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Surface Slope Metrology of BL 8.3.1 M301 mirror substrate with the Upgraded Developmental Long Trace Profiler

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1. Introduction

In the present note we describe the results of the surface slope metrology of the internally cooled single crystal silicon flat substrate of M301 bendable mirror for the Advanced Light Source (ALS) macromolecular crystallography superbend beamline 8.3.1. The flat substrate M301 will, in operational use be bent to an elliptical cylinder for focusing with an average radius of curvature of about 2500 m [1].

According to the engineering specification [1], the mirror substrate with overall size of 880 mm (length) × 1.5 in (width) × 3 in (thickness) should have a residual (after subtraction of the best fit cylindrical shape with radius of curvature more than 10 km) slope variation of less than 0.25 μrad (rms) over the clear aperture along the substrate center line of length 750 mm.

The high accuracy slope metrology required for the reliable characterization of M301 substrate was performed with the Developmental Long Trace Profiler (DLTP) available at the ALS X-Ray Optics Laboratory (XROL). The DLTP, an autocollimator and moveable pentaprism based slope measuring profiler [2,3], is a low-budget, NOM-like [4] instrument. Recently, it was upgraded to provide fast, highly accurate surface slope metrology for long, side-facing, x-ray optics [5]. In Ref [5], it was demonstrated that in the advanced environmental conditions of the XROL, the new clean-room optical metrology facility at the ALS, the inherent precision of the DLTP is below 100 nrad (rms). The performance corresponds to a single scan carried out with the characteristic scanning parameters of the DLTP. Thus, a time increment between the sequentially measured points was about 3 sec and overall scanning time was a few hours corresponding to a single scan of the measurements describe in this note.

2. Handling the substrate and arranging the test measurements

The mirror substrate was originally (as packaged by the vendor) placed between two protective covers made of a hard plastic. The bottom cover has two slots for the water connectors that come out of the cover plane. Therefore in the face up position, the substrate was placed on two clean steel blocks – Fig. 1. Figure 1, shows the substrate on the XROL clean bench with activated air flow. In this case, there are less than 1-2 particles of the size of 0.2 μm and less per cubic foot in the air surrounding the optic.

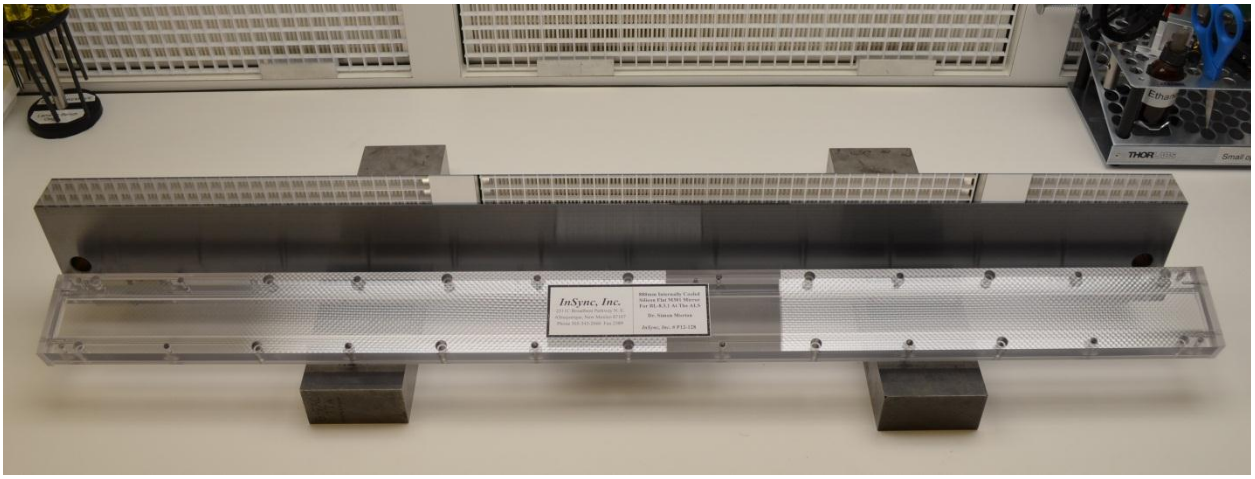


Figure 1: BL 8.3.1 M301 mirror substrate and the top protective cover removed. The substrate and the bottom cover rests on two steel blocks in order to protect the cooling water connectors (not visible here).

A clean-room protocol was used for handling of the substrate in the XROL – Fig. 2.

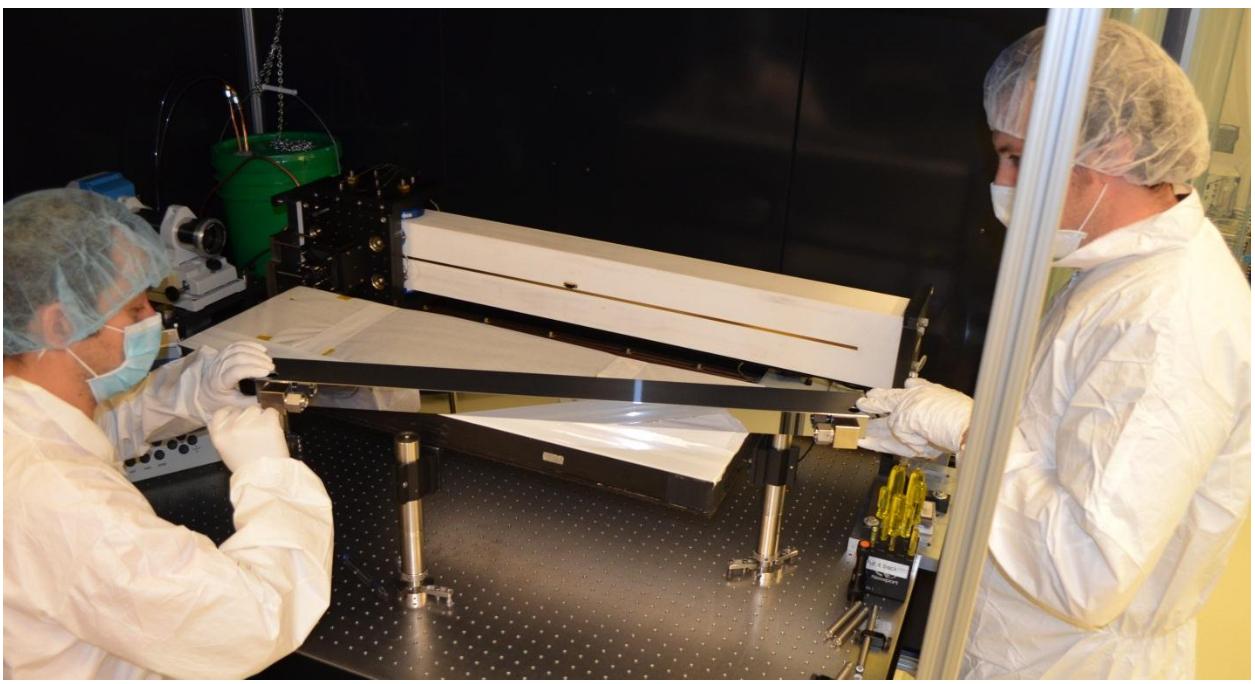


Figure 2: Placing and alignment of the substrate for measurements with the upgraded DLTP.

In the course of measurement, the substrate was placed on its side on top of the adjustable optical bench covered with pure, non-woven, lint-free optical tissues – Fig. 3. The particle contamination inside the DLTP hutch was less than 500 particles per cubic foot, as measured with the Fluke 985 particle counter immediately after completing the assembly and alignment of the set-up.

The substrate was secured against an incidental displacement (as an earthquake precaution) with two 1/2-in dia. posts, screwed into the optical bench through the substrate's mounting holes. A piece of clean Kapton tape was attached to one of the water feedthroughs in order to indicate the orientation of the substrate with respect to the DLTP scanning direction that is from the left to the right (Fig. 3).

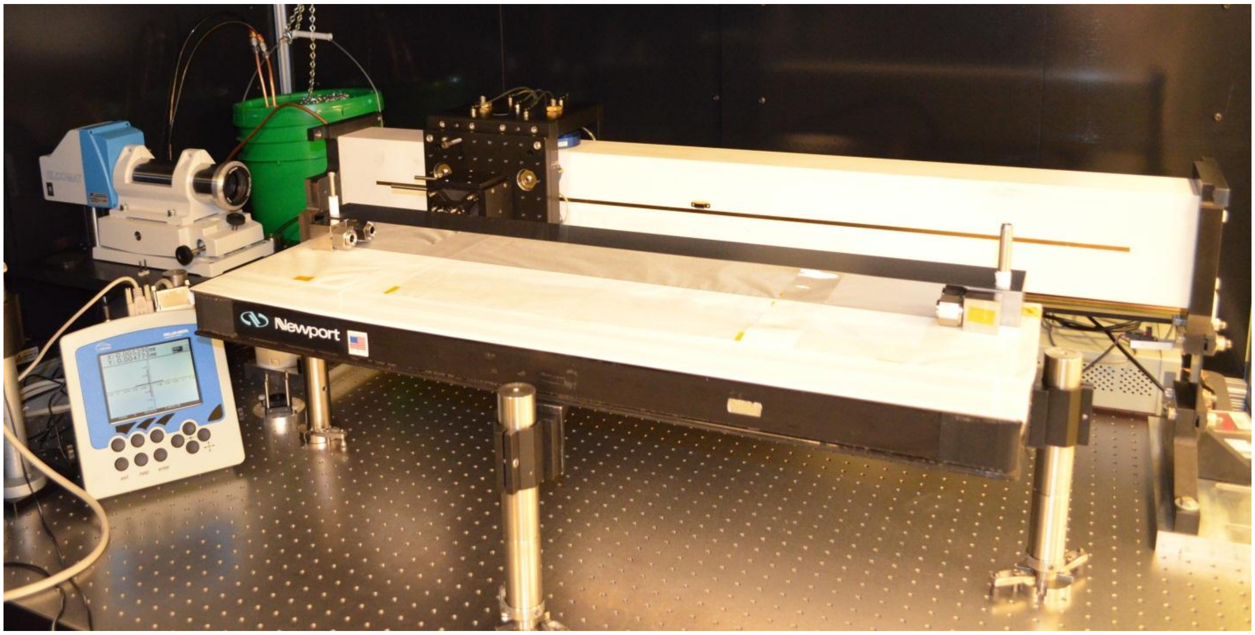
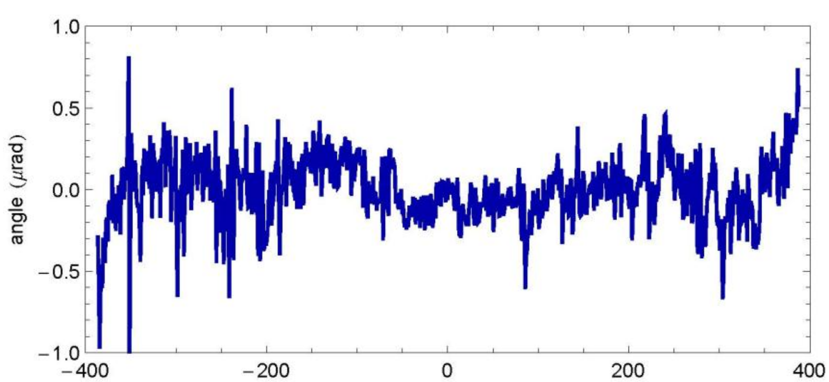


Figure 3: DLTP experimental arrangement with BL 8.3.1 M301 mirror substrate.

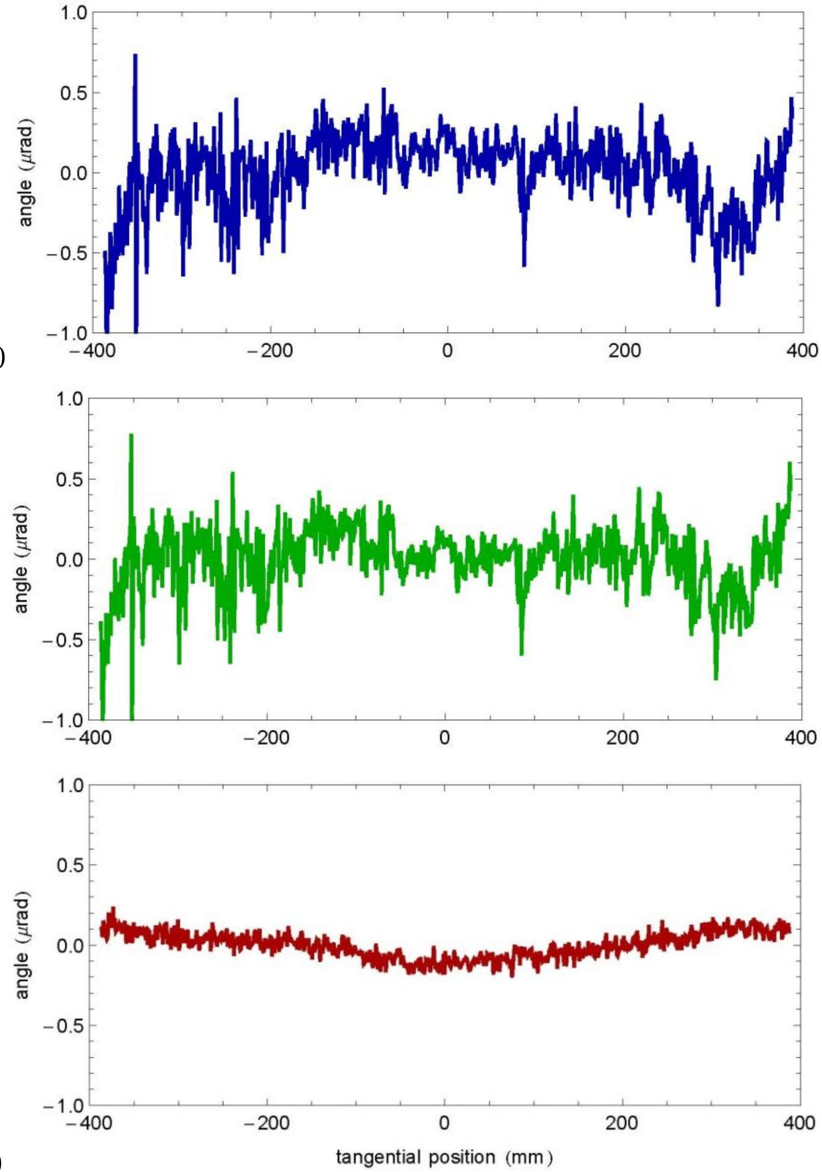
The experimental arrangement with the side-facing orientation of the optic decreases sensitivity to environmental conditions and removes the gravity effect on the optical shape [4]. The latter circumstance is also in coherence with the side-facing orientation of the optic in the course of the vendor metrology, providing more reliable data for cross-comparison.

3. Data acquisition and analysis

Figure 3 reproduces the slope traces recorded in two DLTP runs with the substrate in the opposite orientations, the direct (Fig. 4a) and the flipped (Fig. 4b) ones, with respect to the direction of the DLTP forward scan (from the left to the right in Fig. 3). Each trace is a result of 8 scans performed according to an optimal scanning strategy suitable for suppression of the instrumental drift error up to the 3rd polynomial [6]. The averaged trace (Fig. 4c) has the residual slope variation of about 200 nrad (rms) after the best fit cylindrical shape with a radius of curvature of more than 500 km was detrended. The half of the difference of the traces (average difference; Fig. 4d) can be thought of as a measure of the measurement error, including the instrumental random, systematic, and drift errors.



(a)



(b)

(c)

(d)

Figure 4: Two DLTP measurements with M301 substrate in two opposite orientations. (a) direct run AC-X1441 with rms slope variation 0.202 µrad (b) flipped substrate run AC-X1442 with rms slope variation 0.238 µrad (c) average of the direct and flipped runs, rms 0.205 µrad, and (d) the average difference between the direct and flipped runs with rms 0.082 µrad. The measurements were performed over the specified clear aperture of 750 mm, with 1 mm increments. The diameter of the DLTP aperture was set to 2.5 mm defining the DLTP spatial resolution of about 1.7 mm [7].

The systematic variation observed in the difference trace, Fig. 4d, can be partially due to the mismatching of the traces measured with the substrate in the direct and flipped orientations. In order to scale the possible mismatching effect, an additional measurement with the flipped mirror was performed with the left-hand side of the substrate raised by readjusting the optical bench by approximately 0.2 mm. This value approximately corresponds to the estimated accuracy of the sagittal positioning of a trace for the measurements under discussion.

The average difference of the slope traces recorded with the unraised and raised substrate is shown in Fig. 5. There is a clear systematic variation of the difference trace with the rms variation of about 0.06 µrad that reflects a significant variation of the substrate topography in the sagittal direction. The variation is comparable with the difference of the direct and flipped traces in Fig. 4d.

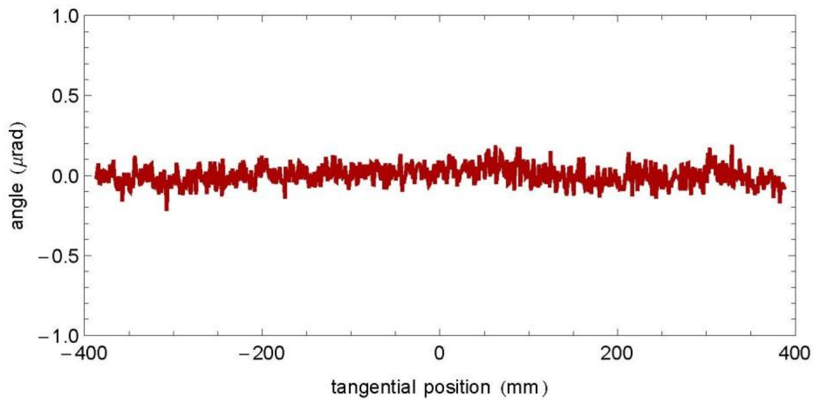
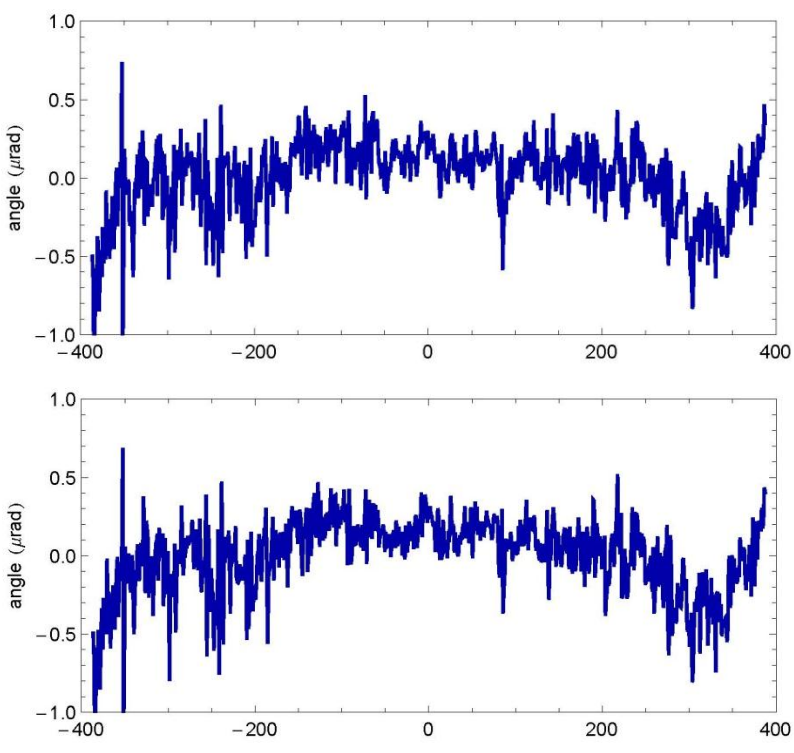


Figure 5: The average difference between the unraised and raised runs with rms 0.060 µrad.

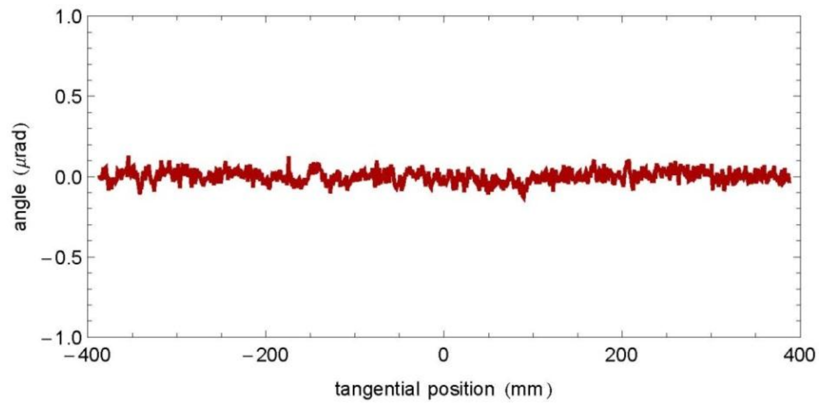
The surface shape variation in the sagittal direction has also been investigated with the ZYGO GPI interferometer. The interferometric measurements have in particular shown that the substrate has a convex shape in the sagittal direction with a radius of curvature of about 6 km that is significantly smaller of that of in the tangential direction. The ZYGO GPI measurements will be presented elsewhere.

Ultimate precision of the DLTP measurements with long flat optics can be understood from the comparison of repeatable measurements performed with the same arrangement of the experimental set-up. The results of such measurements are presented in Fig.6.



(a)

(b)



(c)

Figure 6: Two sequential DLTP measurements with the flipped substrate performed at the same experimental arrangement. (a) day run AC-X1442 and (b) night run AC-X1443; (c) the average difference between successive day and night runs, rms 0.041 µrad.

The plots (a) and (b) in Fig. 6 represent two traces measured in two sequential runs of 8 scans with the flipped substrate and at the same experimental arrangement. Half of the difference of the traces (Fig. 6c) can be thought of as a measure of the ultimate precision (repeatability) of the measurements, described with the rms slope variation of about 40 nrad.

4. Conclusions

We have described the results of the surface slope metrology of the silicon flat substrate of M301 for the ALS BL 8.3.1 performed with the upgraded DLTP. We have demonstrated that the current arrangement of the DLTP in the new ALS optics lab with advanced temperature stabilization and turbulence reduction yields measurements in under 8 hours with the rms error less than 80 nrad (including the instrumental random, systematic, and drift errors) for a long, 750 mm clear aperture, super-polished flat optic. Moreover, the measurement repeatability has shown to be on the level of 40 nrad (rms), limited in most part by the trace positioning and performance of the autocollimator.

The measurement has confirmed the vendor metrology providing the rms slope variation of 0.20 µrad.

Acknowledgements

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References

[1] P. McKean and S. Morton, "ALS bend magnet beamlines BL 8.3.1, branchline M301, mirror substrate," Engineering Specification AL6151 (Berkeley, October 01, 2012) , Sec.3f.

[2] V. V. Yashchuk, S. Barber, E. E. Domning, J. L. Kirschman, G. Y. Morrison, B. V. Smith, F. Siewert, T. Zeschke, R. Geckeler, A. Just, Sub-microradian Surface Slope Metrology with the ALS Developmental Long Trace Profiler, Nucl. Instr. and Meth. A 616, 212-223 (2010).

[3] S. K. Barber, G. Y. Morrison, V. V. Yashchuk, M. V. Gubarev, R. D. Geckeler, J. Buchheim, F. Siewert, T. Zeschke, *Developmental long trace profiler using optimally aligned mirror based pentaprism,* Opt. Eng. 50(5), 053601-1-10 (2011).

[4] F. Siewert, H. Lammert, T. Zeschke, *"The Nanometer Optical Component Measuring Machine,"* in: [Modern Developments in X-ray and Neutron Optics], Springer (2008).

[5] Ian Lacey*, Nikolay A. Artemiev, Edward E. Domning, Gregory Y. Morrison, Brian V. Smith, and Valeriy V. Yashchuk, *"The ALS Developmental Long Trace Profiler for nanoradian metrology of side-facing X-ray optics,"* LSBL Note LSBL-NNNN (Berkeley, February, 2014).

[6] V. V. Yashchuk, Optimal Measurement Strategies for Effective Suppression of Drift Errors, Rev. Sci. Instrum. 80, 115101-1-10 (2009).

[7] Y. V. Yashchuk and V. V. Yashchuk, *"Reliable before-fabrication forecasting of expected surface slope distributions for x-ray optics,"* Opt. Eng. 51(4), 046501 (2012).