On Sub-10 nm 3D CD-SEM Metrology

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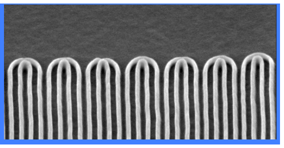


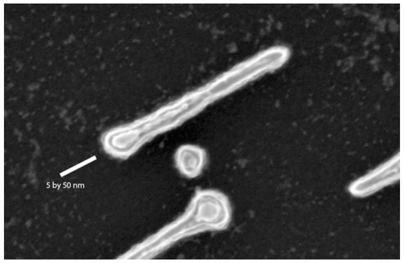
Optical lithography is printing photoresist features that are one tenth or smaller than the wavelength of the 193 nm UV light, with the use of various optical correction methods, which model and compensate for several errors in the lithography process down to sub-nanometer, essentially atomic levels.

The process has to rely on accurate and highly repeatable dimensional metrology, which is beyond the conventional one-dimensional line width measurements, and it must account for the contours and shapes of sub-10 nm structures. For this, the critical dimension measurement scanning electron microscope (CD-SEM) is the key metrology tool, but current instruments and methods cannot fulfill the requirements, especially for future sub-10 nm integrated (IC) structures.

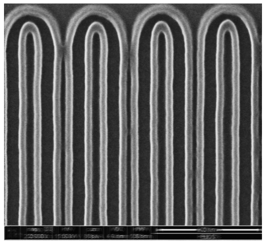
For these structures optimized, better SEMs with sharper focus, sophisticated image and data acquisition methods and shape sensitive, physics-based modeling are needed. We report here on a few key improvements in all of these. These methods deliver unprecedented quality results, and serve as a good basis for the development accurate sub-10 nm 3D metrology.

We believe that with the implementation of these new methods 3D metrology is feasible and will serve well IC production, even on sub-10 nm structures.

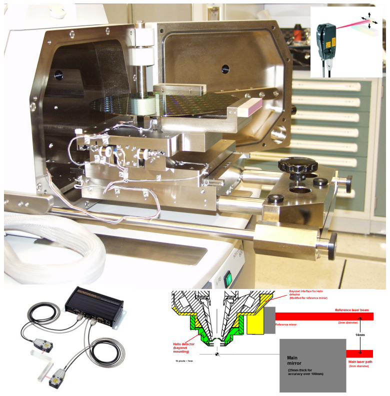
Need for better SEM imaging



Even top-down images reveal a lot of 3D information. On this resist sample of intentional defect arrays delamination is evident. The smallest, about 2 to 3 nm size resist features are clearly visible, therefore measureable. 508 nm horizontal field of view, 8 keV, 86 pA

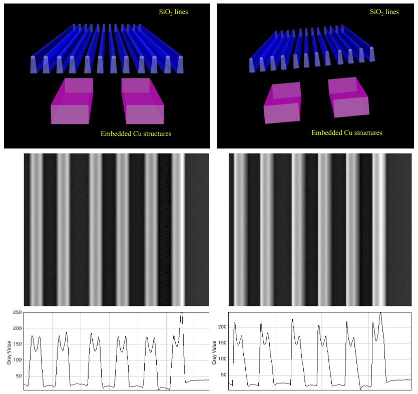


The NIST fast imaging method uses 2D Fourier transform to line up many very noisy, fast images with sub-pixel accuracy to acquire a final sharp image. The traditional fast imaging method would keep the letters sharp, but blur the image. The amount of blur, caused by small, nm-scale drift, is indicated by the fuzziness of the letters.

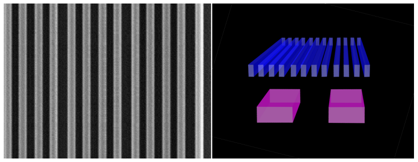


High-speed 38 pm laser interferometry, indispensable for sub-10 nm 3D SEM metrology, can help to compensate for nm-scale sample stage motions and allow for superior compensation of beam-related distortions. These together deliver unprecedented repeatability, and much better quality raw images and data than current methods. Additionally, lasers make fast, few nm accuracy navigation feasible, which improves throughput.

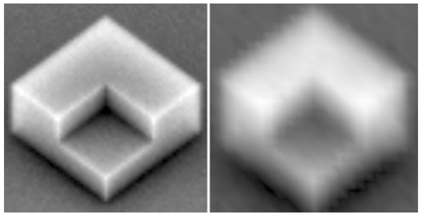
Modeling complex 3D structures



Nominal 16 nm SiO_2 rounded-top lines, imperfect pitches, i.e., spaces and lines of 16/14/16/16/16/14/16/20 at left 0 and right 5 degrees tilt, 5 keV landing energy, 0.5 nm spot size and 1 nm stepping distance, 20 000 electrons per location

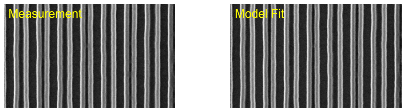


Nominal 8 nm SiO_2 lines, imperfect process, i.e., spaces and lines of 8/7/8/8/8/7/8/10 nm at 0 degrees tilt, 5 keV landing energy, 0.5 nm spot size and 1 nm stepping distance, 4000 electrons per location, 10 hours modeling run time.

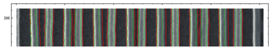


On their sides 30 nm (left) and 6 nm wide (right) 3D structures modeled with 1 keV landing energy, 0.5 nm spot size and 1 nm stepping distance, 4000 electrons per location, 1 day run time (left) and 1 keV landing energy, 0.3 nm spot size and 0.5 nm stepping distance, 4000 electrons per location, 10 hours run time (right)

Pitch, width and line shape by physics



Measured and modeled sample images match closely using physics-based measurement method. In this case a trapezoid model was used, more sophisticated models are also possible and give closer match in the line shape



Superlattice pitch (C+B+A+B) = 129.2 ± 0.5 nm

The 0.5 nm represents variation between periods (i.e., depending on which line is chosen to start.

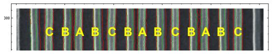
This is larger than the x-ray value by ~0.7%. Two possible causes:

1. The pattern within this SEM field of view differs this much from the average pattern.
2. SEM scale calibration error.

Mean values of the separations within the superlattice:

A = 22.5 ± 0.5 nm.
B = 38.6 ± 0.5 nm
C = 30 ± 1 nm

Highly repeatable pitch values match within less than 1 % with x-ray scatterometry results obtained on the same sample. The quality of these measurements would allow for measuring structures with sub-10 nm sizes.



	A	B	C	D
Top Width	11.8 ± 0.1	11 ± 0.4	10.8 ± 0.2	11.0 ± 0.2
Bottom Width	17.3 ± 0.1	17.6 ± 0.5	19.0 ± 0.2	17.8 ± 0.4

The average sidewall angles are ~5°, and there are significant asymmetries, with the B lines much sharper on the edges facing the wide gap than the ones facing the narrow gap.

Top LWR is ~1.7 nm (3σ)

Highly repeatable top and bottom width values match within less than 1 % with x-ray scatterometry results obtained on the same sample. The quality of these measurements would allow for measuring structures with sub-10 nm sizes.

There is no physical reason that would make sub-10 nm 3D CD-SEM metrology unfeasible. We need to optimize SEMs, implement better image acquisition methods, and use shape sensitive, model-based evaluation techniques. With these 3D CD-SEM metrology will be able to provide indispensable information even on the smallest IC structures of the future.