Physikalisch-Technische Bundesanstalt

Supplementary Comparison According to the Rules of CCL Key Comparisons

EUROMET PROJECT 707

STEP HEIGHT STANDARDS

FINAL REPORT

Braunschweig, Nov. 28th 2005 / L. Koenders

1 INTRODUCTION

Recently the CCL supplementary comparison CCL-S2 for step height (NANO2[1]) has been finished. During this comparison the CMI asked the PTB to perform a comparison on step heights for SPM. Additional need arises from SPM developed at IMGC and NMi-VSL. Therefore the PTB initiated a regional comparison to disseminate the obtained knowledge to additional labs within Euromet. In contrast to CCL-S2 this comparison only focuses on the SPM and uses standards with smaller line width. The Czech Metrology Institute (CMI), CNR Istituto di Metrologia G. Colonnetti (IMGC), Swiss Federal Office of Metrology and Accreditation (METAS), NMi Van Swinden Laboratorium (NMi-VSL) and Physikalisch-Technische Bundesanstalt (PTB) agreed to participate in this comparison using their scanning probe microscopes on a set of step height samples. The comparison should support the MRA. The pilot laboratory for this comparison is the Physikalisch-Technische Bundesanstalt (PTB).

2 STANDARDS

A set of step height standards was used for the comparison. These step height standards, used for scanning probe microscopy were manufactured by the Fraunhofer Institute of Microelectronics, Stuttgart, for the PTB, Berlin. They are available with step heights between 7 nm and 2000 nm. The standards consist of a 5 mm x 5 mm silicon chip, glued on a steel disk with 12 mm diameter. The surface of these standards is made conductive and opaque by a chromium layer approximately 100 nm in thickness.

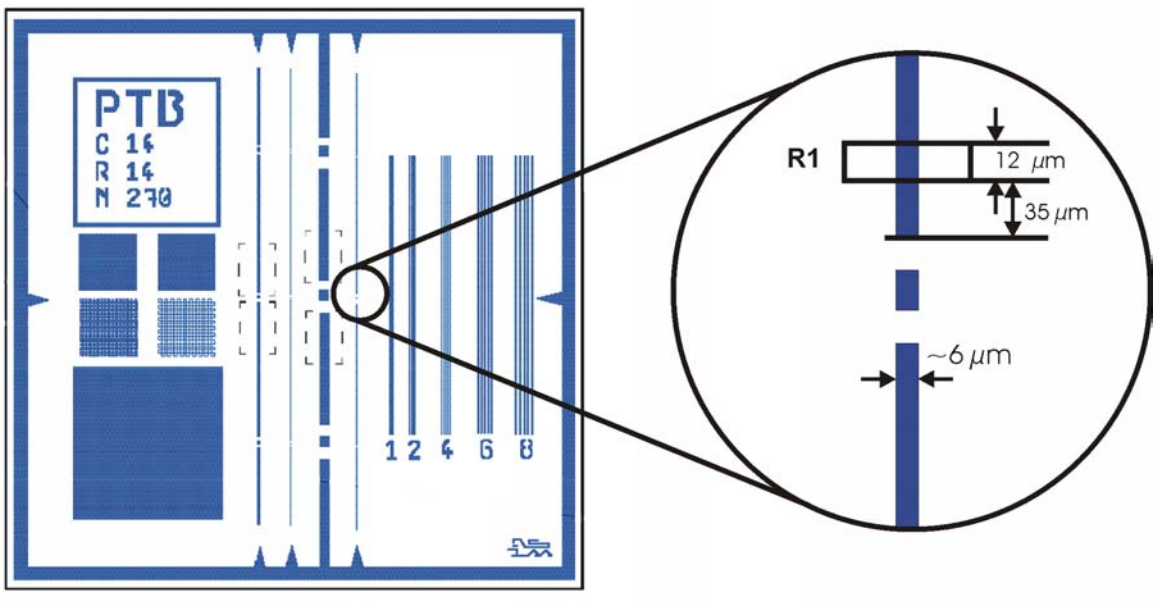

Figure 1: Layout of the step height standards of 40 nm, 1000 nm, and 2000 nm step height. The substrate is silicon, the lines are silicon oxide, and the whole sample is covered by a chromium layer (not shown). There are four lines at the centre with widths of 3 µm, 6µm, 20 µm and 100 µm. The line used for the comparison has a width of 6 µm and is located on the right side.

[1] See Metrologia, Technical Suppl. 40 (2002) 04001

The 40 nm, 1000 nm, and 2000 nm step height standards have four lines with widths of 3, 6, 20, and 100 µm as well as some other pattern which could be used for checking and calibration of the instrument. For this comparison the line with 6 µm width was used (see Fig 1). The field R1 which should have been used for the measurements is shown on the right side in the enlarged view.

3 PARTICIPANTS AND TIME SCHEDULE

3.1 ORGANISATION

Following the rules set up by the BIPM[2] a small group of representatives of the participating laboratories has drafted the technical protocol. These members are: F. Meli, METAS, and L. Koenders, PTB. By their declared intention to participate in this preliminary comparison, the participants accepted the general instructions and the technical protocol written down in the ***Euromet 707 - Technical Protocol*** document which was sent to them and committed themselves to following the procedures.

3.2 REQUIREMENTS FOR PARTICIPATION

According to the WGDM recommendation No 2 (document CCDM/WGDM/97-50b), the participating laboratories should offer this measurement as a calibration service (now or in future) and be willing to participate in a regional comparison in order to provide a link between the interregional and the regional comparisons.

3.3 PARTICIPANTS IN THE CIRCULATION

The participants of this comparison are listed in table 1.

Table 1: List of Participants

Laboratory	*Responsible*	*Address*	*Phone:, Fax, e-mail*
CMI	P. Klenovsky P. Klapetek	Czech Metrology Institute Okruzni 31 638 00 Brno Czech Republic	Phone: +420 5 45 22 27 09 Fax: +420 5 45 22 27 28 e-mail: pklenovsky@cmi.cz klapetek@physics.muni.cz-
IMGC	G. B. Picotto	CNR Istituto di Metrologia G. Colonnetti Strada delle Cacce 73 I-10135 Torino Italy	Phone: +39 011 39 77 469/473 Fax: +39 011 39 77 459 e-mail: g.picotto@imgc.cnr.it
METAS	F. Meli	Swiss Federal Office of Metrology and Accreditation Lindenweg 50 CH-3003 Bern-Wabern Switzerland	Phone: +41 31 323 3346 Fax: +41 31 323 3210 e-mail: felix.meli@metas.ch
NMi-VSL	R. Koops	NMi Van Swinden Laboratorium Schoemakerstraat 97 2628 VK DELFT The Netherlands	Phone: +31 15 269 1642 Fax: +31 15 261 2971 e-mail: rkoops@NMi.nl

[2] see http://www.bipm.fr/enus/8_Key_Comparisons/key_comparisons.html

Pilot laboratory			
PTB	L. Koenders	Physikalisch-Technische Bundesanstalt AG Schichtdicke und Nanostrukturen Bundesallee 100 D- 38116 Braunschweig Germany	Phone: +49 531 592 5120 Fax: +49 531 592 5105 e-mail: Ludger.Koenders@ptb.de

3.4 TIME SCHEDULE AND TRANSPORTATION

The comparison was carried out in circulation type. The period of time available to each laboratory was one month for calibration and transportation to the next participant. Each laboratory should have been capable to perform the measurements in the limited time allocated to it.

During the comparison a delay occurred owing to problems at METAS and at NMi-VSL. In the first case this was caused by a delay with a service of the instrument. The NMi-VSL decided to withdraw their participation and announced their intentions to take part in a future bilateral comparison.

Table 2: Time schedule

Lab.	Country	Original schedule	Confirmation of reception	Comment
PTB	Germany	March 04	-	
IMGC	Italy	April 04	8.4.2004	Samples sent to PTB on 30.4., because of small particles on the SH0040. Dust removed by cleaning in PTB. Samples sent to CMI on 4.5.2004
CMI	Czech Republik	May 04	17.5.2004	
METAS	Switzerland	June 04	8.6.2004	Storage at METAS, because of being waiting for instrument. Sent to PTB 30.8.2004
Nmi-VSL	The Netherlands	July 04		Withdrew their participation on 24.8.2004
PTB	*Germany*	*Aug 04*	*6.9.2004*	*Final measurements*

3.5 STANDARDS

The standards are stored in a special box (fig. 2). In the normal position you will see the back of the sample holder (fig. 3). The samples should be handled with care and under clean conditions.

The box contains a set of four standards (three of them were used for measurements in this comparison):

SH7 (not for measurements!)	***7 nm***	***No. C 19 R 03 N 24,***
SH40	***40 nm,***	***No. C 02 R 18 N 361,***
SH1000	***1000 nm,***	***No. C 05 R 06 N 64, and***
SH2000	***2000 nm,***	***No. C 08 R 11 N 186.***

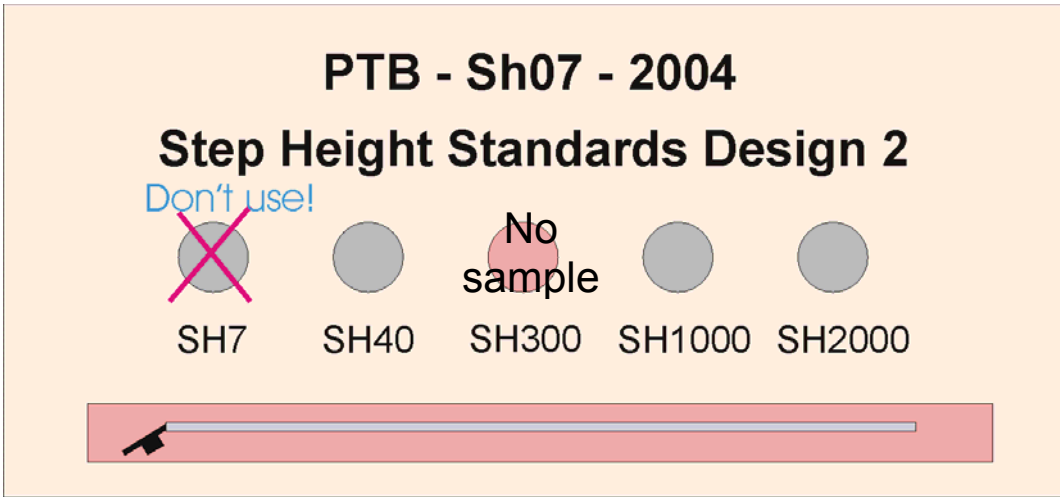

Figure 2: An example for the box with the standards and the tool for handling. In the normal position you can see the back of the sample holder (steel disk ∅ ~12mm).

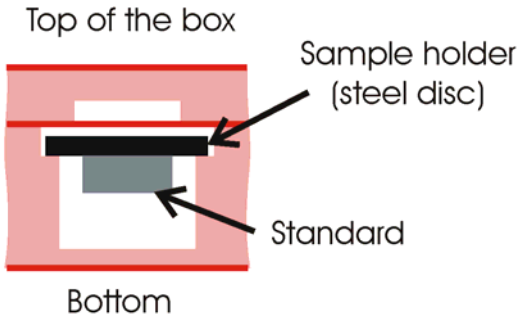

Figure 3: Section showing the position of a standard glued on the steel disk (∅~12mm) in the box.

4 MEASURAND

4.1 POSITION OF MEASUREMENT

For the comparison the measurements were performed at the area denoted as R1 (see fig 1). The area R1 is located 35 µm above the lower end of the line. The evaluation field should be 15 µm * 12 µm. At least 5 measurements should have been made over this area for the determination of the step height.

4.2 DEFINITION OF STEP HEIGHT

The step depth *h* is defined in analogy to ISO 5436. A continuous straight mean line is drawn over the line to represent the lower level of the surface and another representing the upper level, both lines extending symmetrically about the centre of the line (fig. 4). The surface at the top of the line is assessed only over the central part of its width. The step height *h* is defined as the perpendicular distance of the mean of the portion C to the line through the mean of portion A and the mean of portion B.

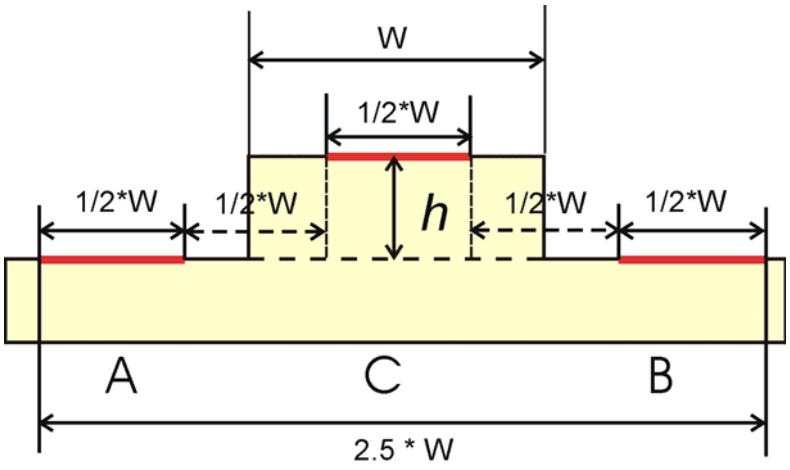

Figure 4: Definition of step height *h* used in the comparison

The measurand used in this comparison is the average height h obtained from measurements within the reference area R1 as shown in fig. 1.

4.3 REPORTING

The participating laboratories sent their report to the pilot laboratory. Their individual report contains:

- the measurement set-up and the conditions
- the result(s) of the measurements,
- the combined standard uncertainty
- the degrees of freedom,
- the complete uncertainty budget and the evaluation method.

The measured step height *h* has to be stated for the reference temperature at 20°C. The expansion coefficient of the amorphous silicon dioxide is $0.5*10^{-6}$/K. The uncertainty of the measurement has to be estimated according to *the Guide to the Expression of Uncertainty in Measurement*.

5 MEASUREMENT INSTRUMENTS

Table 3 gives an overview about the instruments used and their traceability. The full description of the measurement methods and instruments by the participants can be found in Appendix A.

Table 3. Methods of measurements

No	Institute	Method	Instruments	Traceability
1	CMI	AFM	Topometrix Accurex II	Calibrated by internal standards (see Appendix)
2	IMGC	AFM	Homebuilt SPM with plane mirror interferometer for x-y and three capacitance transducers for z-direction	Calibration of the displacement of the SPM z-stage is carried out in situ using an heterodyne interferometer with a plane mirror linear set-up. The vacuum wavelength is traceable to the iodine stabilized laser.
3	METAS	AFM	AFM profiler with interferometric long range linear displacement stage. AFM with DI metrology head.	Laser traceable to METAS standards
4	PTB1	AFM	Large Range SPM	Laser traceable to PTB standards
5	PTB2	AFM	Veritekt C with integrated laser interferometers for x, y, and z axis.	Laser traceable to PTB standards

6 STABILITY OF THE STANDARDS

Each participant was asked to inspect the standards after reception (see Euromet 707 - Technical Protocol) and to send a report to the pilot laboratory. The reference area R1 on the standards remained almost unchanged. The stability of the standards was estimated by comparing the measurement results from the LR-SPM at the beginning and at the end of the comparison.

Table 4. Stability of the step height of the standards as measured by LR-SPM

	SH0040	SH1000	SH2000
Date	*h* / nm	*h* / nm	*h* / nm
Mar-Apr 04	43.00	1012.50	2089.70
Nov-04	43.80	1012.76	2088.17
Difference	-0.80	-0.26	1.53

The results show that there is no significant change in the step height. Additional observation of the reference areas on the standards by optical microscope and interference microscope did not show any irregularities at the reference area.

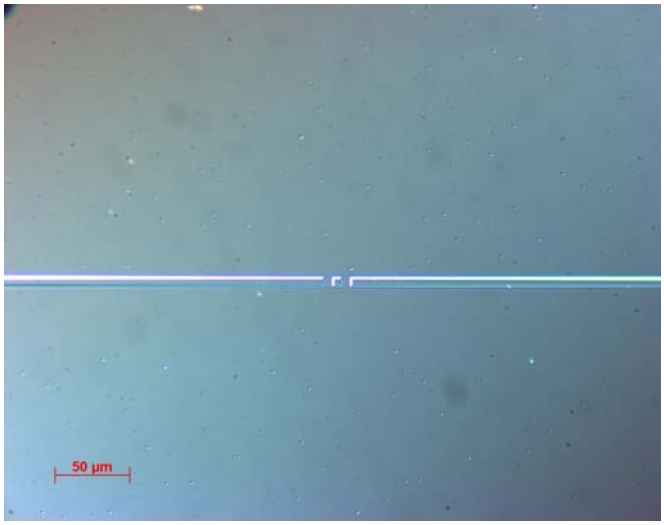

Figure 5: Picture of the SH0040 obtained by optical microscope 20x.

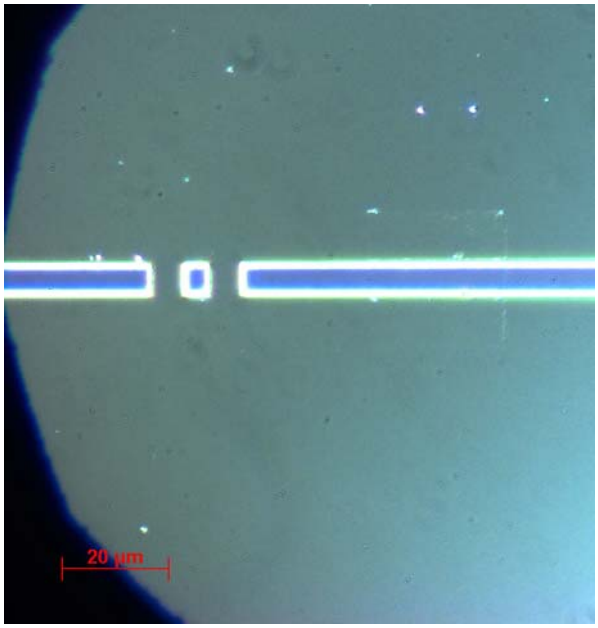

Figure 6: Picture of the SH1000 obtained by optical microscope 50x.

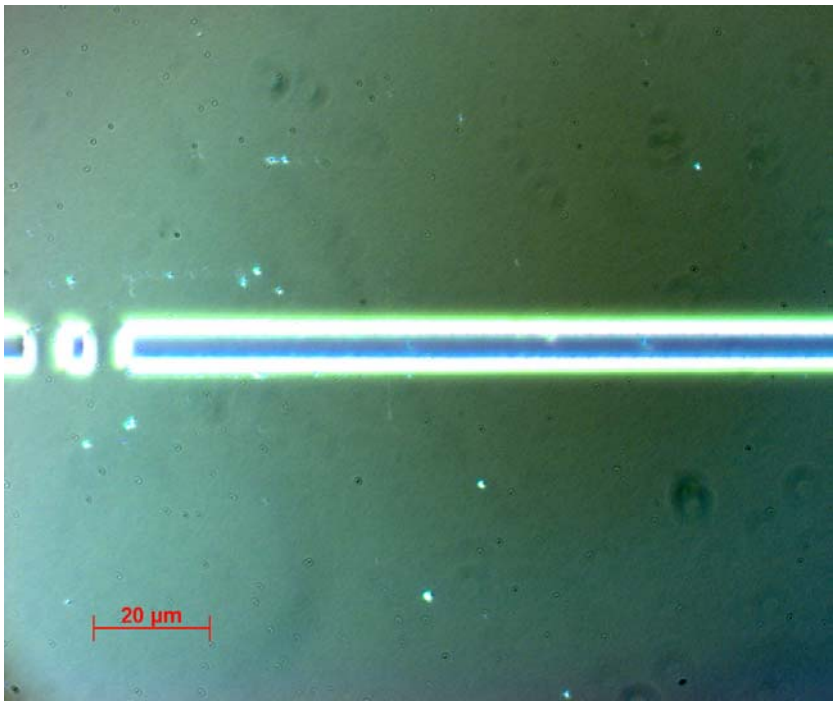

Figure 7: Picture of the SH2000 obtained by optical microscope 50x.

7 MEASUREMENT RESULTS

The results received from all the participants are presented. Besides the measured values for the step height h, the combined standard uncertainty u_c, the degree of freedom ν_{eff} and the expanded uncertainty U(k=2) are given. The En value is explained below.

7.1 RESULTS ON STEP HEIGHT STANDARD SH0040

Table 5: Step height standard SH0040

SH0040 C02 R18 N361								
Institute	Country	Meas.	h / nm	u_c / nm	$\nu_{eff}(h)$	k	U(k=2) /nm	E_n
CMI	CZ	May 04	44.9	4.4	1150	2	8.8	0.20
IMGC	IT	Apr 04	43.7	0.6	30	2	1.20	0.56
METAS	CH	Aug 04	42.92	0.59	248	2	1.18	0.19
PTB_LRSPM	DE	29.3.-6.4.	43.00	0.53	30	2	1.06	0.13
PTB_VC	DE	22.3.-6.4.	42.85	0.59	159	2	1.18	0.26

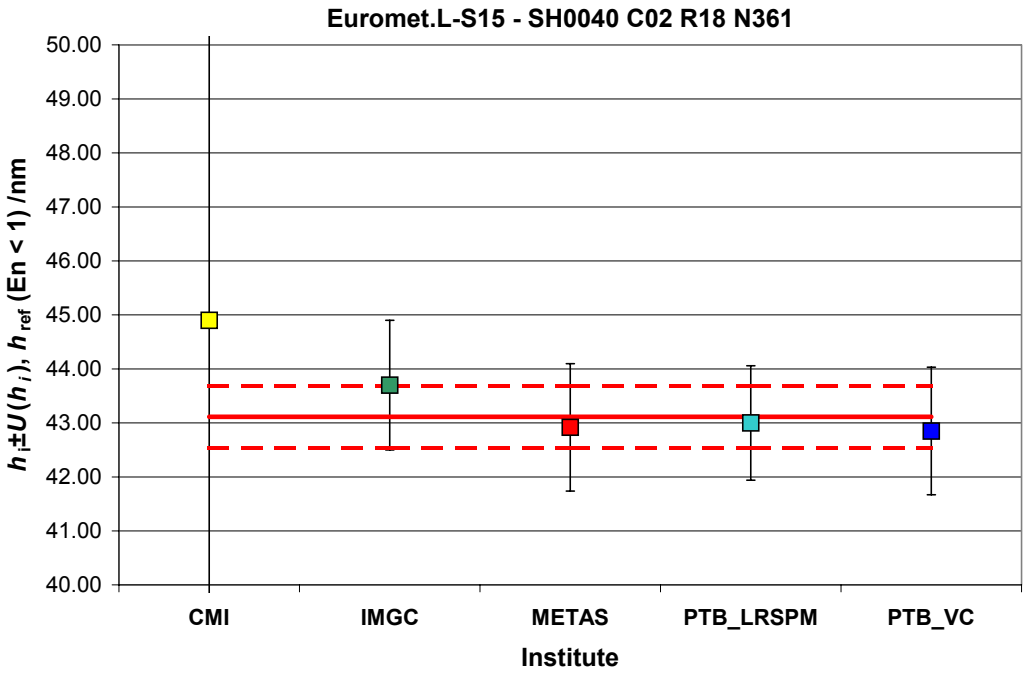

Figure 8: Measured step heights h_i of the institutes on standard SH40, reference value h_{ref} (red line) and its expanded uncertainty U_{ref} (dashed red lines) calculated from all values.

7.2 RESULTS ON STEP HEIGHT STANDARD SH1000

Table 6: Step height standard SH1000

SH1000 C05 R06 N64								
Institute	Country	Meas.	h / nm	u_c / nm	$\nu_{eff}(h)$	k	$U(k=2)$ /nm	En
CMI	CZ	May 04	1035	54	102	2	108	0.21
IMGC *)	IT	Apr 04	1035.9	3.3	25	2	6.6	3.50
METAS	CH	Aug 04	1011.2	2.4	136	2	4.8	0.30
PTB LR-SPM	DE	29.3.-6.4.	1012.5	0.57	23	2	1.14	0.12
PTB VC	DE	22.3.-6.4.	1012.8	0.62	158	2	1.24	0.22

*) IMGC: first iteration with all values gave En=3.50 by using the "-" sign if eq. 7; after omitting the IMGC value for the calculation of the reference value En has been calculated using the "+" sign in eq. 7. See also comment of IMGC in Appendix A.

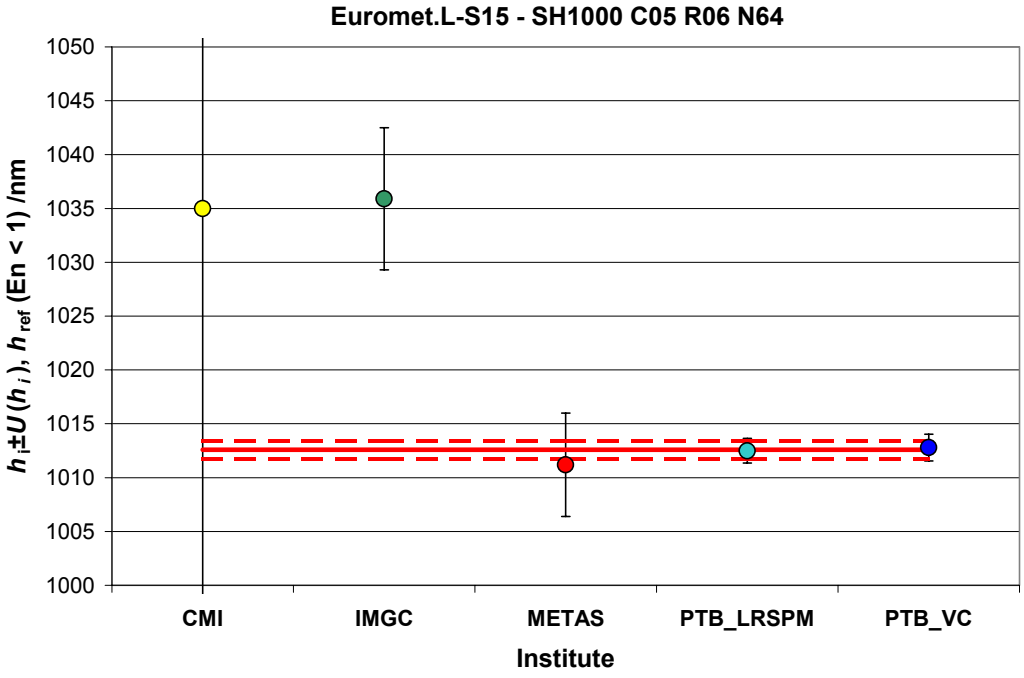

Figure 9: Measured step heights h_i of the institutes on standard SH1000, reference value h_{ref} (red line) and its expanded uncertainty U_{ref} (dashed red lines) calculated from all values with En≤ 1.

7.3 RESULTS ON STEP HEIGHT STANDARD SH2000

Table 7: Step height standard SH2000

SH2000 C08 R11 N186								
Institute	Country	Meas.	h / nm	u_c / nm	$\nu_{eff}(h)$	k	$U(k=2)$ /nm	En
CMI	CZ	May 04	2107	110	101	2	220	0.08
IMGC *)	IT	Apr 04	2128.5	4.8	30	2	9.6	3.98
METAS	CH	Aug 04	2086.6	4.8	121	2	9.6	0.36
PTB LR-SPM	DE	29.3.-6.4.	2089.7	0.76	14	2	1.52	0.29
PTB VC	DE	22.3.-6.4.	2090.4	0.74	188	2	1.48	0.37

*) IMGC: first iteration with all values gave En=3.98 by using the "-" sign if eq. 7; after omitting the IMGC value for the calculation of the reference value En has been calculated using the "+" sign in eq. 7. See also comment of IMGC in Appendix A.

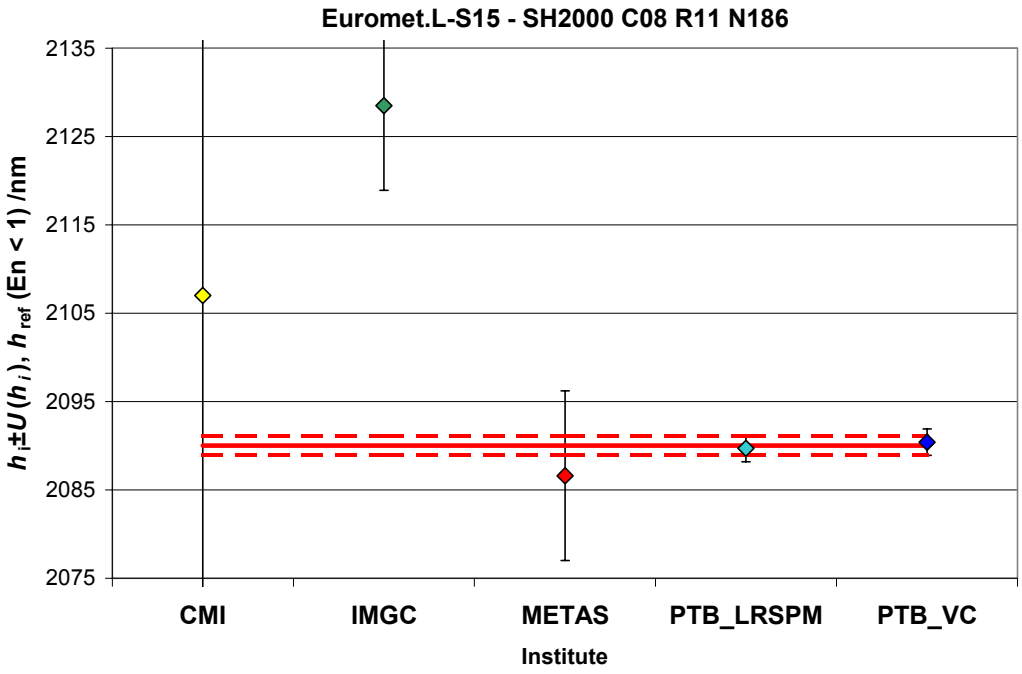

Figure 10: Measured step heights h_i of the institutes on standard SH2000, reference value h_{ref} (red line) and its expanded uncertainty U_{ref} (dashed red lines) calculated from all values with En≤ 1.

8 UNCERTAINTY BUDGET

The uncertainty of the measurement was estimated according to the *Guide to the Expression of Uncertainty in Measurement*. The participating laboratories were encouraged to use all known influence parameters for the measurement method applied by

them. The step height h of the standards is expressed as a function of the input quantities x_i

$$h = f(x_i). \qquad (1)$$

The combined standard uncertainty $u_c(h)$ is the square sum of the standard uncertainties of the input quantities $u(x_i)$, each weighted by a sensitivity coefficient c_i

$$u_c^2(h) = \sum_i c_i^2 u^2(x_i) \text{ with } \qquad c_i = \frac{\partial h}{\partial x_i}. \qquad (2)$$

The uncertainty components should be divided into components associated with the realisation of the object compared, and those associated with the comparison method.

Contributions to the uncertainty budgets depend on the method and the instrument used (some added in the Appendix):

1. calibration
- vacuum wavelength of laser
- refraction index of the air
- interferometer alignment
- uncertainty of calibrated standards used
- non-linearity of the instrument
- angular motion of translation stages
- Abbe offset

2. measurement
- sample alignment
- noise of instrument
- repeatability

3. evaluation
- profile evaluation and filtering
- roughness of the standard
- non-planarity/out of plane motion
- temperature of the standard

9 ANALYSIS OF DATA

9.1 REFERENCE VALUE AND ITS UNCERTAINTY

The reference value (h_{ref}) for this step height comparison is calculated as the weighted mean of all measurements (h_i). The weights are $u^{-2}(h_i)$. For each step height standard a reference value was calculated. To set up the $|En| \leq 1$ criterion [3], the expanded uncertainty U with a coverage factor of $k = 2$ was used [4]. Measurements with $En > 1$ have to be omitted one by one for the calculation of the reference value. By this all values contributing to the reference value fulfil $En \leq 1$.

[3] http://www.euromet.org/pages/guides/guide.htm in Guidelines for the organisation of comparisons
[4] W. Wöger, Remarks on the E_n –Criterion Used in Measurem. Comp.: PTB-Mitteilungen 109 (1999) 24

Reference value $$h_{ref} = \frac{\sum_{i=1}^{n} u^{-2}(h_i) \cdot h_i}{\sum_{i=1}^{n} u^{-2}(h_i)} \quad (3)$$

Combined standard uncertainty $$u_c(h_{ref}) = \left(\sum_{i=1}^{n} u^{-2}(h_i) \right)^{-\frac{1}{2}} \quad (4)$$

Degree of freedom $$\nu_{eff}(h_{ref}) = \frac{u_c^4(h_{ref})}{\sum_{i=1}^{n} \frac{u_i^4(h_{ref})}{\nu_{eff}(h_i)}} \text{ with } u_i(h_{ref}) = |c_i| \cdot u(h_i) = \frac{u^{-1}(h_i)}{\sum_{i=1}^{n} u^{-2}(h_i)} \quad (5)$$

Expanded uncertainty using k=2 $$U(h_{ref}, k=2) = 2 \cdot u_c(h_{ref}) \quad (6)$$

En-criteria $$En(h_i) = \left| \frac{h_i - h_{ref}}{\sqrt{U^2(h_i) \pm U^2(h_{ref})}} \right| \quad (7)$$

The minus sign in the denominator of (7) should be used for values contributing to the reference value, because of correlation effects, but a plus sign for values not contributing to the reference value.

One fact has to be pointed out:

In this comparison there are two results for each standard from PTB, because this institute used a modified Veritekt (Veritekt C) and a new Large Range SPM. Both instruments are traced back to a iodine stabilized HeNe laser. The calculation showed that the influence of correlation effects is negligible. Therefore both instruments were included in the calculation as independent instrument.

Performing the calculation using the above formulas we obtained the En values listed in the tables 5 to 7.

In detail:

1. For the SH0040 all values reported here fulfil the En criteria. The value of the CMI considering its uncertainty overlaps with the reference value.

2. The SH1000 value of IMGC does not fulfil the En ≤ 1 criteria. All other values reported here fulfil the En criteria. The value of the CMI lies above the reference value (see Fig. 9), but including the uncertainty of the CMI value given overlaps with the reference value.

3. The IMGC value for the SH2000 has an En of 2.43 after the first iteration. Therefore it has been neglected during further calculation of the reference value. All other values reported here fulfil the En criteria. The value of the CMI considering its uncertainty overlaps with the reference value (see Fig. 10).

The final reference values calculated with the remaining results are listed in table 8 together with their uncertainties and the calculated Birge ratio R_B.

Table 8: Reference values, uncertainties, expanded uncertainty, degree of freedom ν_{eff} ***and the Birge ratio*** R_B

Standard	h_{ref} / nm	u(h_{ref}) /nm	U(k=2) /nm	ν_{eff}	R_B	n
SH0040	43.11	0.29	0.57	193	0.61	5
SH1000	1012.60	0.41	0.83	75	0.46	4
SH2000	2090.0	0.53	1.1	56	0.57	4

R_B is the Birge ratio and n is the number of results used for the calculation of the reference value. The Birge ratio defined as

$$R_B = \frac{u_{ext}}{u_{in}} \tag{8}$$

$$\text{with} \quad u_{ext} = \sqrt{\frac{\sum_{i=1}^{n}\left[\left(h_i - h_{ref}\right)/u_i\right]^2}{(n-1)\sum_{i=1}^{n}u^{-2}(h_i)}} \qquad \text{and } u_{in} = u_c(h_{ref}) \tag{9}$$

and is calculated to check the statistical consistency of a comparison. It compares the observed spread of results u_{in} with the spread of the estimated uncertainty u_{ext}. A value of R_B close to 1 or less suggests that results are consistent, whereas values much greater than 1 suggest that results are inconsistent. [5] For this comparison the Birge ratio R_B calculated is in the range of 0.6.

Also a Chi Square test was made following the procedure described by Cox[6]. All data used here fulfil the Chi Square criteria.

10 CONCLUSIONS AND REMARKS

The following conclusions are drawn from this comparison:

1. The comparison was performed between a small number of participants and in a short time. All participants performed their measurements very carefully and with best detailed knowledge of their instruments.

2. Compared to NANO2 the step height range measured was extended from 800 nm up to step heights of 2000 nm. The results show that such step heights on samples can be measured with very small uncertainties using sophisticated instruments.

[5] R. Kacker, R. Datla, A. Parr, Metrologia 39 (2002) p. 279 - 293
[6] M. G. Cox , Metrologia, 2002, 39, 589-595

3. Nevertheless, the comparison reveals clearly, that an instrument has to be very carefully examined before it should be used for daily calibration, specially for very high steps in the micrometer range.

4. In the case of large uncertainties this has to be checked carefully. What are the reasons? What could be done to improve this in the future? Scanning probe microscopes have the advantage of very high lateral resolution, but on the other side some tasks could also be realised with stylus instruments and interference microscopes with small enough uncertainty as it has been shown in the NANO2 comparison.

11 APPENDIX A

CMI

AFM Accurex II.L (commercial instrument, Topometrix), contact mode, standard pyramidal AFM contact tip, measured several times according to internal calibration methodics, step height evaluated using all the prescribed area that was selected on 50 μm x 50 μm micrometers, 1000 x 1000 pixels large AFM scan.

Calibration and Traceability
The AFM is calibrated in the x-y direction by means of interferometric grating calibrated in CMI Prague branch by means of laser diffraction. Thus traceability in the x-y direction is direct.

Z direction is calibrated from the x-y direction using an anisotropic etched silicon sample that have angles strictly known from crystallography. This unfortunately leads to higher uncertainty as there are two steps more in comparison to use of the step height standard or interferometer in the z-direction.

Comment by CMI
Unfortunately, our relatively new AFM head (Explorer, Veeco) that we use mostly for metrology purposes was in repair during the comparison. Therefore we has to use a very old system we have (Topometrix Accurex II.L). The z-axis of this instrument is unfortunately calibrated in relatively complicated manner and the large number of steps in traceability result in very large uncertainty. However, the results of the comparison are valuably for us anyway. We see now that we have to redesign the calibration process even for the old instrument.

IMGC

The instrument is based on a sample-moving scanning device operating in a working volume of 30 µm x 30 µm x 15µm with interferometer and capacitance-based controls of displacements.

The *xy* stage uses plane-mirror linear interferometers and fast phase-meters to monitor and control the horizontal movements of precise ball-bearing stages, whereas the *z*-stage uses three pairs of capacitive sensors and PZT bimorph plates driving a kinematic sandwich-like assembling of two plates, the upper one supports the sample and can be easily removed and precisely repositioned for sample handling. The capacitive sensors have the double purpose to guarantee a pure parallel movement, namely *z* displacements free of pitch and roll tilts, and to deliver a measurement of the displacement itself.

On the upper part of the microscope structure, either tunnel or atomic force heads can be accommodated following the measurement needs. The SPM microscope makes use of the electronic control and data acquisition system of a commercial SPM.

The vertical displacements driven by the z-stage have been calibrated off-line by means of a plane-mirror linear interferometer along the z-axis and with a small moving mirror mounted on the sample support.

Comment by IMGC

The IMGC results show a deviation (about 2% higher than the reference values) for the larger step heights of 1000 nm and 2000 nm. At the time we were asked by the pilot to check our results we could check the results for data evaluation. Nevertheless, we could not check the instrument because the control system of the SPM used has got a break down in between.

Now, the SPM system has been provided with new electronics. The IMGC would be very pleased to participate in a follow-up bilateral comparison to get evidence that the z-scale factor has been corrected.

METAS

An AFM profiler system consisting of a linear long range sample displacement stage and a commercial metrology AFM head (Digital Instruments) was used for the step height measurements. The linear displacement stage moves the sample up to 380 µm horizontally while the AFM head probes the surface with a sharp silicon tip and measures the local height. An optical zoom video microscope and a coarse x-y table allow an easy positioning of the location of interest below the tip (Fig. 1). The linear long range displacement stage consists of monolithic flexures forming a double parallelogram and is piezo actuated. The position is adjusted by a 21 bit DSP controller using a capacitive position sensor signal for the feedback [1].

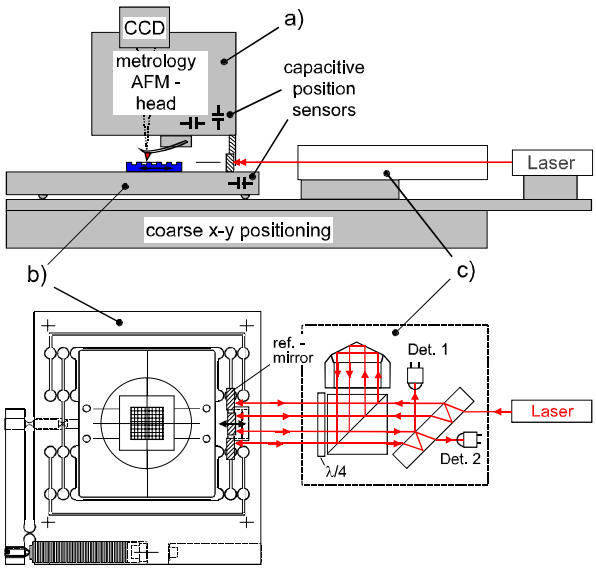

Figure 1: General setup of the long range AFM profiler system. a) metrology AFM head including a video microscope, b) piezo actuated linear long range displacement stage with monolithic flexures forming a double parallelogram and c) schematic of the differential double pass plane mirror interferometer with HeNe-laser.

The z-position of the AFM tip is measured by a capacitive position sensor inside the AFM head. The calibration of this sensor was made interferometrically using a 90°-deflection mirror with almost the same configuration as for lateral measurements [2]. Figure 2 shows the setup for the interferometric z-axis calibration. A target mirror was fixed below the AFM tip and a 90°-deflection mirror below the scanner was used to deflect the two laser beams of the differential plane mirror interferometer into the vertical direction. The reference mirror of the differential interferometer is attached to the linear displacement stage. X-movements of the stage with respect to the interferometer are therefore cancelled.

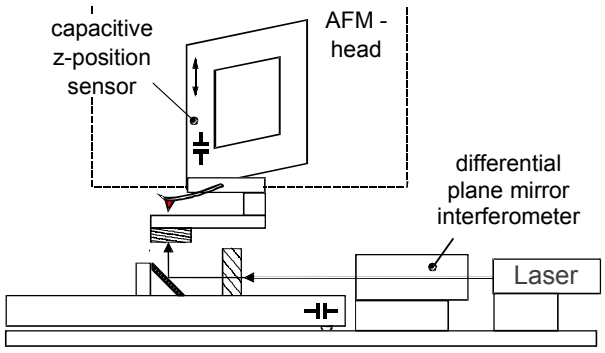

Figure 2: General setup of the AFM z-axis calibration with interferometer and 90°-deflection mirror.

The measurement strategy

The AFM was always operated in tapping mode. To reduce the effect of drift always a pair of trace and retrace profiles were evaluated together. On each sample 13 profile pairs, distributed equally over the measurement field R1 with the area of 15 µm x 6 µm were acquired. The profiles were measured over a length of 35 µm with approximately 25 nm data spacing. For each profile the evaluation was made on the central 15 µm with sub ranges for the upper and lower part of the ridge according to the instructions. Two lines were fitted through the corresponding ranges and the local height was calculated to be the distance of the two lines at the centre of the ridge. To reduce the influence of impurities only profile data points within two sigma were used for the line fitting. Finally the step height is given as the average of all 13 local height pairs (see evaluation illustrations below).

Uncertainty

Since the Nano2 comparison the AFM head had to be repaired and new investigations were made. The behaviour of the z-stage is now better but still not perfect. This fact was considered by a new contribution to the uncertainty called hysteresis of the z-stage. The observed hysteresis is in fact a hysteresis of the angular distortion of the linear movement and depends on the z-range (step height).

References:

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[2] Measurement Science and Technology, **9**, 1998, p. 1087-1092)

PTB 1 - LRSPM

The measurement of the step height was carried out with a metrological Large Range Scanning Probe Microscope (LR-SPM) (Fig. 1).The system is described in more details in several papers [1-3].The positions on the three coordinate axes were measured using three optical interferometers that were illuminated with stabilized lasers. The optical frequencies of the lasers were calibrated using an iodine frequency stabilized laser.

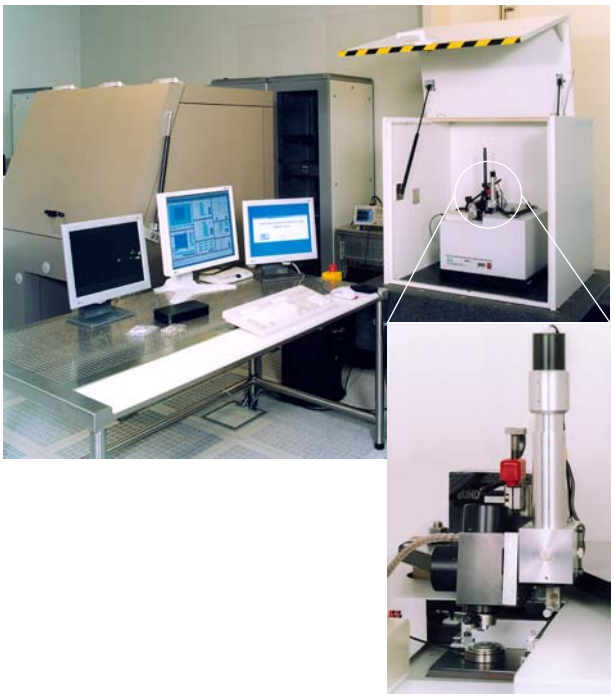

Figure 1: Large Range SPM environment and the SPM-head of the instrument on Nano-Measuring-Maschine (NMM)

References

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PTB 2 – Veritekt C

A principle sketch of the M-SFM "Veritekt C" is shown in figure 1. The version "C" is a modified version of the "Veritekt B". That type of SPM has been described in several papers including the report about NANO2 [1-3] in more detail. It is a scanning sample system with a stationary fixed cantilever probe. The 3D monolithic flexure-hinge stage with a scanning range of 70 µm x 15 µm x 15 µm along x-, y- and z-axes, respectively, is driven by piezoelectric translators (PZTs) equipped with capacitive sensors. The sample holder is fixed on the flexure-hinge stage. Its position is measured by three homodyne planar interferometers, which were designed in co-operation with *SIOS Messtechnik GmbH* and the Technical University of Ilmenau [4]. When the sample is mounted, its measurement point lies at the point of intersection of the three interferometer measurement beams so that the Abbe error can be minimized.

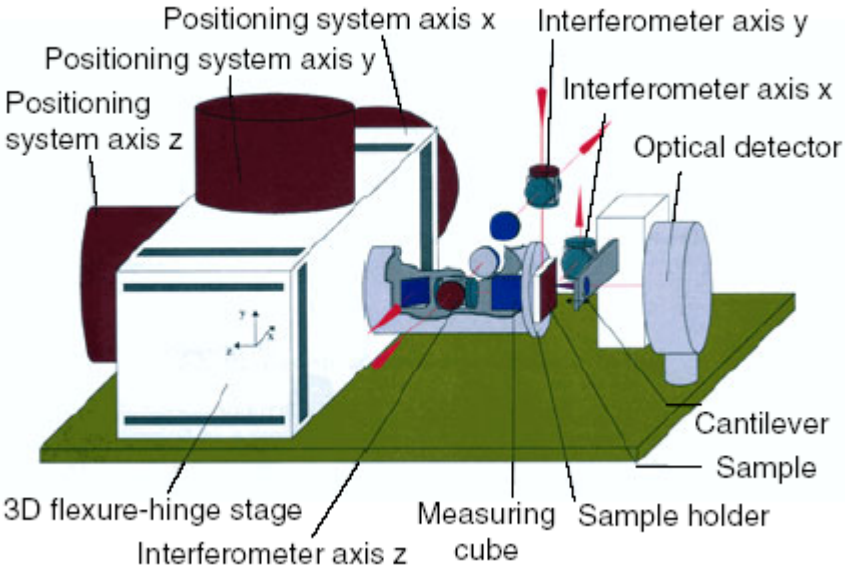

Figure 1: Sketch of the Veritekt C

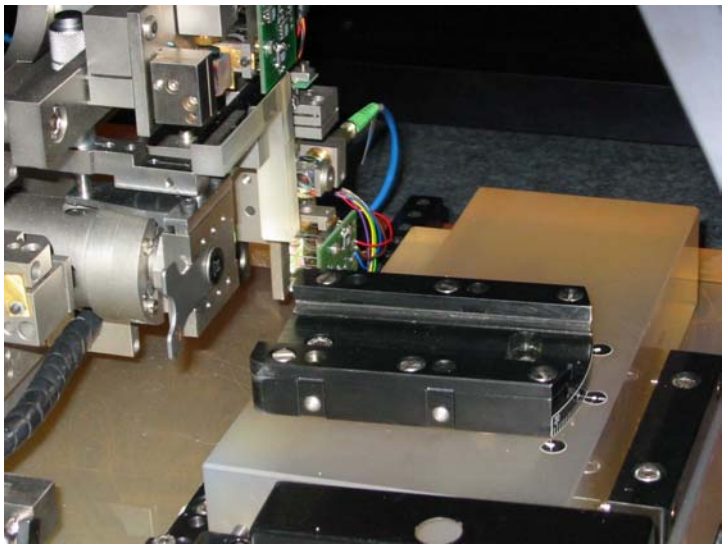

Figure 2: View of the metrological SFM (tip sensor unit removed)

For measurement, the sample is coarsely approached to the tip by a step motor (not shown in figure 2), and is then scanned in contact mode. In this mode, the bending of the cantilever, measured by an optical detector, is kept constant. The base plate is made from Zerodur and the remaining structures are almost all made from super invar to enhance the thermal stability.

The “Veritekt C” is implemented with a newly designed DSP-based signal processing system. By implementing this design [5], the “Veritekt C” is improved at two important aspects. Firstly, the interferometer signals are processed with online Heydemann corrections result in a reduction of the non-linearity of the interferometers from about 3.5 nm to less than 0.3 nm. This allows us to use the interferometers for direct position measurement, and thus change from the calibration mode to the direct measurement mode. Secondly, sensors of the M-SFM, including all interferometers and the optical detector of the cantilever, are sampled synchronously; this permits to significantly increase the scanning speed of the M-SFM.

The bending of the cantilever has to be calibrated traceably since it is incorporated in the measurement results. For this purpose, an automatic procedure has been implemented to calibrate the tip signal against the z-axis interferometer *in situ*: after approaching the tip towards the sample, the sample is moved in the z-direction for about 50 nm while keeping its x-, y-position unchanged; therefore, a fixed point on the sample is measured by the SFM tip, and the sum value of the z-axis interferometer and the bending of the cantilever should be constant. By recording simultaneously the values of the z-axis interferometer and the tip signal, the tip signal can be calibrated. This automatic calibration procedure does not need any other additional devices or changes in the experimental set-up and can be executed easily within the measurement software.

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