Artefacts –realization and characterization- for calibration of nanoscale instruments

D. Apostol, V. Damian, Iuliana Iordache , National Institute for Laser Plasma and Radiation Physics, Bucharest,
B. Savu, Gh. Stanciu, Centre for Microscopy, Microanalysis and Information Processing, "Politehnica" University, Bucharest
Dana Cristea, A. Dinescu , Raluca Muller, National Institute for R&D in Microtechnologies, Bucharest

- ***Calibration*** is the process of checking and correcting the performance of a measuring instrument against the accepted standard. An instrument or specimen of unknown accuracy is compared to an artefact of known accuracy.
- ***Calibration specimens or artefacts*** with feature sizes directly traceable to international length standards are key tools for obtaining accurate and reliable results in **mass production** at nanoscale level.

- When you can measure what you are speaking about, you know something about it.

Lord Kelvin, 1883

- Moralizing measurement: (Dis)Trust in People, Instruments and Techniques,

The Morals of Measurement, Graeme J.N. Gooday, IOP 2004

- In modern industrial production metrology is moving increasingly nearer to production. In the ideal case it is even integrated in production lines in order to achieve shortest possible loops of production control. Thus, metrology can be regarded as an immediate factor of productivity

- The first use of the term nanometrology in a peer reviewed publication
appears in April 1992, in the journal Metrologia
(K. Nakayama, M. Tanaka, F. Shiota and K. Kuroda, Metrologia, 1992, 28(6), 483–502).

Nanometrology is the foundation of *nanotechnology*.

Since the initiation of the *National Nanotechnology Initiative* (NNI) announced by President Clinton in the United Sates in 2000, there has been a significant increase in the research and development activity in *nanotechnology* all around the world. Much of this activity has been directed toward understanding the phenomena that are being discovered.

However, one critical need for the implementation of nanomaterials and devices is their characterization and measurement science, i.e., their metrology.

Principles of measurement that work well at the macroscopic level often become completely unworkable at the nanometre scale – about 100 nm and below. Imaging, for example, is not possible on this scale using optical microscopes, and it is virtually impossible to weigh a nanometre-scale object with any accuracy.

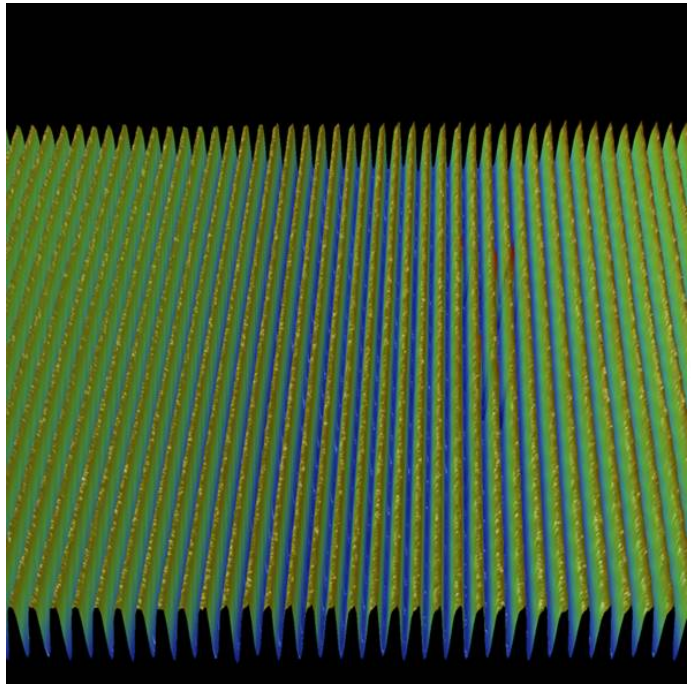
Presently tools are being used at the limits of their resolution to probe these materials and phenomena, resulting in large measurement errors. Similarly, there is a lack in nanoscale calibration standards, thereby contributing to inconsistency in results being obtained around the world.

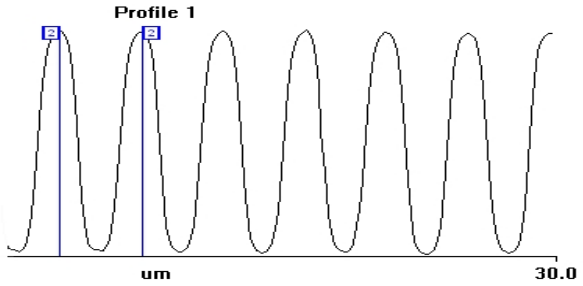
For many properties, it is not known whether the exciting novel behavior found in these new materials is due to new physics or to a logical extension of large-size behavior to small dimensions.

Nanometrology is one of the preconditions that have been searched for solving many high precision and nanometer resolution problems emerged today and in the future.

3 micrometri pitch linear grating made by beam electron lithography

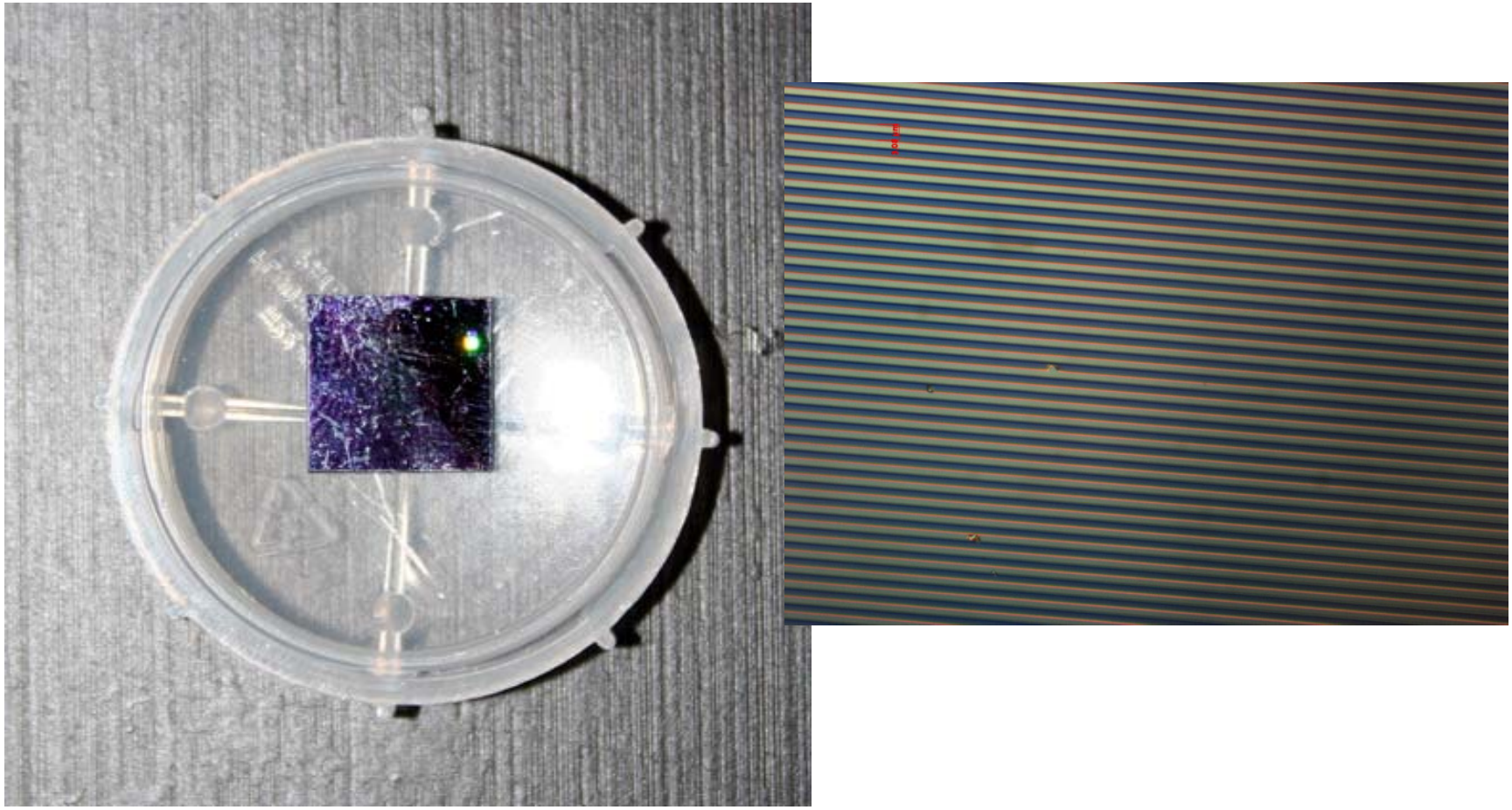
Lateral standards such as 1D and 2D gratings are used as transfer standards
for microscopes to calibrate the magnification and to characterize
the image distortions of the *xy*-plane of all kinds of microscopes.





Delta Z =	0.00
Delta XY =	3.05
Theta =	0.02
Mean	0.43 um
Sq	0.04 um
Sa	0.03 um
Peak/Valley	0.09 um

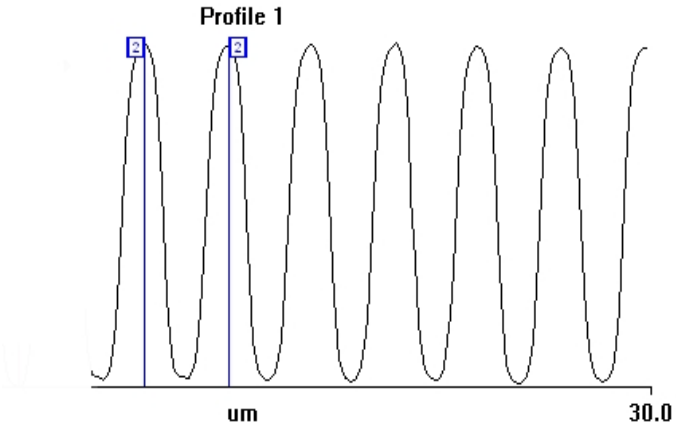
1 micrometer grating pitch artefact



ARTEFACTS 3µm

- 3,080µm Optical Microscope

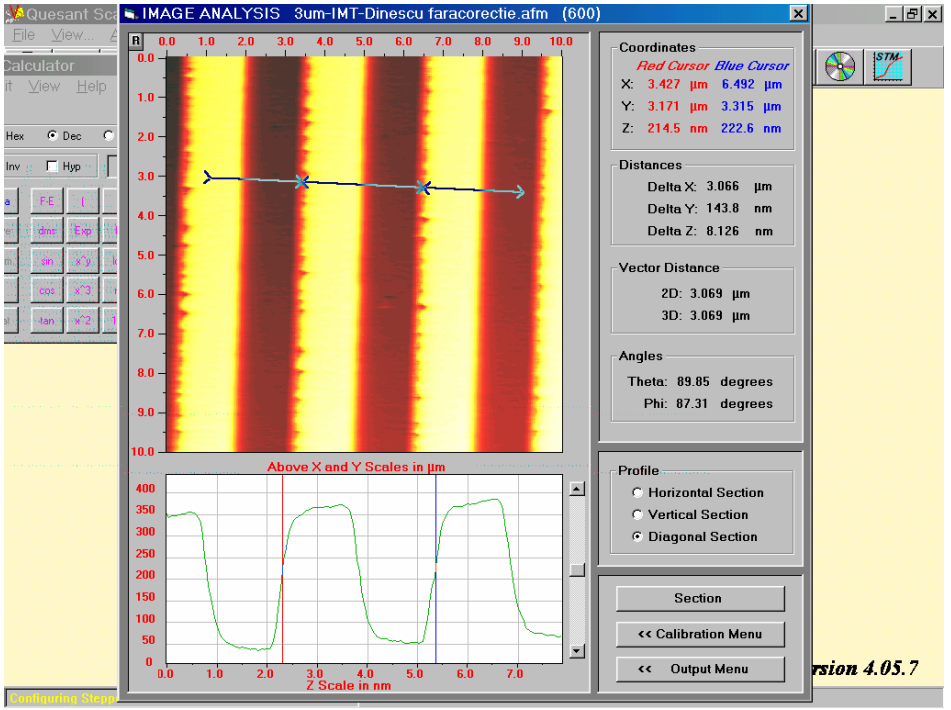
- 3,050µm WLI



Delta Z =	0.00
Delta XY =	3.05
Theta =	0.02
Mean	0.43 um
Sq	0.04 um
Sa	0.03 um
Peak/Valley	0.09 um

AFM

- 3 micrometer
- 3,066µm±?!
- PROFILUL!?
- Nu e indicata incertitudinea de masura ci doar rezolutia de 1nm



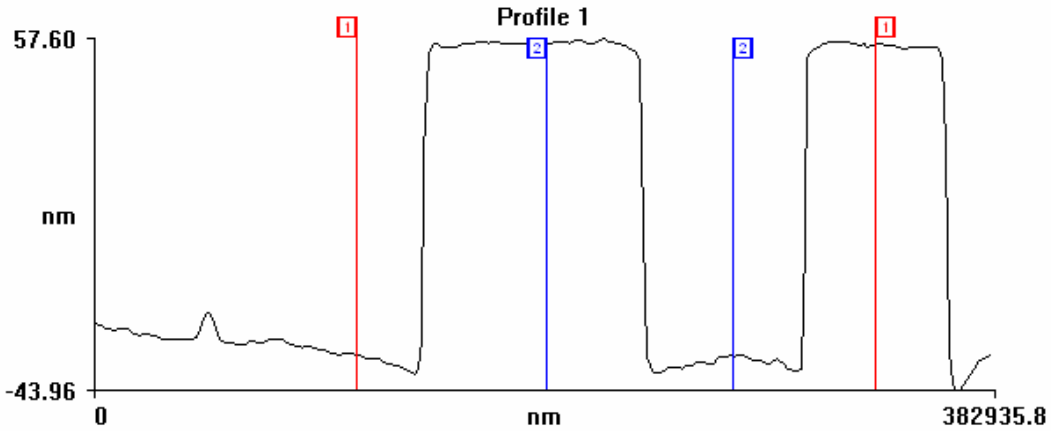
Difractometry-for medium pitch value measurement

Grating	I	II	III	IV	V
Pitch Λ (μm)	1.945	4.158	9.923	24.134	48.136
Absolute error $\delta\Lambda$ (nm)	1.0	2.1	7.2	21	53
Relative error $\varepsilon\Lambda$	$5.5\ 10^{-4}$	$5.0\ 10^{-4}$	$7.3\ 10^{-4}$	$8.5\ 10^{-4}$	$1.1\ 10^{-3}$

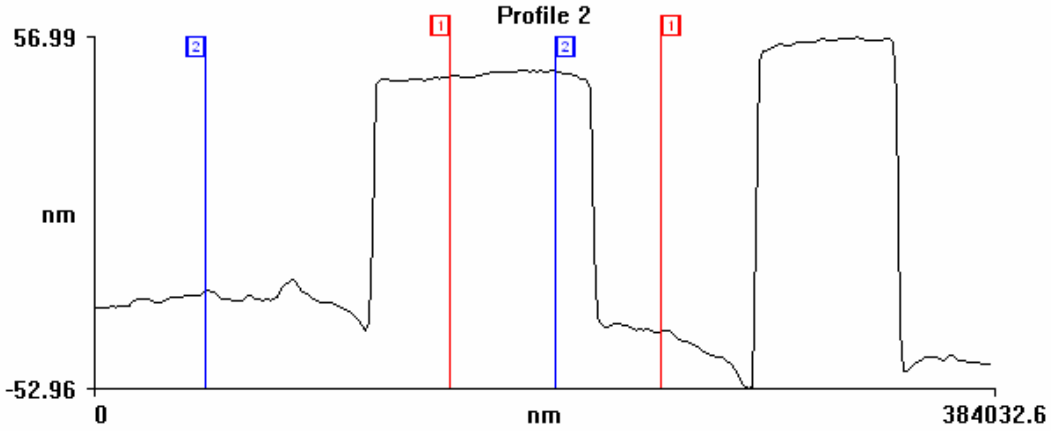
Caracteristici	Valori propuse	Unitate de masura	Valori rezultate
Material	/silica	-	/silica
Working area	1 mm	mm	(1±0,1)mm
Weigh dimensions (XxYxZ)	Φ=40	mm	(40 ±1)mm
the average step of the encoder measured individualy	3 000 nm	nanometer	**(3050±10)nm**
the average step of the encoder measured globaly	3 000 nm	nanometer	small area
The depth of the profile	(30-100) nm	nanometer	**(90±10)nm**
Profile	rectangular	-	Quasi rectangular
The maximum interval of uncertainity	±20nm	nm	±10nm

Caracteristici	Valori propuse	UM	Valori rezultate
Material	/silica	-	CROM/silica
Working area	10X10 mm	mm	(10±0,1)mm
Weigh dimensions (XxYxZ)	40X40	mm	0,1±mm
the average step of the encoder measured individually	24 micrometers	micrometers	**(24 003±10)nm**
The relative error of the step	1%	-	**0,04%**
the average step of the encoder measured globally	24 000nm	nanometers	**(24.134±12)nm**
The depth of the profile	(1000) nm	nanometers	(1240±30)nm
profile	rectangular	-	rectangular
The maximum interval of uncertainty	±10nm	nm	±12nm

Vertical standards, such as step height or depth setting standards, are utilized to calibrate the *z*-axis of scanning probe microscopes (SPMs) and stylus profilometers.



Delta Z =	89.43
Delta XY =	221384.73
Theta =	0.02
Delta Z =	89.47
Delta XY =	79279.67
Theta =	0.06
Mean	2.64 nm
Sq	43.30 nm
Sa	42.00 nm
Peak/Valley	101.56 nm



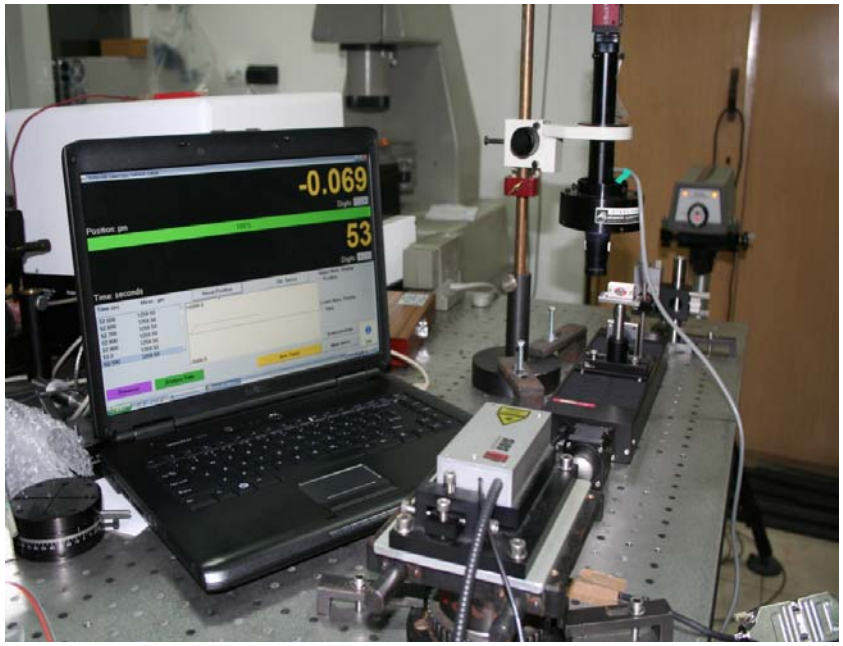
Delta Z =	79.54
Delta XY =	90007.64
Theta =	0.05
Delta Z =	68.91
Delta XY =	150012.74
Theta =	0.03
Mean	0.18 nm
Sq	40.55 nm
Sa	38.87 nm
Peak/Valley	109.95 nm

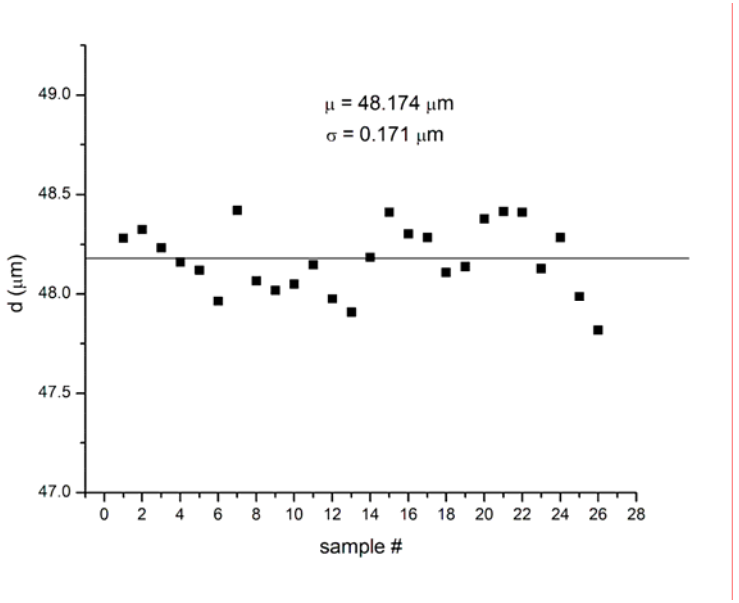
Traceable set up (optical microscope and laser interferometere) for pitch measurement

- Optical microscope
- Laser interferometer SIOS Germany
- Artefacts on moving table

2 interferometers measuring set up

There are multiple measurement techniques for measuring length at the nanoscale. However, only the interferometric techniques are readily traceable and metrological. They can be used for the calibration of other measurement techniques, either for vertical or lateral calibration. The traceability of the interferometric length measurement techniques is due to the definition of the meter standard, connected to the frequency stabilized lasers. This occurrence makes the interferometric measurement techniques naturally traceable and metrological.





Sios VERSUS Agilent

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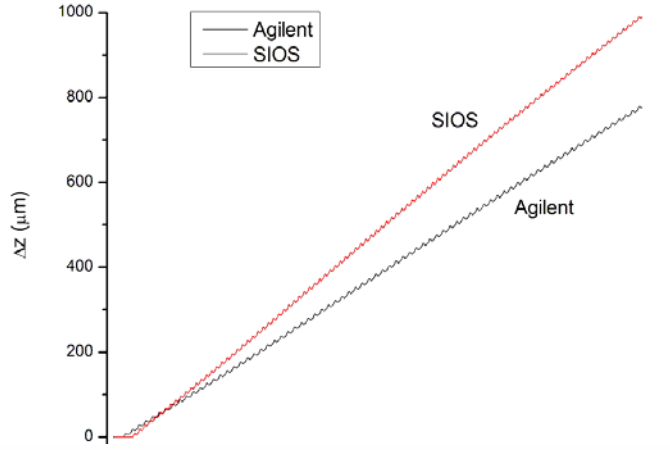
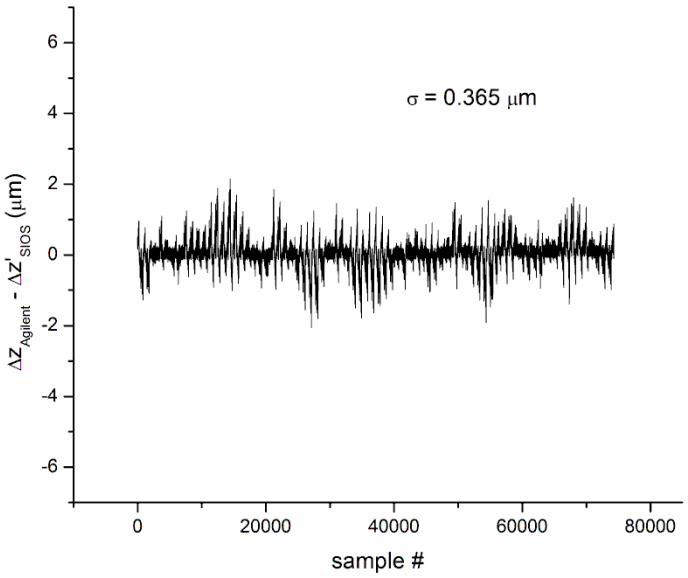
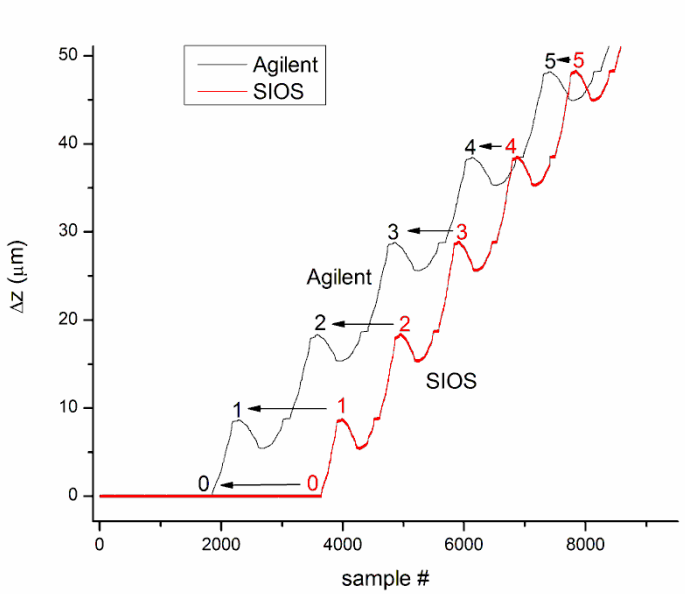
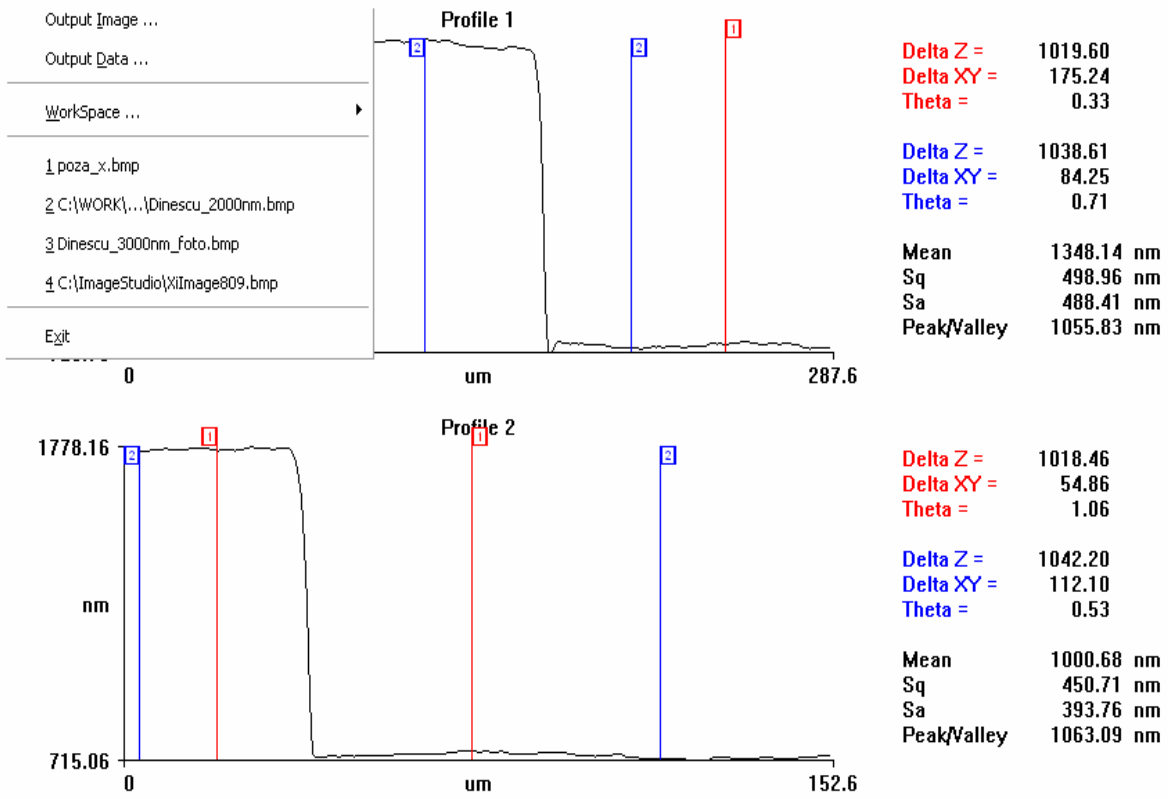






Etalon (step) de calibrare verticala (strat subtire)
Se observa ca inaltimea stratului subtire difera intre 1018nm si 1042 nm

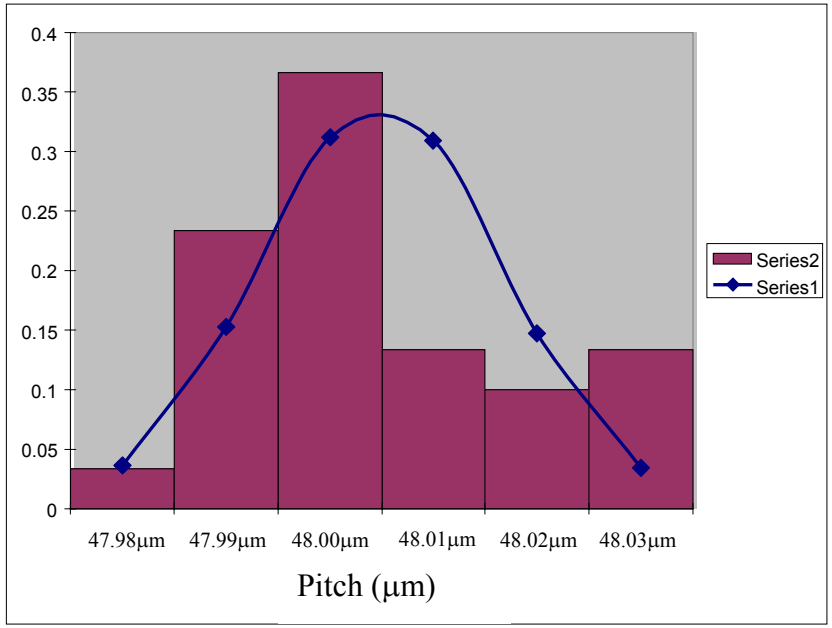


Delta Z =	1019.60
Delta XY =	175.24
Theta =	0.33
Delta Z =	1038.61
Delta XY =	84.25
Theta =	0.71
Mean	1348.14 nm
Sq	498.96 nm
Sa	488.41 nm
Peak/Valley	1055.83 nm

Delta Z =	1018.46
Delta XY =	54.86
Theta =	1.06
Delta Z =	1042.20
Delta XY =	112.10
Theta =	0.53
Mean	1000.68 nm
Sq	450.71 nm
Sa	393.76 nm
Peak/Valley	1063.09 nm

Grating	Optical Microscop	Profilometer AMBIOS XP2	SIOS laser interferometer	REMARKS
1	(48 000 ±29)nm	(48000 ±21) nm	(48007 ±10) nm	60 measurements For a 30 lines package.
2	(24000 ±39)nm	(24000µm±32)nm	(24 003 ± 10) nm	60 measurements For a 25 lines package.

. Distribution of pitch measured values obtained using the SIOS interferometer



- WLI 48µm crom -siliciu