Contrast Reversal Effect in SEM due to Charging

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Scanning electron microscopy (SEM) is widely used in semiconductor manufacturing. In metrology and inspection, accuracy is the most critical factor. In addition to systematic measurement errors, charging of a wafer is an important factor, distorting the SEM signal, especially when the wafer or mask includes dielectric layers. Charging adds a dynamic component to the CD measurement error.

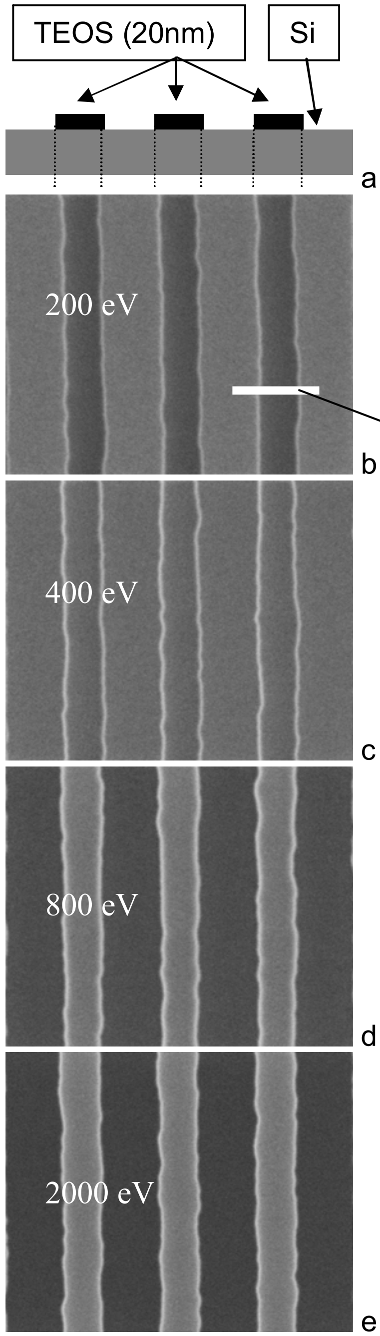
In this paper, the effect of contrast reversal was measured. CD-SEM images of 20 nm SiO_2 line patterns on silicon were taken at various beam conditions. Experimental results were compared to simulations.

It was found that the image contrast of a line reverses when beam voltage is changed from 200 V to 2 kV. At less than 500 V, the SiO_2 line was brighter than silicon; at higher voltages, the line was darker. This effect was first attributed to the fact that backscattering coefficients of silicon dioxide and silicon vary with voltage; therefore, the coefficient can be larger for one material than for another at different voltage ranges. However, this was not the case. The reason for the contrast reversal was determined to be charging of a line.

Monte Carlo simulation software with the ability to simulate charging was used to model this phenomenon. First, backscattering coefficients as a function of voltage were simulated for each material. It was found that the two curves do not intersect: backscattering from SiO_2 was higher than that of Si over the entire range of simulated voltages. So the effect cannot be explained by variation of backscattering coefficients. Then the image was simulated, taking charging into account. Trajectories of backscattered electrons in the presence of a local electrical field became curved, causing electrons to return to the sample, producing new generations of backscattered electrons, or being absorbed. The simulation revealed contrast change, similar to that in experiment.

Time dependence of contrast change was measured and then simulated. The simulation data is in good agreement with experimental results.

These results are important for optimizing CD-SEMs and electron-beam inspection tools and improving accuracy of CD measurements.



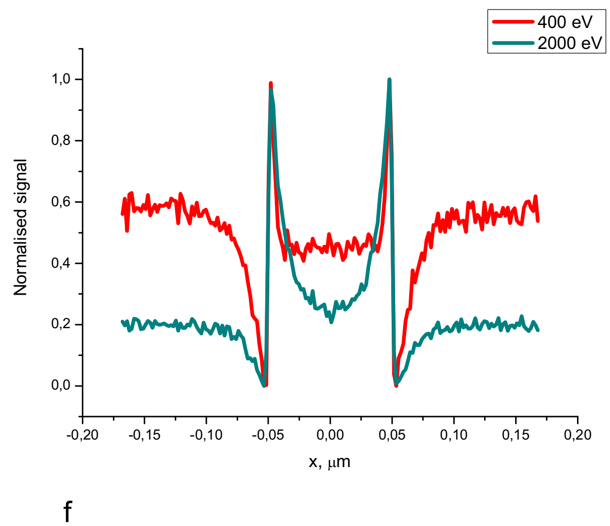


Figure 1. Contrast reversal in SEM:
a) 90 nm wide thermal oxide lines on silicon.
b-e) SEM images at electron energies from 200 eV through 2 keV display contrast reversal.
f) Simulation results of SEM signal across a line taking into account charging also show contrast reversal.