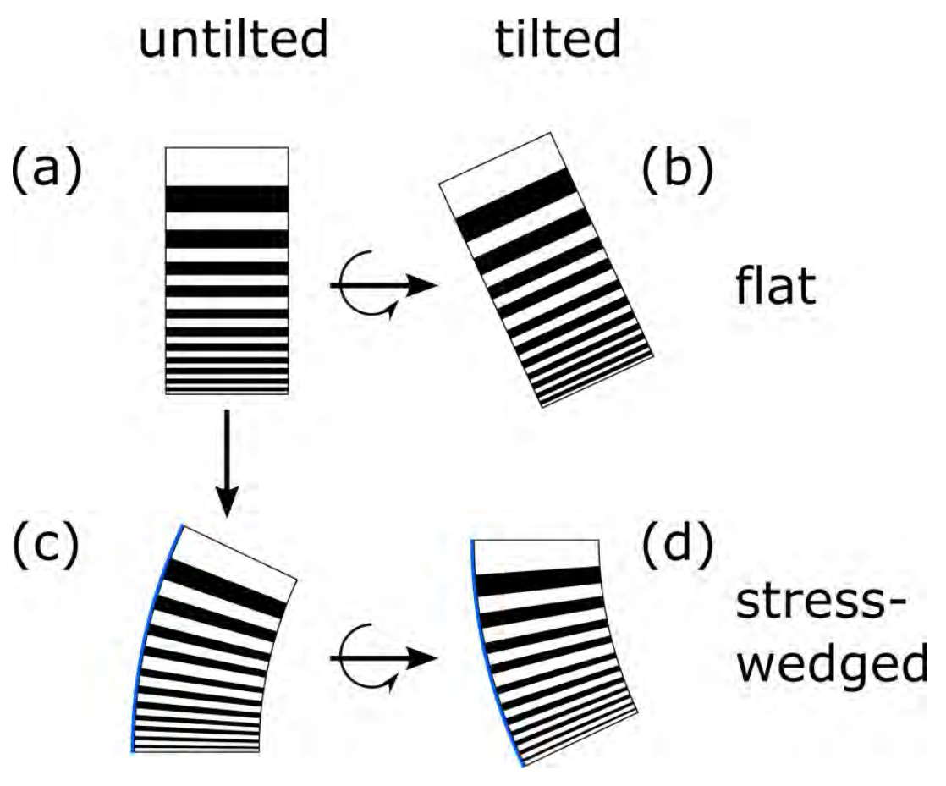
MLLs (Multilayer Laue Lenses) are diffractive focusing and imaging optics made using thin film deposition and micromechanical preparation techniques such as magnetron sputter depositon and focused ion beam milling, respectively [1]. Two linear focusing MLLs can be combined to a point focusing and imaging device.



Tilted MLL with schematic setup and several diffraction orders.



Crossed MLLs for point focusing and full field imaging.



MLL geomtries: flat, tilted and stress wedged [6]

In recent years MLLs have shown their potential to achieve resolutions significantly better than 10 nm in hard x-ray microscopy and nanoprobe setups as well as relatively large efficiencies for the hard X-ray regime [2,3].
A significant motivation of current MLL development is to make these optics feasible for experimental setups with bulky sample environments. This requires to make lenses with working distances of several millimeters. However, large working distances can be achieved only with long focal lengths, which reduce the numerical aperture and thus degrade the potential resolution. Furthermore, a reduction of the complexity of adjustments needed for MLL installation at beamlines is a major goal in recent developments.

We have developed a low stress multilayer system for MLL, based on Molybdenum, Carbon and Silicon. This system allows the multilayer deposition with a thickness of more than 100 micrometer and large diffraction efficiency [4]. A crossed MLL setup was assembled as an easy-to-install plug-in device, which achieved a sub 25 nm resolution in horizontal and vertical directions combined with a measured working distance in the order of 3 mm with the IWS High Resolution Design [5].

Current IWS MLL Designs:

Long Working Distance - High Resolution MLL Design:

Focal Length:	9 mm @12 keV
Working Distance:	**3.1 mm**
Stack Height:	50 µm
Zone Numbers:	970 - 6970
Individual Layers:	12000
Zone Widths:	5.8 - 15.5 nm
Materials:	Mo/C/Si/C
Geometry:	tilted MLL
Nominal Resolution:	**18 nm**

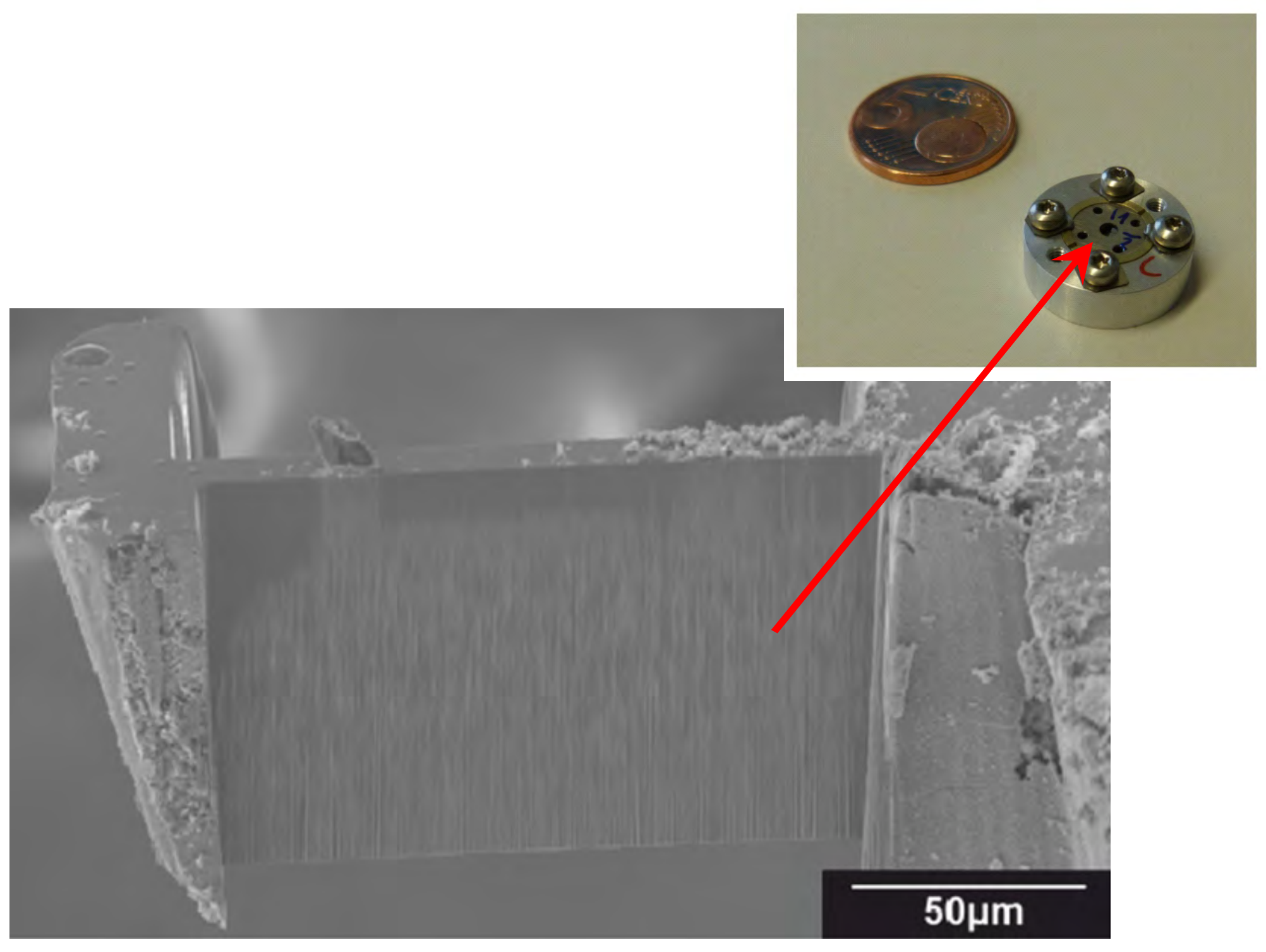
Very Long Working Distance - Medium Resolution MLL Design:

Focal Length:	45 mm @12 keV
Working Distance:	**25 mm**
Stack Height:	100 µm
Zone Numbers:	4000 -12500
Individual Layers:	17000
Zone Widths:	9.6 - 17.0 nm
Materials:	Mo/C/Si/C
Geometry:	tilted MLL
Nominal Resolution:	**45 nm**

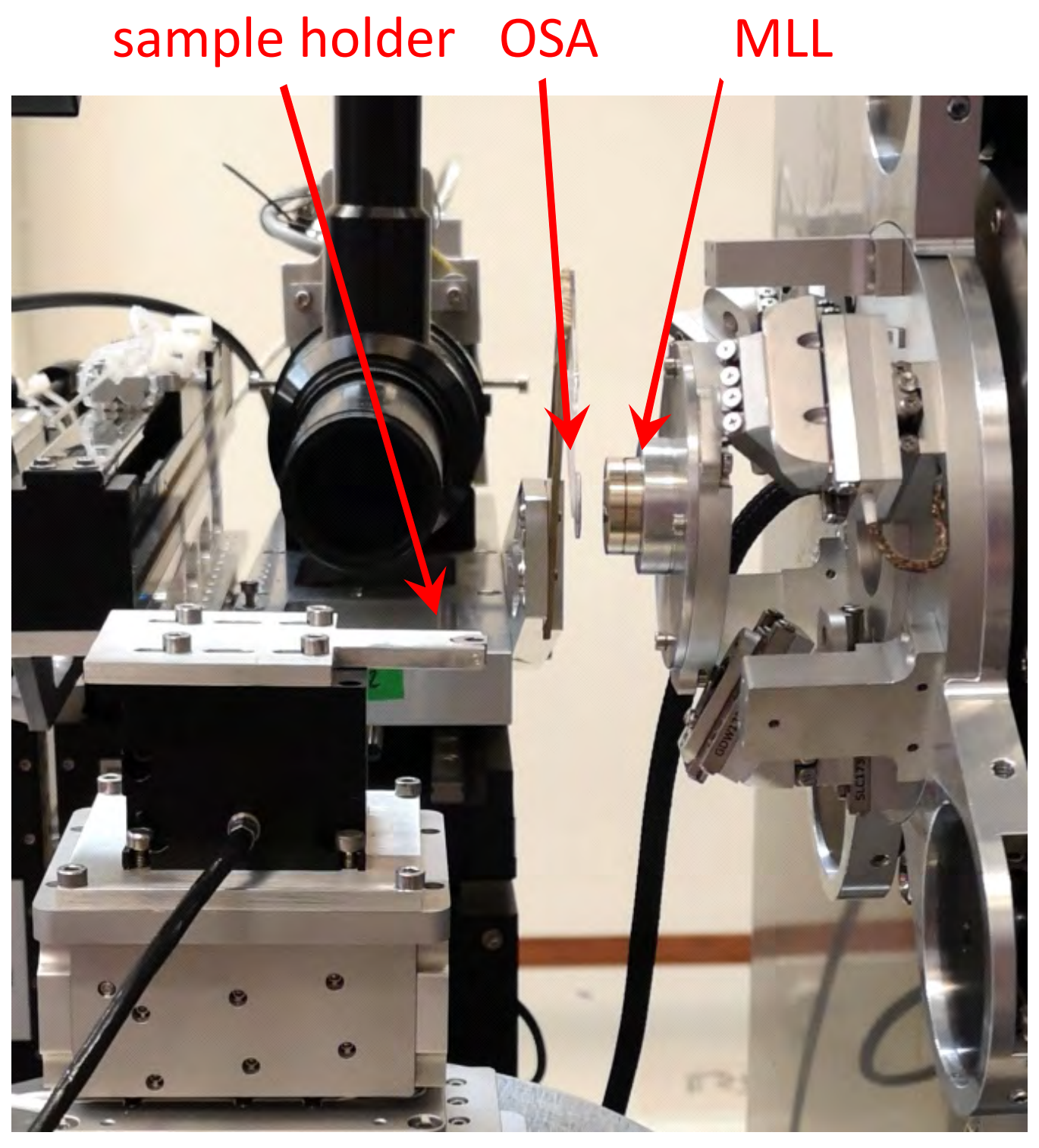
Acknowledgments:
Experiments were performed on beamlines DESY/P03 (LTP II-20180007 EC) and at the European Synchrotron Radiation Facility (ESRF/ID13), Grenoble/France. The authors are grateful to M. Burghammer and M. Rosenthal from ESRF for providing assistance in using beamline ID13. We would like to thank the colleagues of Montanuniversität Leoben for the excellent collaboration within the Long Term Project.

Long Working Distance MLL Experiments

Recently >100 µm thickness MLL-stacks have been grown for both long working distance designs. The multilayers have been cut down to lamellae using laser cutting and focused ion beam milling [4]. Thereafter assembly and adjustment of two crossed lamellae into a monolithic MLL plug-in optic was realized. Thus beamline integration of such MLL housing is just similar to installation of a Fresnel zone plate.
Both of the IWS MLL designs have been tested at DESY and ESRF beamlines for in-situ measurements. Recently a Long-Term-Project at DESY/P03 (II-20180007 EC) is underway for further developments. E.g. wedged MLLs using a stress layer in order to further increase the efficiency is planned for later manufacturing iterations [6].



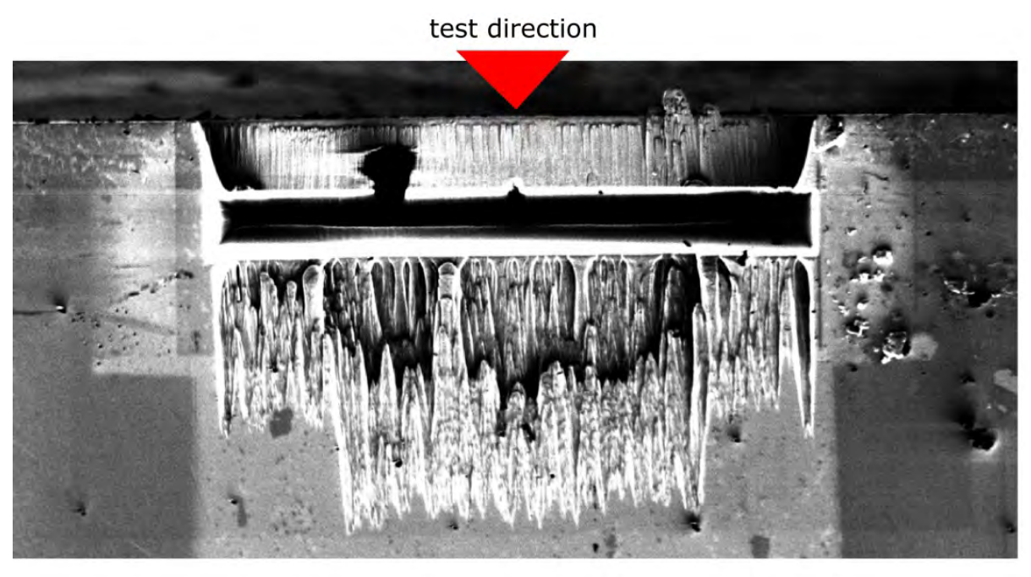
SEM image of a FIB-milled MLL deposition with an aperture of 100 µm.



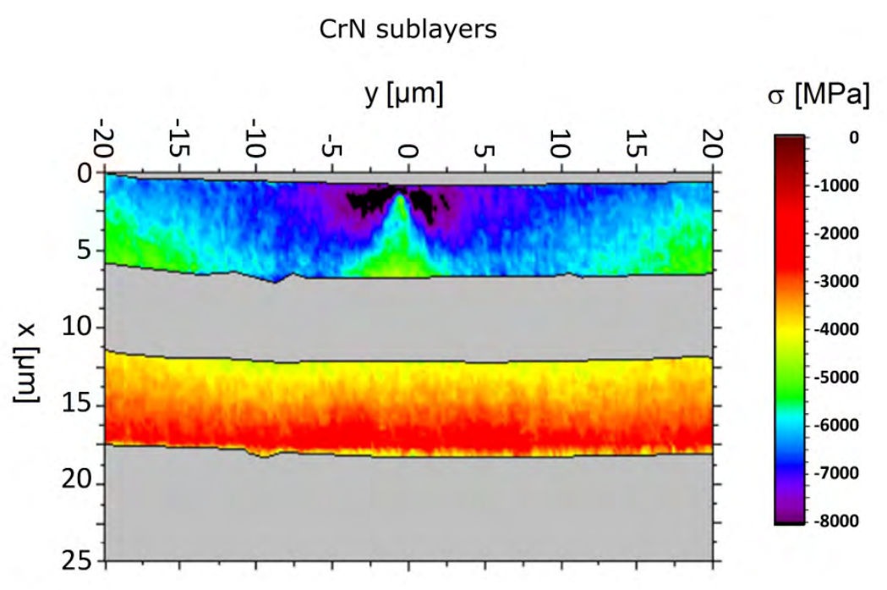
Photography of the MLL setup at DESY/P03 with mount, pinhole (OSA) and test sample holder.

In-situ Measurements

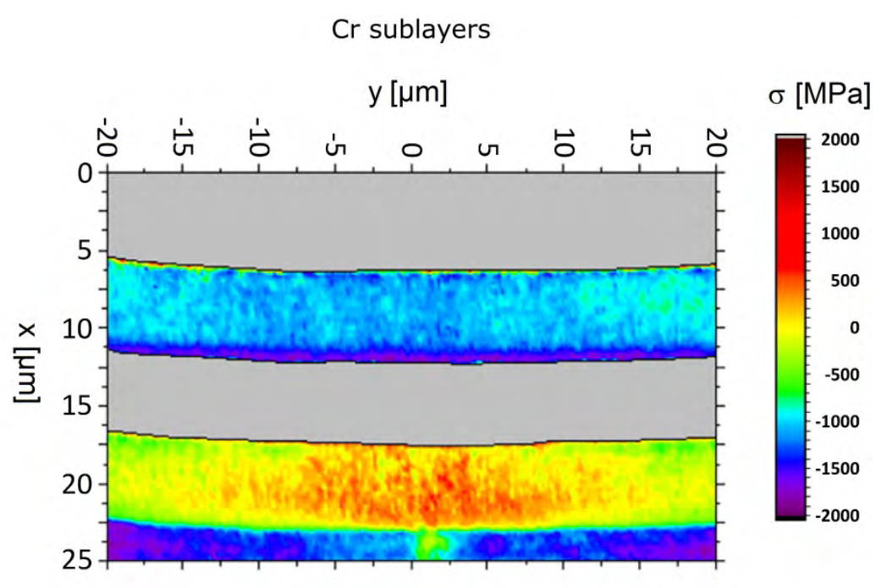
µMechanical tests are used to study deformation mechanisms in individual micro-structural features of complex nanomaterials. In this experiment deformation fields were evaluated at different loads by nano X-ray diffraction measurements. In-plane stress distributions in CrN and Cr sublayers reveal the stress concentrations induced especially by wedge indenter in CrN sublayer and by notch in Cr sublayer. It is interesting to observe in-situ that the interfaces between the sublayers induce stress concentrations blunting.



SEM image of a micro-bridge of 5 µm CrN/Cr/CrN/Cr layers.



In-plane stress for CrN sublayers under load of ~0.5 N.



In-plane stress for Cr sublayers under load of ~0.5 N.

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[5] A. Kubec, et al.: *Sub 25 nm focusing with a long working distance using multilayer Laue lenses.* (2018)
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