

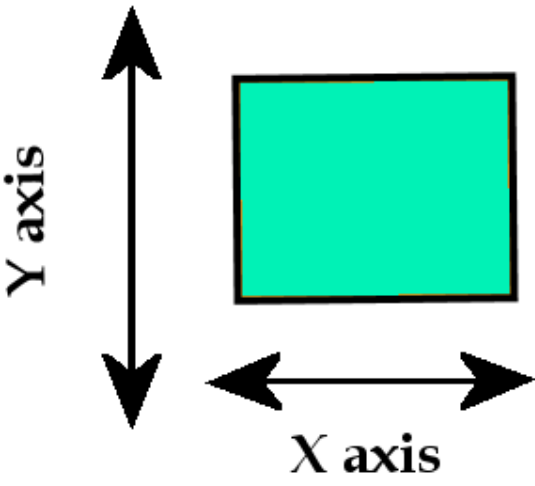
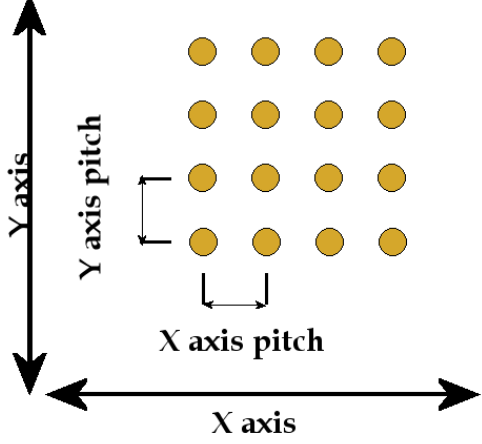
Certificate of Traceable Calibration of Pitch Standard

Object: X and Y calibration standard for Scanning Electron and Scanning Probe Microscopes

Model: 150-2DUTC

Serial Number: 3206J02◊

Material: A 2-dimensional calibration grating with a nominal pitch of 144 nm. The standard comprises Al bumps on a rectangular Si substrate (approximately 3x4 mm). The rows and columns are approximately parallel to the edges of the rectangle. The pattern covers the entire surface. The X and Y axes and the X pitch and Y pitch values are indicated in the following sketches.

 <p>The diagram shows a cyan square representing the substrate. A vertical double-headed arrow to the left is labeled 'Y axis', and a horizontal double-headed arrow below is labeled 'X axis'.</p>	 <p>The diagram shows a 4x4 grid of yellow circles representing Al bumps. A vertical double-headed arrow to the left is labeled 'Y axis'. A horizontal double-headed arrow below is labeled 'X axis'. A bracket between two rows is labeled 'Y axis pitch', and a bracket between two columns is labeled 'X axis pitch'.</p>
<p>The X axis is parallel to the long (4 mm) edge of the substrate.</p>	<p>The X axis pitch is the distance from column to column. The Y axis pitch is the distance from row to row.</p>

Identification: The standard itself is unmarked, but its package is marked with the model and serial numbers.

Date of Calibration: ◊

Date of Certification: ◊

Reference Number: ◊

Certified Measurements (in nm)

X axis Pitch: 143.931 +/- 1.3 nm

Y axis Pitch: 143.945 +/- 1.3 nm

The uncertainty refers to measurements of a single pitch value.

Number of independent pitch measurements: more than 300

The reported uncertainty provides a 95% confidence interval, with a coverage factor k=2, as recommended in ANSI/MCSL Z540-2-1997 "American National Standard for Calibration - U.S. Guide

SAMPLE

to the Expression of Uncertainty in Measurement”.

Environmental conditions

During this measurement run, the temperature and humidity ranges were:

Temperature: $\langle \rangle^{\circ}\text{C}$

Relative Humidity: $\langle \rangle\%$

Measurement Procedure

Traceable calibration is accomplished by measuring 2 objects repeatedly during the same data capture run:

- the calibration standard
- the object to be calibrated (test specimen)

The calibration standard was Advanced Surface Microscopy Model 150-2DUTC calibration grating, serial number 3206J0202, which was calibrated at Physikalisch-Technische Bundesanstalt (PTB). PTB is the German counterpart of the USA NIST (National Institute of Standards and Technology). Like NIST, measurements by PTB are traceable to the international standard meter. The calibrated pitch values for this grating are: X axis 143.928 ± 0.015 nm and Y axis 143.931 ± 0.015 nm, where the uncertainty provides a 95% confidence interval, with a coverage factor $k=2$. This uncertainty refers to measurements of the average pitch value.

For the calibration standard, up to 10 spots were selected on a grid covering most of the area of the specimen, excluding a margin about 0.5 mm from each edge.

For the object to be calibrated (150-2DUTC specimen), 10 spots were chosen randomly within a region covering most of the area of the specimen, excluding a margin about 0.5 mm from each edge.

We used a Veeco Metrology/Digital Instruments NanoScope IIIA/Dimension 3100 Scanning Probe Microscope, operating in contact mode. At each spot, we captured a $10\ \mu\text{m}$ image consisting of 512×512 pixels. The scan rate was 5 Hz.

In the X axis run, we used 10 calibration images and 10 test specimen images.

In the Y axis run, we used 10 calibration images and 10 test specimen images.

Data Analysis

We analyzed the height images using Advanced Surface Microscopy’s DiscTrack Plus™ software. In a given run of the software, we measured the pitch using one test specimen image and two calibration reference images, one captured before the test image and one captured after. This procedure increases accuracy by correcting for short term drift in the instrument’s calibration and it increases precision by using redundant calibration data.

The measurements were made according to procedures described in "Automated, high precision measurement of critical dimensions using the Atomic Force Microscope", Donald A. Chernoff and David L. Burkhead, J. Vac. Sci. Technol. A 17, 1457 (1999) and US Patents 5,644,512 and 5,825,670. Briefly, the software measures individual pitch values in the calibration images, creates a length scale which corrects for the microscope magnification error and nonlinearity which is revealed by the calibration image, and applies that length scale to produce corrected pitch measurements from the test specimen image.

Advice to users of this pitch standard

Our observations indicate that the uncertainty of single pitch values is dominated by random surface and

edge roughness. It is necessary to average many points in order to obtain high accuracy. This averaging can be done by eye using a straightedge or by use of an automated measurement system, as is done here. Because of these random effects, one can use a simple model to estimate uncertainty of pitch measurements. For a measurement interval corresponding to N pitch intervals ($N < 11$), the uncertainty can be estimated by dividing the uncertainty of a single pitch value by the square root of N .

Other Notes

It is generally accepted within the community of scientists working on micrometer and nanometer scale calibration that pitch measurements made on different kinds of instruments (AFM, SEM, OM, optical diffraction) are equivalent.

Additional technical information about the certification is available on request.

If this certificate is reproduced, the entire certificate must be reproduced. Any exceptions require written authorization from Advanced Surface Microscopy, Inc.

Signature of Responsible Scientist

Donald A. Chernoff, Ph.D.