Development of Tilt-SEM for In-line 3D Measurement and Inspection of Semiconductor Devices

N. Okai, M. Sakakibara,
Research&Development Group, Hitachi, Ltd., Kokubunji, Tokyo 185-8601, Japan
nobuhiro.okai.ym@hitachi.com

N. Suzuki, Y. Sohda, K. Onuki
Metrology and Analysis Systems Product Div., Hitachi High-Tech Corporation, Hitachinaka, Ibaraki 312-8504, Japan

As IoT continues to grow, 3D measurement and inspection of semiconductor devices using scanning electron microscope (SEM) during their fabrication processes becomes increasingly important because IoT devices have 3D structures and the performance strongly depends on the 3D shape such as height and slope. They are mainly fabricated on wafers less than 200 mm in diameter using a mature process node technology. To satisfy the needs, we developed a tilt-SEM capable of loading and tilting a wafer to observe the 3D devices from various directions.

Figure 1 and Table 1 show the schematic and specifications of tilt-SEM. A snorkel-type conical objective lens is developed to achieve both high resolution and large stage tilt angle. Electron beam generated in the electron gun is focused by the the objective lens and irradiated onto the wafer. Secondary electrons (SEs) emitted from the irradiated position go through the objective lens and the extraction electrode before deflected by an ExB and detected by an SE detector. Stage moves to cover the whole wafer, rotates at any angle, and tilts up to 55 degrees with eucentric motion. Working distance (WD), which is the distance between the bottom of the objective lens and the wafer, is set to 6 mm for tilt observation and 12 mm for EDS. Resolution achieved at landing energy of 1 kV and WD of 6 mm is 7 nm. Image drift caused by tilting wafer up to 55 degrees including stage precision is less than 10 μm. Table 2 shows comparison of experimental and simulated SEM images for dug patterns on Si wafer. Simulated SEM images are generated by combining electron-scattering and electron-trajectory simulations. They show similar contrast at surface and edge regions.

The biggest challenge in developing the tilt-SEM is image drift by wafer tilt which is caused by electron optics and stage precision. The drift caused by electron optics is due to the generation of asymmetric electric field between polepiece and wafer because negative voltage is applied to wafer to improve detection efficiency of SEs. To reduce the drift by keeping the electric field symmetric around optical axis, an assist electrode is equipped between the objective lens and the wafer. Figure 2 shows measured and simulated image drifts. The contribution of stage precision is subtracted. Inserted are schematics of electron-beam deflection due to horizontal electric field between polepiece and wafer. The direction and magnitude of the drift largely depend on the voltage of the assist electrode. By applying the optimum voltage, we achieved the drift due to electron optics less than 1 μm, which is in good agreement between experiment and simulation.

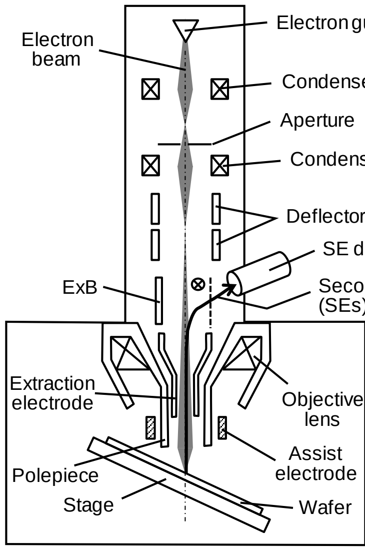


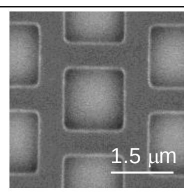
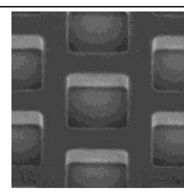
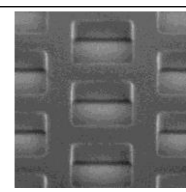
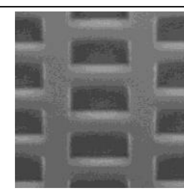
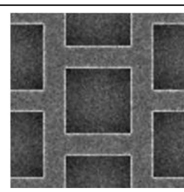
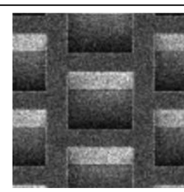
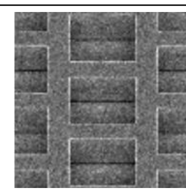
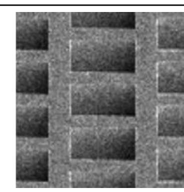
Figure 1 Schematic of tilt-SEM

Table 1 Specifications of tilt-SEM

Item	Specifications
Wafer size	4, 6, 8 inch
Stage	X: 0 ~ 205 mm Y: 0 ~ 205 mm Tilt: 0 ~ 55˚ Rotation: −180 ~ 180˚
Working distance (WD)	6 mm (observation) 12 mm (EDS)
Landing energy	0.8 ~ 15 kV
Resolution	7 nm @ WD 6, 1 kV
Image drift by wafer tilt up to 55˚	≤ 1 μm (optically) ≤ 10 μm (including stage precision)

EDS: Energy Dispersive x-ray Spectroscopy

Table 2 Comparison of experimental and simulated SEM images for dug pattern with width of 1.5 μm and depth of 0.8 μm on Si wafer

	0˚	30˚	45˚	55˚
Experiment				
Simulation				

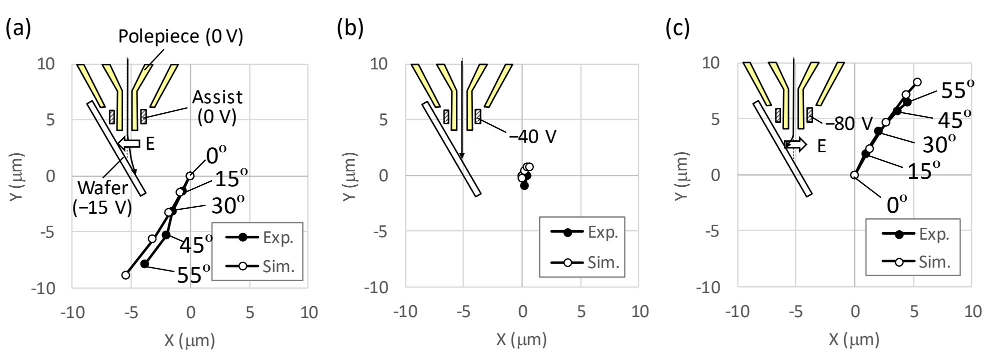


Figure 2 Measured and simulated image drifts at assist electrode of (a) 0, (b) −40, and (c) −80 V when wafer is tilted up to 55 degrees. Inserted are schematics of electron-beam deflection due to horizontal electric field between polepiece and wafer.