Investigations of the optics at the laser port of DDC

M.Hänel, G.Klemz, 17.Feb. 2010

The laser port consists of three sections: first, the entrance window (viewport), second, the holder of the actual vacuum mirror and finally the mirror itself.
Four different mirror holders are available. Two of them are of old type (before gun 4.x). In this design the viewport and the holder are combined in one piece. One of those is packed in plastic bag (unused) and the other one was used in the DDC of gun 3.2 and is now part of the vacuum mirror test setup in the laser hut. In the second design, the viewport and the holder are split. One of these holders is still installed in the DDC of the former gun 4.2 (stored in the vacuum lab), the second one is dedicated for the use in the DDC of the current gun 4.1.

The viewport

The important properties of the viewport are:

1. they must have are neither magnetic nor magnetizable (relative magnetic permeability μ_r=1)
2. the material of the view glass must be UV capable fused silica featuring a two-sided AR coating for 257.5nm designed for an angle of incidence around 0 deg.

Up to now viewports have been used, which comprise a high quality stainless steel for the flange but the ring holding the view glass was probably made of *Kovar*. This is an alloy of nickel, iron and cobalt which has very good mechanical properties but a μ_r between 1000 and 3000.
To avoid problems, new viewports had been ordered (*MDC Vacuum Products Ltd.*). Their flange consists of low-μ_r stainless steel 1.4429 (316LN) (μ_r = 1.005). The fixing ring is made of Tantalum (μ_r = 1.000018). The glass material is AR coated SPECTROSIL quartz with Surface quality Scratch/Dig of 20/10. The residual reflectivity is specified to be less than 0.5 % per surface (i.e. approx. 1 % for the complete window).

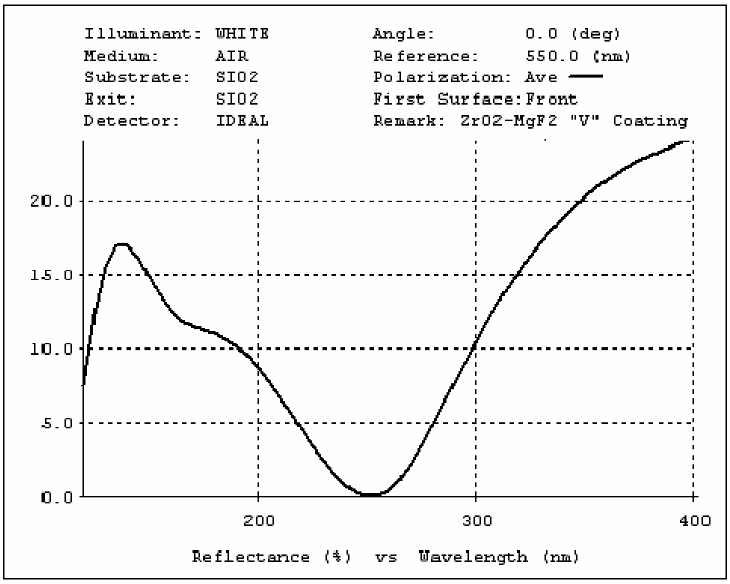


Fig. 1: Expected residual transmission of V-AR Coating on fused Silica viewports optimized for 257.5nm (Diagramm provided by LT-Ultra)

- Own Measurements with a Förster Probe (Ferro-Master, *Stefan Mayer Instruments*) confirm that the viewports are sufficient non-magnetic.

- In contrast to the laser viewport of the last run period during 2009 we did not observe any fluorescence excitation by the UV beam for the new viewports.

The mirror holder

As described in the introduction four mirror holders are available. Two of them were tested with the Förster Probe. The first one is of old type and was installed in the DDC of gun 3.2 while the second one was of new type and is planned to be used in the current DDC. The following image shows how these holders look like:

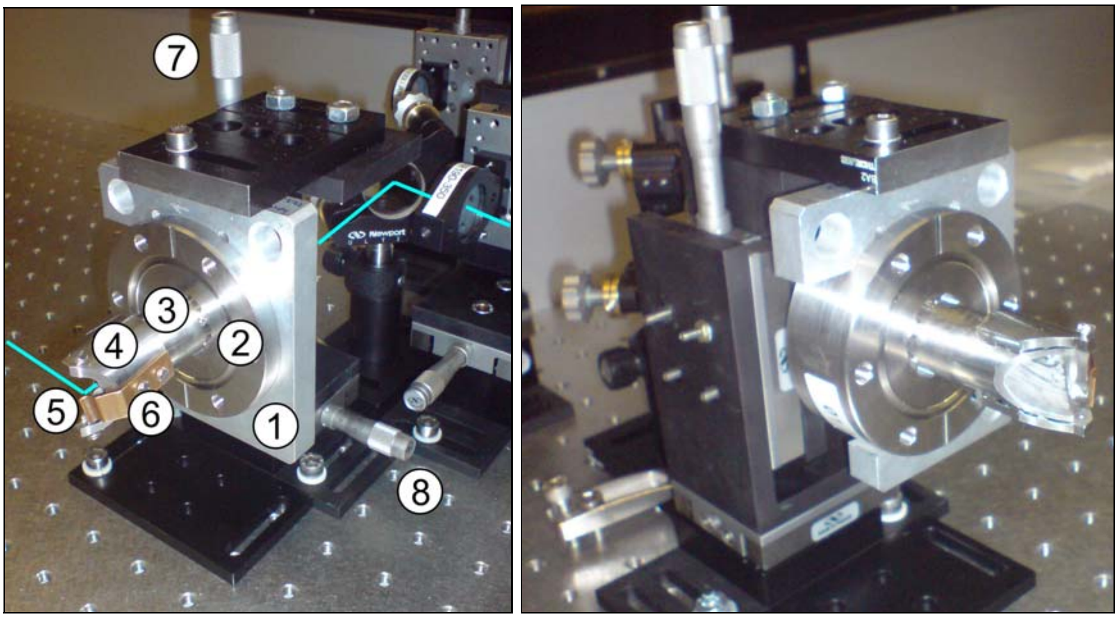


Fig. 2: Holder of the old type used in the UV-test beam line for the metal mirror. From the shown perspectives the differences between old and new type are not visible. (1: installation frame, 2: flange, 3: tube connector, 4: cylinder cap, 5: screws, 6: fixing spring, 7: vertical actuator, 8: horizontal actuator)

The measurement results are compiled in the following table. Please note, that the measurement device displayed μ_r = 1.015 as “zero-value”.

Position	**1**	**2**	**3**	**4**	**5**	**6**
old holder	1.015	1.03 – 1.13	1.007-1.02	1.08-1.2	1.015	1.015
new holder	1.015	1.02	1.015	1.02-1.1	1.015	1.015

It is evident that the new holder performs better and since there is no other available we should install it. At position four we observed a significant deviation (red numbers) The fact, that for the cylinder cap a range of values was measured even though it was made out of one piece, points to the conclusion that the higher μ_r-values are introduced by the machining process and are not due to an unsuitable choice of material.

The vacuum mirrors

Four mirrors according to the DESY design shown in Fig. 3 below have been purchased by the company *LT Ultra-Precision Technology GmbH*. They are made out of stainless steel 1.4429 and feature an unprotected Aluminium coating on their polished surfaces The coating was optimized for the wavelength region 257 nm. According to *LT-Ultra* the shape accuracy (planarity) of the reflecting surface amounts to ≤ 0,75µm; and the roughness is ≤ 5nm Ra.

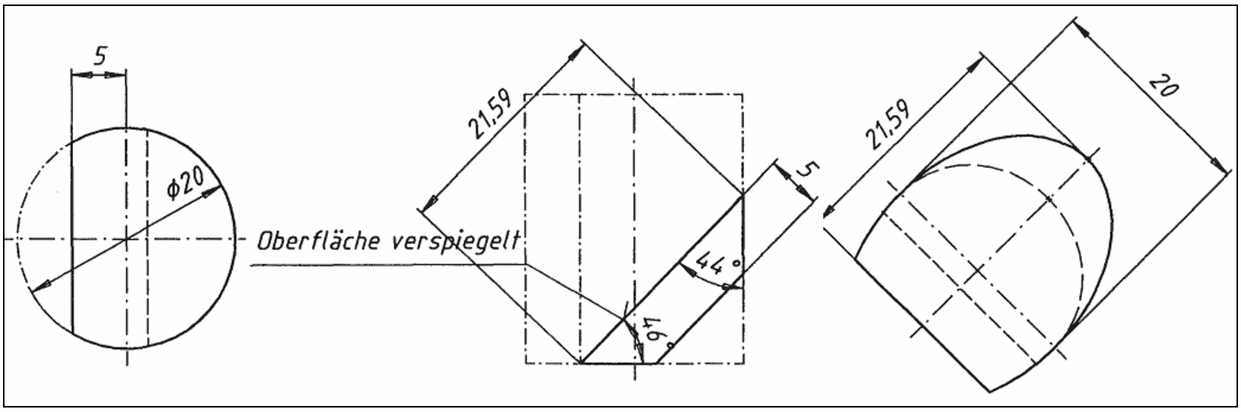


Fig. 3: Design of the vacuum mirror (DESY 1997).

We measured a relative magnetic permeability μ_r = 1.015 +/- 0.005 which equals the value that is displayed by the permeability meter when the sensorhead is far away from any magnetizable material.

These mirrors have been studied in a UV test beamline (257 nm wavelength) at the PITZ laser table. Additional measurements were done by the HZB (BESSY-II).

The PITZ-setup consists of a telescope which provides a six-fold magnification of the laser beam and also imaging of the UV source (frequency doubling nonlinear optical crystals) onto a beam shaping aperture as shown in Fig. 4. This is followed by a telescope of unit magnification which images the BSA onto a camera (JAI Pulnix TM-1406 GE with UV-option). The vacuum mirror is placed as close as possible behind the last lens so that the path length between mirror and camera (500mm) comes as close as possible to the value of 723 mm which is used in the actual machine setup.

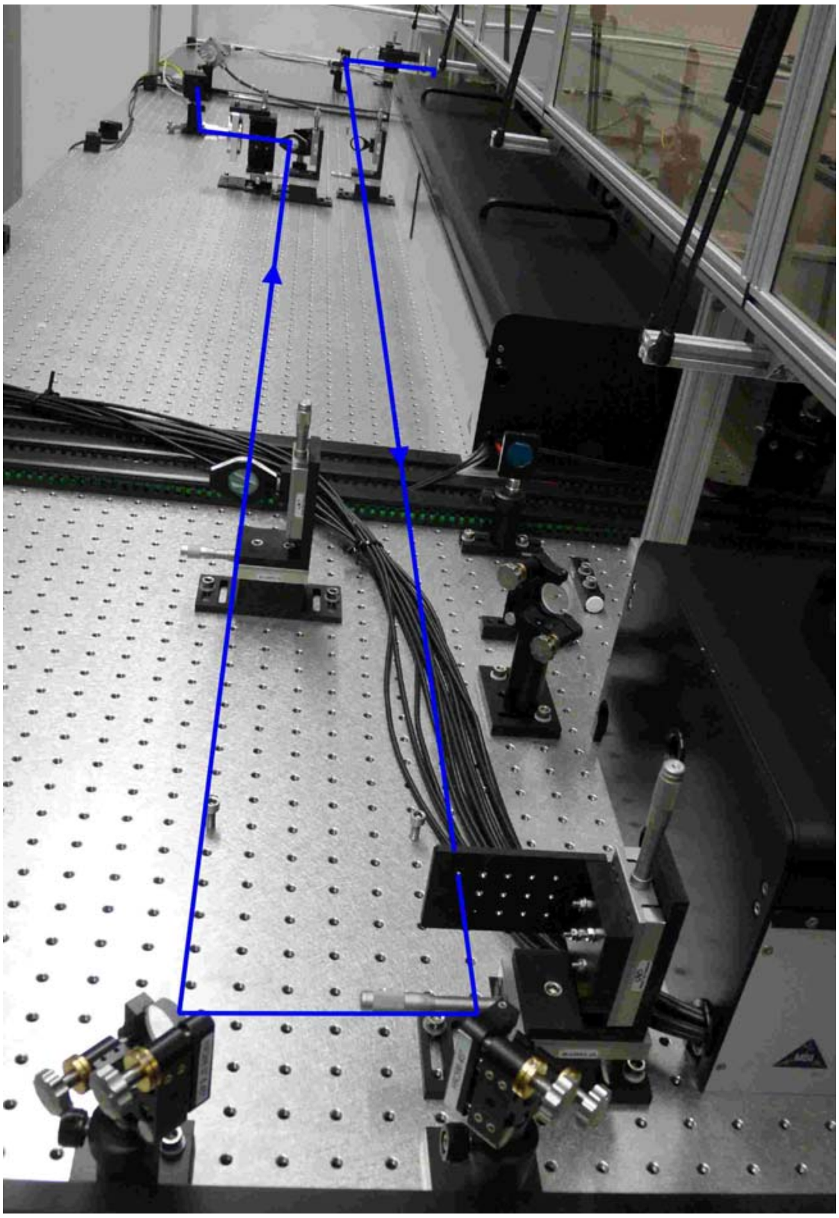


Fig. 4: UV Test beamline on the PITZ laser table The frequncy doubling crystals (source of the UV-beam) are hidden by the black amplifier box.

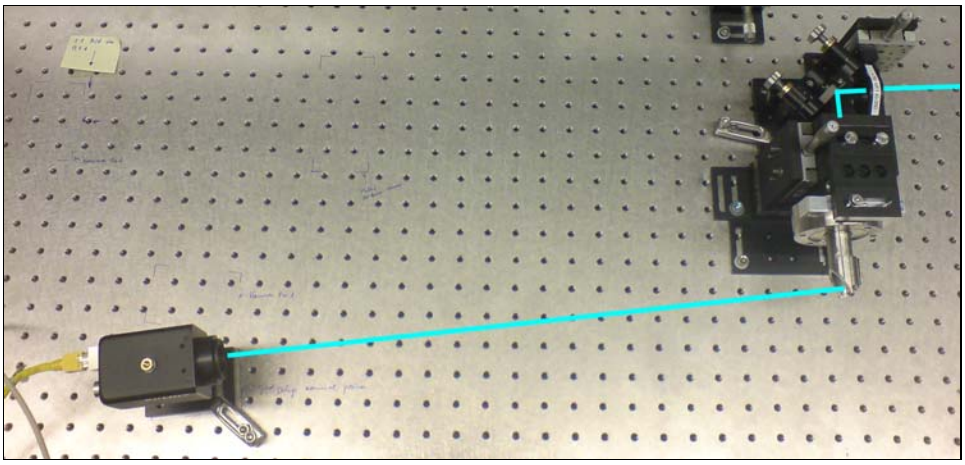


Fig. 5: Close-up view around the holder of the metal mirror.

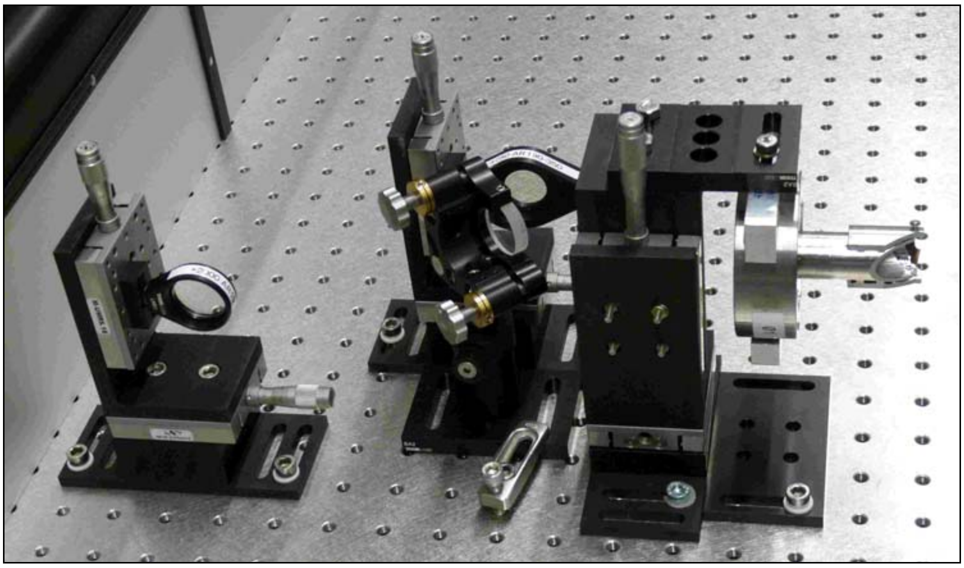
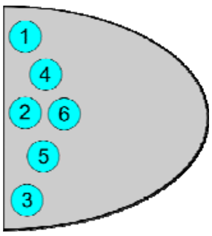


Fig. 6: Another close-up view around the holder of the metal mirror.

The horizontal and vertical actuators for the metal mirror were used to change the position at which the laser hits the vacuum mirror. The sketch below demonstrates qualitatively the location of the UV-spots. All readings at the actuators are summarized in the subsequent table.



Position	x in mm	y in mm
1	2.70	13.00
2	2.70	18.50
3	2.70	25.50
4	3.00	15.50
5	3.00	23.00
6	4.00	18.50

The gain settings of the camera are summarized in the next table (most probably the gain does not scale linearly). The reference image was obtained by removing the dielectric mirror between last lens and vacuum mirror.

Mirror	Camera gain (max 255)
direct (without mirror)	95
LTU10/1	200
LTU10/2	140
LTU10/3	190
LTU10/4	190
Al#1	190
Al#6	200
No. 5	200

Fig. 7 shows the reference image obtained without metal mirror. A beam shaping aperture of 1.5mm diameter was used throughout these investigations:

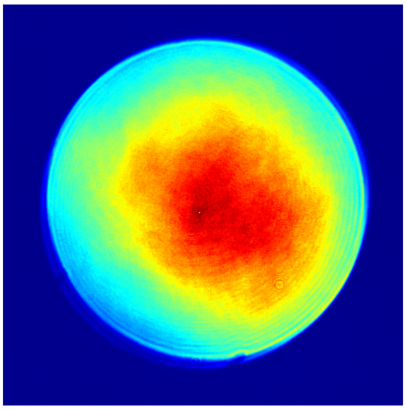
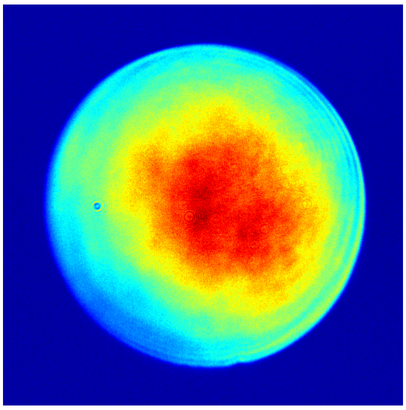
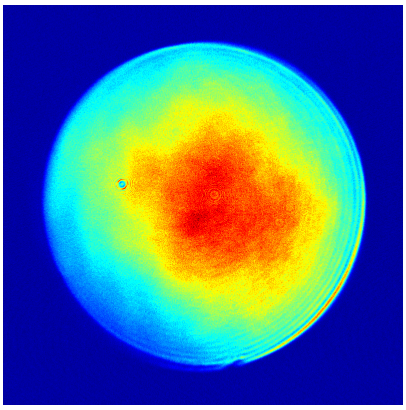


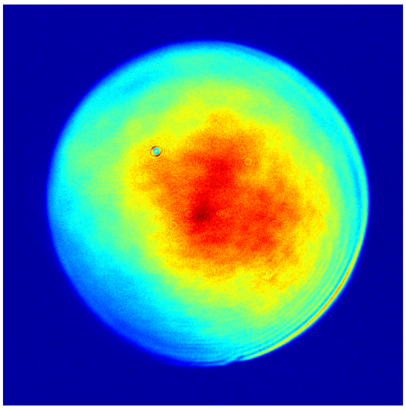
Fig. 7: Reference Image without metal mirror.

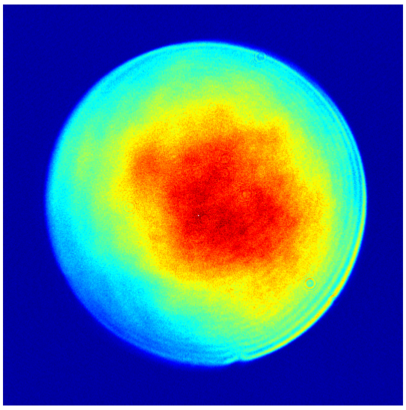
The resulting beam profiles obtaind with the mirrors from *Kugler* and *LT Ultra-Precision Technology GmbH* are shown on the next pages. The mirrors from *Kugler* are completely made out of Aluminium.

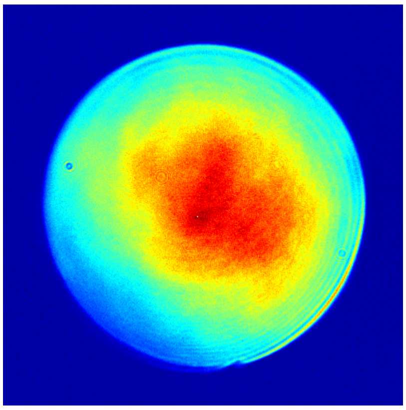
LT-Ultra #1

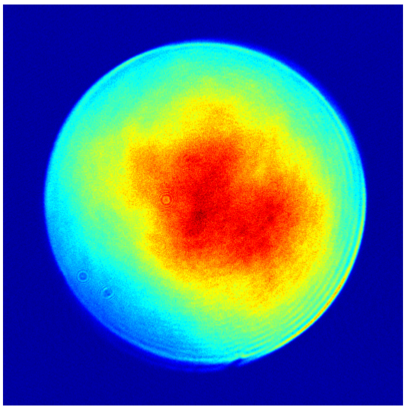

Position 1

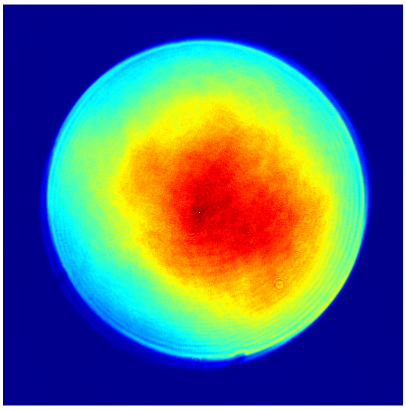

Position 2


Position 3

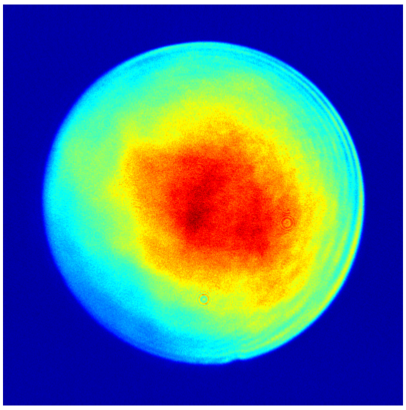

Position 4


Position 5

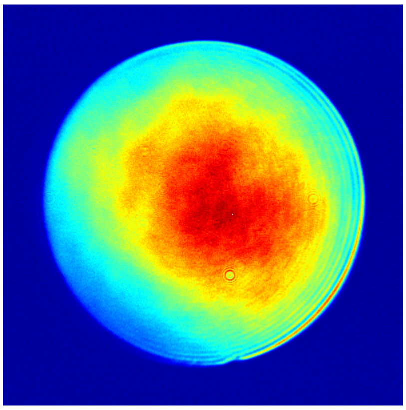

Position 6


Reference without mirror

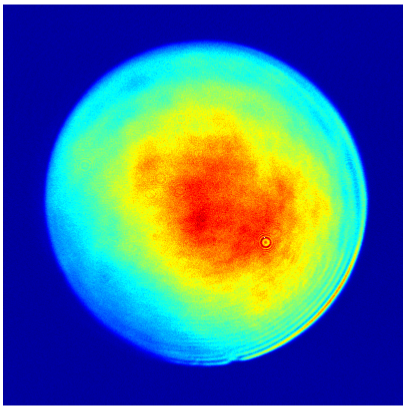
LT-Ultra #2



Position 1



Position 2



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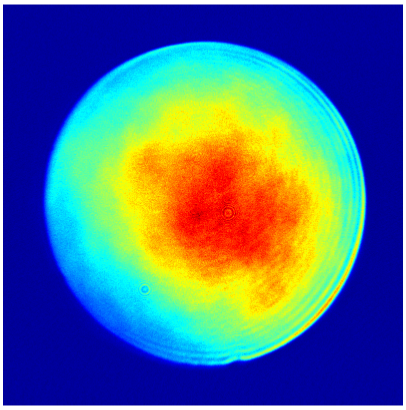

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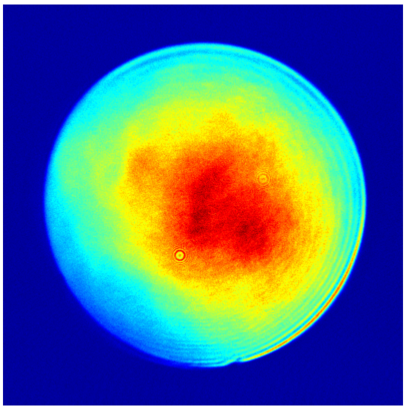

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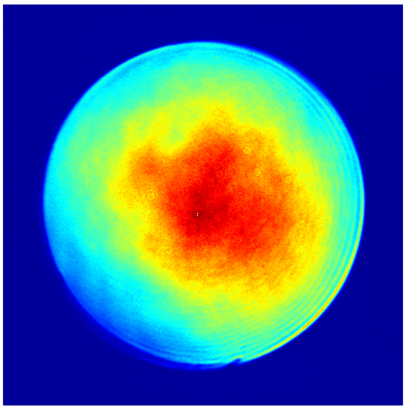
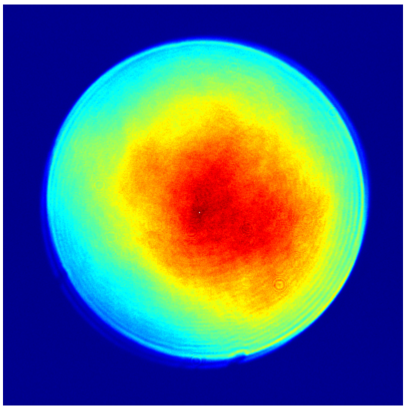
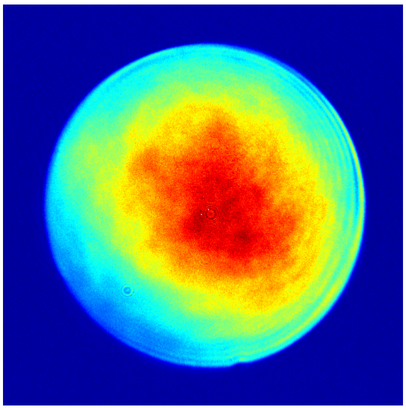


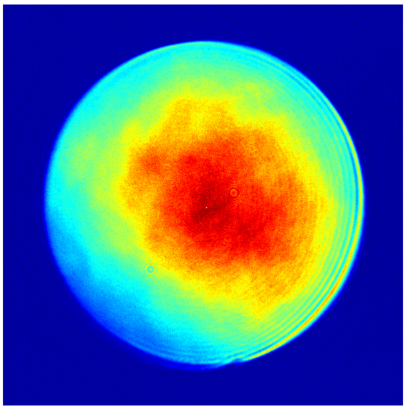
Position 6



Reference without mirror

LT-Ultra #3


Position 1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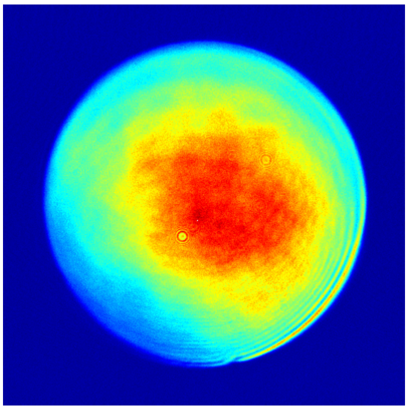
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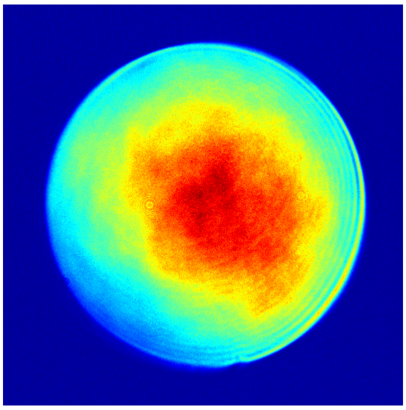
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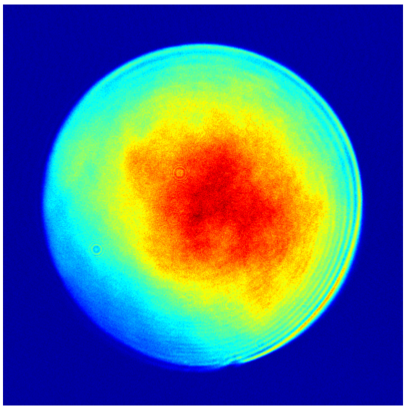
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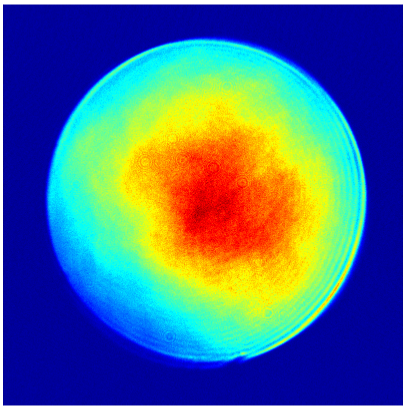
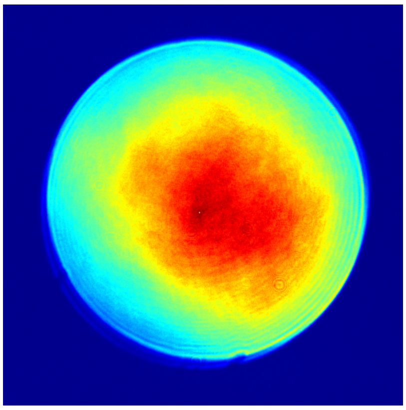
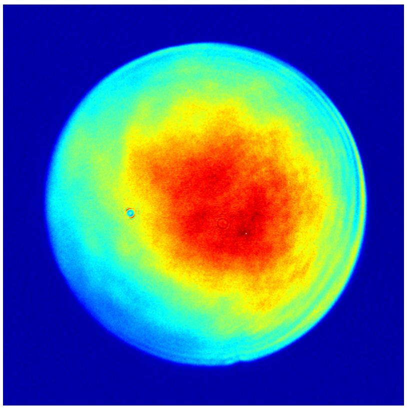
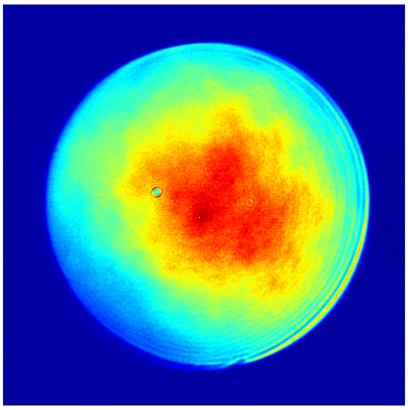
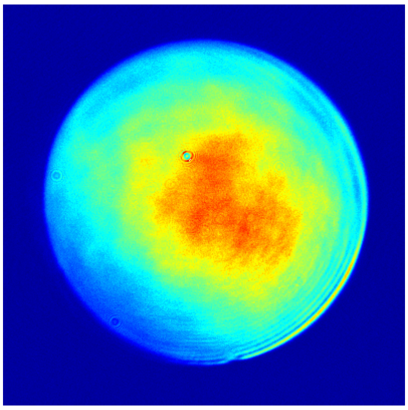

Position 6


Reference without mirror

LT-Ultra #4


Position 1


Position 2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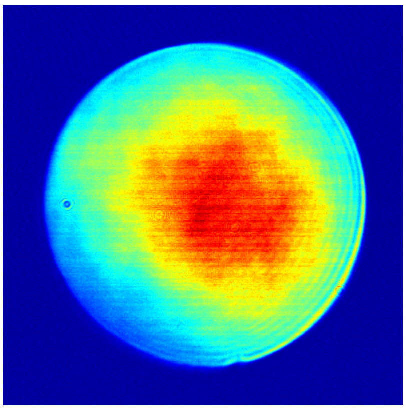
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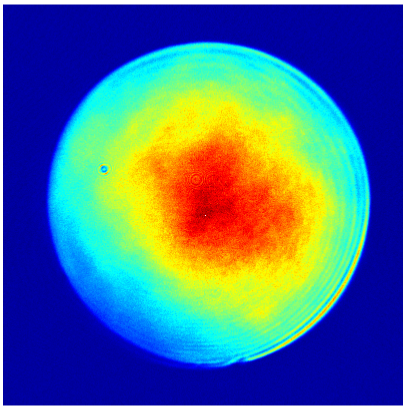
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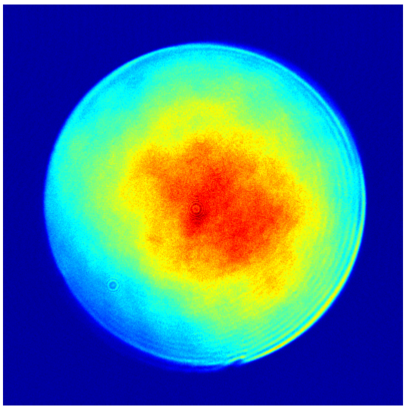
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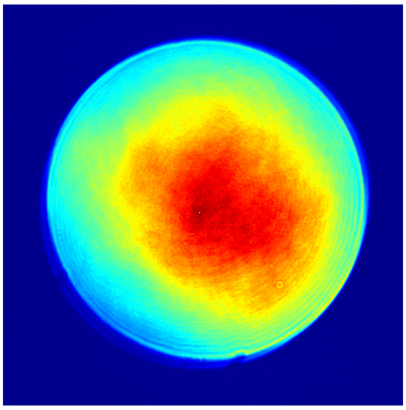
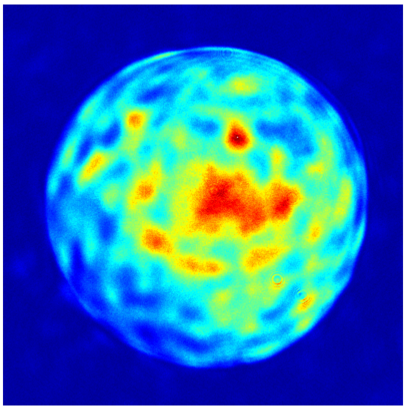
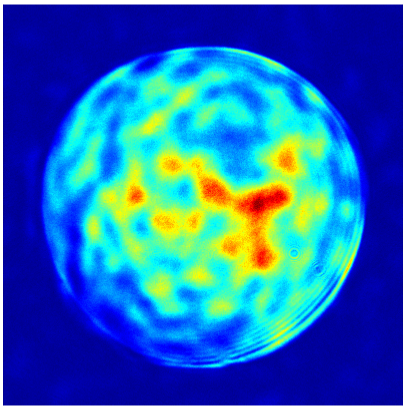
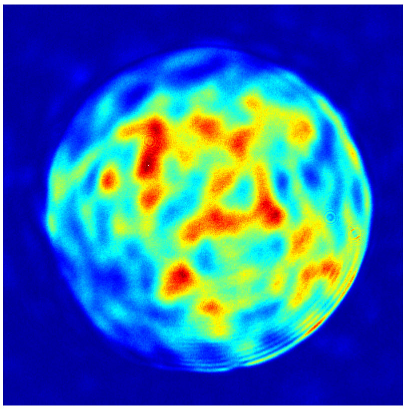

Reference without mirror

Al #1 (unused Kugler mirror, 2007 order)


Position 1


Position 2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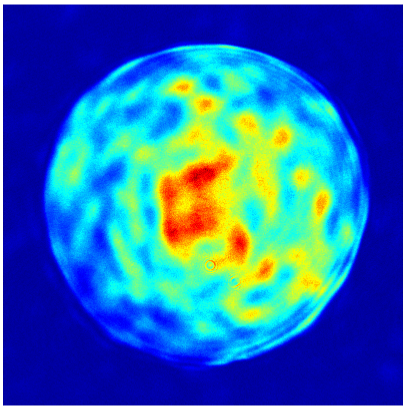
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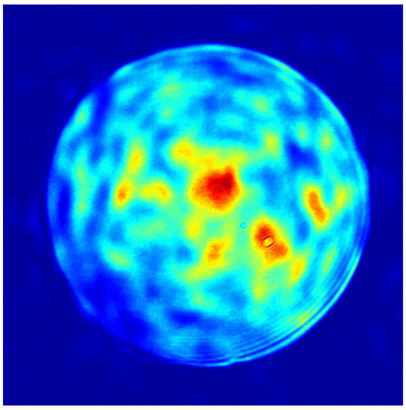
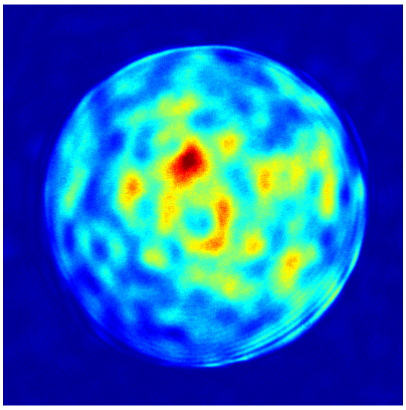
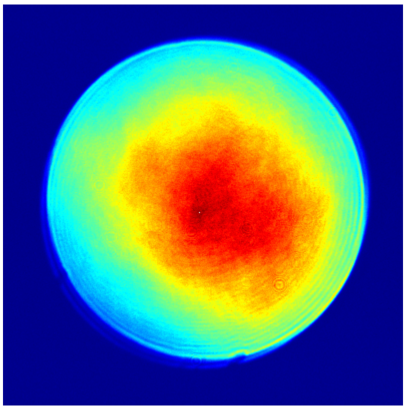
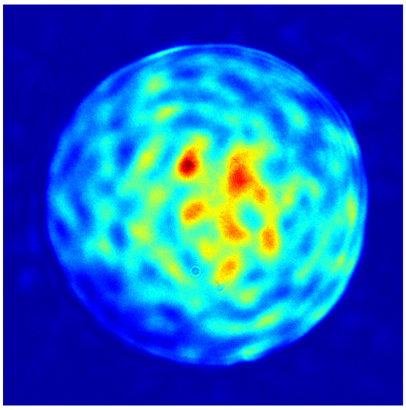
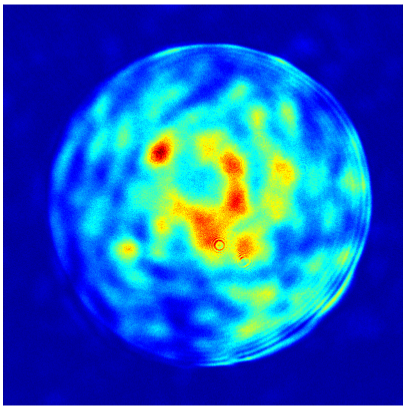

Position 5


Position 6


Reference without mirror

Al #6 (Kugler mirror, from DDC, gun 4.2)


Position 1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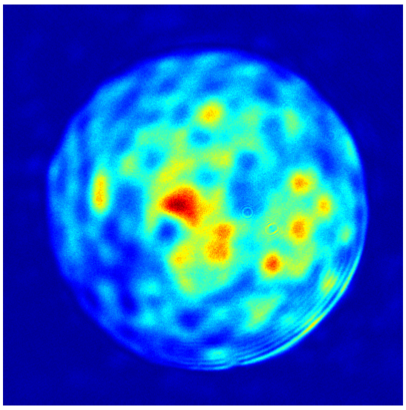
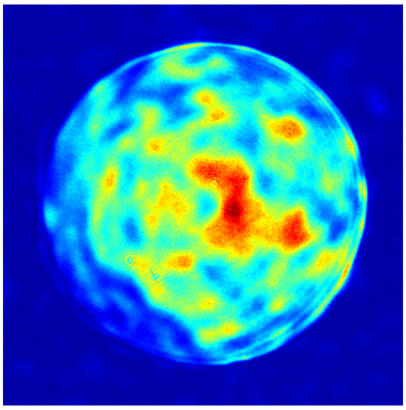

Position 3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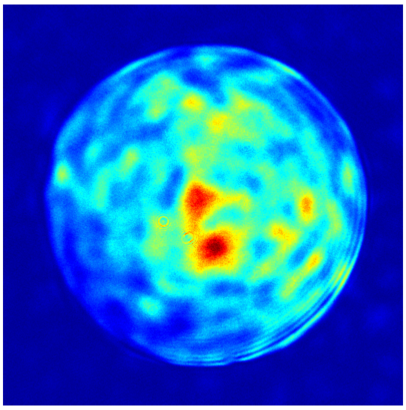
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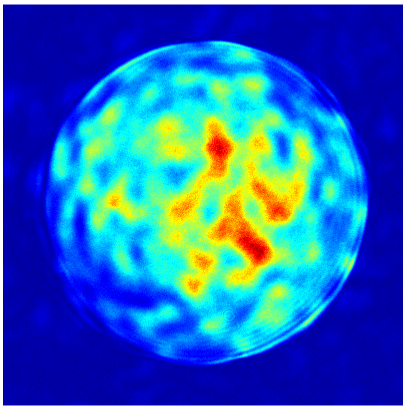
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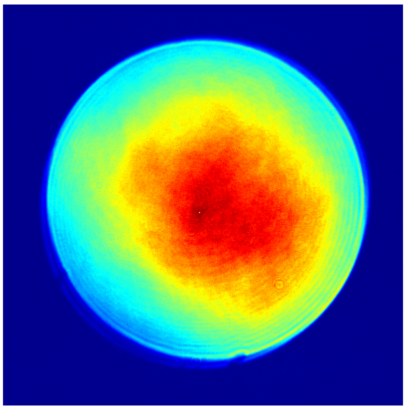
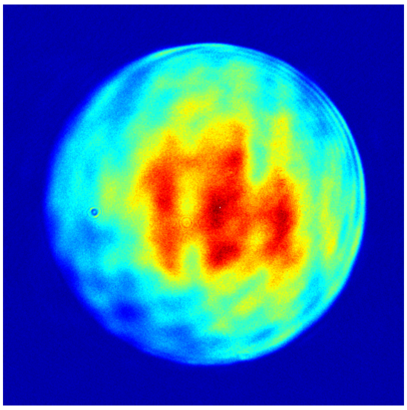
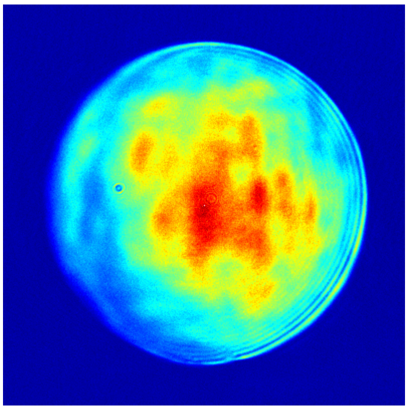

Reference without mirror

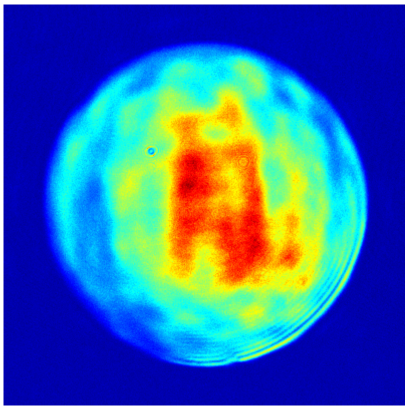
Al #7 (Kugler mirror, from DDC, gun 3.2, lots of scratches)



Position 1



Position 2



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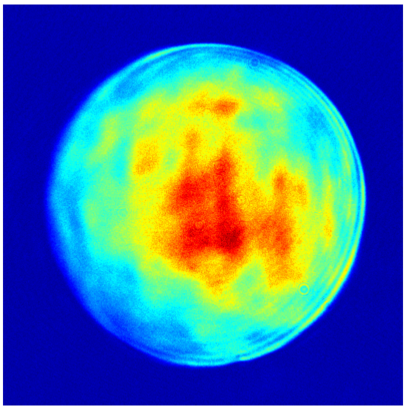
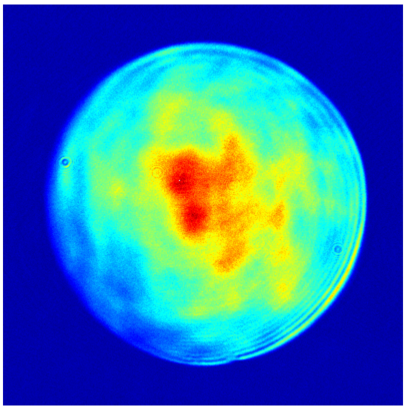
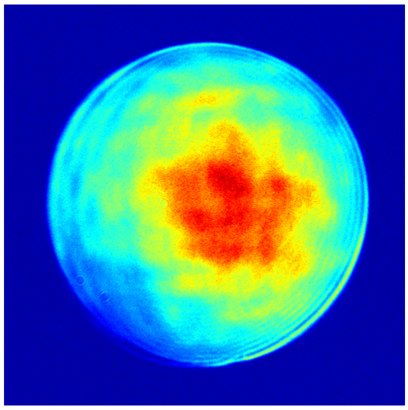


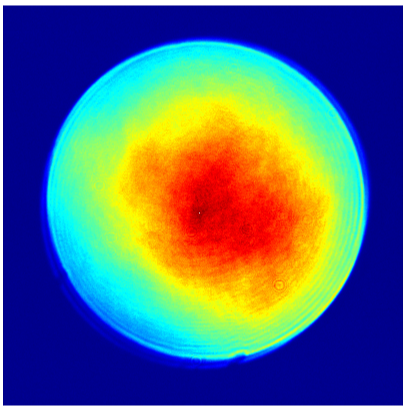
Position 4



Position 5



Position 6



Reference without mirror

Conclusion from own measurements at PITZ

1. In clear contrast to the mirrors from Kugler, all mirrors from LT-Ultra clearly produce a beam profile that is close to the reference (direct profile without mirror).

2. Using mirrors from *LT-Ultra* the homogeneiity is better compared to the results obtained from the Kugler mirrors.

3. However, some weak structures are introduced by the mirrors from *LT-Ultra*. These structures move together with the mirror surface across the observed beam profile when the horizontal or vertical atctuator are used.

4. Mirror LT-Ultra #1 causes least additional structures.

5. Experience at PITZ: The quality of mirrors purchased from Kugler varies to a large extent between different orders in an unpredictable manner.

Measurements by HZB (Bessy-II) [1]

In the optical metrology laboratory of BESSY-II microscopic measurements of the surface finish (peak-to-valley height) as well as interferometric measurements of the surface planarity have been carried out.
For the interferometric measurements the complete mirror surface has been analyzed. The results are shown on the following pages for each individual mirror in the upper diagram.

The surface roughness was, however, investigated in quadratic samples of size 0.235 mm x 0.235 mm within the blue shaded area in Fig. 8. According to the experience of Mr. Siewert such a size represents an appropriate choice for investigation of such mirror surfaces.

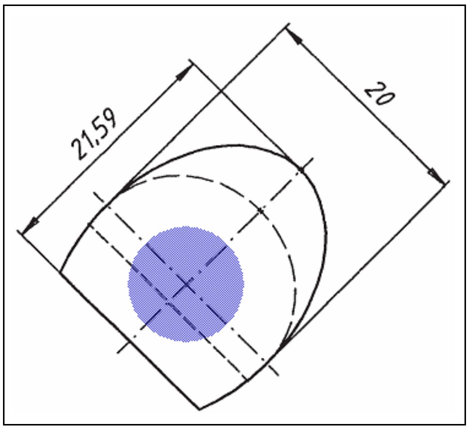
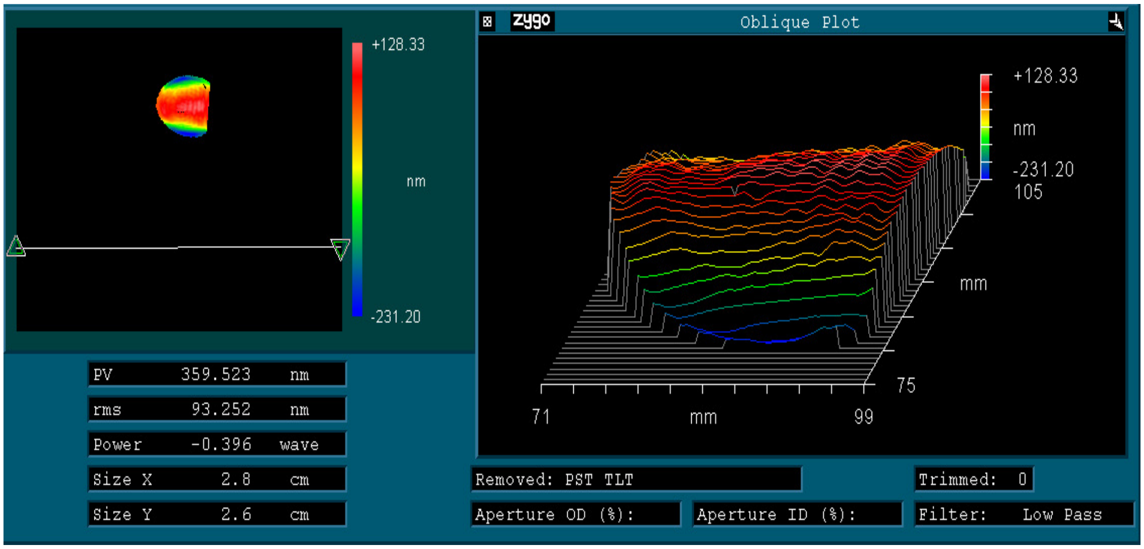


Fig. 8: Location of representative samples for measuring the roughness of the mirror surface.

The roughnessmap is depicted for two location as a colour-coded area graph on the following pages.

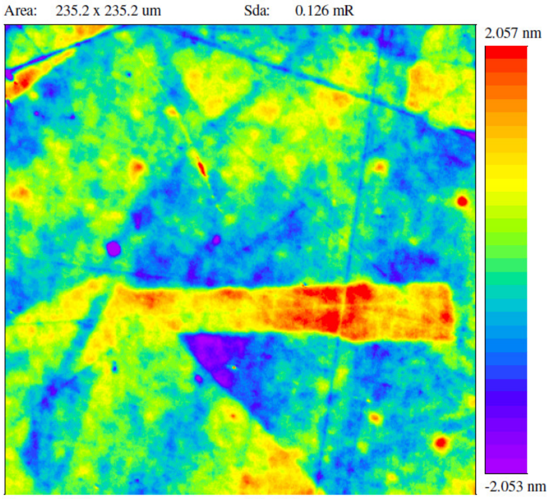
[1]) We thank Dr. Frank Siewert for carrying out these measurements.

Spiegel 1 (LT-Ultra):



Sp1_01.MMD
MBI-Laserspiegel No1
2010-01-28 13:40:53

RS: 22140 mm
RCa: -8492 mm
RCb: 4806 mm
Area: 235.2 x 235.2 um
Sda: 0.126 mR



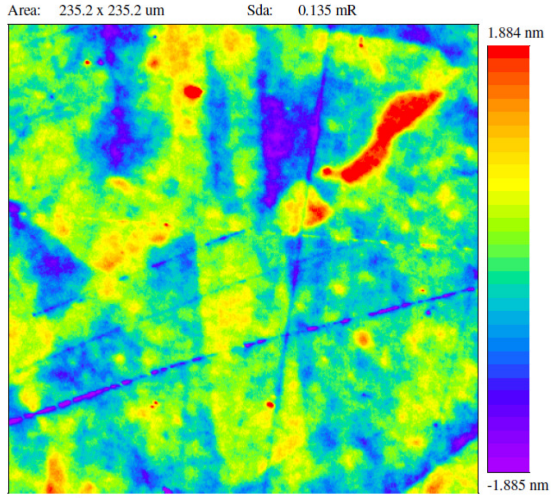
Sq: 0.685 nm
Sa: 0.501 nm
St: 28.26 nm

Points: 230400
QUARTIC

480x480
1/2" CCD
1.0X Body
No Relay
520 nm Phase
20X

Sp1_02.MMD
MBI-Laserspiegel No1
2010-01-28 13:42:02

RS: 449300 mm
RCa: -8197 mm
RCb: 7909 mm
Area: 235.2 x 235.2 um
Sda: 0.135 mR

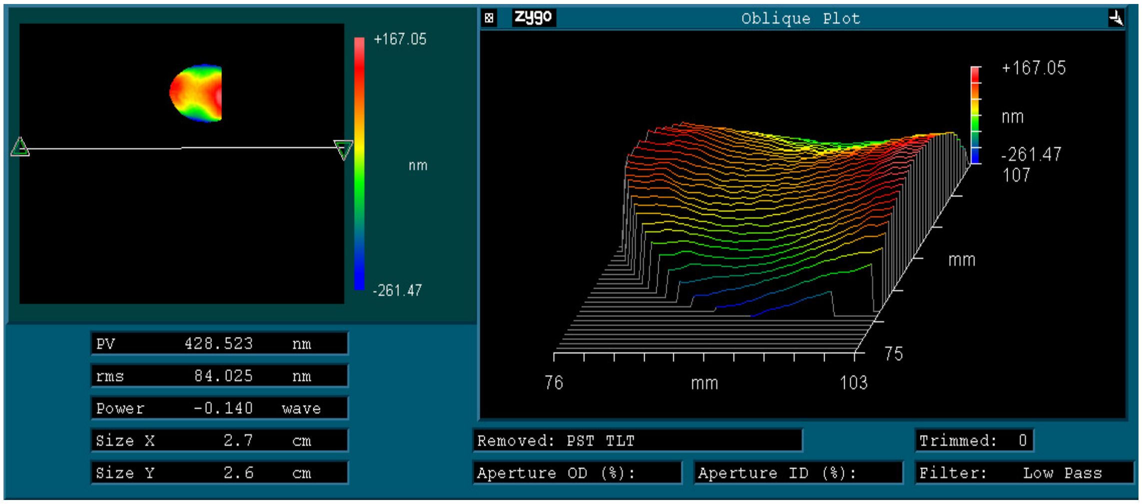


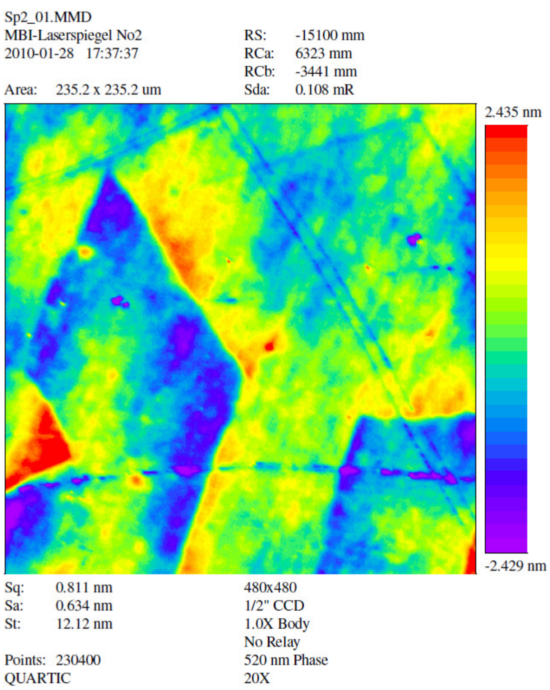
Sq: 0.628 nm
Sa: 0.432 nm
St: 36.53 nm

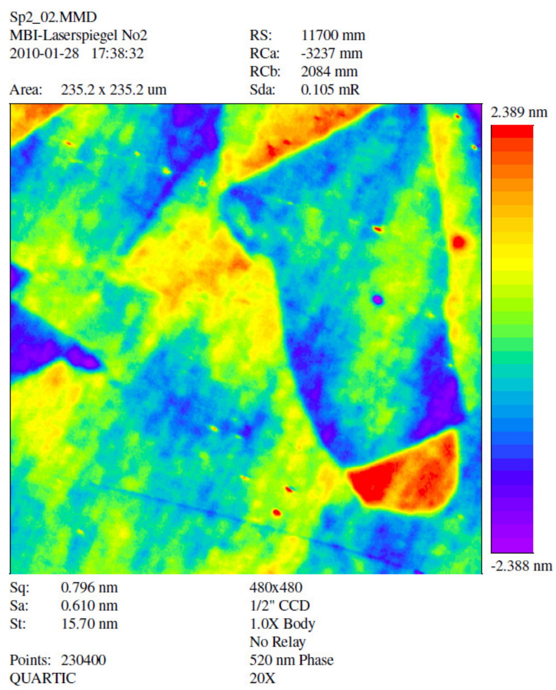
Points: 230400
QUARTIC

480x480
1/2" CCD
1.0X Body
No Relay
520 nm Phase
20X

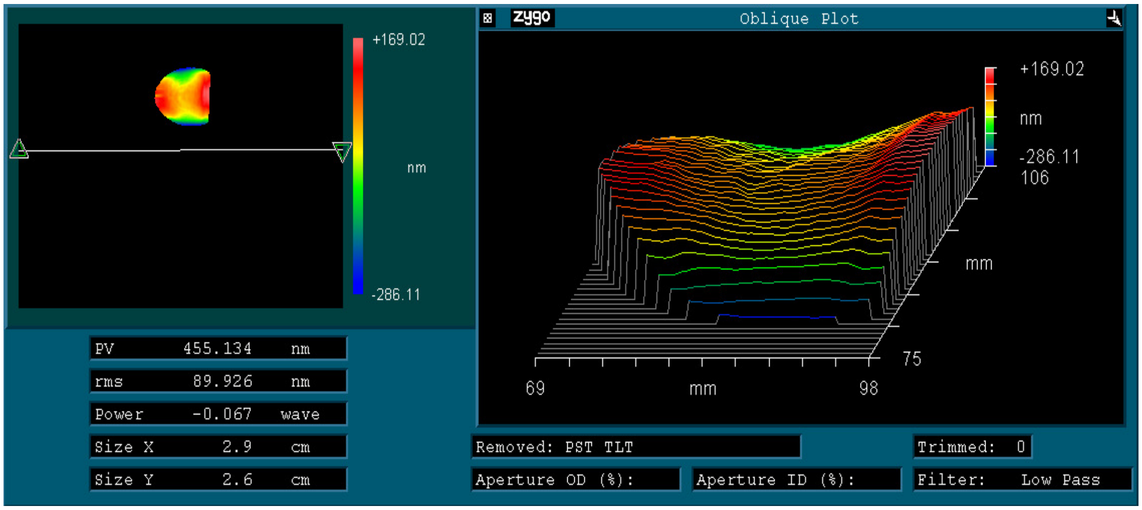
Spiegel 2 (LT-Ultra):

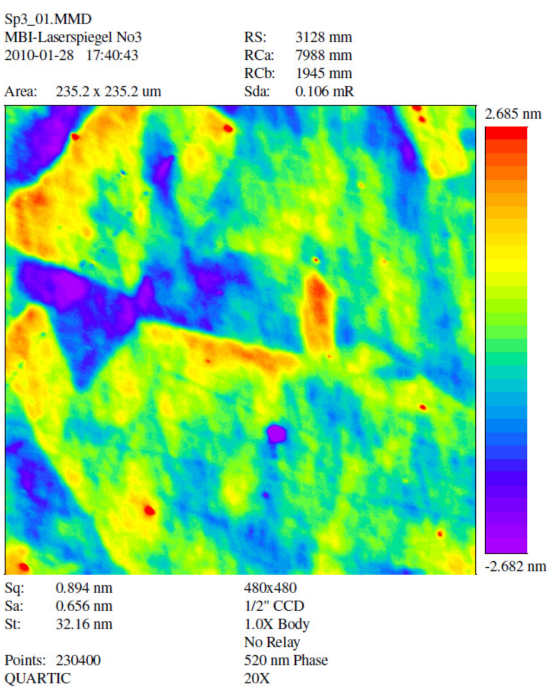


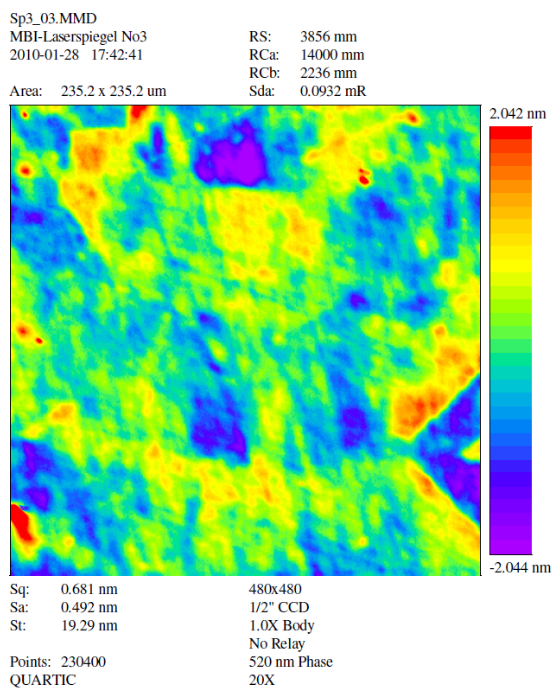




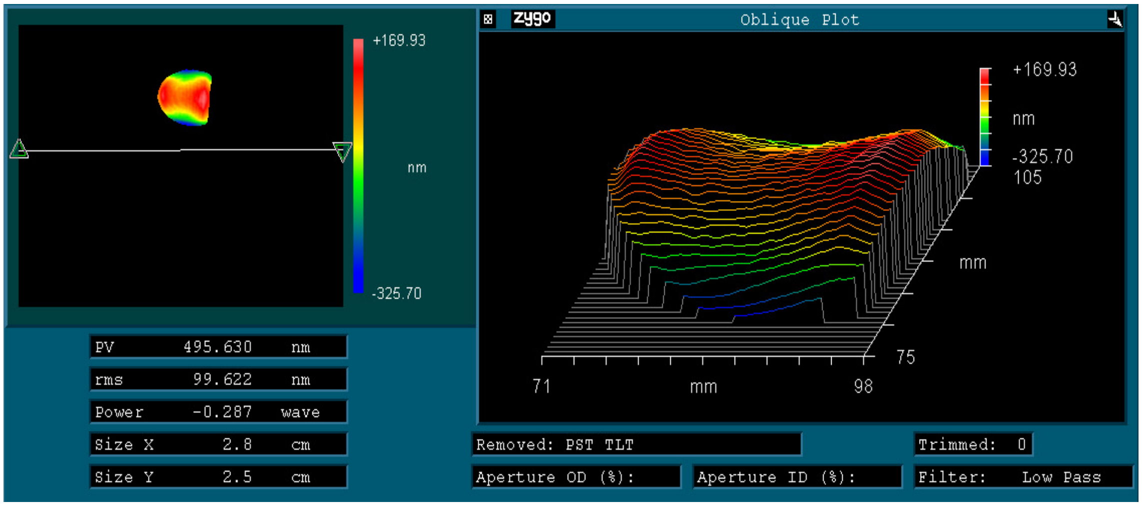
Spiegel 3 (LT-Ultra):







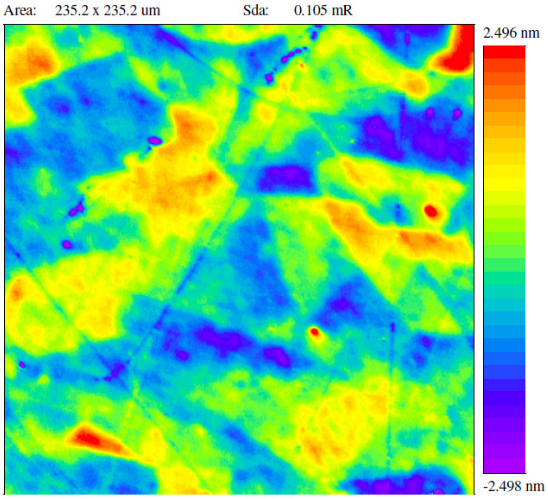
Spiegel 4 (LT-Ultra):



Sp4_01.MMD
MBI-Laserspiegel No4
2010-02-01 10:24

RS: -2984 mm
RCa: -12980 mm
RCb: -1686 mm

Area: 235.2 x 235.2 um
Sda: 0.105 mR



Sq: 0.832 nm
Sa: 0.670 nm
St: 14.25 nm

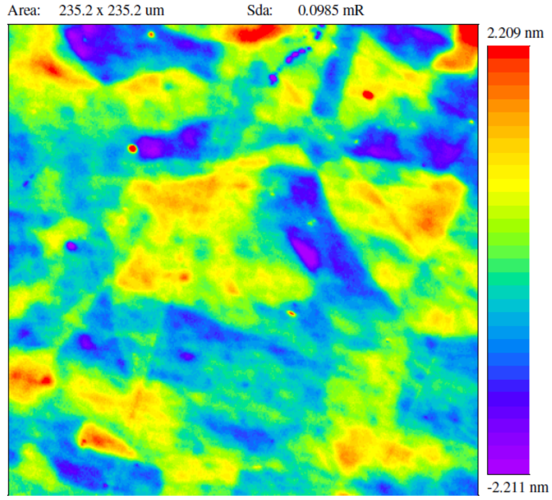
480x480
1/2" CCD
1.0X Body
No Relay
520 nm Phase
20X

Points: 230400
QUARTIC

Sp4_02.MMD
MBI-Laserspiegel No4
2010-02-01 10:25

RS: -4453 mm
RCa: -8905 mm
RCb: -2969 mm

Area: 235.2 x 235.2 um
Sda: 0.0985 mR

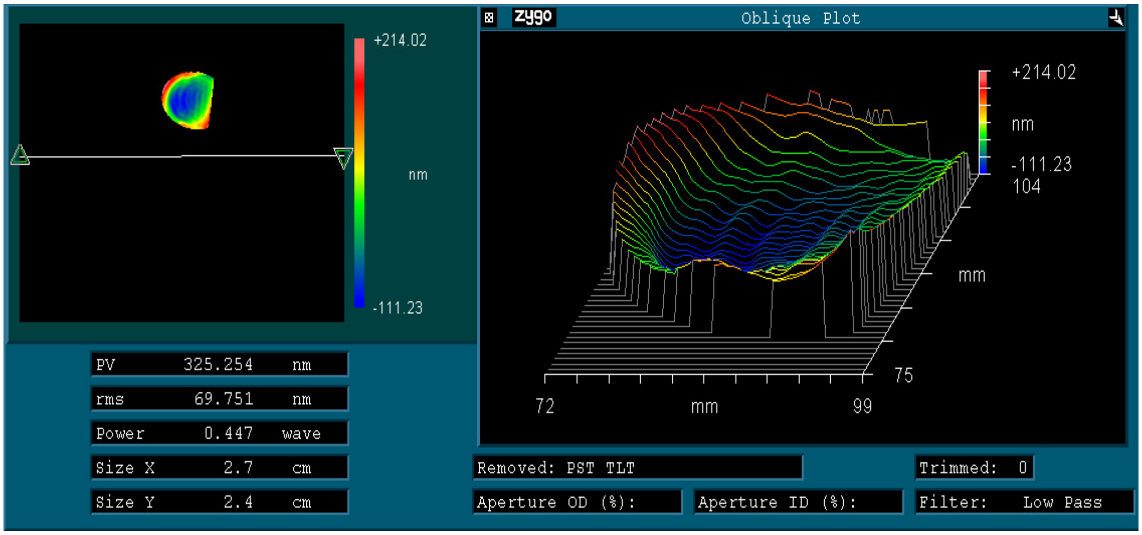


Sq: 0.737 nm
Sa: 0.584 nm
St: 12.25 nm

480x480
1/2" CCD
1.0X Body
No Relay
520 nm Phase
20X

Points: 230400
QUARTIC

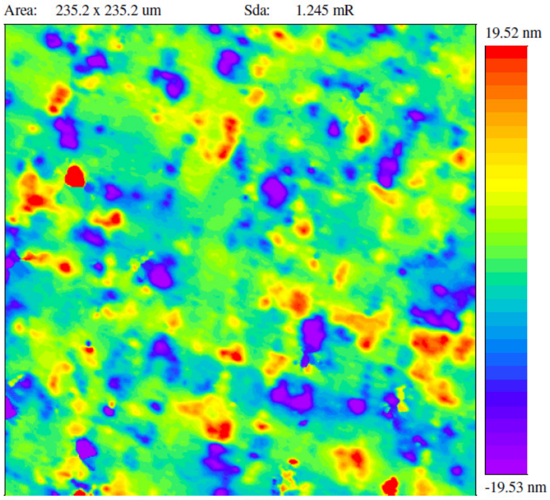
Spiegel 5 (Kugler):



Sp5_01.MMD
MBI-Laserspiegel No5
2010-02-01 10:30

RS: -3319 mm
RCa: -8317 mm
RCb: -2073 mm

Area: 235.2 x 235.2 um
Sda: 1.245 mR



Sq: 6.508 nm
Sa: 4.393 nm
St: 126.0 nm

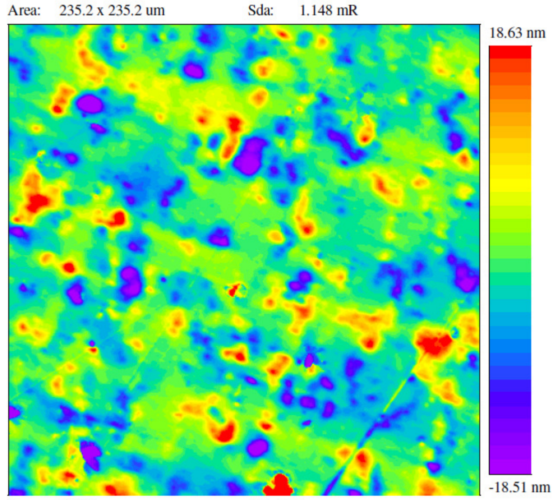
Points: 230400
QUARTIC

480x480
1/2" CCD
1.0X Body
No Relay
520 nm Phase
20X

Sp5_02.MMD
MBI-Laserspiegel No5
2010-02-01 10:32

RS: 1976 mm
RCa: -15770 mm
RCb: 929.7 mm

Area: 235.2 x 235.2 um
Sda: 1.148 mR

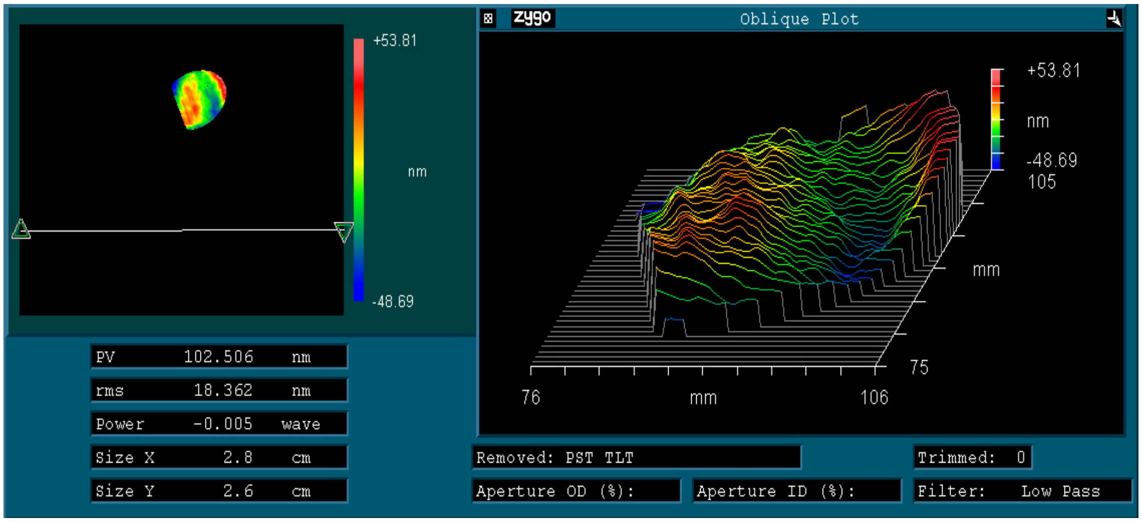


Sq: 6.190 nm
Sa: 4.003 nm
St: 181.7 nm

Points: 230400
QUARTIC

480x480
1/2" CCD
1.0X Body
No Relay
520 nm Phase
20X

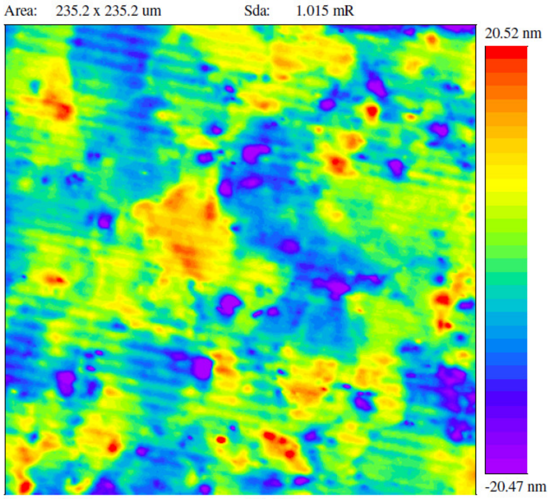
Testspiegel (Kugler):



Sp_test_01.MMD
MBI-Laserspiegel No.test
2010-02-01 10:36

RS: -389.5 mm
RCa: -808.6 mm
RCb: -256.6 mm

Area: 235.2 x 235.2 um
Sda: 1.015 mR



Sq: 6.831 nm
Sa: 5.302 nm
St: 96.73 nm

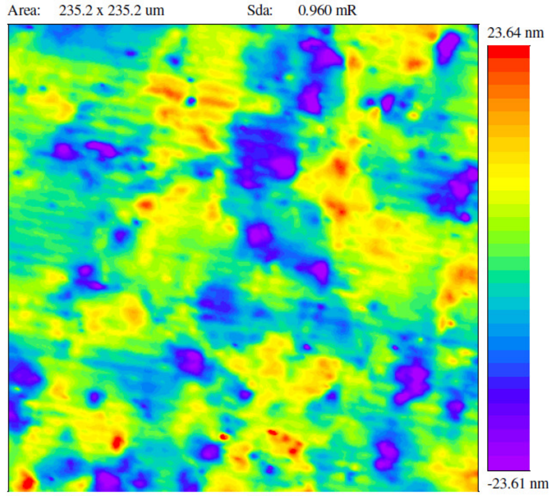
Points: 230400
QUARTIC

480x480
1/2" CCD
1.0X Body
No Relay
520 nm Phase
20X

Sp_test_02.MMD
MBI-Laserspiegel No.test
2010-02-01 10:38

RS: -21430 mm
RCa: 2504 mm
RCb: -2030 mm

Area: 235.2 x 235.2 um
Sda: 0.960 mR



Sq: 7.876 nm
Sa: 6.142 nm
St: 80.52 nm

Points: 230400
QUARTIC

480x480
1/2" CCD
1.0X Body
No Relay
520 nm Phase
20X

Results of the measurements by HZB (Bessy-II)

optical property	interferometric & micromap measurement	Specification of manufacturer	manufacturer
Planarity	Mirror 1 359 nm pv	≤ 750 nm	LT-Ultra
”	Mirror 2 428 nm pv	≤ 750 nm	LT-Ultra
”	Mirror 3 455 nm pv	≤ 750 nm	LT-Ultra
”	Mirror 4 495 nm pv	≤ 750 nm	LT-Ultra
”	Mirror 5 325 nm pv		Kugler
”	Test Mirror 102 nm pv		Kugler
Surface roughness	Mirror 1 S_q = 0.6 – 0.7 nm rms	≤ 5nm	LT-Ultra
”	Mirror 2 S_q = 0.8 nm rms	≤ 5nm	LT-Ultra
”	Mirror 3 S_q = 0.7 – 0.9 nm rms	≤ 5nm	LT-Ultra
”	Mirror 4 S_q = 0.7 – 0.8 nm rms	≤ 5nm	LT-Ultra
”	Mirror 5 S_q = 6.2 – 6.5 nm rms		Kugler
”	Test Mirror S_q = 6.6 – 7.9 nm rms		Kugler

pv denotes the hight difference between peak and valley.

1. The interferometric measurements revealed a kind of saddle surface for the mirrors from *LT-Ultra*. This saddle surface can in principal cause a distorted optical image.

2. The average planarity amounts to pv = 434 (57) nm.(*LT-Ultra*) and pv ~ 210 nm (*Kugler*). ➔**Mirrors from Kugler have a better planarity.**

3. On a microscocopic scale the mirrors surface of all mirrors from *LT-Ultra* exhibit a better smoothness. Their surface finish is below 1 nm. It is around 7 nm for the tested mirrors from *Kugler optics*.
   - ➔ **Mirrors from LT-Ultra clearly feature a better surface finish and therefore less scattering.**

Conclusion

1. The better planarity of the tested mirrors from Kugler is masked by their strong scattering.

2. The expected distortion of the circular image of the beam shaping aperture was not observed for the mirrors from *LT-Ultra* in the UV test beamline at PITZ. This distortion is below the detection limit.

3. Therefore we recommend to choose a mirror from LT-Ultra for the next run period of PITZ.

Mirror LT-Ultra #1 should be used. According to the measurements of BESSY-II it has the best planarity. It also showed the best image quality in terms of additional structures that this mirror causes in the UV test beam line.