Ion beam etching of a flat silicon mirror surface: a study of the shape error evolution

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OUTLINE

- PROJECT CONTEXT
- ION BEAM SOURCE CHARACTERISTICS
- MIRROR SURFACE METROLOGY
- SHAPE ERROR MINIMIZATION and ROUGHNESS SURVEY
- SUMMARY AND PERSPECTIVES

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- ✷ **PROJECT CONTEXT**
- ✷ **ION BEAM SOURCE CHARACTERISTICS**
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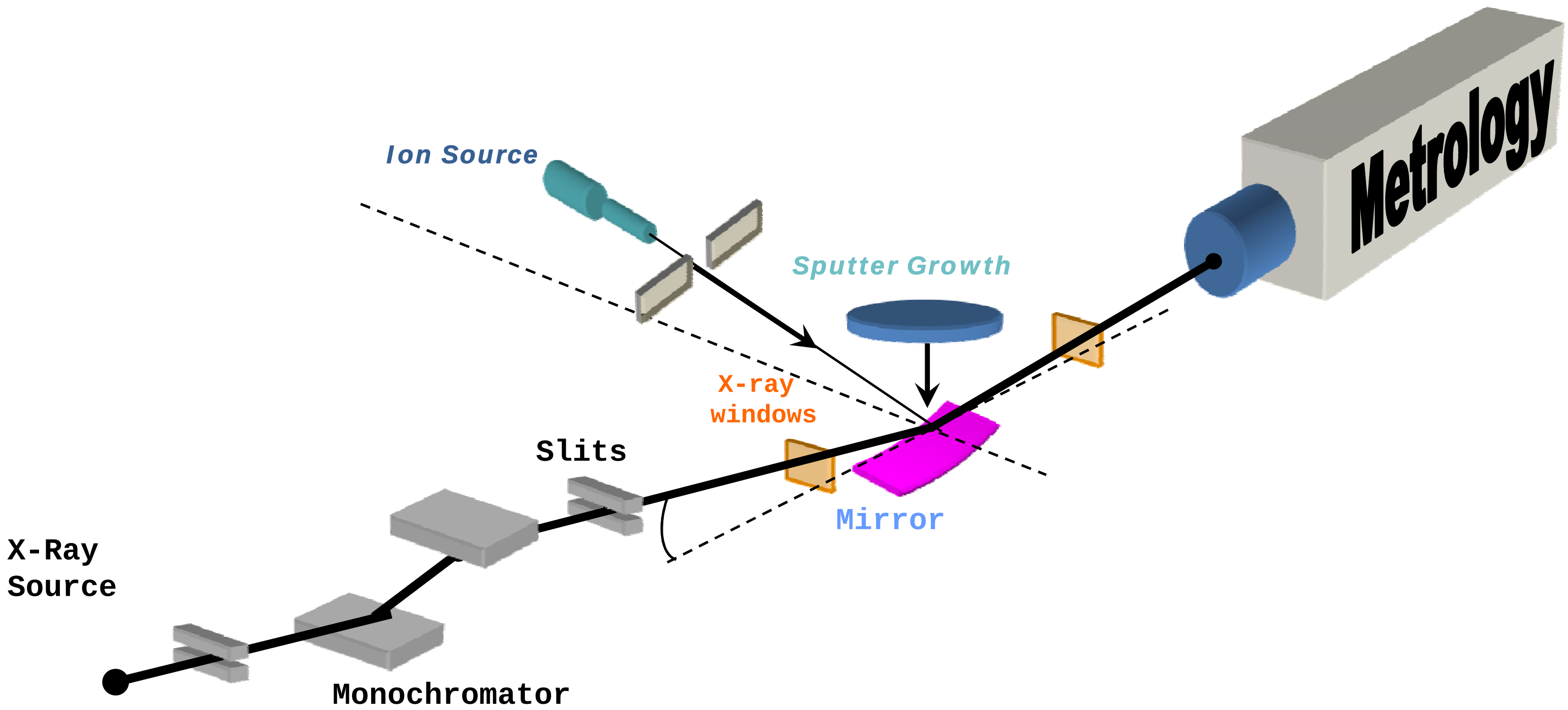
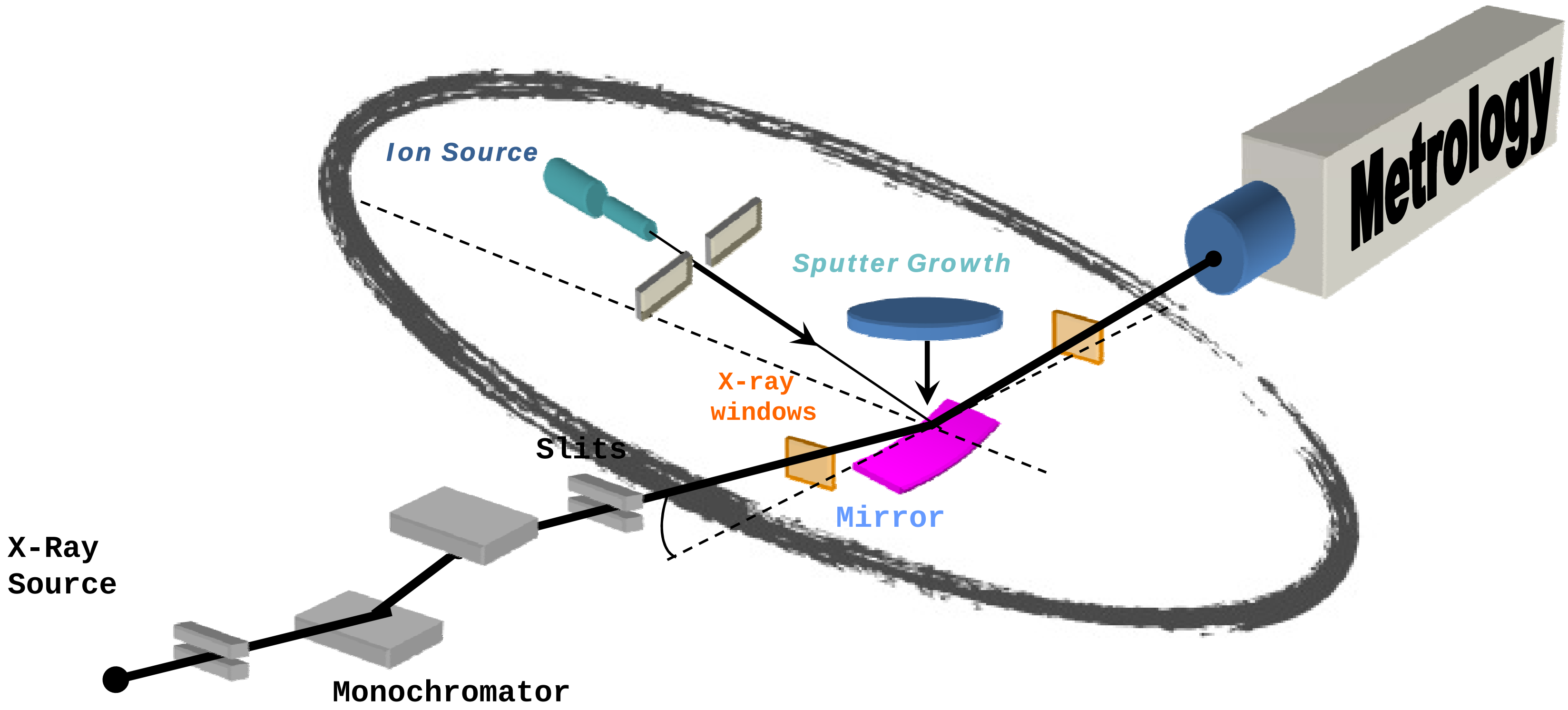
- ✷ **SHAPE ERROR MINIMIZATION and ROUGHNESS SURVEY**
- ✷ **SUMMARY AND PERSPECTIVES**

General goal:
Configuration of an on-line mirror surfacing station

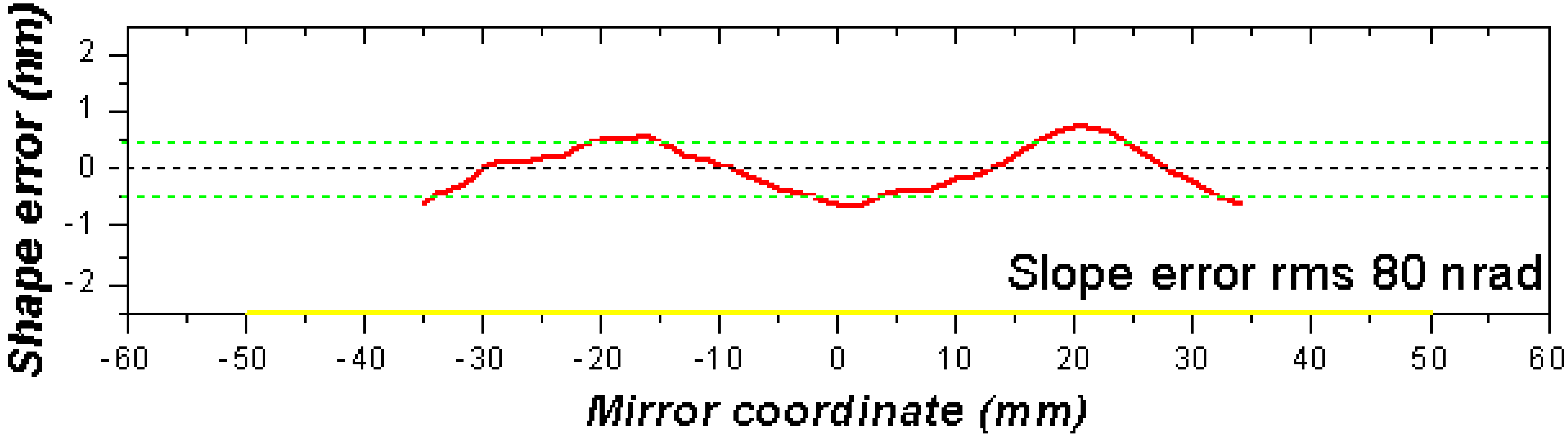


This presentation:
Determination of a suitable ion beam process



First objective: mirror surface flattening.

Meet the performance of the round-robin mirror



Ref. L. Assoufid, A. Rommeveaux, H. Ohashi, K. Yamauchi, H. Mimura, J. Qian, O. Hignette, T. Ishikawa, C. Morawe, A.T. Macrander, A. Khounsary, S. Goto, Proceedings SPIE 5921, 59210J-1-12 (2005)

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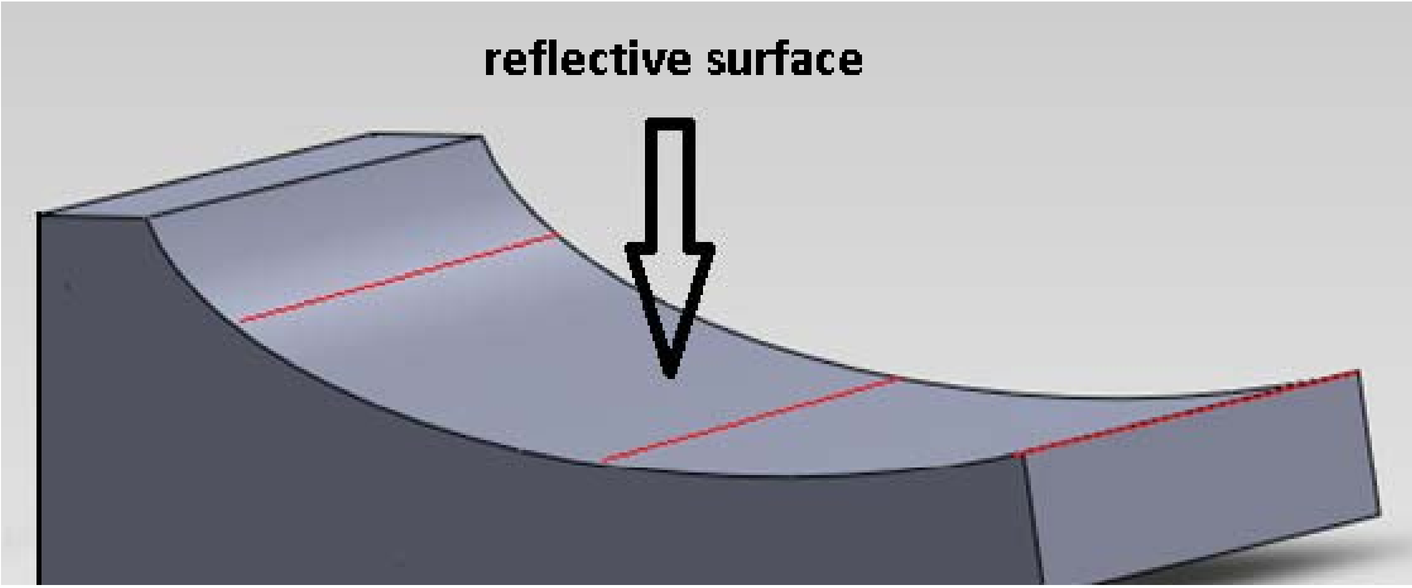
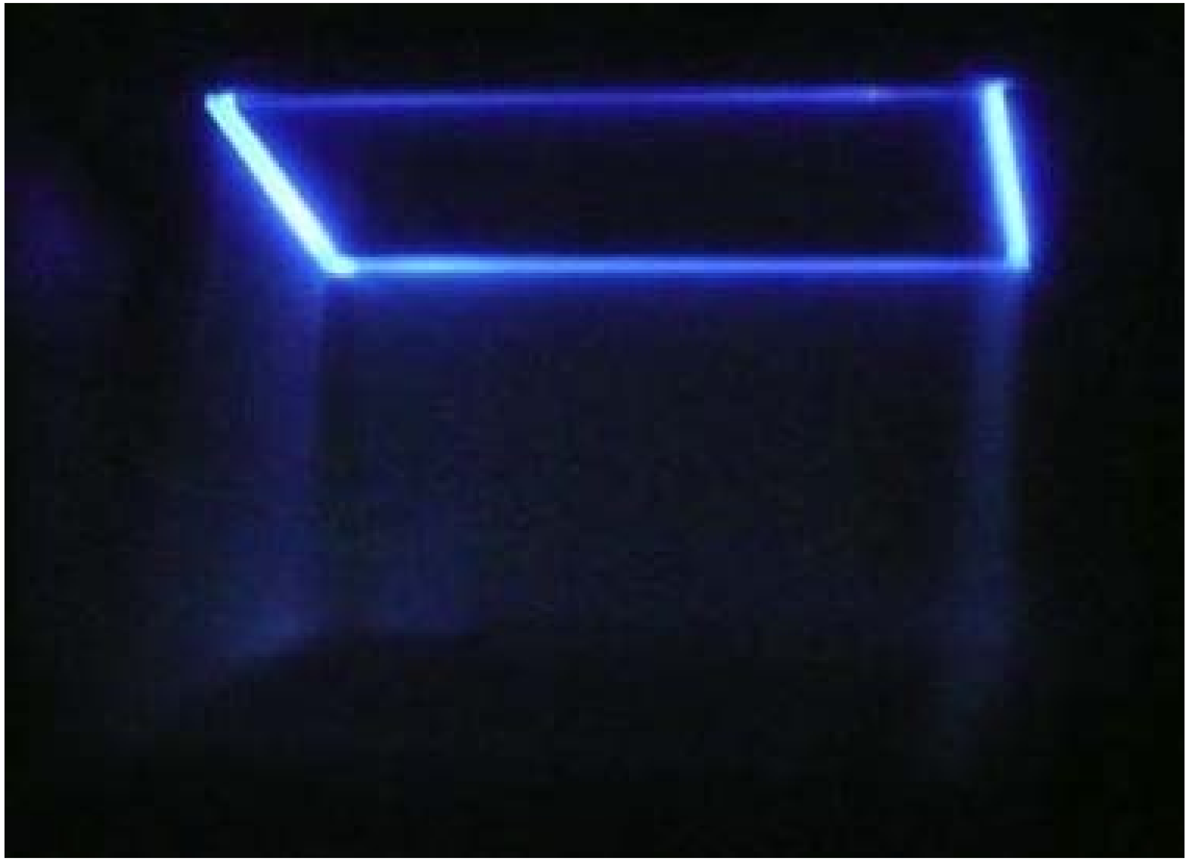
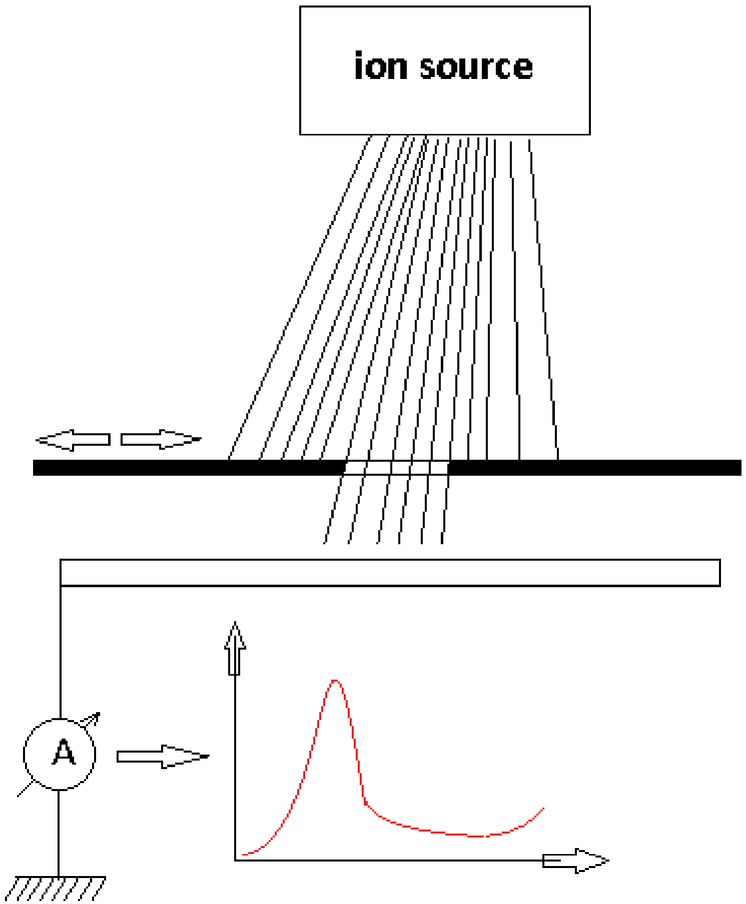
Manufacturing a flat or cylindrical surface mirror would require a linear ion beam parallel to the generatrix.



Custom-designed ion beam which it works on the principle of an Anode Layer Source.



Ion beam intensity profile as a function of gas feed, pressure and the applied voltage.



4th International Workshop on Metrology for X-ray Optics, Mirror Design and Fabrication

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ALBA

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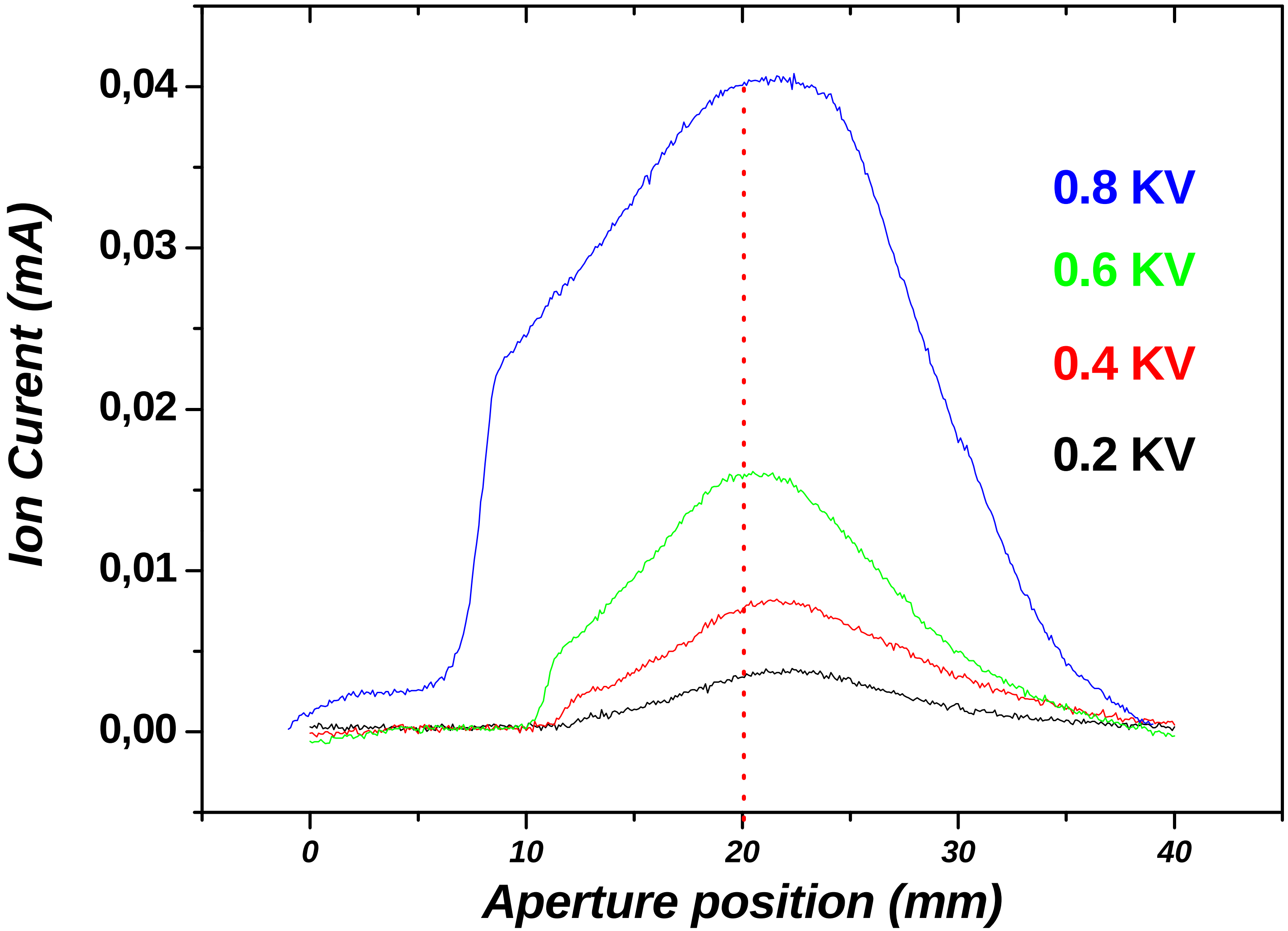
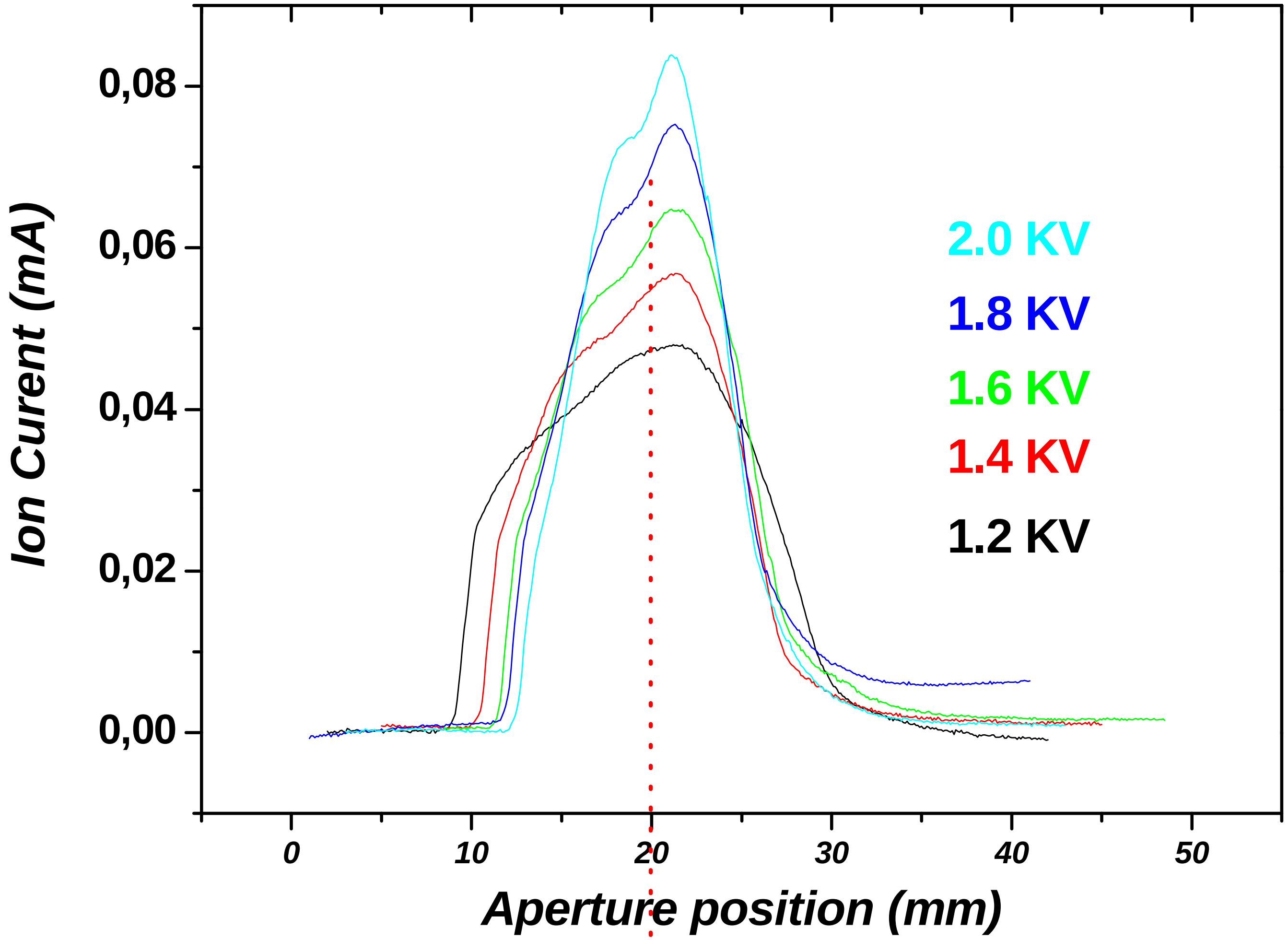
Gravit innovation

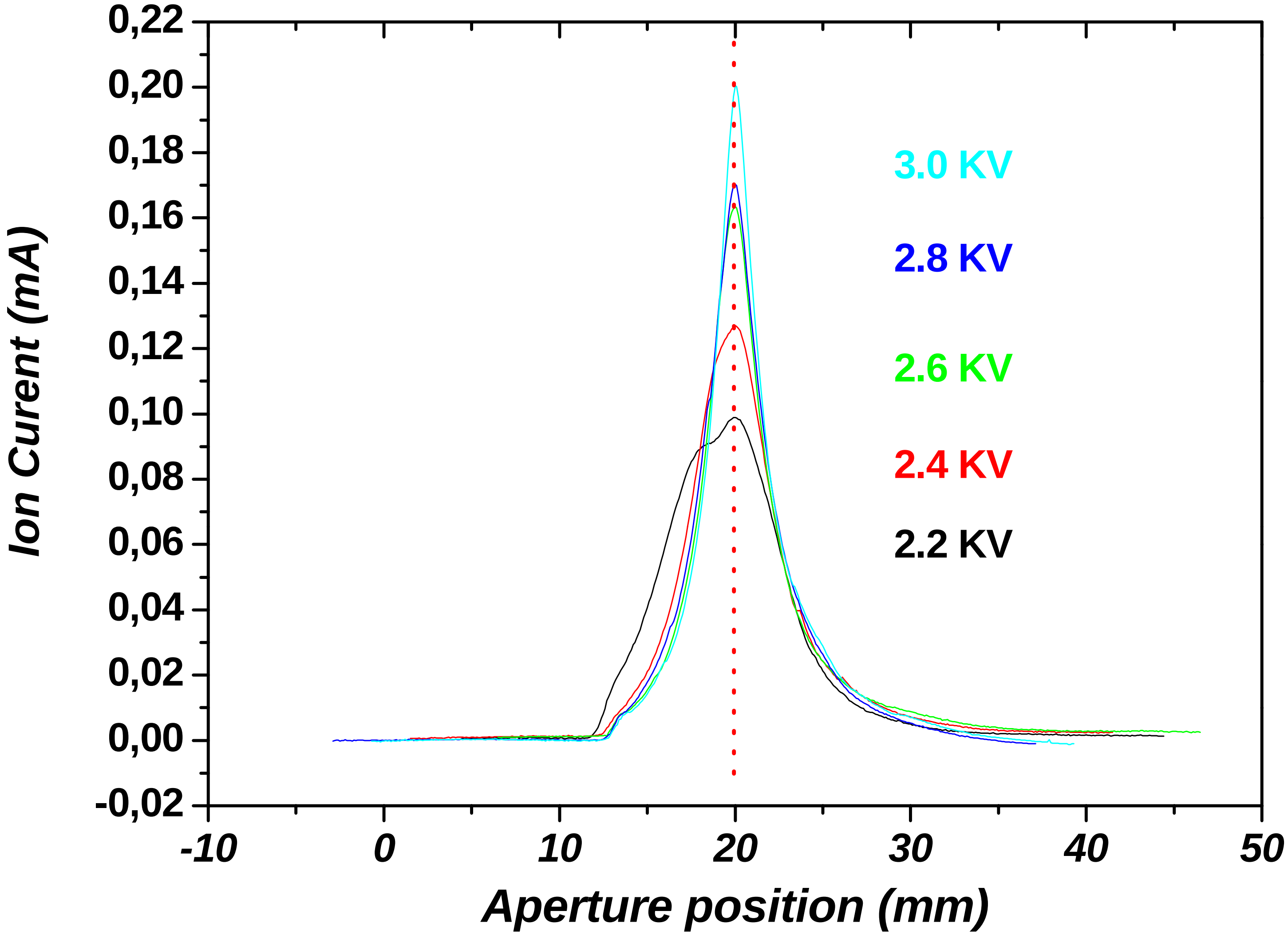
Ion beam intensity profile: f^n (V, P_{gas}, F_{gas})



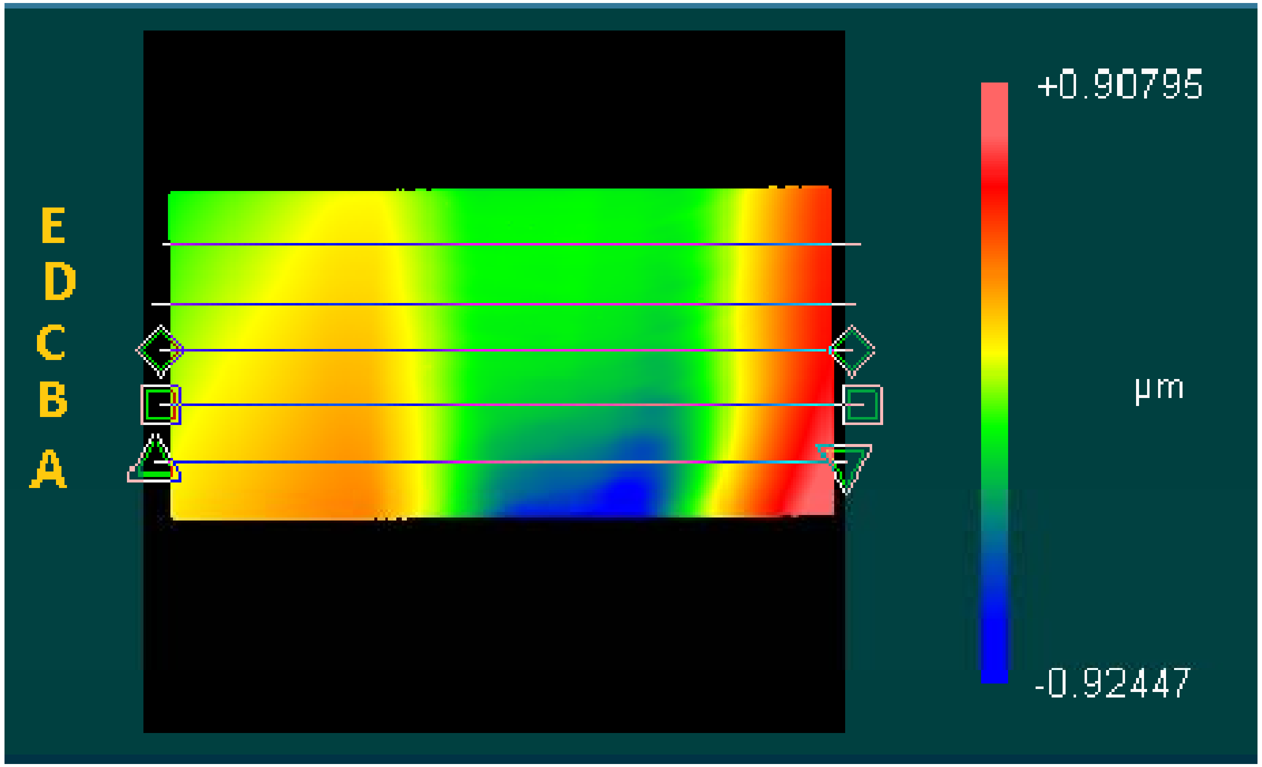
Ion beam intensity profile: f^n (V, P_{gas}, F_{gas})



Ion beam intensity profile: f^n (V, P_{gas}, F_{gas})



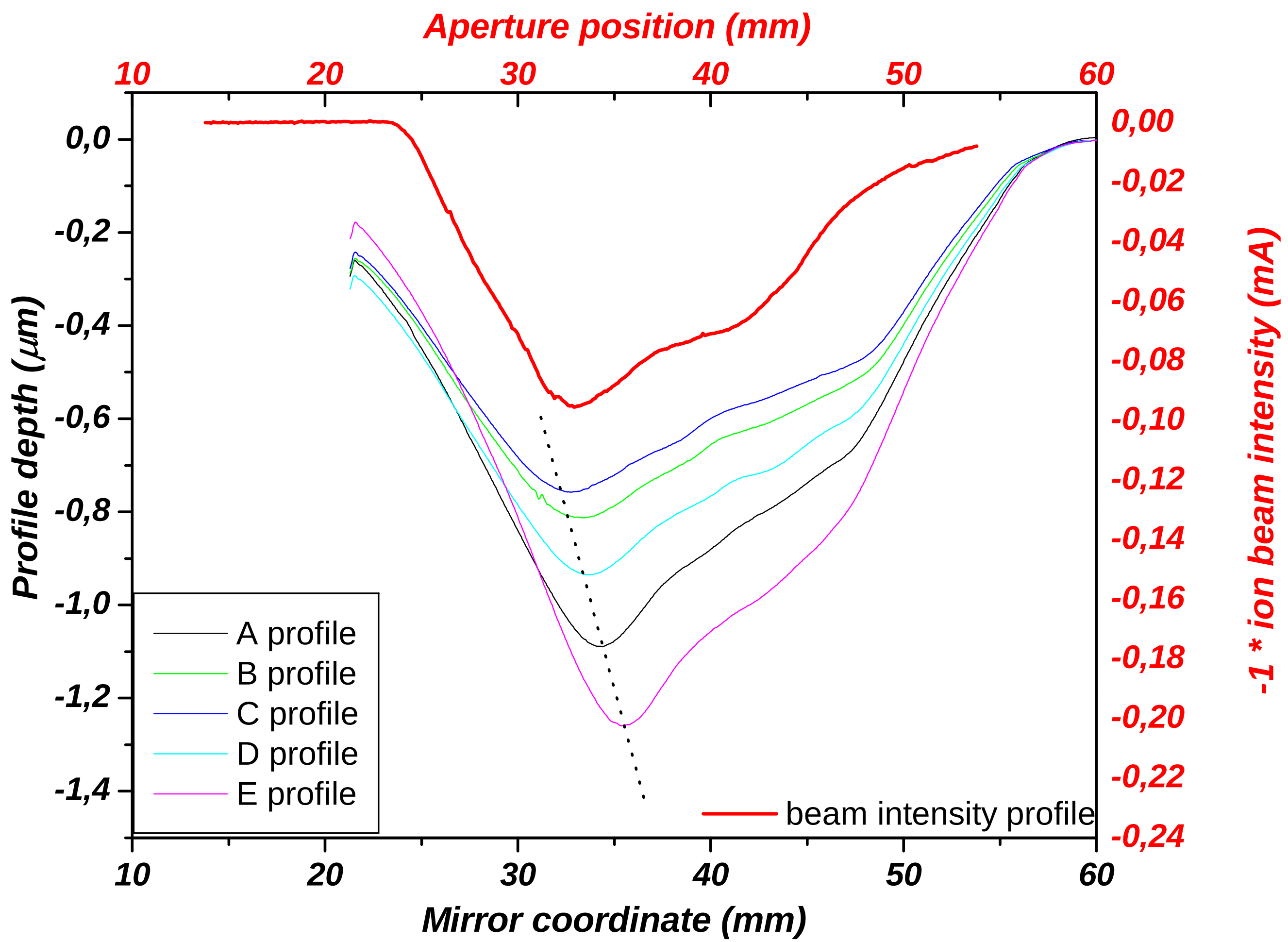
Profile depth of an exposed surface is strongly related to the ion beam intensity profile.



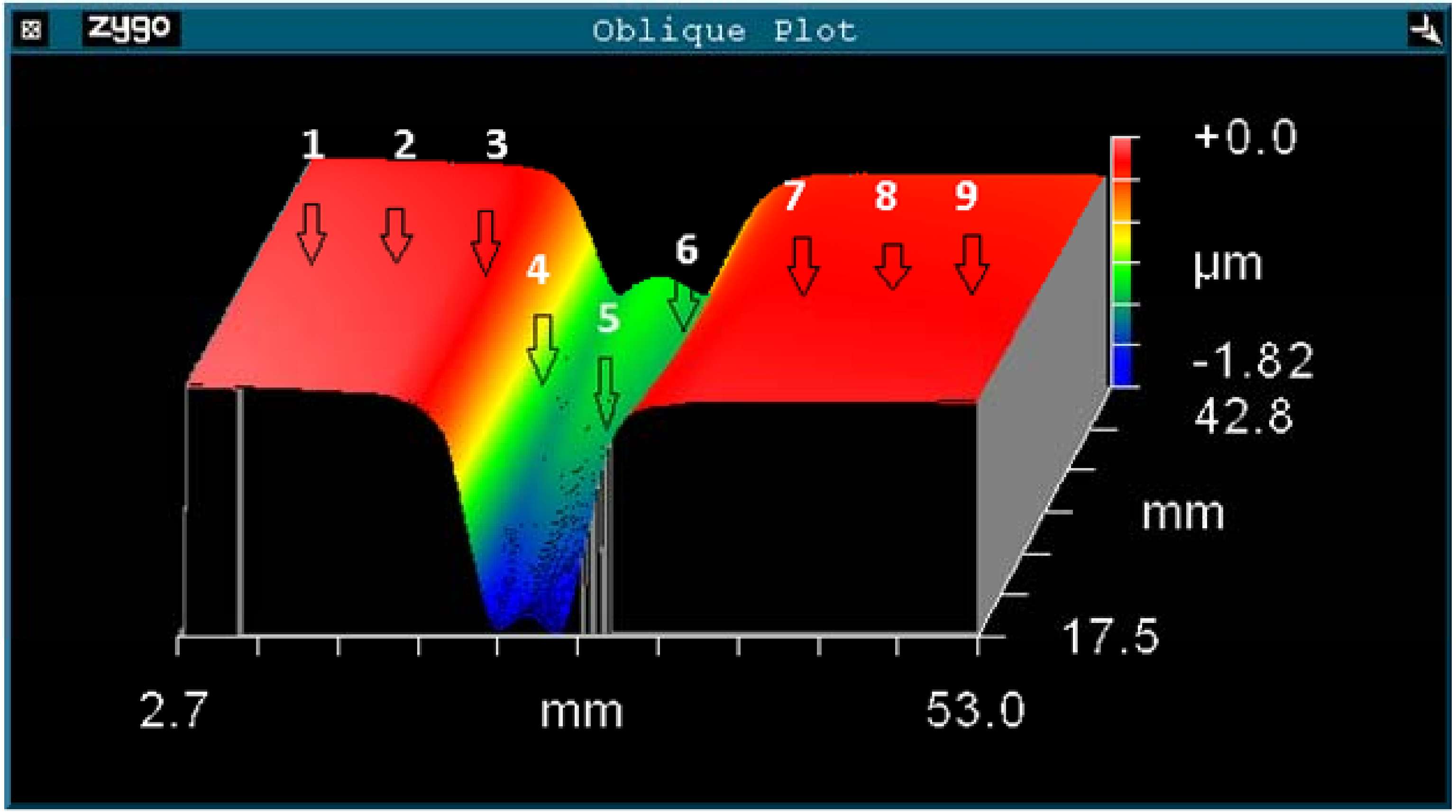
Phase shifting Fizeau micro-interferometer *(Zygo VeriFIRE AT+ 150mm aperture).*

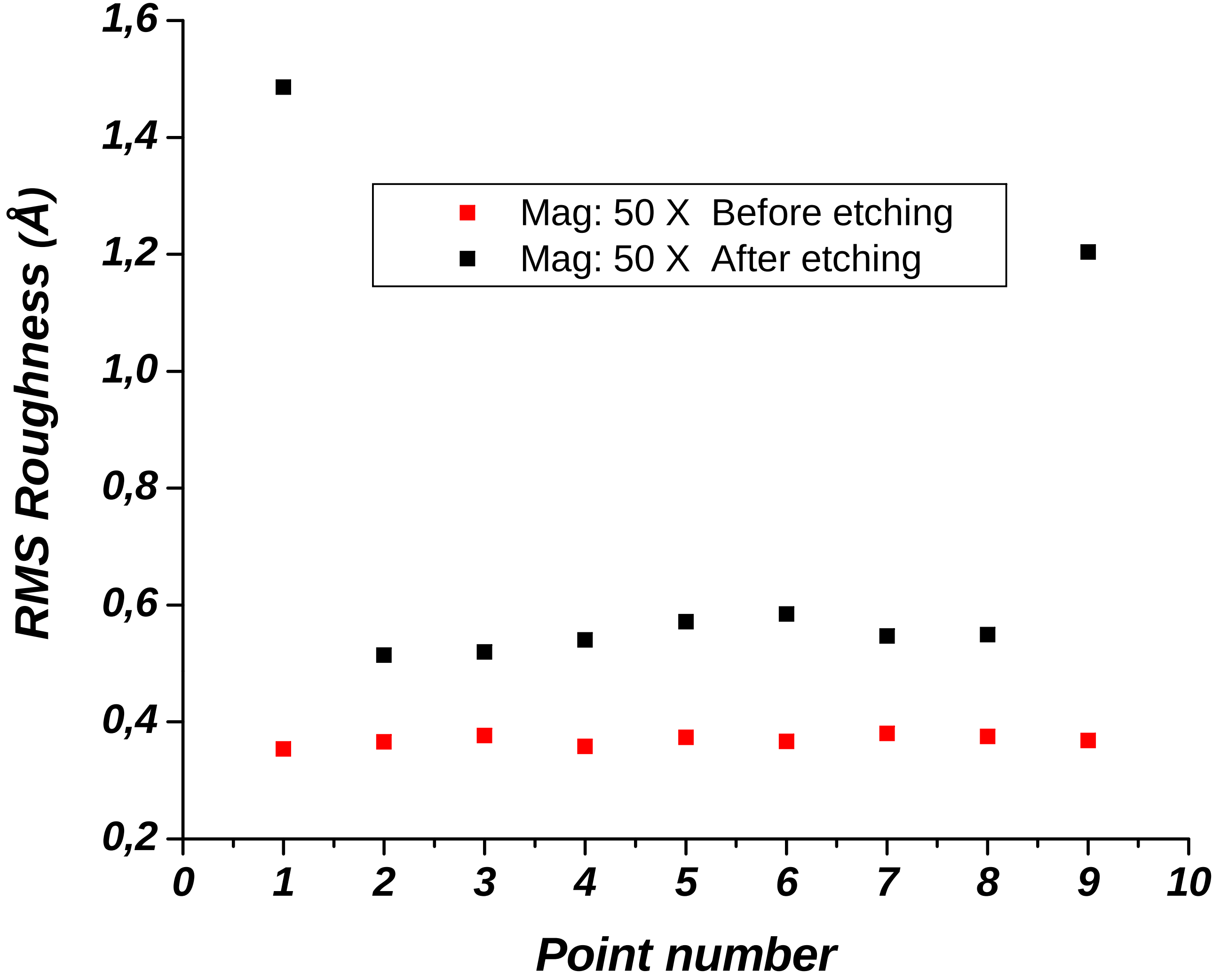
Measurements performed by Amparo Vivo at Optical Metrology Laboratory at ESRF.

Profile depth of an exposed surface is strongly related to the ion beam intensity profile.



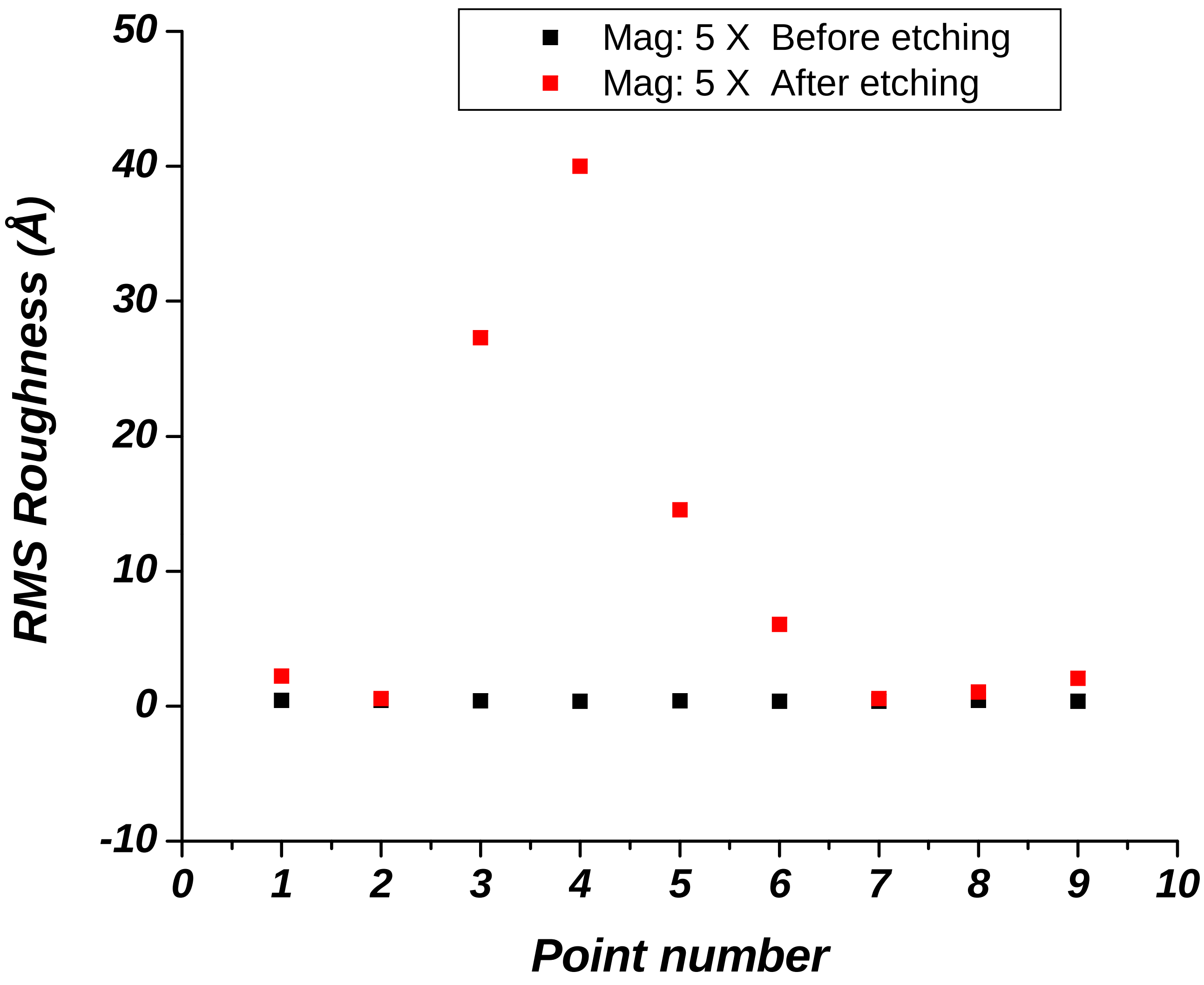
Roughness measurements of a silicon mirror surface exposed (stationary condition) to the ion beam through an aperture.



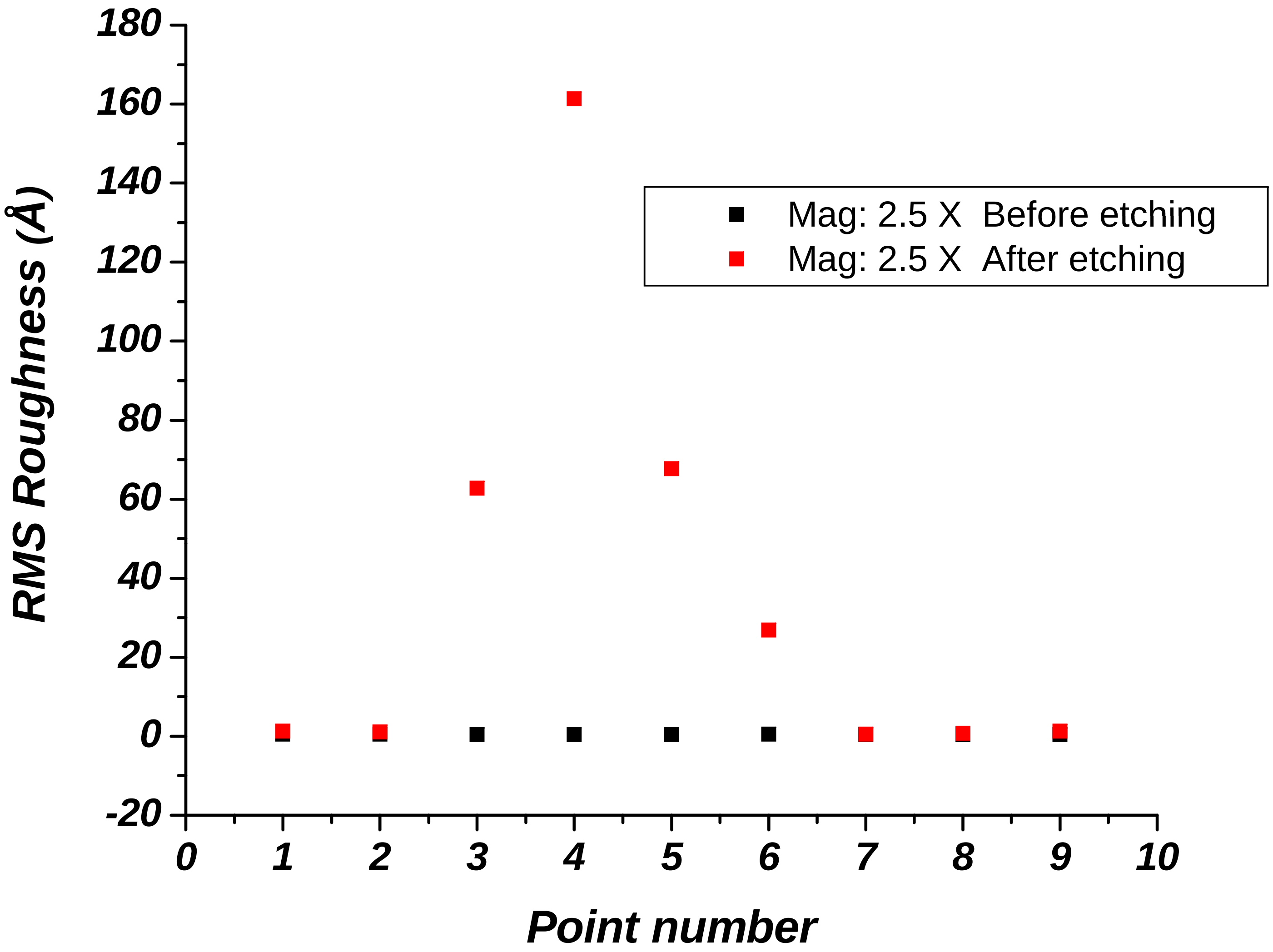


Phase shifting micro-interferometer *(modified Veeco NT9300)*

Measurements performed by Amparo Vivo at Optical Metrology Laboratory at ESRF.



Mag: 5 X Before etching
Mag: 5 X After etching
RMS Roughness (Å)
50
40
30
20
10
0
-10
0
1
2
3
4
5
6
7
8
9
10
Point number



180
160
140
120
100
80
60
40
20
0
-20
RMS Roughness (Å)
Mag: 2.5 X Before etching
Mag: 2.5 X After etching
0
1
2
3
4
5
6
7
8
9
10
Point number

Mag: 2.5 X

Mode: PSI

Surface Data

Date: 02/28/2012

Time: 15:22:25

Surface Statistics:

Ra: 13.76 nm

Rq: 16.13 nm

Rz: 84.01 nm

Rt: 95.77 nm

Set-up Parameters:

Size: 640 X 480

Sampling: 3.94 um

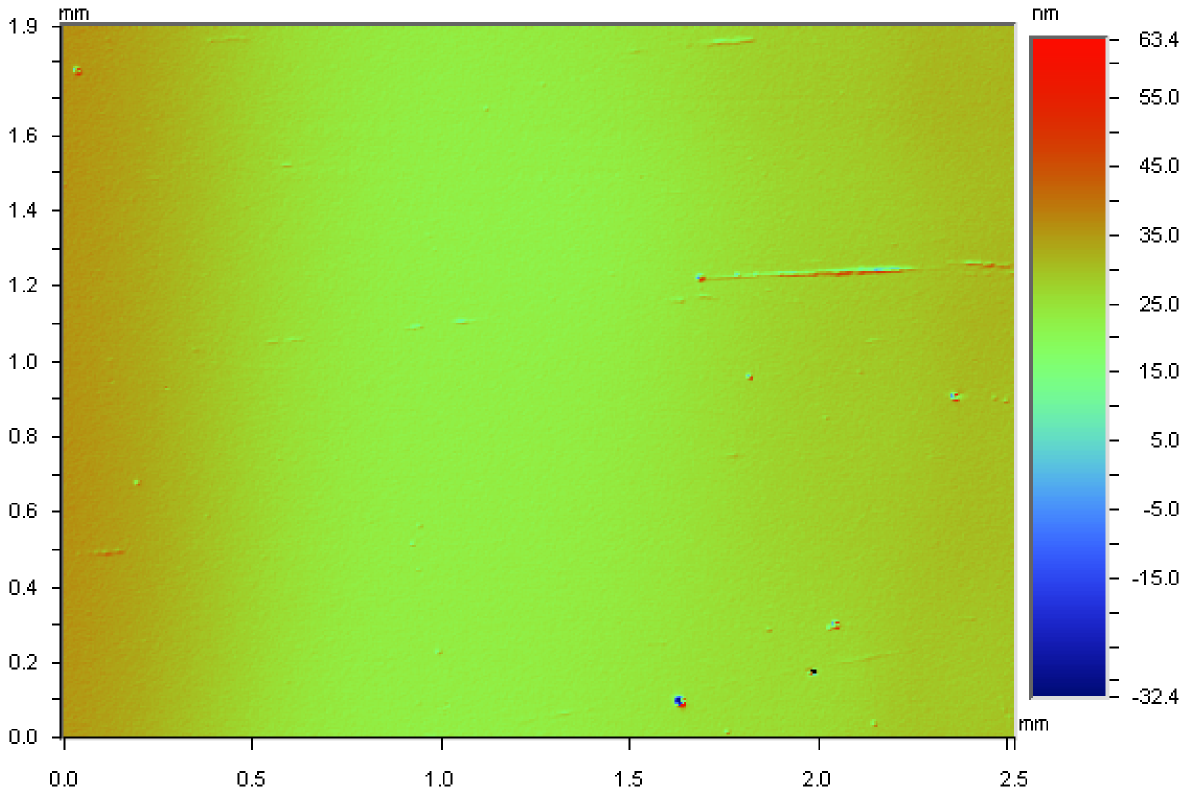
Processed Options:

Terms Removed:

Cylinder & Tilt

Filtering:

None



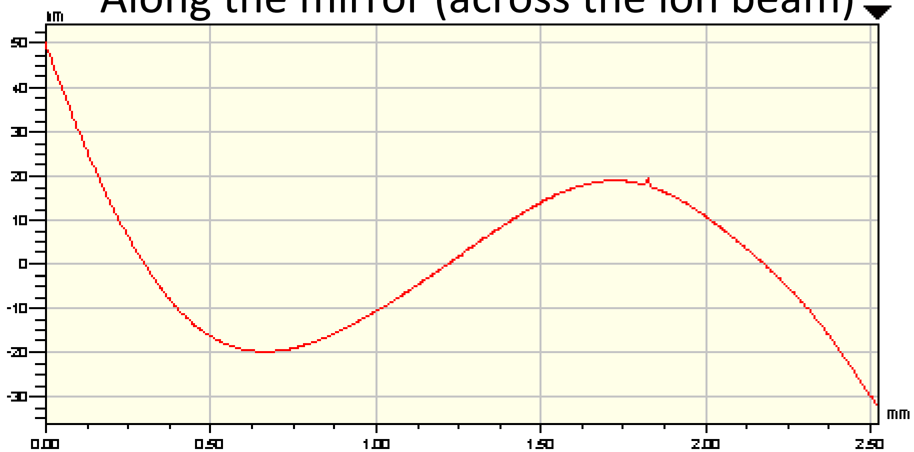
Title: 4

Phase shifting micro-interferometer *(modified Veeco NT9300)*

Veeco

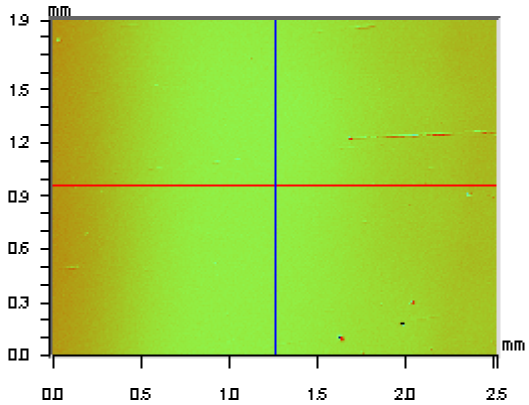
X Profile

Along the mirror (across the ion beam)

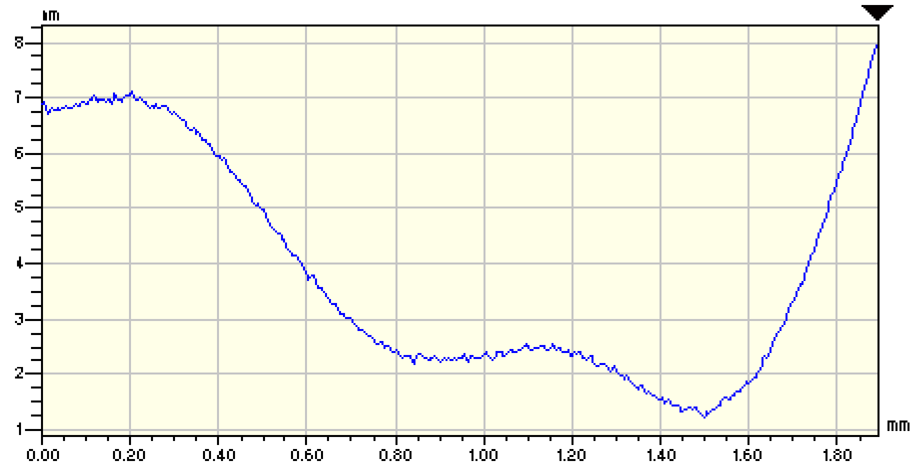


Rq	16.40	nm
Ra	13.89	nm
Rt	81.95	nm
Rp	49.75	nm
Rv	-32.20	nm

Angle	-32.52	urad
Curve	0.43	km
Terms	None	
Avg Ht	0.55	nm
Area	1.38	um2



Y Profile

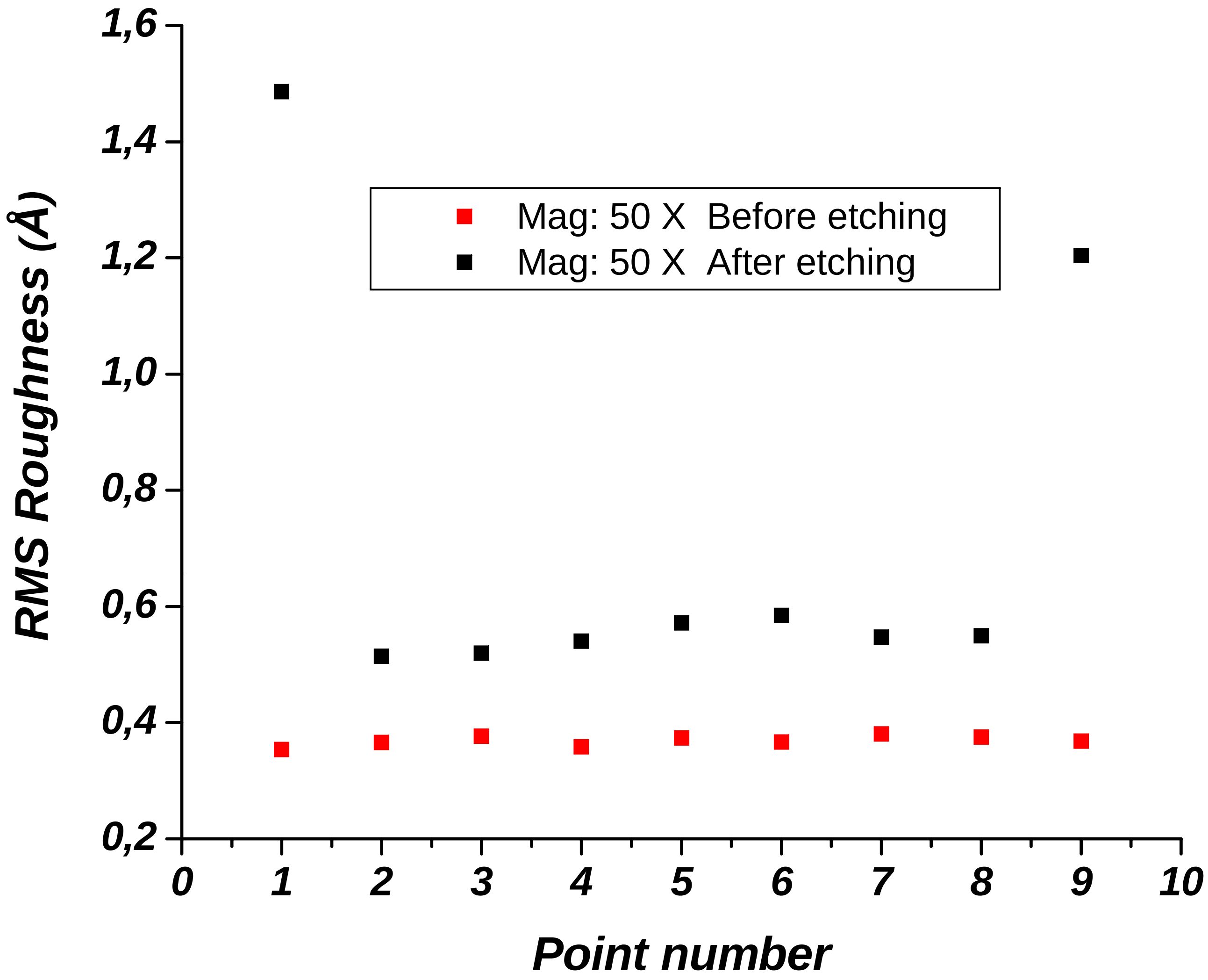


X	1.26	-	-	mm
Y	0.96	-	-	mm
Ht	2.24	-	-	nm
Dist			-	mm
Angle			-	°

Title: 4

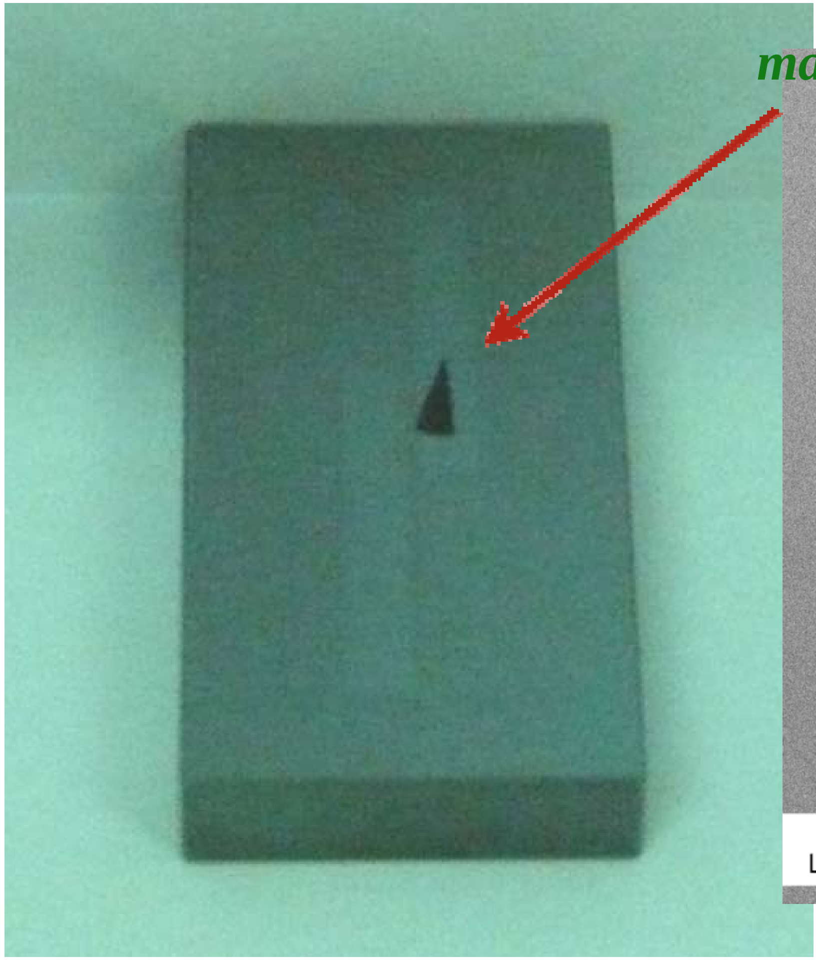
Rq	2.02	nm
Ra	1.82	nm
Rt	6.72	nm
Rp	7.95	nm
Rv	1.23	nm

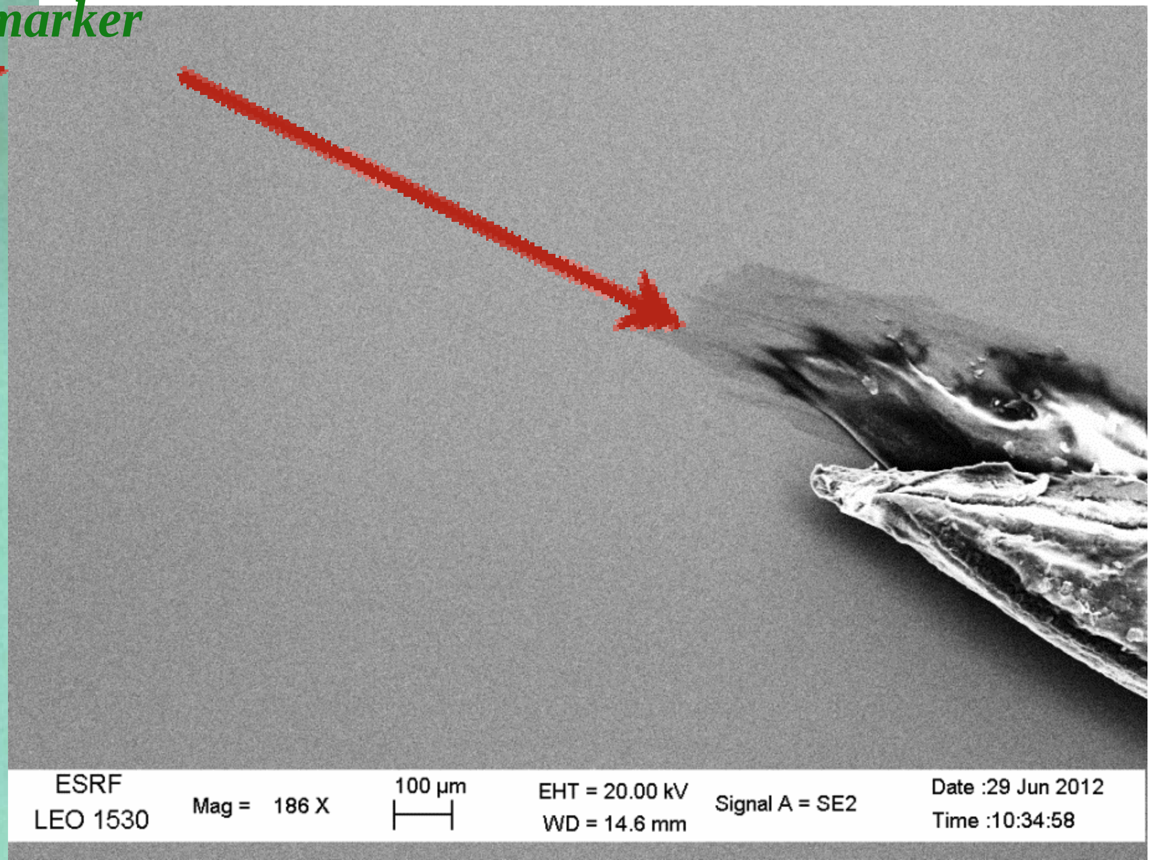
Angle	0.57	urad
Curve	93.82	m
Terms	None	
Avg Ht	3.84	nm
Area	7.25	um2



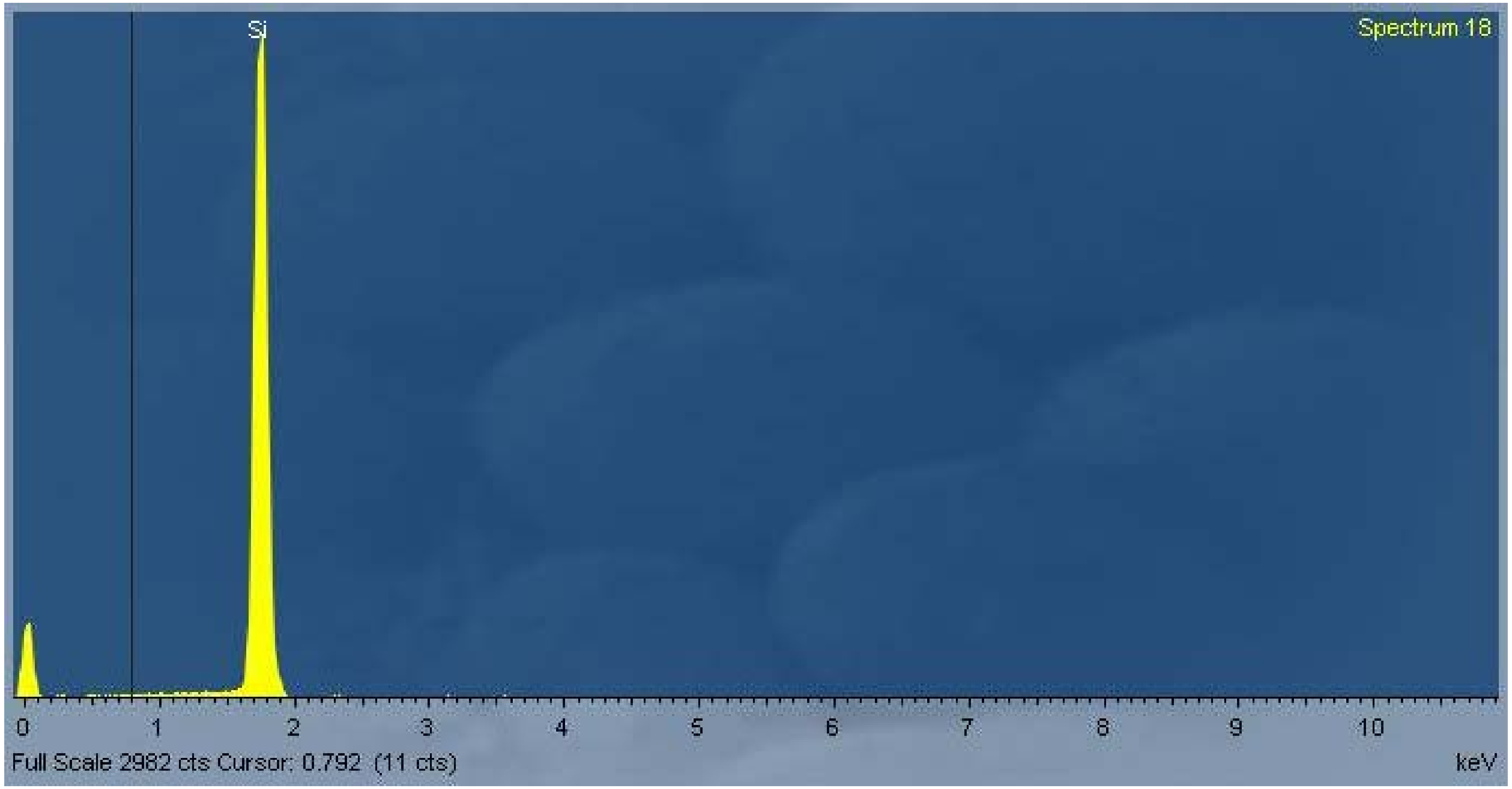
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
RMS Roughness (Å)
Mag: 50 X Before etching
Mag: 50 X After etching
0
1
2
3
4
5
6
7
8
9
10
Point number

Surface chemical analysis of eroded silicon surface



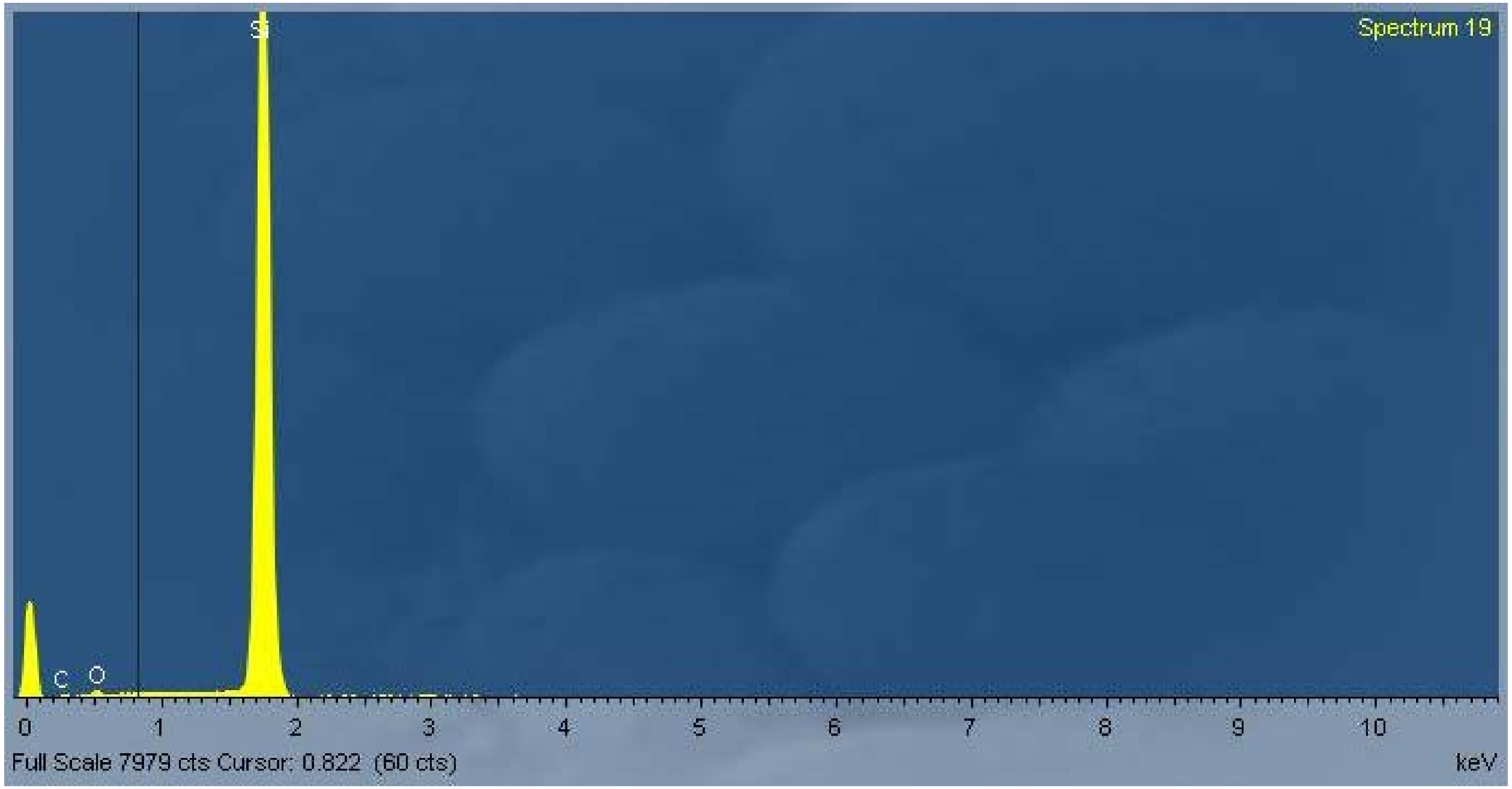


Surface chemical analysis of eroded silicon surface



Fluorescence spectroscopy measurements performed by Irina Snigireva, ESRF EXPD Chemistry & Micromanipulation Laboratory

Surface chemical analysis of eroded silicon surface



Process concept for obtaining a high quality flat / shaped surface:

- ***ion beam with a fully described erosion rate***
- ***ion beam conditions favoring a high erosion rate while preserving surface roughness***
- ***surface local exposure time proportional to the excess of amount of material (it suppose that the surface profile is known)***
- ***ion beam size reduced progressively by reducing the apertures width, aperture made in low density material masks***

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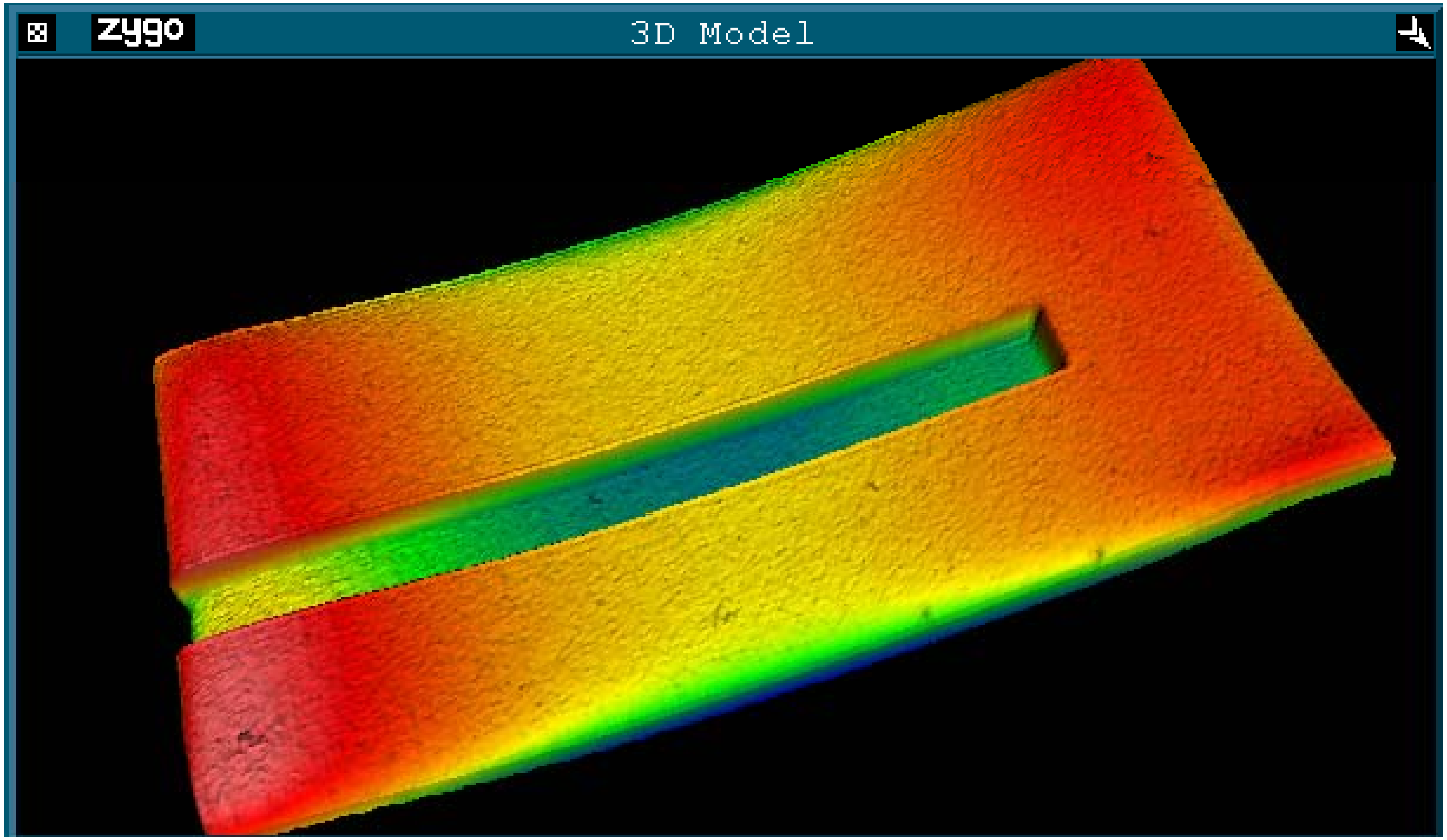
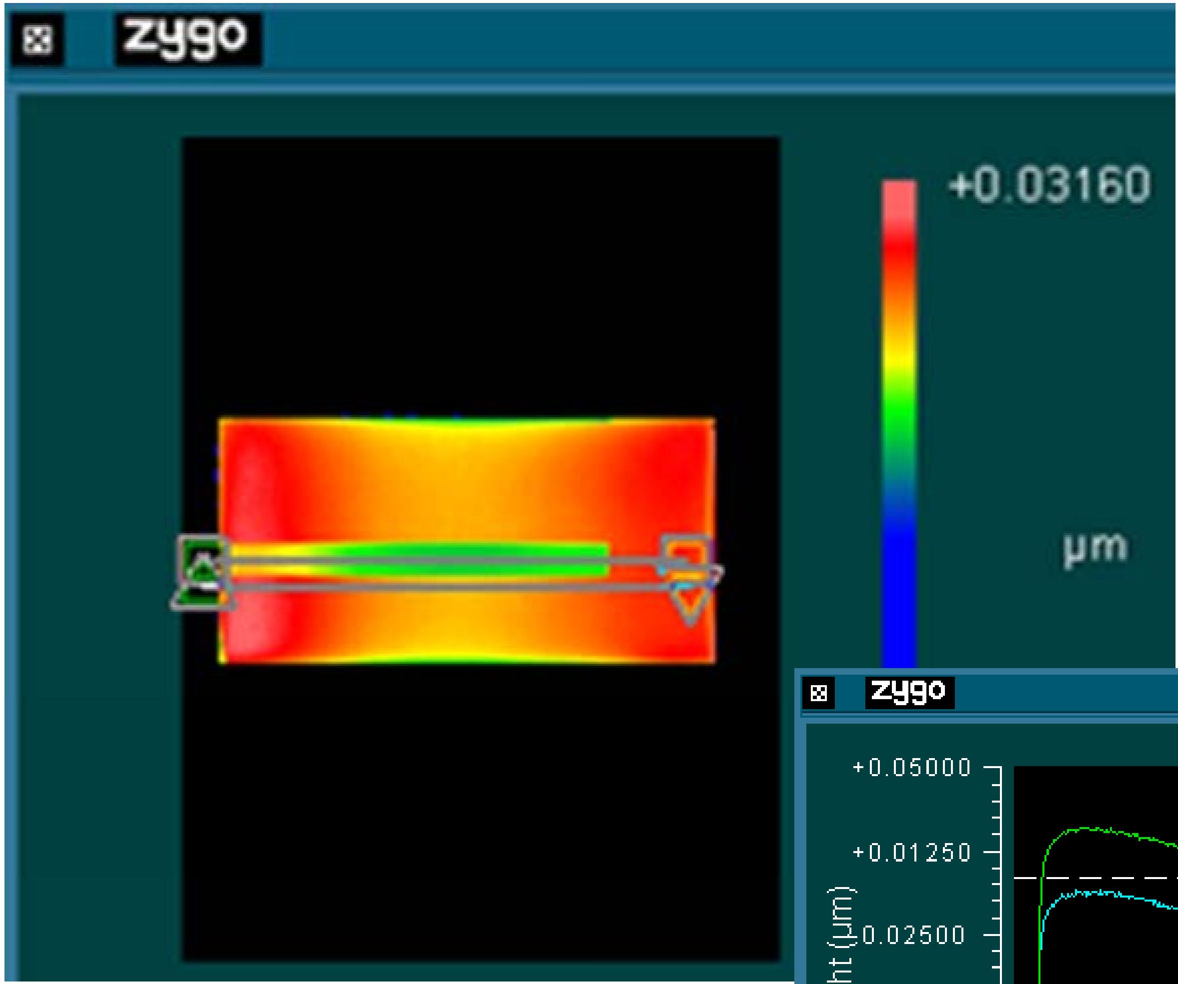
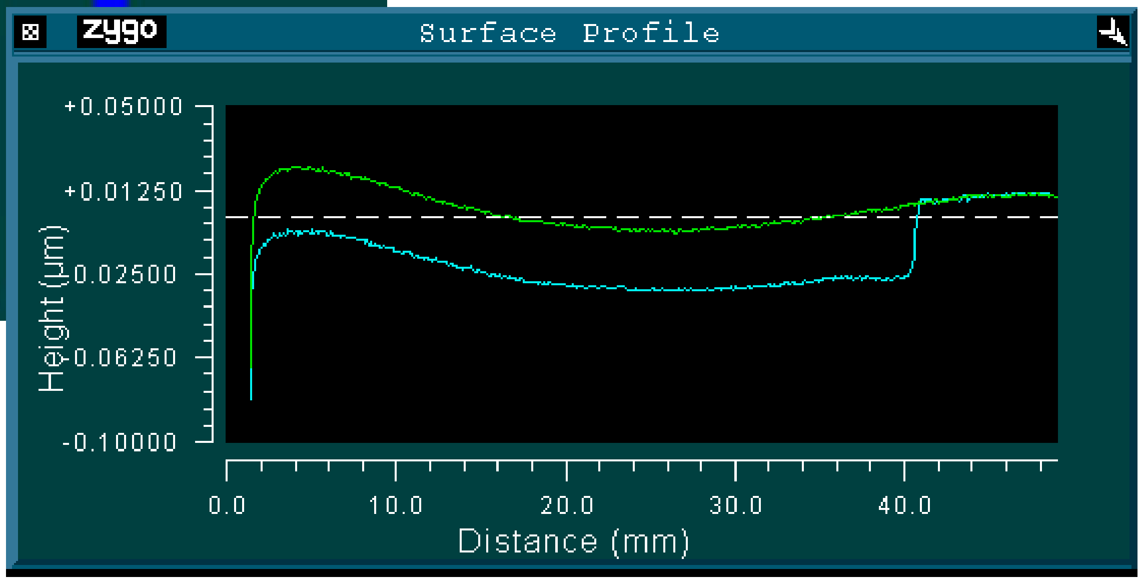
Surface shape and roughness measurements performed at the ESRF Optical Metrology Laboratory using:

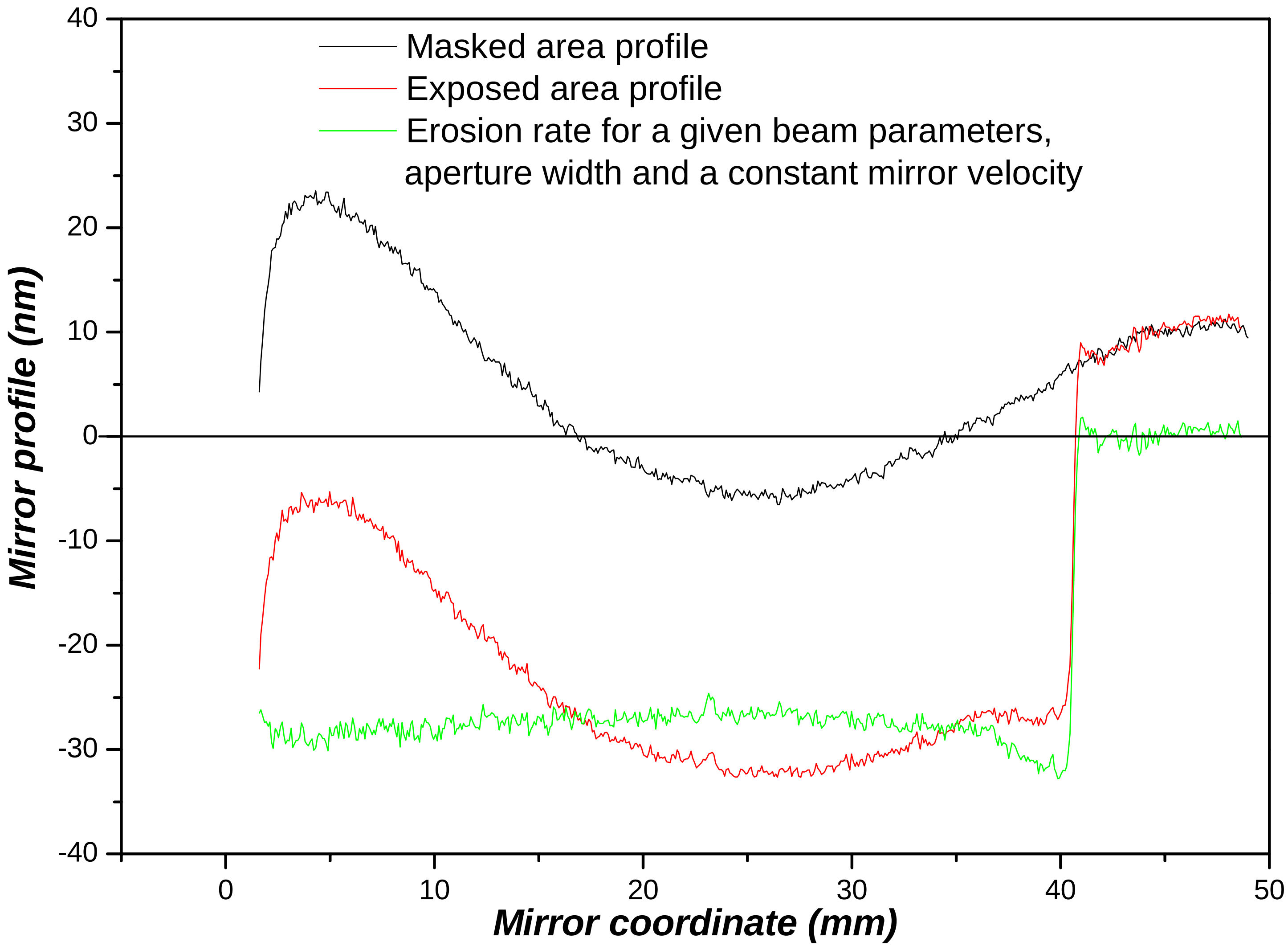
- ***Phase shifting Fizeau micro-interferometer*** *(Zygo VeriFIRE AT+ 150mm aperture)*
    - Repeatability on 2 successive measurements: 0.2 nm rms
    - Rms deviation over 10 successive measurements: 0.03 nm
- ***Phase shifting micro-interferometer*** *(modified Veeco NT9300)*
    - Spatial frequency: mm^{-1}- μm^{-1}
    - Repeatability: 5 pm rms
    - Noise level: 19 pm
- ***Long Trace Profiler***
    - Repeatability: by averaging > 5 successive scans
    - Noise level: 0.08 µrad over 6 h

Erosion rate description




zygo
+0.03160
µm


zygo
Surface Profile
+0.05000
+0.01250
-0.02500
-0.06250
-0.10000
Height (µm)
0.0
10.0
20.0
30.0
40.0
Distance (mm)


Masked area profile
Exposed area profile
Erosion rate for a given beam parameters, aperture width and a constant mirror velocity
Mirror profile (nm)
Mirror coordinate (mm)
40
30
20
10
0
-10
-20
-30
-40
0
10
20
30
40
50

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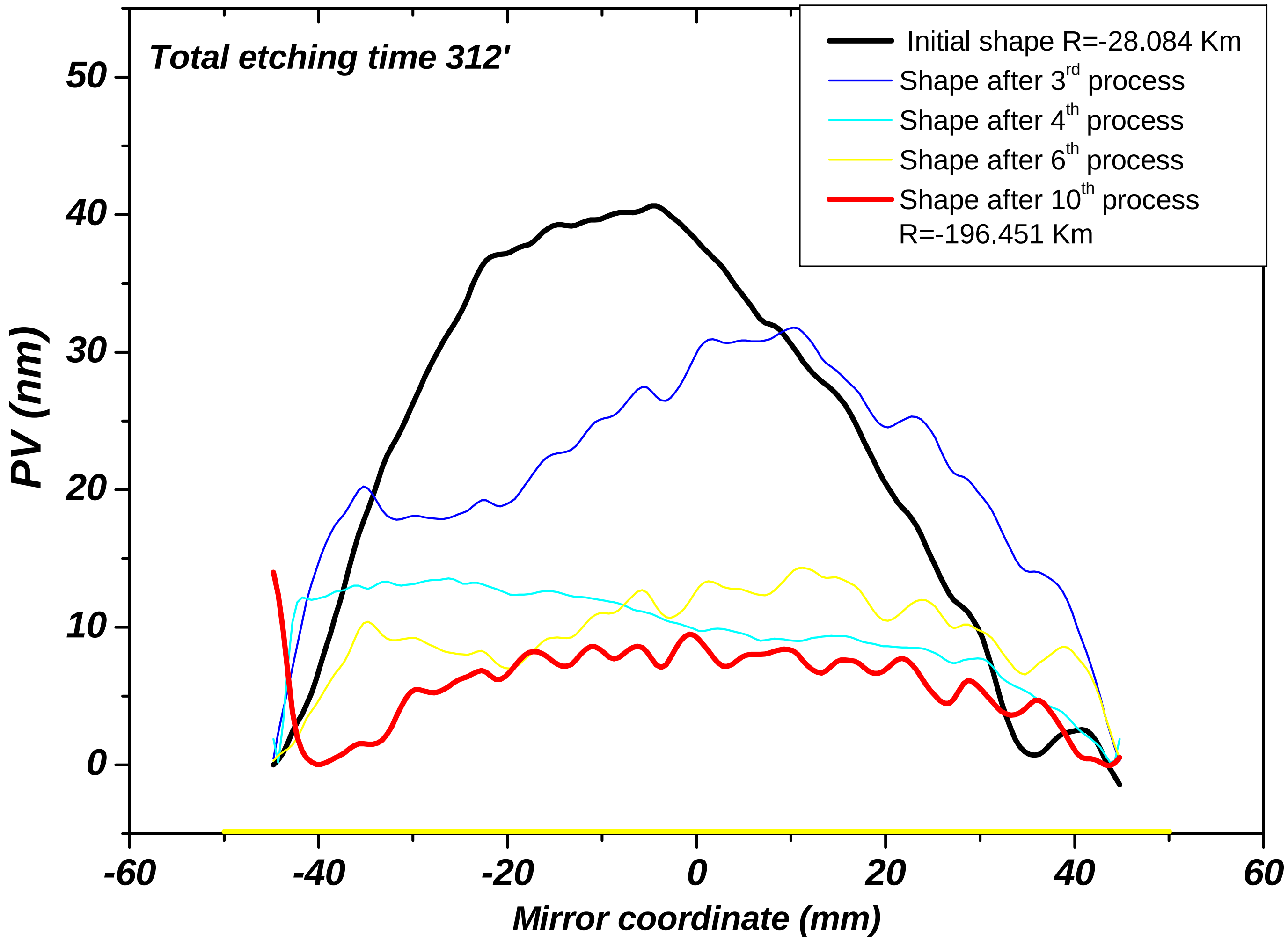
Surface shape evolution of the 1st sample



Roughness survey

Before etching processes: R_q= 0.44 nm

Veeco

Mag: 49.6 X

Mode: PSI

Surface Data

Date: 03/20/2012

Time: 16:16:56

Surface Statistics:

Ra: 0.29 nm

Rq: 0.44 nm

Rz: 13.08 nm

Rt: 34.49 nm

Set-up Parameters:

Size: 640 X 480

Sampling: 199.56 nm

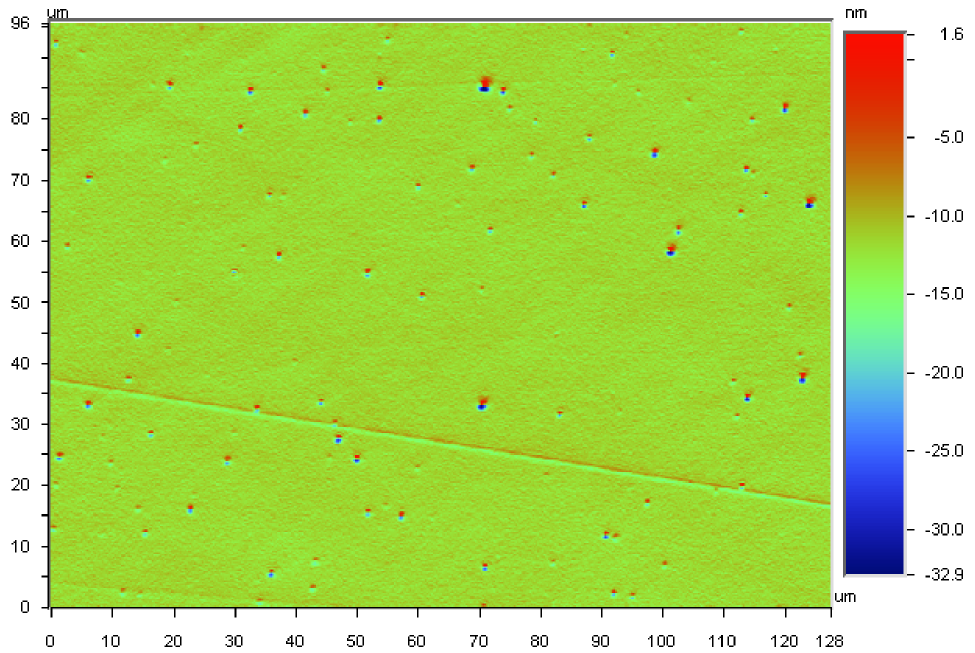
Processed Options:

Terms Removed:

Cylinder & Tilt

Filtering:

None



Title: 3

Central area on the mirror surface

After etching processes: R_q= 0.42 nm

Veeco

Mag: 49.6 X

Mode: PSI

Surface Data

Date: 03/27/2012

Time: 14:37:11

Surface Statistics:

Ra: 0.29 nm

Rq: 0.42 nm

Rz: 10.67 nm

Rt: 29.96 nm

Set-up Parameters:

Size: 640 X 480

Sampling: 199.56 nm

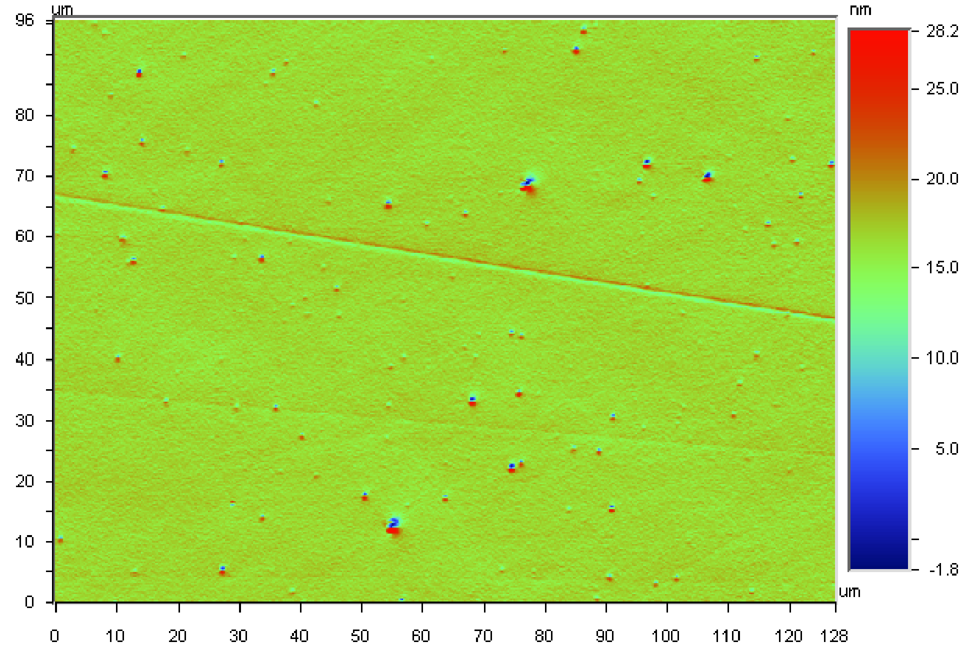
Processed Options:

Terms Removed:

Cylinder & Tilt

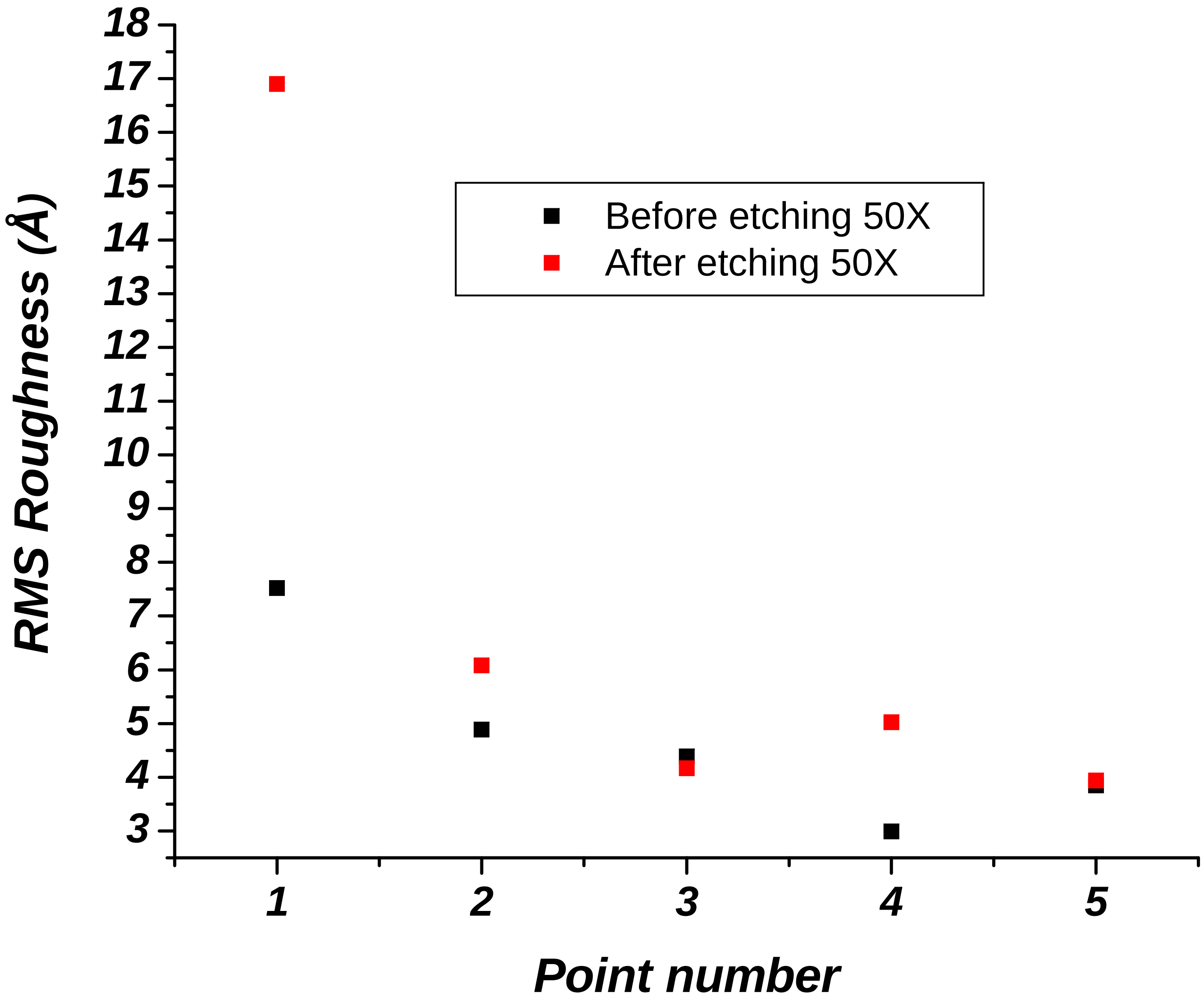
Filtering:

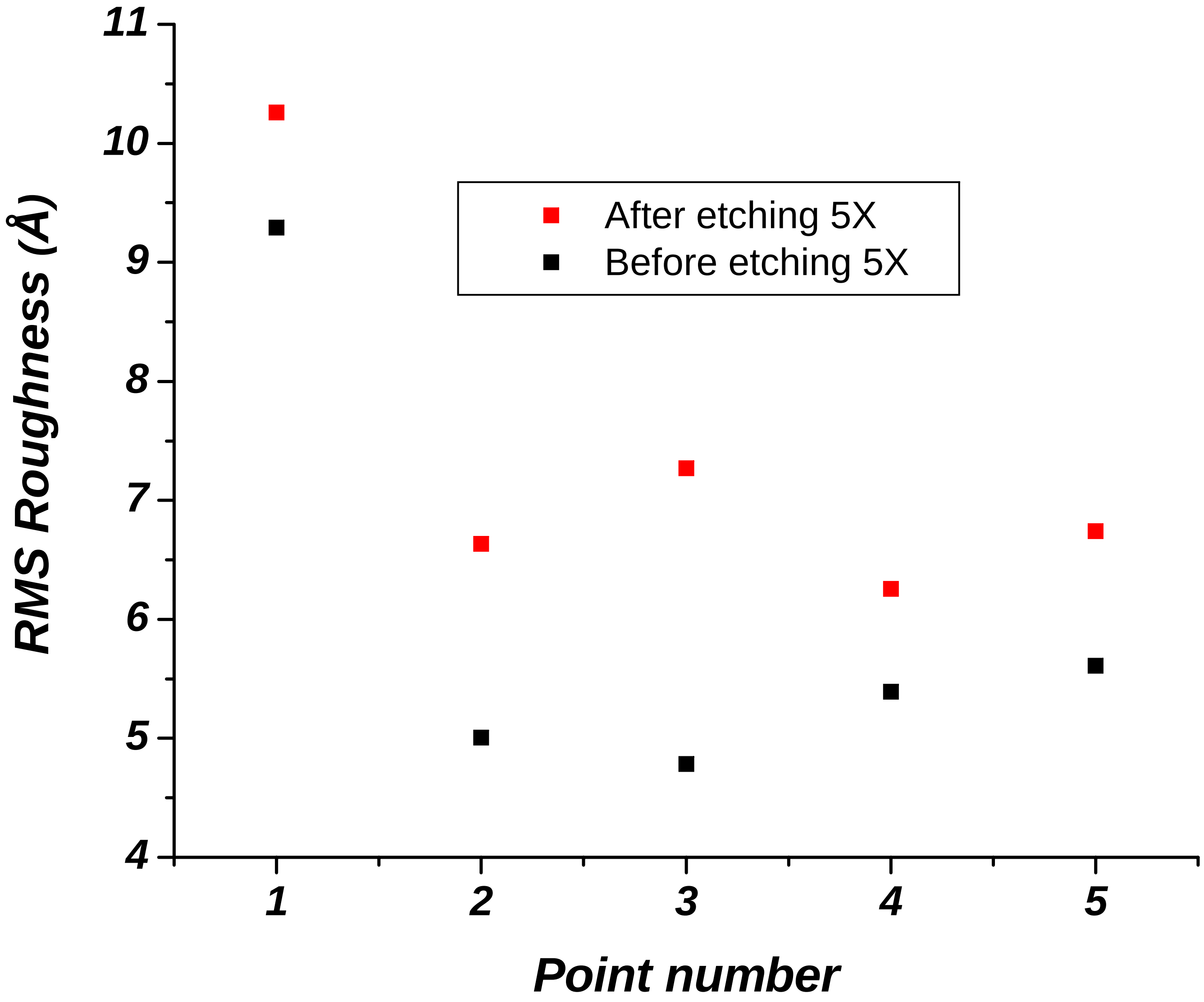
None



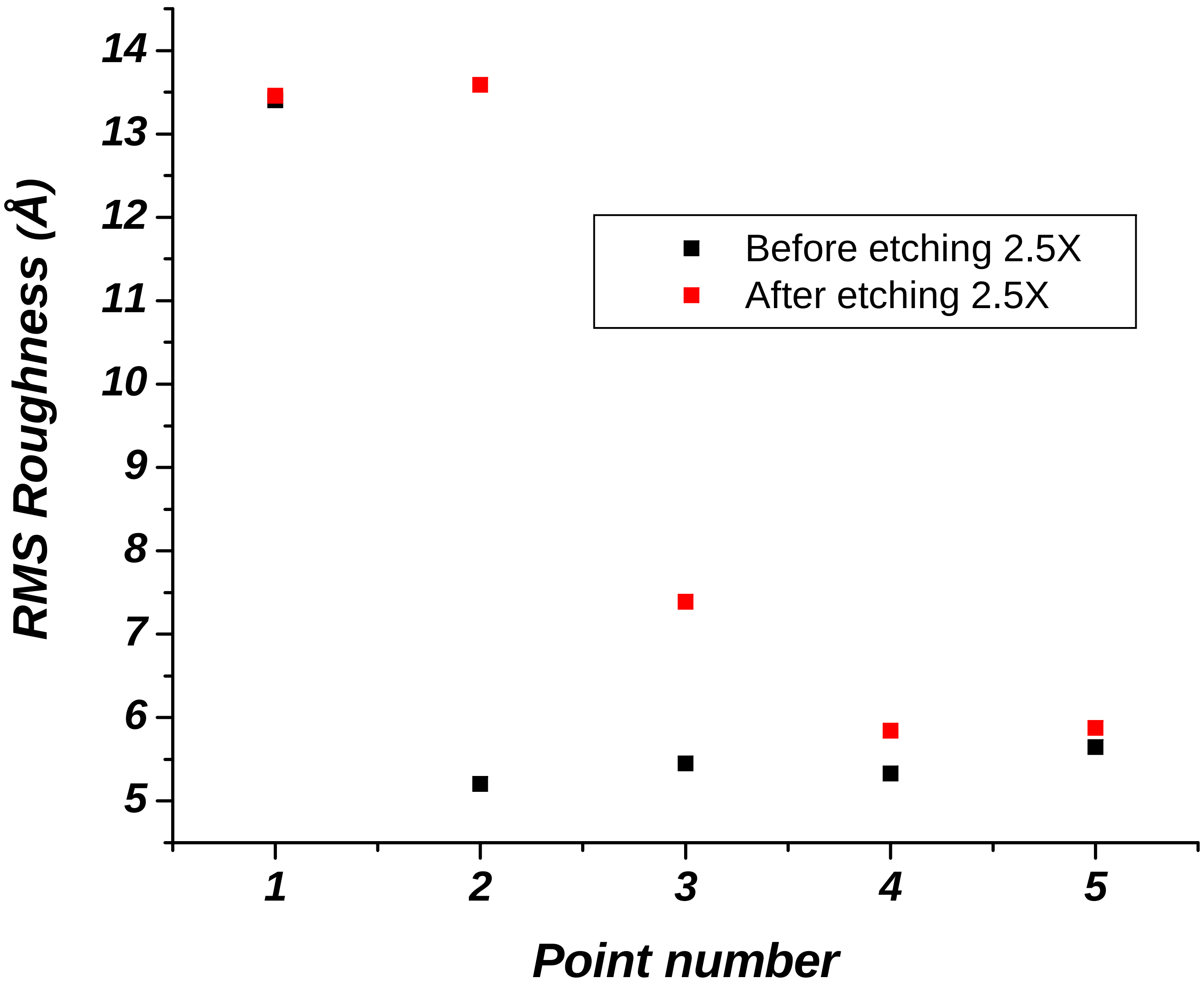
Title: 3

Central area on the mirror surface


RMS Roughness (Å)
Point number
Before etching 50X
After etching 50X
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
1
2
3
4
5



11
10
9
8
7
6
5
4
RMS Roughness (Å)
1
2
3
4
5
Point number
After etching 5X
Before etching 5X

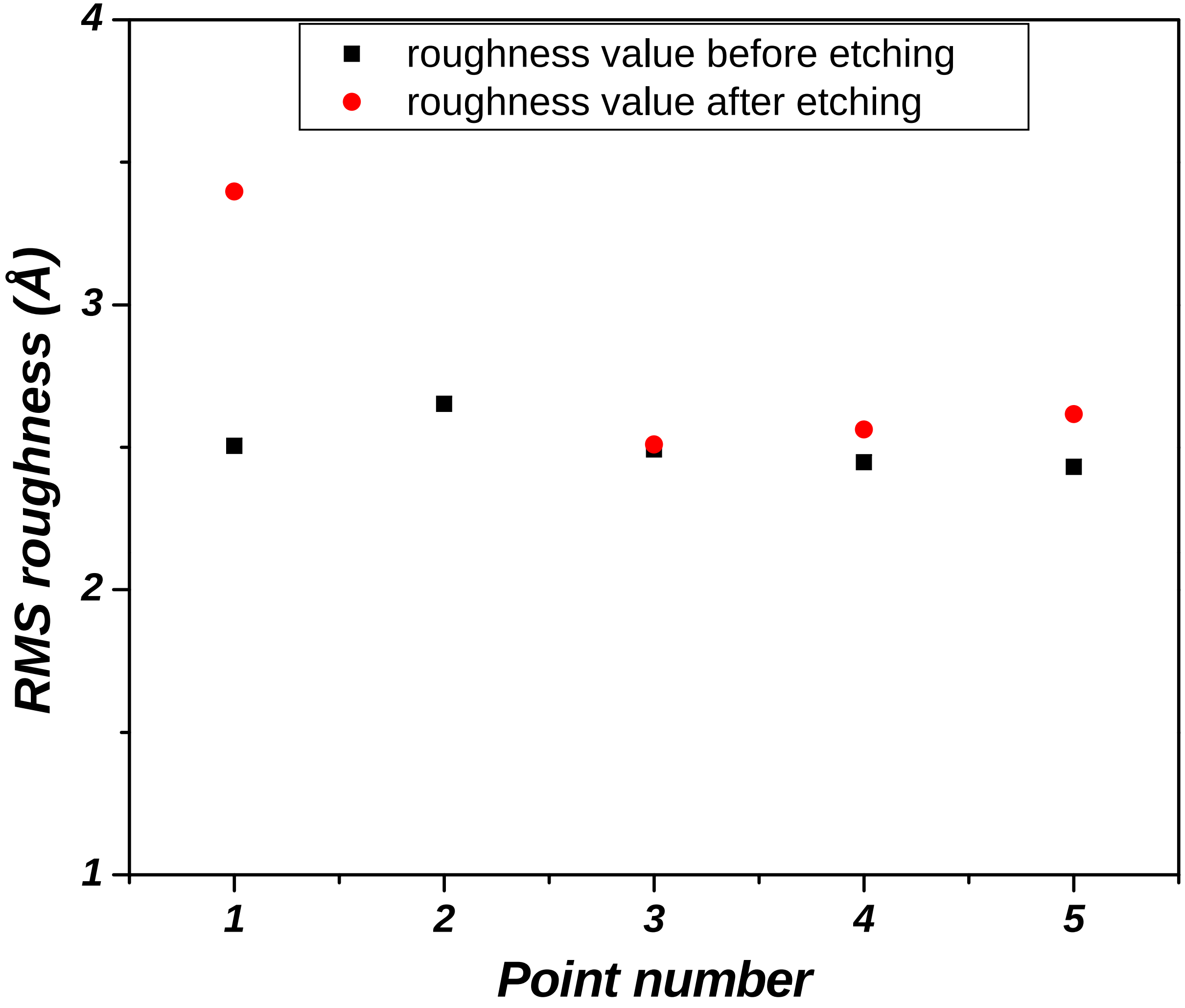


RMS Roughness (Å)
14
13
12
11
10
9
8
7
6
5
1
2
3
4
5
Point number
Before etching 2.5X
After etching 2.5X

On a **second** sample

optical zoom	point	roughness (Å) initial	final
50 X	1	2,5	3,3
	2	2,6	31
	3	2,4	2,5
	4	2,4	2,5
	5	2,4	2,6

On a **second** sample



Mag: 5.0 X

Mode: PSI

Surface Data

Date: 06/19/2012

Time: 09:43:50

Surface Statistics:

Ra: 0.20 nm

Rq: 0.26 nm

Rz: 5.49 nm

Rt: 11.23 nm

Set-up Parameters:

Size: 640 X 480

Sampling: 1.99 um

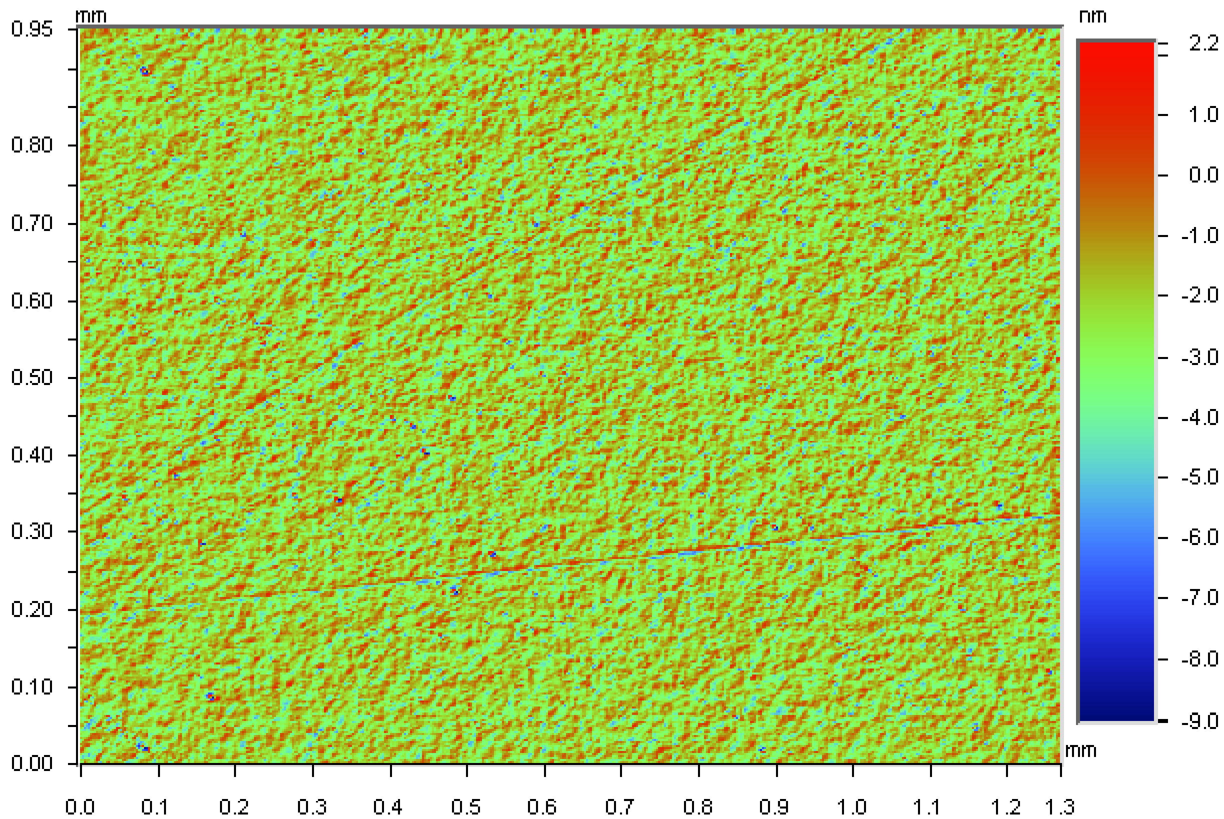
Processed Options:

Terms Removed:

Cylinder & Tilt

Filtering:

None



Title: 2

Mag: 49.6 X

Mode: PSI

Surface Data

Date: 06/28/2012

Time: 14:51:36

Surface Statistics:

Ra: 0.53 nm

Rq: 3.14 nm

Rz: 103.18 nm

Rt: 231.54 nm

Set-up Parameters:

Size: 640 X 480

Sampling: 199.56 nm

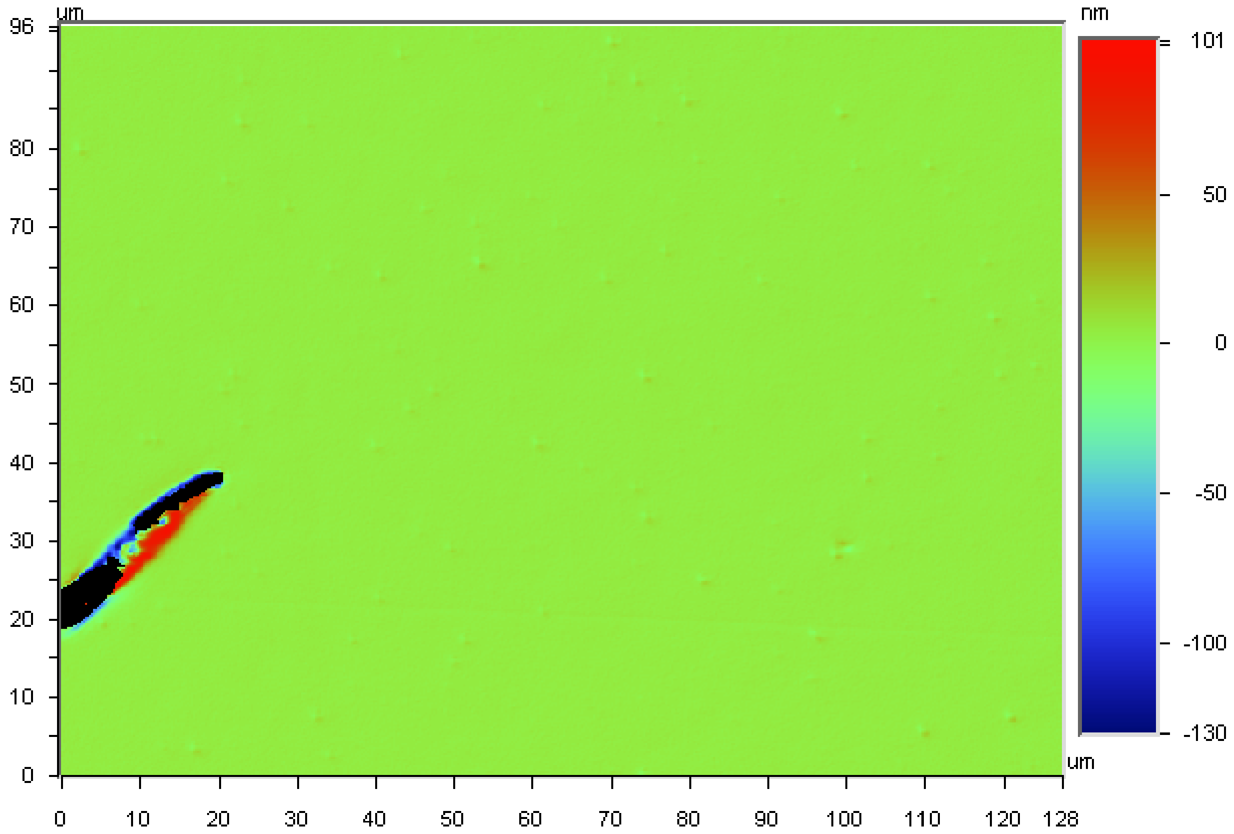
Processed Options:

Terms Removed:

Cylinder & Tilt

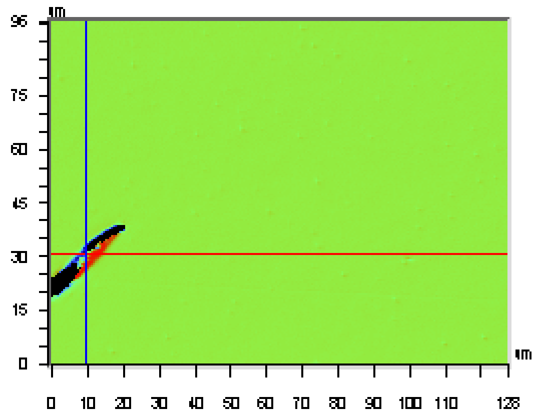
Filtering:

None



Title: 2

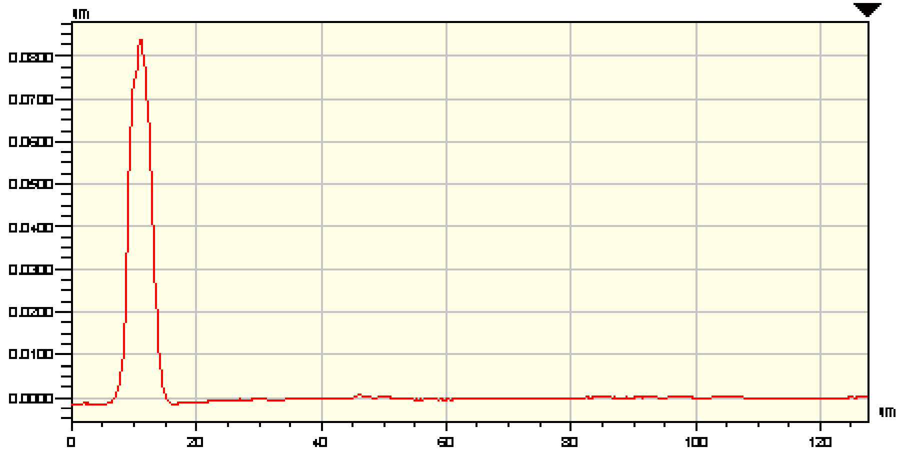
Iulian Preda – 4th IWMX – Barcelona, July 2012



X	9.58	-	-	um
Y	30.73	-	-	um
Ht	68.17	-	-	nm
Dist			-	um
Angle			-	°

Title: 2

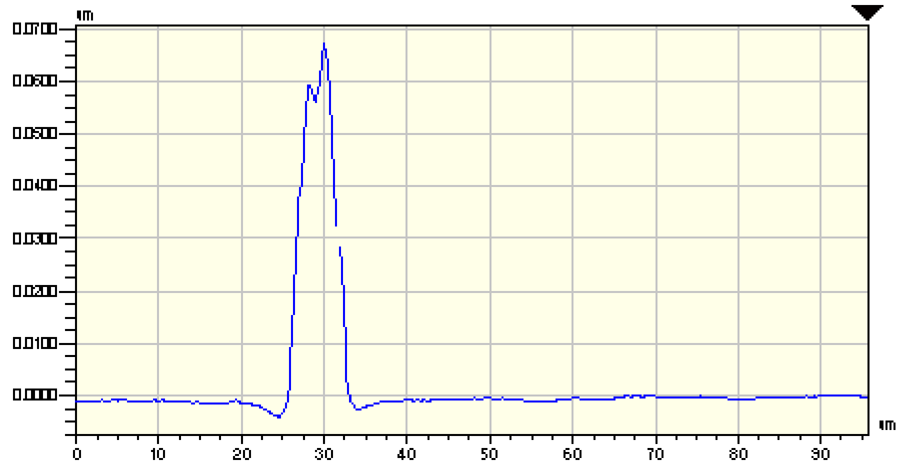
X Profile



Rq	0.01	um
Ra	0.00	um
Rt	0.08	um
Rp	0.08	um
Rv	-0.00	um

Angle	13.56	urad
Curve	0.21	m
Terms	None	
Avg Ht	0.00	um
Area	0.29	um2

Y Profile



Rq	0.01	um
Ra	0.01	um
Rt	0.07	um
Rp	0.07	um
Rv	-0.00	um

Angle	8.37	urad
Curve	-0.19	m
Terms	None	
Avg Ht	0.00	um
Area	0.22	um2

Mag: 49.6 X

Mode: PSI

Surface Data

Date: 06/28/2012

Time: 14:51:36

Surface Statistics:

Ra: 0.21 nm

Rq: 0.29 nm

Rz: 7.44 nm

Rt: 15.94 nm

Set-up Parameters:

Size: 640 X 480

Sampling: 199.56 nm

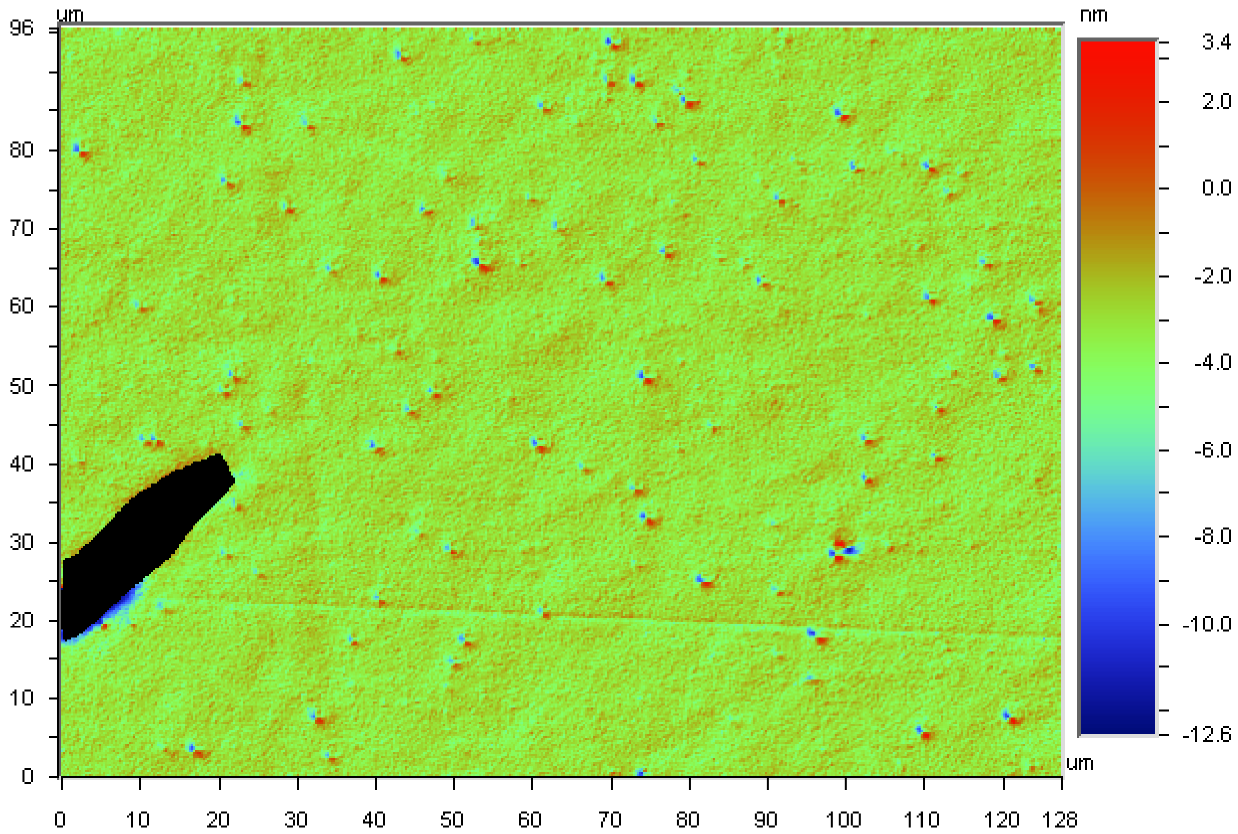
Processed Options:

Terms Removed:

Cylinder & Tilt

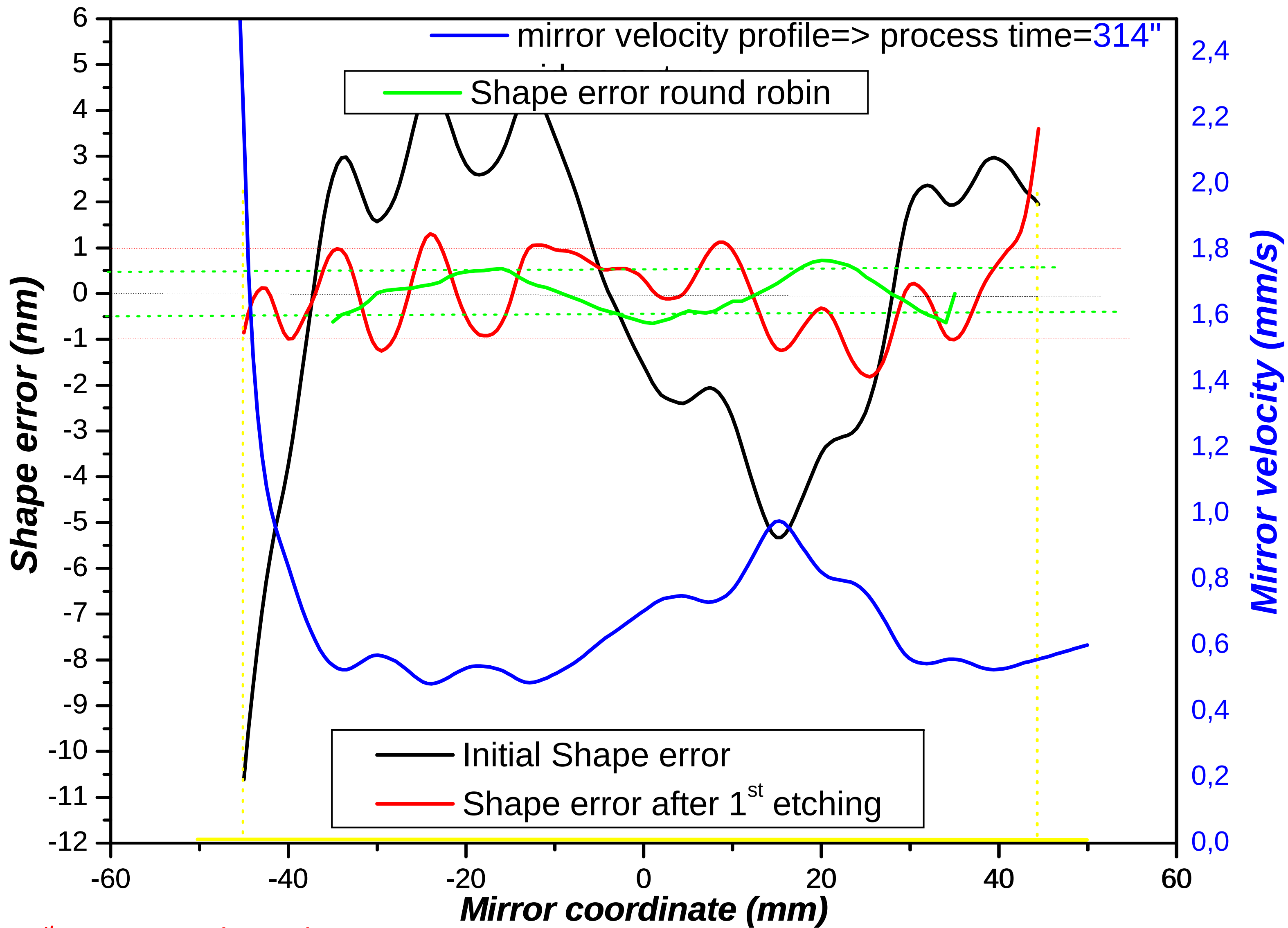
Filtering:

None



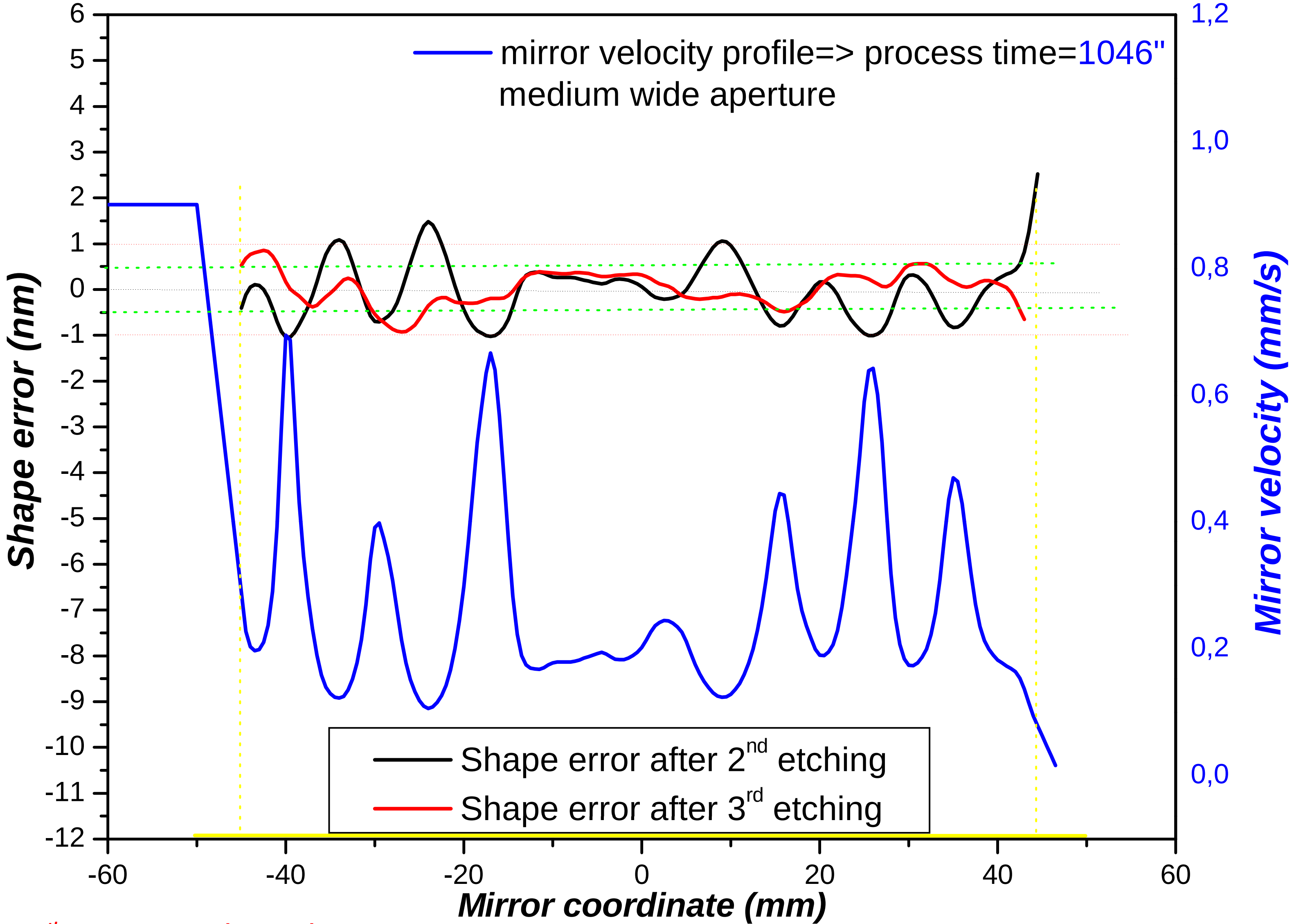
Title: 2

Shape error evolution of the 2nd sample

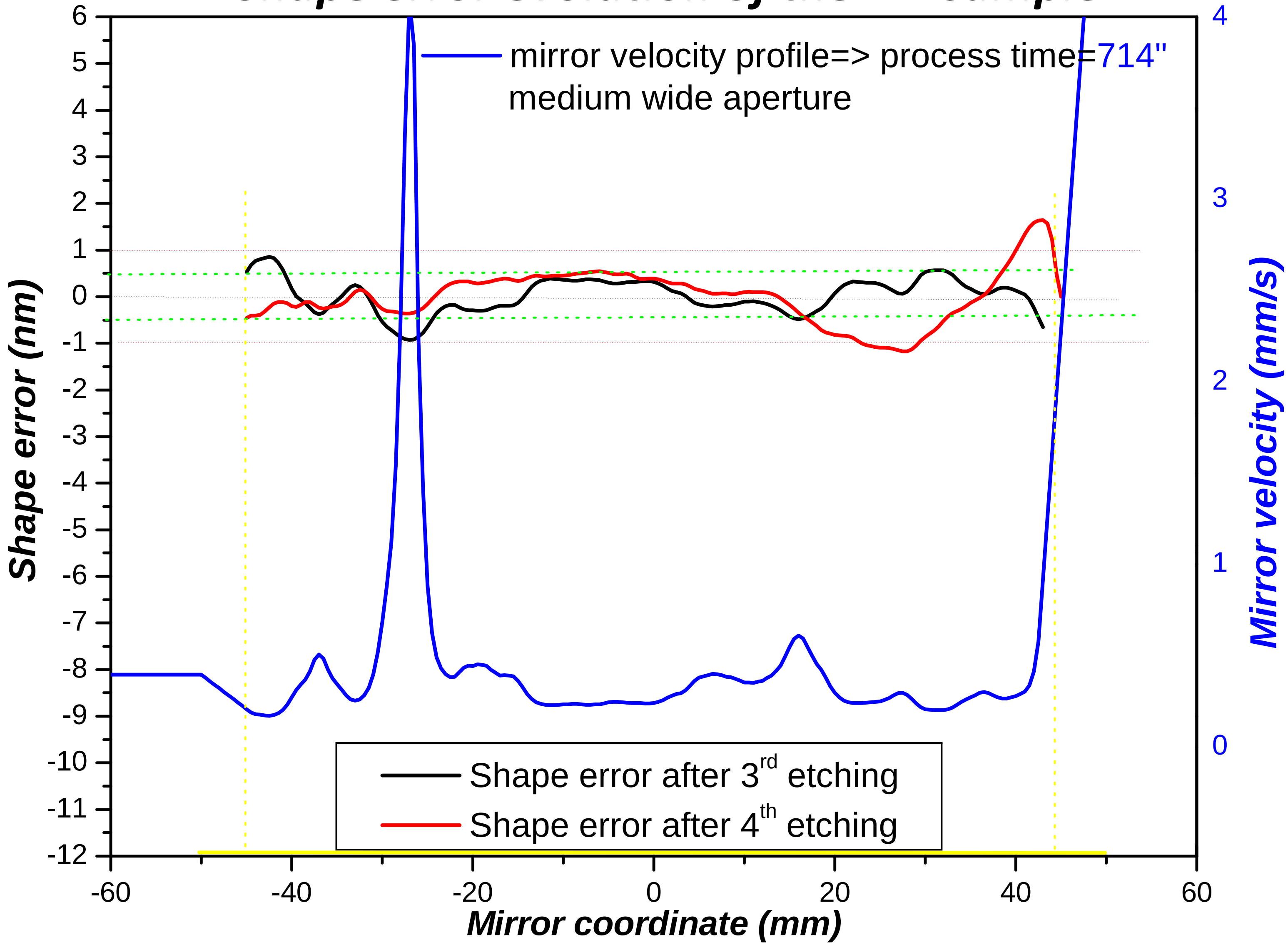


Iulian Preda – 4th IWMX – Barcelona, July 2012

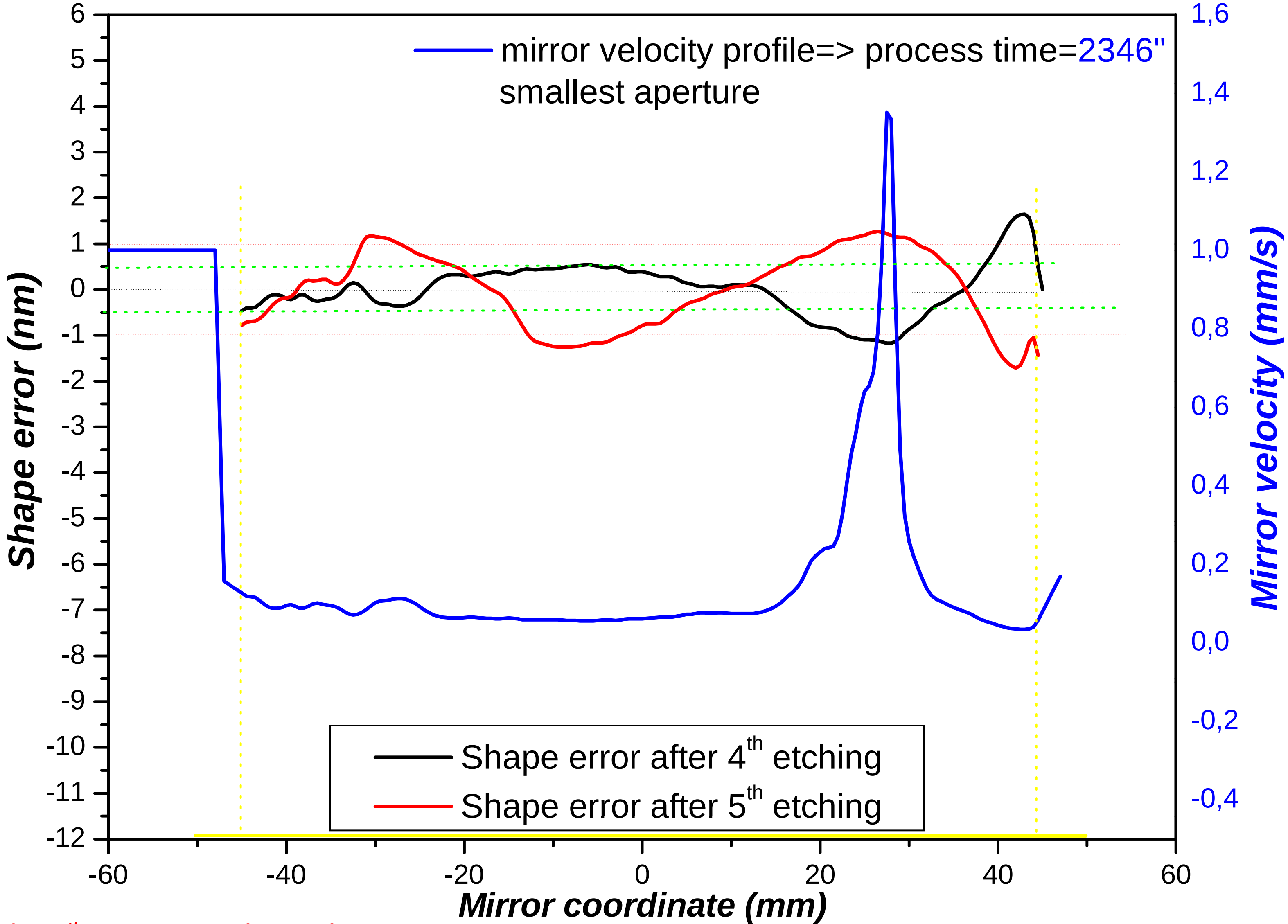
Shape error evolution of the 2nd sample



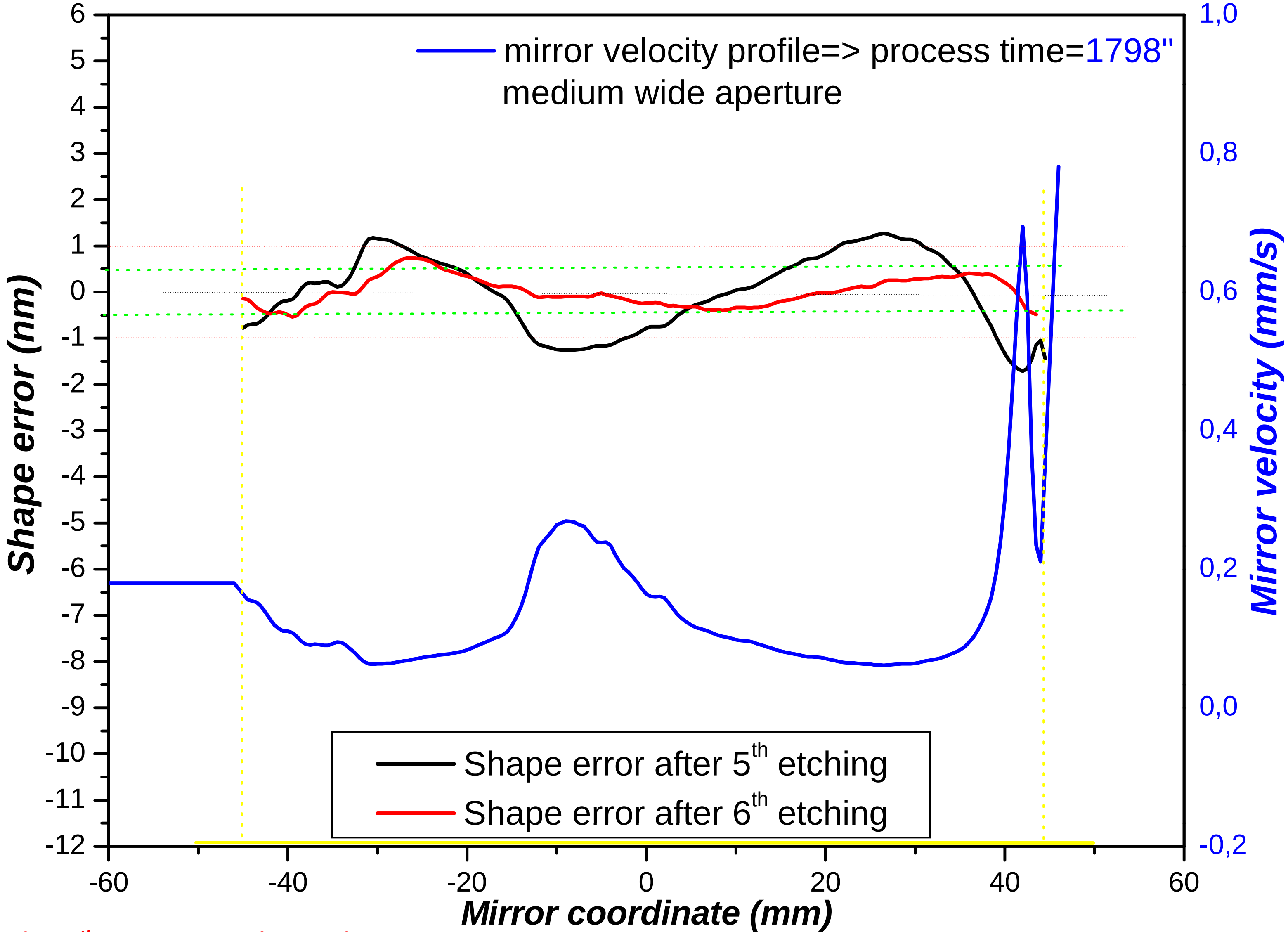
Shape error evolution of the 2^{nd} sample



Shape error evolution of the 2nd sample



Shape error evolution of the 2nd sample



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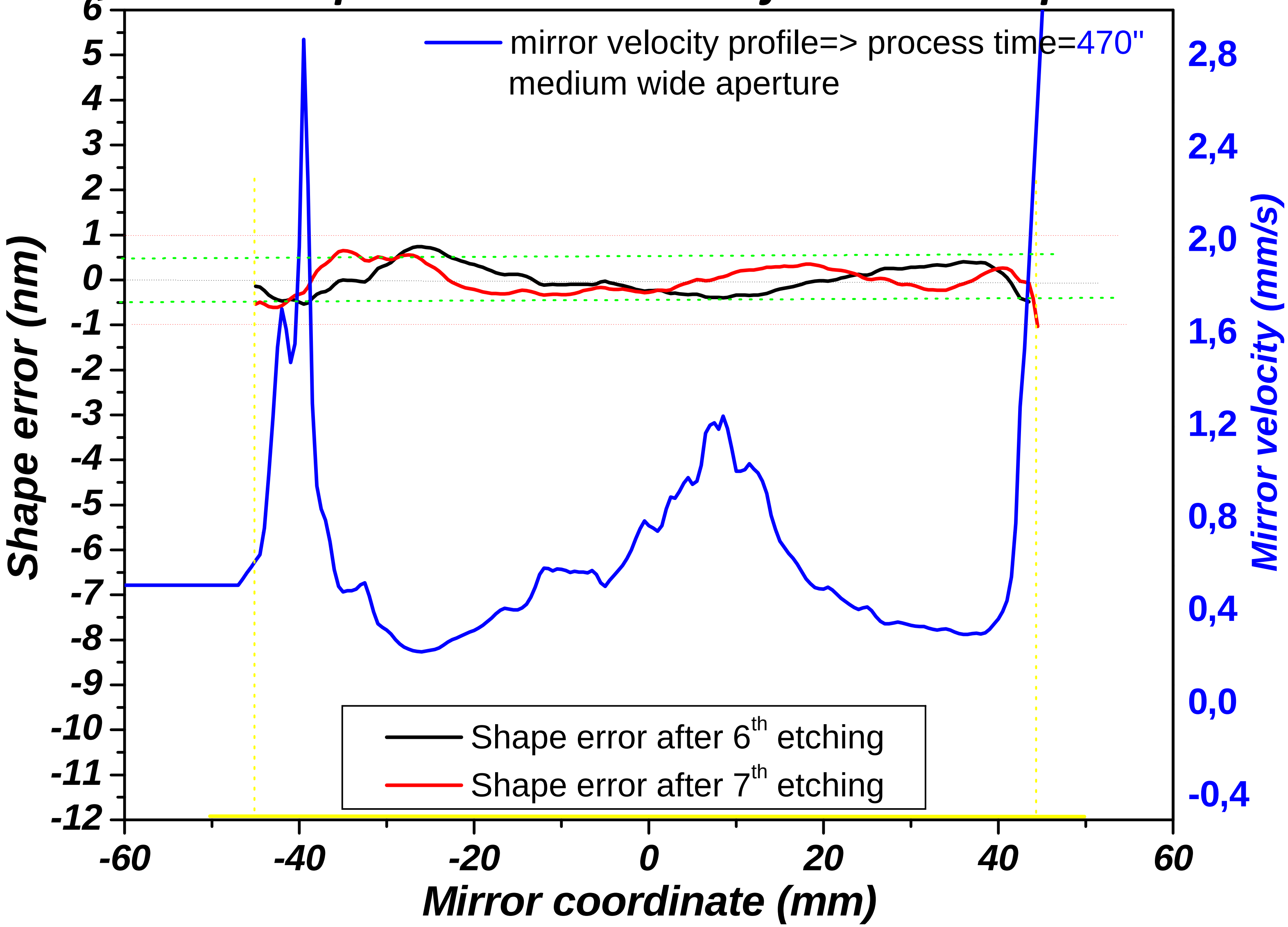
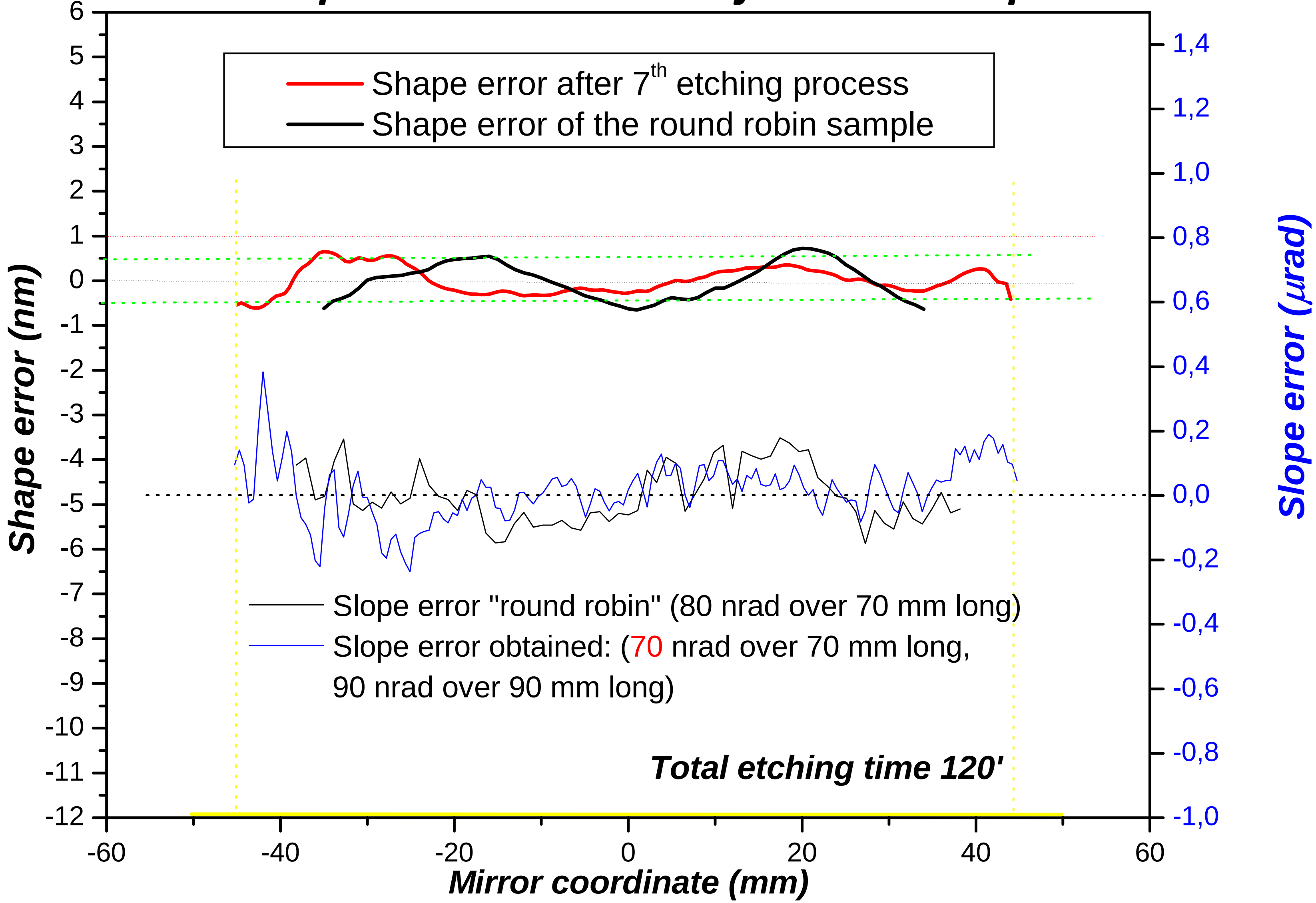
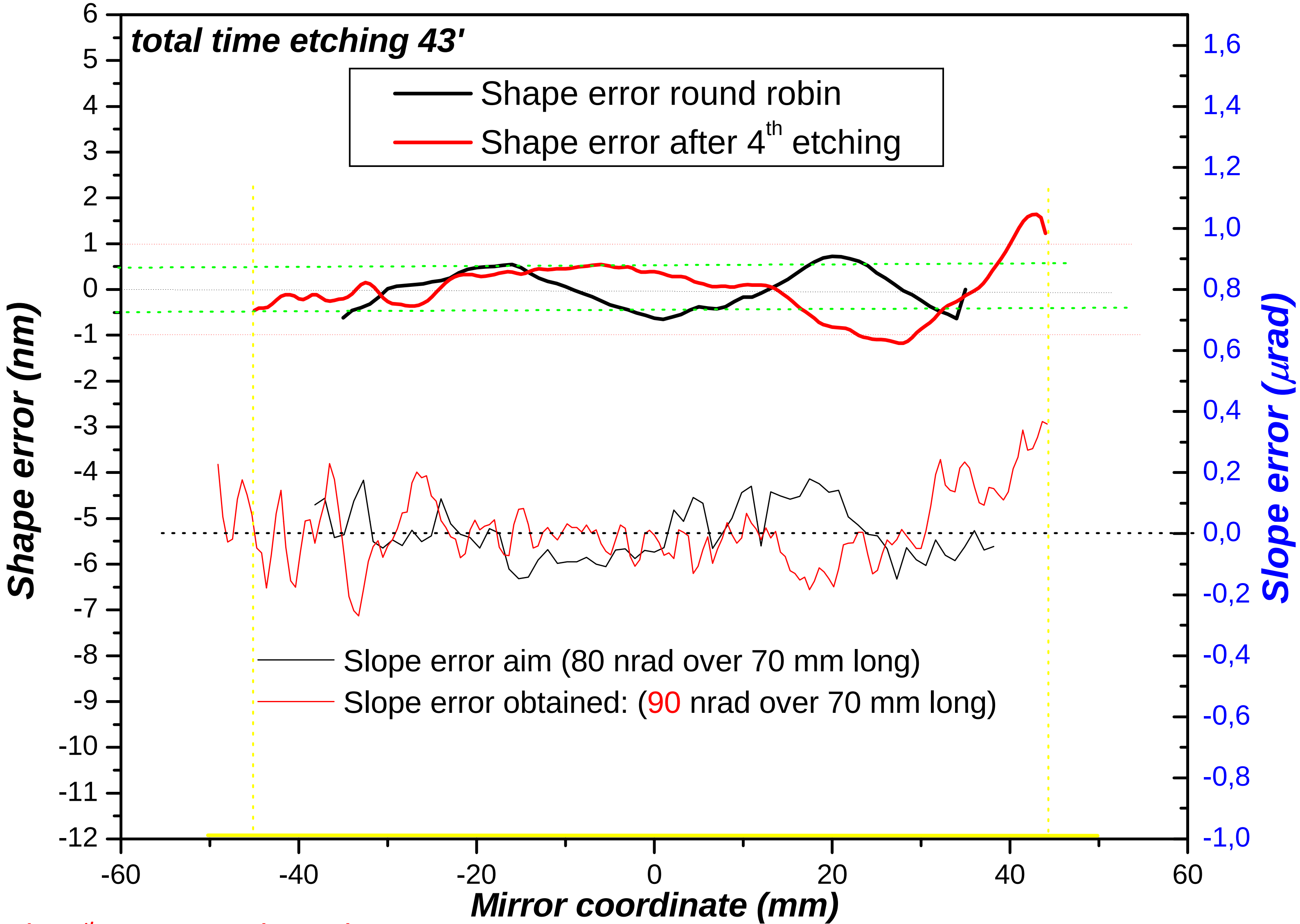


Shape error evolution of the 2nd sample



Shape error evolution of the 2nd sample



Iulian Preda – 4th IWMX – Barcelona, July 2012

CONCLUSION & PERSPECTIVES

- ion beam source found.

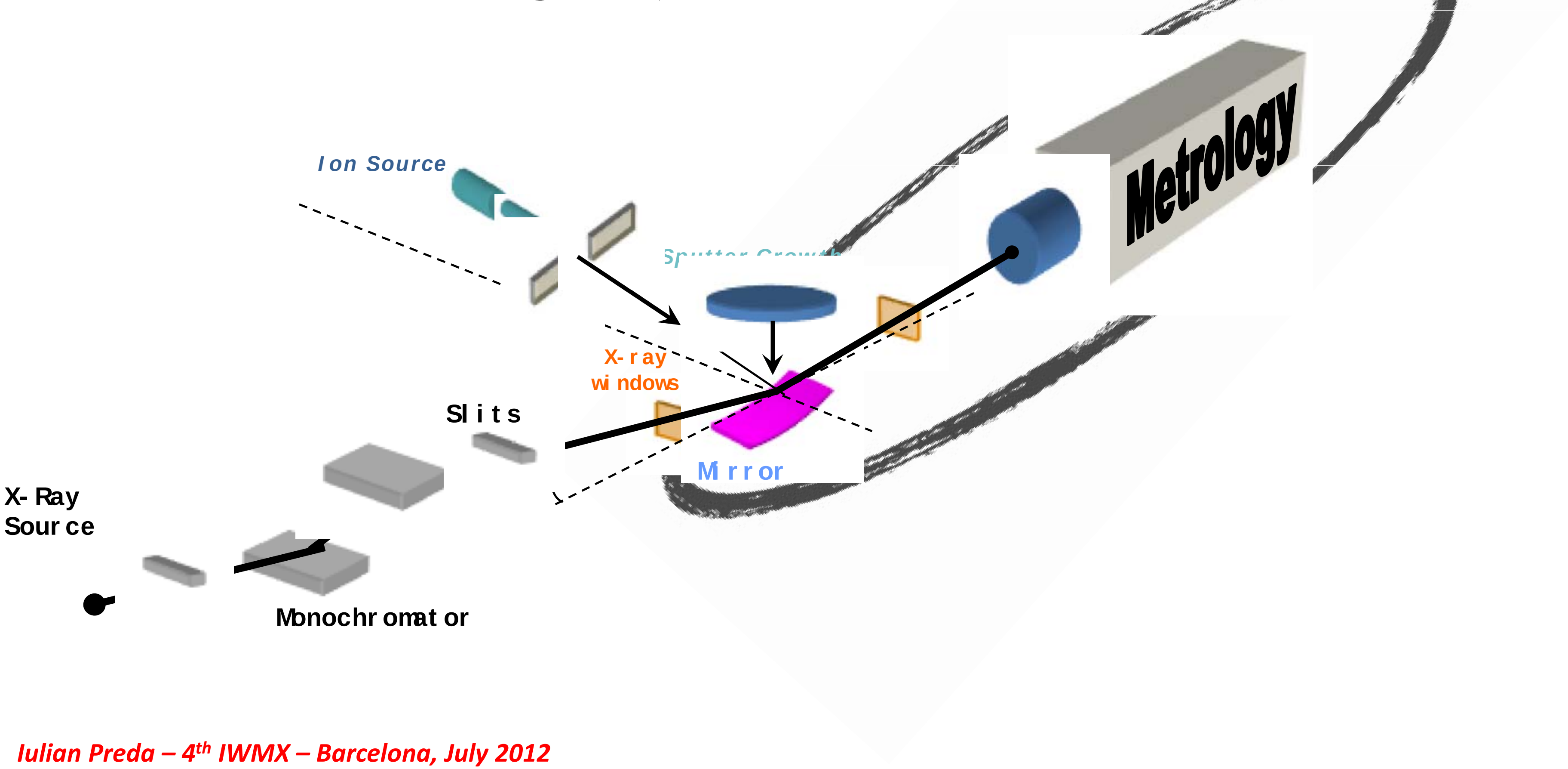
- verified concept.

- optimized etching process (three more points to be improved in the very near future).

- Final OMLS station to be installed at BM05

On-line X-ray metrology:

S. Berujon *(TU-E-C11, SRI Lyon)*



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