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Nanometer level sampling and control of a scanning electron microscope

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Abstract
The National Institute of Standards and Technology (NIST) is developing a specialized, metrology scanning electron microscope (SEM), having a metrology sample stage measured by a 38 picometer resolution, high-bandwidth laser interferometer system. The purpose of the NIST Reference Metrology SEM system is to carry out traceable calibrations of pitch and line width on standard reference samples using nanometer-level positioning of the sample under the electron beam in the SEM. Using the laser interferometer, with displacement measurements traceable to the International System of Units (SI), the X-Y sample-stage position is measured with a bandwidth of nearly 3 MHz while recording the secondary or backscattered electron output signal. This high-bandwidth measurement capability also becomes a tool to measure and compensate for the effects of environmental impacts on SEM measurements that evidence themselves as vibration and drift. This paper presents the metrology data acquisition and control system design, calibration methods and will show results obtained with the NIST Reference Metrology SEM.

Keywords: SEM, X-Y stage, laser interferometer, nanometer measurement

1. Background

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 Reference Metrology SEM (RM-SEM) that utilizes high-throughput sampling techniques and interferometer-measured, nanometer-level positioning of the sample under the electron beam in the SEM. This high-bandwidth stage-position measurement capability also then serves as a tool to measure and compensate for the effects of environmental impacts on SEM measurements that evidence themselves as vibration and drift [3]. At present, the RM-SEM will be used for the certification of scale calibration standards and other standards used in integrated circuit and nanotechnology development and production.

2. Reference Metrology SEM

The RM-SEM is composed of several key systems as outlined below.

2.1. Environmental SEM

The RM-SEM has a large sample capability (200 mm and 300 mm wafers and 6" photomasks) with 100 mm by 100 mm measurement coverage as shown in Figure 2. With variable landing energy and variable vacuum capability (ESEM, VPSEM), the SEM is able to 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 RM-SEM is housed in a special laboratory incorporating an air-suspension vibration isolation slab and a clean enclosure, thus achieving high-end SEM performance.

Figure 1. The sample stage with a 300 mm wafer and the high-precision sample exchange mechanism.

2.2. Laser metrology setup

The homodyne interferometer system with phase sensitive photo detector uses fiber-optic delivery of the laser light directly to the measurement axes, without prior beam splitters, fold mirrors or adjustable mounts. This results in a reduced optical path complexity, lower thermal drift and a smaller footprint, enabling the interferometer optics to mount directly on a modified SEM chamber. The measurement mirrors and beam paths are completely within the SEM vacuum. The interferometer system provides sub-nanometer non-linearity and a resolution of 38 picometers, and 36-bit parallel position data output with a maximum data transfer rate of 3 MHz. The interferometer will resolve velocities up to 1 m/sec, and positional accuracy levels of 1 ppm. Plane mirrors are mounted on the SEM column and motion stage in both X-Y directions for measurement of sample position with respect to column position as shown in Figure 3.

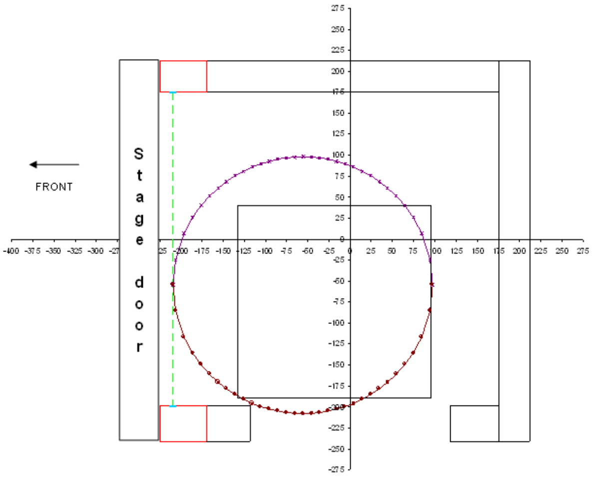

Figure 2. Extended sample chamber accepts up to 300 mm wafer

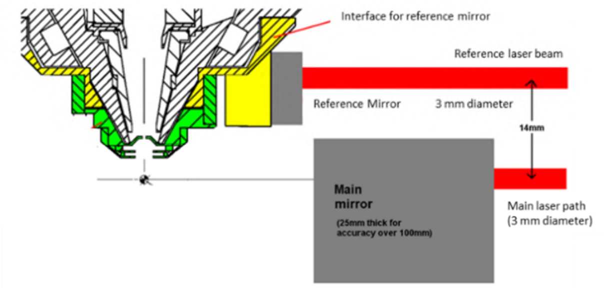

Figure 3. Interferometer configuration. The column-mounted mirrors (X and Y) serve and the references for the stage-measurement interferometers.

2.2. Measurement and control setup

A computerized measurement and control system was developed to operate at high data throughput. Fast scanning of the SEM minimizes the inter-frame drift due to environmental effects. The maximum data acquisition throughput for the combined SEM column detector, the SEM horizontal and vertical raster scan signals and the X-Y laser stage position is 3 MHz. The SEM scan and detector data is collected using a high-throughput data acquisition board while the stage position data is simultaneously acquired through a custom-programed FPGA board that interfaces to the interferometer hardware. Complete synchronization of the hardware (and thus data acquisition process) is achieved by generating a master clock signal within the FPGA which, in turn controls the analog SEM column data acquisition. The measurement and control system uses a custom interface board to remotely execute commands on the SEM through the normal user control interface. The system accepts custom measurement recipes to programmatically move, image and sample the SEM column data.

3. Measurement results

Specialized software was developed to process the vast amounts of data. The measurement and control system records the SEM outputs during a single image capture executed on the SEM. The first step is to reduce the data down to individual image frames. Shown in Figure 4(a) is an image frame produced from the captured raw raster scan and column detector data; shown in Figure 4(b) is the simultaneously acquired SEM instrument image. Figure 4(c) shows a subtraction of the two images. A perfect result would be a completely black image. The small magnitude of the difference between the images gives confidence in our data collection and processing methods.

For metrology purposes, each pixel in the image has corresponding X-Y laser stage position readings associated with it. To calibrate the pixel size based on the interferometer data, multiple images are acquired of a unique feature that is displaced throughout the SEM field of view by moving the laser stage. The correlation of the pixel displacement in the SEM images with the stage position displacements measured by the interferometers give the nanometer/pixel calibration gain. The specialized software also has algorithms for defining line locations and edges from images for calculating line pitch and line width measurements. Further ongoing work uses the high-speed laser position readings of the sample stage to compensate for drift and vibration of each acquired pixel [3].

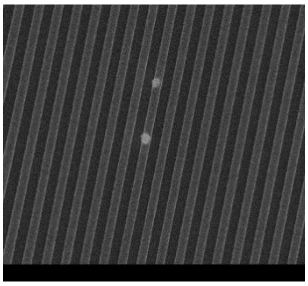

Figure 4(a). Image reconstruction using column detector and scan generator data

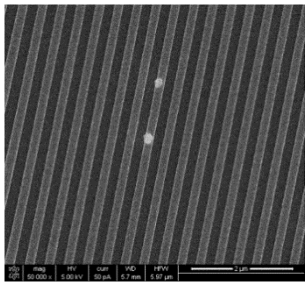

Figure 4(b). Instrument generated image

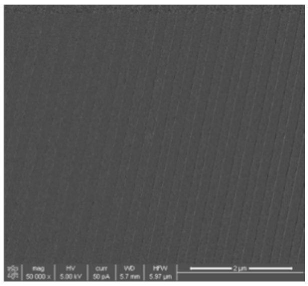

Figure 4(c). The left image is the result of Figure 4(a) subtracted from Figure 4(b). A perfect result would yield a solid grey scale image.

At present, the reference metrology SEM is nearly complete. The next steps are to verify measurement uncertainty values and prepare measurement recipes for calibration of customer samples. Further work involves reducing the raw data set size to aid faster processing of the measurements.

References

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