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Traceable Measurements using a Metrology Scanning Electron Microscope

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The increasing need for traceable nanometer-level metrology [1,2] has led to the development at the National Institute of Standards and Technology (NIST) of a specialized, metrology scanning electron microscope (M-SEM) having a metrology stage measured by a laser interferometer system. The purpose of the M-SEM is to carry out traceable calibrations of pitch and linewidth on standard reference samples using nanometer-level positioning of the sample under the electron beam in the SEM. The M-SEM will also be used for customer measurements on other reference materials such as those used in integrated circuit and nanotechnology development and production. This paper introduces the metrology, measurement and control system design, uncertainty budget, preliminary results, and the design of a planned reference artifact.

The M-SEM uses laser interferometers for sample displacement measurements traceable to the International System of Units (SI). The X-Y sample-stage position is measured while synchronously recording the secondary or backscattered electron output signal of the SEM. The M-SEM has a large sample capability (200 mm and 300 mm wafers and 150 mm photomasks) with 100 mm by 100 mm measurement coverage in the center. With variable landing energy and variable vacuum capability, the SEM can measure a large and diverse set of samples without conductive coatings. The field emission electron gun has better than 1 nm ultimate spatial resolution. The M-SEM is housed in a special laboratory incorporating an air-suspension vibration-isolation slab and a clean enclosure, thus achieving high-end SEM performance.

The 40 pm resolution homodyne interferometer system with phase sensitive photo detectors uses fiber-optic delivery of the laser light directly to the measurement axes. This results in a reduced optical path complexity, lower thermal drift, and a smaller footprint, enabling the interferometer optics to mount directly on the SEM sample chamber. High planarity mirrors are mounted on the SEM column and motion stage in both X-Y directions for differential measurement of sample position with respect to electron optical column, as shown in Figure 1. The interferometer system provides sub-nanometer non-linearity and will track velocities up to 1 m/s.

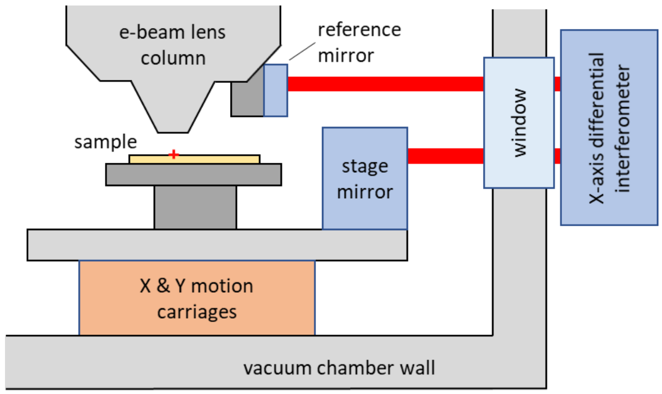

Figure 1. M-SEM block diagram showing laser interferometer beam path for the X-axis. The Y-axis components are not shown for clarity.

Two measurement modes are implemented: 1) Image magnification calibration, where a set of images at constant magnification are collected as a feature is moved systematically within the field of view by translating only the interferometrically-measured sample stage. The position of the feature within the SEM image field (pixel coordinates) is correlated with the interferometer-measured X-Y position of the stage in order to calibrate the field magnification scale or pixel size. 2) Spot mode metrology, where the primary electron beam is stationary, and the sample is moved under the beam while simultaneously recording the secondary-electron signal intensity and the interferometer-measured X-Y position of sample stage. The spot mode method is applicable to long distances, in principle up to the full 100 mm measurement range.

Preliminary spot-mode measurements have been made on grating artifacts with 500 nm, 700 nm, and 1 µm pitches by traversing their full 100-µm fields. Individual uncertainty components are combined as root sum of the squares. The uncertainty arising from the measurement of the 100 µm distance is $[(5\times10^{-7} \times 100\ \mu m)^2 + (1\ nm)^2]^{1/2} = 1$ nm, which is a relative uncertainty of 1×10^{-5} (coverage factor k = 1). However, the overall average pitch measurement uncertainty is overshadowed by the sample-related components totaling 30 nm, resulting in a relative uncertainty of 3×10^{-4}. The sample uncertainty for this preliminary measurement was dominated by the crude, unmeasured alignment of the sample with respect to the measurement axis resulting in a large cosine error uncertainty. As measurement distances increase, the achievable relative uncertainty should improve up to the interferometer limit of 5×10^{-7} once sample alignment is measured and corrected. For comparison, in the image-magnification calibration mode, a typical relative uncertainty for a scale measurement would be 5×10^{-4}, dominated by the feature location determination uncertainty, which would be affected by noise, feature quality, and pixel resolution.

At present, an improved temperature measurement system is being implemented so that corrections can be made for thermal expansion of the sample. After validation of measurement performance by comparing measurement adjustments to the instrument and measurement methods are being carried out. to verify measurement uncertainty values and prepare measurement scripts for calibration of customer samples.

Shown in Figure 2 is the design of a NIST scale calibration artifact under development. It is part of a larger chip dedicated to integrated circuit dimensional metrology. Many chips have been created on 300

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mm Si wafers using photolithography. A large number of critical dimension SEM measurements have been carried out already demonstrating high uniformity of dimensions die to die. This will facilitate batch certification by measuring a statistically representative sample with the M-SEM.

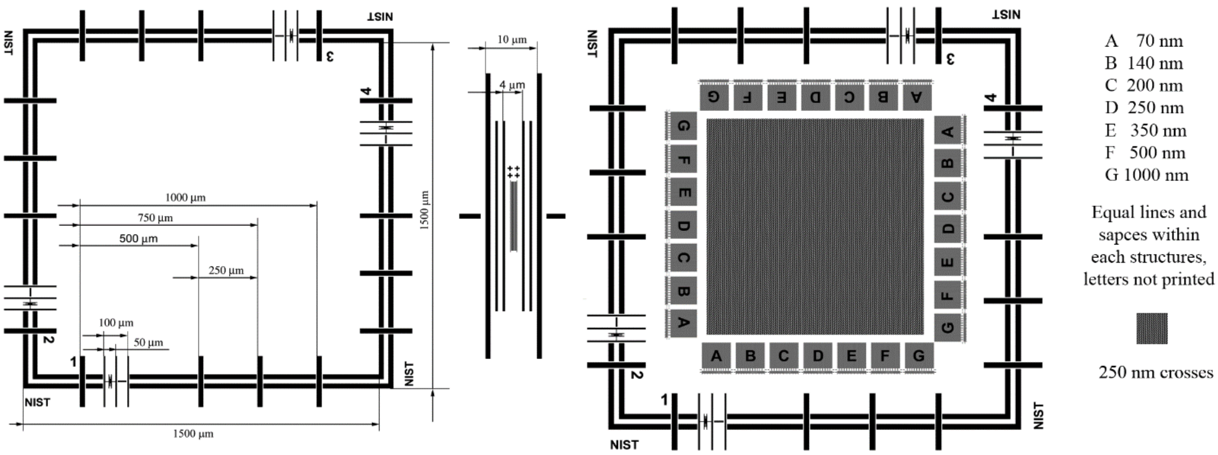

Figure 2. NIST Standard Reference Material under development for accurate, traceable scale calibrations for SEMs, atomic force microscopes and optical microscopes. With suitable computational methods, it is also useful for non-linearity and stray beam/sample tilt measurements. It has pitches ranging from 1.5 mm to 70 nm.

References:

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