NIST Accurray Standards – Scale Factor Calibration

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Nanoscale position errors due to inaccurate microscopy measurements, such as by scanning electron microscopy (SEM), atomic force microscopy (AFM), and optical microscopy (OM), cause problems in many applications. Tool matching and hybrid metrology become difficult in semiconductor manufacturing, with a target uncertainty of ± 0.1 nm at 68 % coverage.[1] Production yield decreases in the integration of quantum emitters and photonic structures.[2] Spurious bodies of literature emerge due to aberration effects in colloidal tracking.[3] To address the root issue, we are developing NIST Accurray Standards, with the goal of disseminating microscopy standards and calibrations that are, if not completely universal, then widely applicable, broadly available, and easily usable.

Microscopy standards have several important features. Beyond the need for stability, the most reliable standards are traceable to the International System of Units (SI) with low uncertainty. As well, arrays of nanostructures enable calibration of magnification and correction of distortion, among other common aberrations. However, no nanostructure array is available with two key metrics—a scale factor uncertainty of 10^{-6} to limit resulting position errors to less than 0.1 nm across a field of up to 100 µm, and feature position maps with absolute position uncertainty of less than 0.1 nm for local calibrations.

The NIST Length Scale Interferometer (LSI) has supported the previous development of microscopy standards by certifying traceable pitches for a few master standards. Some of us recently recommissioned the LSI,[4] and we are currently developing line–space gratings with optimal contrast and automating the acquisition of replicate measurements to reduce scale-factor uncertainty toward a potential floor of 10^{-7}. We presently surpass the historical performance of the LSI (Figure 1), achieving a relative uncertainty of 3×10^{-6} for a submillimeter distance between the bounding lines of a grating (Figure 2a).

A challenge of calibrating previous microscopy standards was transferring scale factor from one master standard to many individual working standards, as well as mapping many feature positions for each working standard, requiring a metrology method with low uncertainty and high throughput. Super-resolution OM with a hybrid of Fourier and localization analyses can meet this need. Accordingly, we prototype a microscopy scale-factor transfer standard (MiSFTS) to extend a calibration chain from LSI, through OM, and on to SEM and AFM. We show the potential for scale-factor transfer by OM with additional relative uncertainty of 3×10^{-7} (Figure 2b), which we can reduce further to negligibility, while OM self-calibration can minimize localization uncertainty to map individual features.

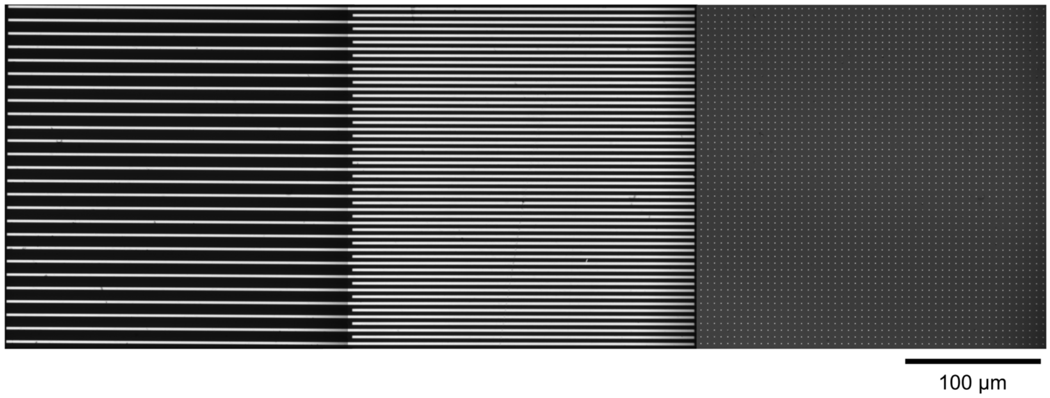

Figure 1. NIST Accurray Standards. Composite optical micrograph showing (left) a line–space grating with a nominal pitch of 10 µm, (center) a line–space grating with a nominal pitch of 5 µm, and (right) a nanopillar array with a nominal pitch of 5 µm.

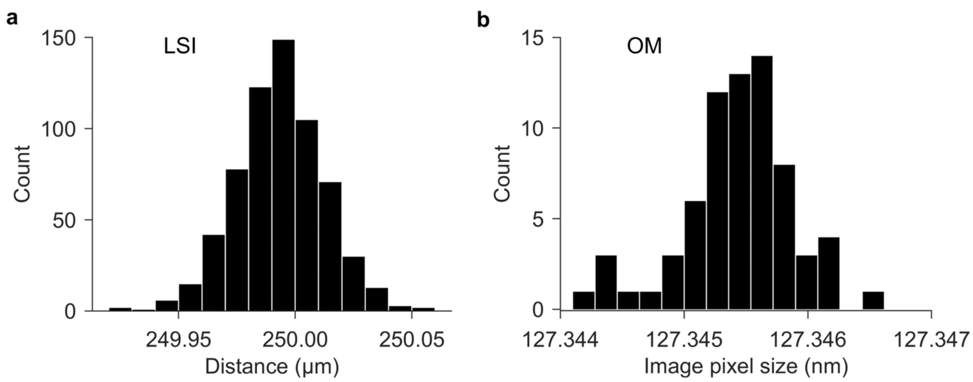

Figure 2. (a) Histogram showing traceable measurements of the distance between the first and last lines of a line–space grating. The nominal distance is 250 µm. Replicate measurements give a mean distance of 249.9934 µm ± 0.0007 µm, or a relative uncertainty of 3×10^{-6}, which surpasses the historical performance of the NIST LSI. The relative error of distance for this particular grating is 3×10^{-5}, resulting from electron-beam lithography with interferometric measurements of stage position to correct electron-optical aberrations.[2] (b) Histogram showing scale-factor calibration of an optical microscope.[2] The pitch of a line–space grating gives a nominal reference value to calibrate image pixel size, using Fourier analysis and accounting for angular misalignment. Replicate measurements give a mean pixel size of 127.3454 nm ± 0.00005 nm, or a relative uncertainty of 3×10^{-7}. Uncertainties are 68 % coverage intervals, corresponding to a standard error of the mean.

Acknowledgements

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