Low voltage SEM imaging of photoresist line arrays using GEMINI® technology

Application Note

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Introduction

In order to increase storage density and performance of nanoelectronic products, structure sizes in integrated circuits have to be decreased further. To reach this aim, smaller lithography exposure wavelengths were introduced. The photoresist materials used for lithographic patterning had to be adapted to the new wavelengths. Essential changes in their chemistry were made. Curing and patterning behaviour of these new resists have to be controlled precisely. In the production line, scanning electron microscopy (SEM) is used for CD (critical dimension) control, i.e., resist line width and distance measurement. In the off-line analytical lab, the detailed analysis of resist line profiles on cross sectioned samples by SEM is a critical task for process development.

UV (ultra-violet) resist materials are susceptible to electron beam damage. This leads to significant shrinking of the material during imaging in a SEM. Such irradiation induced shrinkage is a serious problem especially for 193 nm resist systems used in recent technology nodes. Reliable film thickness and line profile control by standard SEMs cannot be guaranteed any more. Resist shrinkage will continue to be a major challenge when new techniques like immersion and EUV (extreme ultra-violet) lithography are introduced in the future.

Quantitative studies of the shrinkage of resist line width and film thickness as a function of specimen preparation and SEM imaging conditions have shown that the amount of volume reduction strongly depends on the acceleration voltage. Although metal sputter coating procedures for cross sectioned samples can stabilize the resist structures to a certain extent, low voltages are needed to minimize the impact of SEM imaging on the sample morphology.

In standard SEMs, using voltages low enough to produce only negligible resist shrinkage reduces their resolution drastically. The low voltage imaging capabilities of the ultrahigh resolution field emission GEMINI® electron column, however, provide high resolution even at ultra-low voltages with very short working distances (Fig. 1). The high efficiency of the integrated in-lens SE detector at low voltages results in superb imaging of beam sensitive resist structures even at very low electron energies down to 100 eV.

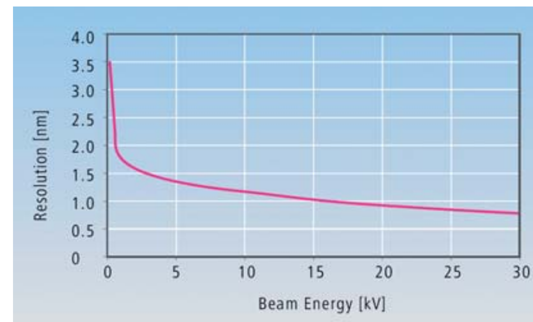

Fig. 1: Resolution of the GEMINI® column versus beam energy.

Instrumentation and sample preparation

Samples of 193 nm UV photoresist line arrays (line width 60-70 nm) on a BARC (bottom anti-reflexive coating) layer were prepared by sputter deposition of AuPd, cleaving the array of interest in liquid nitrogen, and another AuPd sputter deposition onto the cross section. The samples were mounted in a clamping holder in a way such that a large area of the AuPd coated resist arrays made electrical contact with the clamping jaw surface. Thus, sufficient grounding of the resist structures was achieved to prevent the samples from charging. The samples were imaged

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at 160, 300, 1000 and 3000 V acceleration voltage and 75 pA beam current using the in-lens detector of the GEMINI® column. For each voltage, an overview image of a new, not previously exposed area of interest was taken at a magnification of 41 kX. The central area of the area of interest was then scanned at 200 kX for 1 min (pixel dwell time 3.2 μs, frame time 2.55 s), and another overview image was taken. These experiments were repeated at different working distances (WD) to find the WD that provides the best resolution and contrast for each voltage.

Results

The images shown below demonstrate the effect of electron beam exposition at different voltages on the resist structure. At 3000 V and WD 3 mm, significant resist shrinkage, as well as a reduction of the thickness of the underlying BARC layer, occurs immediately upon the first exposure of the material to the electron beam. Therefore, not even the very first scan (Fig. 2, bottom left) represents the original state of the structure. Further scanning at 200 kX causes more shrinkage of the zoomed-in area (Fig. 2, right and bottom right).

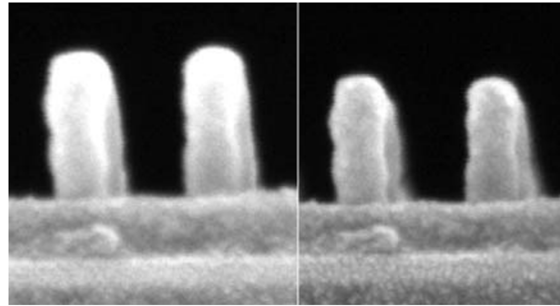
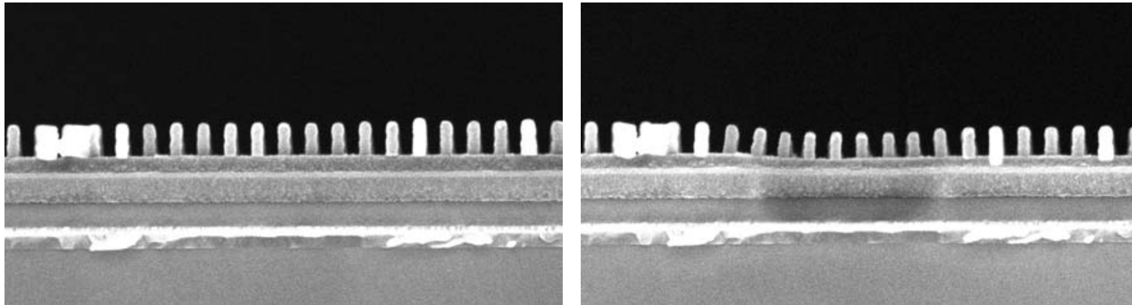
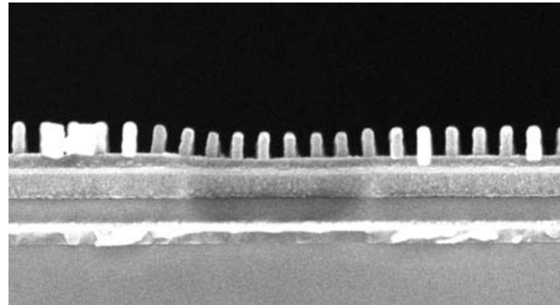


Fig. 2:
Right: Two 193 nm UV photoresist lines on a BARC layer imaged at 3 kV, WD 3mm, and a magnification of 200 kX before and after 1 min of scanning. Severe three-dimensional shrinkage is obvious.
Bottom: Overviews at 41 kX of the same photoresist line array before and after scanning of the central area at 200 kX for 1 min.
The material was already damaged upon the very first exposition to the electron beam. Thus, the left image does not even represent the pristine structure.





Lowering the voltage to 1000 V slows the shrinking down while maintaining sufficient resolution to show the resist morphology in detail (Fig. 3) at WD 2.0 mm.

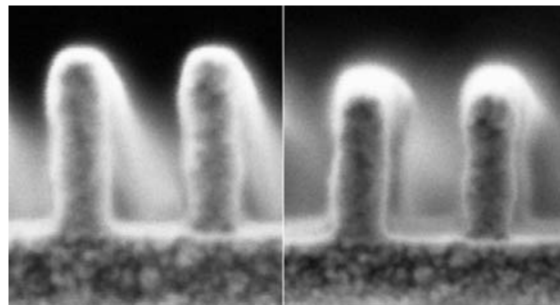
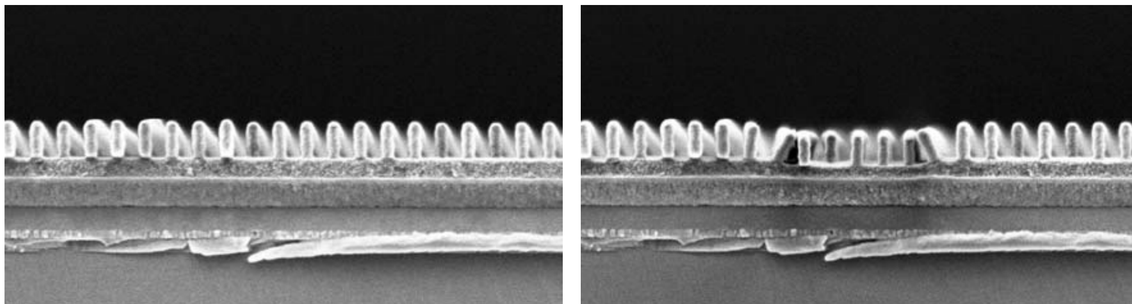
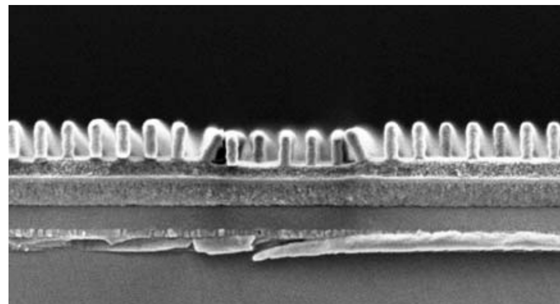


Fig. 3:
Same experiment at 1 kV and WD 2.0 mm.
Smaller shrinkage and still good resolution.





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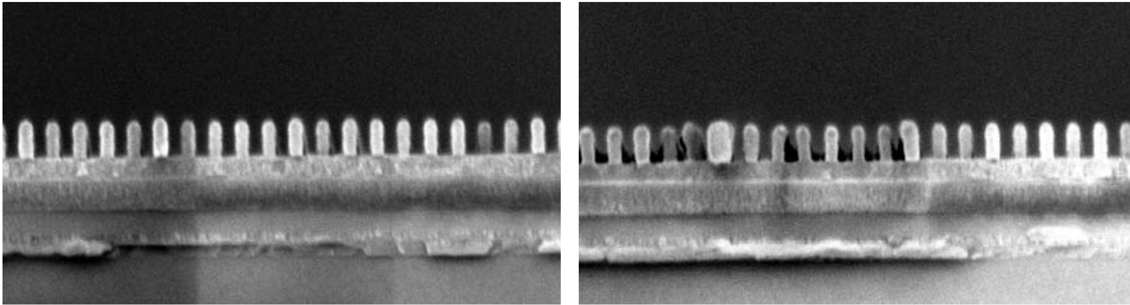
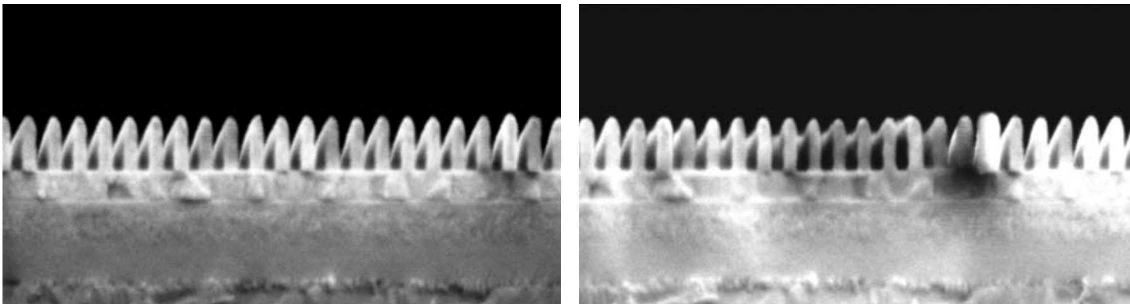
Using 300 V, shrinkage is greatly reduced while maintaining sufficient edge contrast at WD 1.5 mm (Fig. 4).

Fig. 4:
Same experiment at 300 V and WD 1.5 mm.
Greatly reduced shrinkage while maintaining sufficient edge contrast.



Shrinkage is negligible at 160 V, but resolution and edge contrast at WD 1.75 mm are still sufficient to measure the resist line mean width and height (Fig. 5).

Fig. 5:
Same experiment at 160 V and WD 1.75 mm.
Negligible shrinkage while resolution still sufficient for measuring mean width and height of the resist lines.



According to these findings, a practical scheme for resist line analysis would consist of imaging the sample at 160 V and a very short WD of about 1.75 mm for dimensional control of the resist lines without shrinkage, followed by imaging at 1000 V or below and a WD of about 2.0 mm to evaluate line profile characteristics in detail without excessive beam damage.

Further applications

Besides the dimensional control of resist structures as described here, low voltage imaging with the GEMINI® column can be used in many more applications where beam induced sample damage limits the usefulness of conventional SEMs. In the field of nanoelectronics,

imaging of low-k dielectric structures is such an application. These low permittivity interlayer dielectric materials, mostly organic silicon oxide compounds, have been introduced in the manufacturing process to further improve the performance of nanoelectronic devices. They are susceptible to beam damage in the SEM. Typical artifacts are layer thinning and delamination of the material from surrounding materials. Another field of application of high resolution low voltage SEM is polymer chemistry, where samples are often highly susceptible to electron beam damage.

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