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APPLICATION NOTE

Extreme High Resolution Electron Microscopy

A new dimension in photolithography process control

The low-voltage scanning electron microscope (SEM) is widely used in many industrial and research applications due to its ability to image surface details with high resolution and fidelity. However, fundamental limitations in performance have existed, notably resolution at low beam voltages.

To overcome this limitation, the Verios Extreme High Resolution (XHR) SEM was developed to reveal fine surface detail with sub-nanometer resolution at very low beam voltages. The Thermo Scientific™ Verios™ G4 XHR SEM is ideally suited to help characterize electron beam sensitive photoresist.

The system uses a source monochromator to reduce the beam energy spread resulting in a more tightly-focused electron beam. While the monochromator is a necessary enabler of improved low voltage imaging performance, further system elements, such as scanning, detectors, stage and environmental controls are also key to usability and throughput in practical day-to-day operation. Verios G4 XHR SEM maintains ease-of-use and sample throughput similar to, or better, than other current generation SEMs.

A key driver for the development of improved low voltage SEMs comes from the semiconductor market. New processes being developed at the 22 nm design node and below are driving demand for higher resolution imaging on electron beam sensitive materials such as photoresist.

Electron beam's influence on photoresist

The sample used was a photoresist for 193 nm exposure to create photolithographic structures. Photoresist is known to be very sensitive to exposure to an electron beam, with the most noticeable effect being local shrinkage. The samples described have been cleaved and coated with gold/palladium to reduce charging effects, although excellent results were also obtained on uncoated samples (discussed below).

The work was focused on determining whether there is an optimal combination of low accelerating voltage and low beam current that would minimize the structural effects of beam exposure on the photoresist. The effect is immediately observed while doing slow scans or high quality photo scans. Even at 1 kV, the charging effect may be slowed, but the sample still begins to degrade immediately (Figure 1). Ultimately this degrades the precision and accuracy of the measurements and, therefore, the ability to tightly control the photolithographic process. The main target for this experiment was to find image conditions where the photoresist alteration is minimized as much as possible, but the image quality and resolution remains at a level where the operator can accurately and precisely measure the imaged structures.

Finding optimum conditions

In an effort to find a beam condition that would minimize damage, both voltage and beam current were reduced. At 500 V and 6.2 pA, no damage was observed over a period of time sufficient to allow image optimization. The final image was then taken (Figure 2) with a slow scan. The image was acquired at a magnification of 300 kX (Polaroid mode) and has a HFW (horizontal field width) of 423 nm.

Rather than viewing the resist lines exactly "end on," it is often beneficial to tilt and rotate the sample slightly, which allows a good overview of the cross section itself, the space in between the photoresist structures and the sidewalls of those lines. This special view will also allow process engineers to get very detailed information about possible exposure problems as well as information about the uniformity of their processes (Figure 3).

Verios G4 XHR SEM imaging improves analysis of photoresist structures dramatically. Low voltage, low current imaging with high resolution opens a new dimension in photolithography process control. Going even lower with the beam current and the accelerating voltage is possible with the use of "beam deceleration mode". This mode helps with completely uncoated photoresist samples to mitigate charging effects (Figure 4). This allows the operator to load the sample with very minimal sample preparation and still achieve outstanding results.

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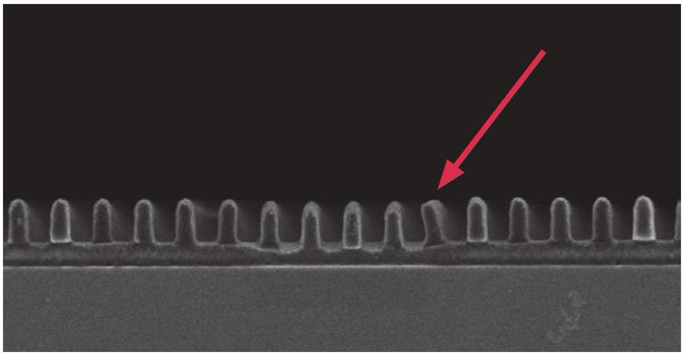

Figure 1. At 1 kV and 16 pA the photoresist structure started shrinking immediately in the local area used for observation.

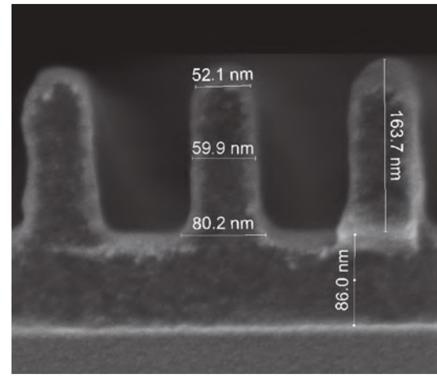

Figure 2. At 500 V and 6.2 pA the photoresist was stable. The image shows very small details of the photoresist structures. High magnification and well defined surface interfaces permit accurate, precise metrology.

Conclusion

Historically, the SEM has been the fastest solution to nanometer scale resolution images. Typically, samples can be loaded into a SEM with limited sample preparation and imaged within a matter of minutes. In contrast, the transmission electron microscope (TEM) offers higher ultimate spatial resolution, but more involved sample preparation. These factors make the Verios G4 XHR SEM very complementary to the expansion in the need for TEM analysis that is occurring due to continued shrinks in critical dimensions.

Verios G4 XHR SEM extends the utility of SEM in microelectronic applications by enhancing resolution and image quality at very low beam energies. The results shown here demonstrate the additional benefit of moving to lower accelerating voltages to minimize sample damage while maintaining the resolution required for accurate and precise metrology.

The benefit of reduced beam damage at very low beam voltages also give new possibilities for materials like low-K dielectrics and other beam sensitive samples. Moreover, Verios G4 XHR SEM delivers its remarkable low voltage performance while retaining all the benefits of conventional SEM in speed, flexibility and ease of use.

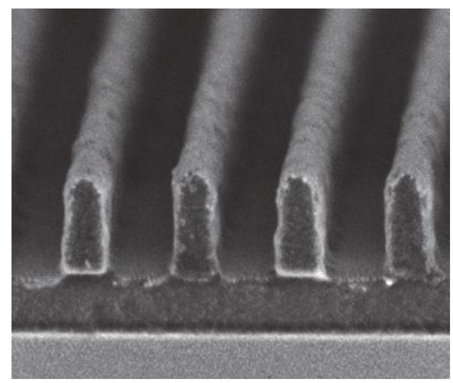

Figure 3. The depth of focus at 500 V in the tilted image allows inspection of the footing and roughness of the sidewalls of the photoresist lines.

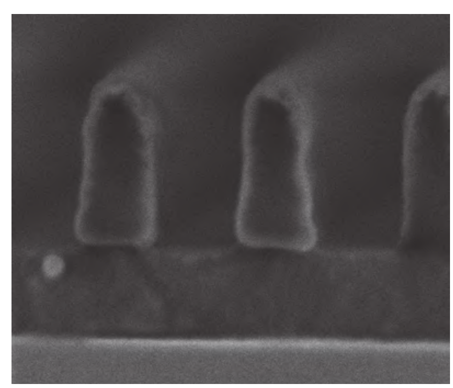

Figure 4. Uncoated photoresist using 2 mm working distance provides a nearly charge free image combined with a clear view of the cross section and very detailed surface information. No beam damage is apparent.

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