Ultra low voltage SEM for high accuracy measurements of CD/LWR/LER

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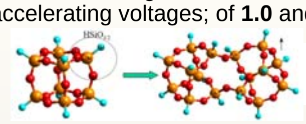
INTRODUCTION

The continuous reduction of the critical size in the lithography process is one of the key problems for the next generation of IC´s. ITRS roadmap has pointed out the most difficult challenges for the next technology nodes (32 nm and beyond) not only for the reduction of the critical dimension (CD) but also in terms of line edge roughness (LER) and line width roughness (LWR). ITRS defines LWR as 3 times the standard deviations (σ) of the line width measurements, performed at equidistant positions in a line section of predetermined length . It is lower than 3 nm for the 90 nm node and will become less than 2 nm for the next generations [1]. As the pattern roughness in particular has an enormous influence on the characteristic of the corresponding electronic devices it is extremely important to examine the roughness with high accuracy. For the measurement of LER/LWR and CD, CD-SEM, AFM and Scatterometry have been applied; however, neither of these techniques is a standardized method [2,3,4]. Up to now SEM is the most common technique in the field of line metrology. LER/LWR and CD are currently calculated in top-view SEM images [5,6]. Many factors which relate to the type of resist, patterning process and settings of SEM machine used for the imaging contribute to the roughness of the patterned structures. Furthermore, the software and the calculation algorithms can influence the statistical analysis and at least the final results in a decisive way.

EXPERIMENTAL DESIGN & METHODS

▪ Nano-scale lines patterned in **HSQ** resist at **30** and **50 keV** (variable shaped e-beam writers) respectively have been recorded using an Inlens detector and two different accelerating voltages; of **1.0** and **0.3 kV.**



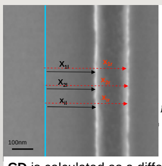
HSQ **(HSiO3)2n**

Inorganic Negative Resist

Amorphous Network Structure ~SiO_2

▪ The lines have been recorded with a multipurpose, laboratory SEM (Supra 40 VP provided by Zeiss). For all recorded lines the SEM processing parameters such as; **working distance, aperture, noise reduction, dwell time** have been kept constant.

▪ The lines have been measured with respect to **width and roughness (LWR , LER).**



LER_{left} is calculated as 3 σ of the distances between a reference-line and the left edge accordingly **LER_{right}** is calculated as 3 σ of the distances between the same reference-line and the right edge. **LER** is calculated as average of **LER_{left}** and **LER_{right}**

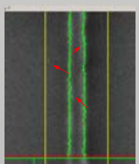
$$LER_l = 3\sqrt{\frac{\sum_i (x_{il} - x_l^{avg})^2}{n-1}} \quad LER_r = 3\sqrt{\frac{\sum_i (x_{ir} - x_r^{avg})^2}{n-1}} \quad LER = \sqrt{\frac{LER_l^2 + LER_r^2}{2}} \quad LWR = 3\sqrt{\frac{\sum_i ((x_{ir} - x_{il}) - CD^{avg})^2}{n-1}} \quad CD = \frac{1}{n}\sum_i (x_{ir} - x_{il})$$

LWR is defined as 3 σ of the line widths in each measured image line

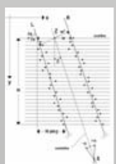
CD is calculated as a difference from distances between a reference-line to the right edge and between a reference-line to the left edge

▪ For the measurements a "Line Width Measurement"- module of the "Scandium" software package has been adapted. In order to enhance the measurement accuracy specific **algorithms for the removal of data outliers and for the correction of the line misadjustment** have been developed.

Calculation Mask



Data Outliers



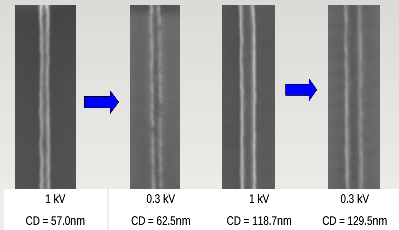
In a laboratory SEM the lines are not perfectly aligned with respect to the y – axis. The measured line width W will be too large compared to the "true" line width W' by a factor ~ 1/cosβ

RESULTS

▪ Comparison of the lines recorded at **1 kV and 0.3 kV**

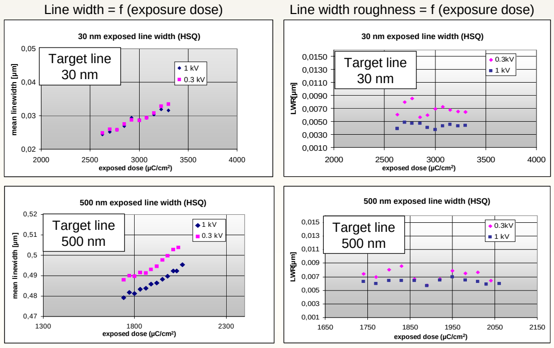
Compared to the lines recorded at 1 kV the lines recorded at 0.3 kV show higher width as well as much greater details of line roughness.

Section of Test Pattern



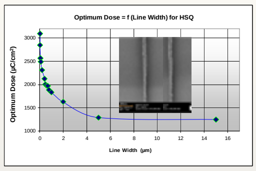
▪ Comparison of the numerical data (line width, line width roughness) calculated from test patterns exposed at 50 keV and recorded with SEM at **1 kV and 0.3 kV**.

Line width = f (exposure dose) | Line width roughness = f (exposure dose)

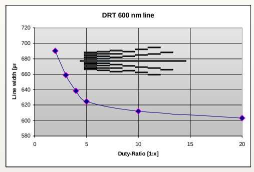


Line width and line width roughness at 1 kV < line width and line width roughness at 0.3 kV for both target lines

▪ Calculation of exposure parameters needed for the exposure optimization and the simulation work using test patterns exposed at 50 keV and recorded with SEM at **0.3 kV**



Optimum dose for line widths in the range from 1500 and 30 nm



Proximity test – 600 nm line exposed in duty ratio

CONCLUSION

The obtained results showed that the lines recorded at 1 kV are characterised by a smaller width compared to the lines captured at 0.3 kV. This observation relates to the slimming effect which becomes pronounced with increasing beam energy [7]. Furthermore, the lines recorded at 1 kV in comparison with the lines recorded at 0.3 kV exhibit much greater details of line roughness what promises a higher accuracy of measurements. Hence in the presented study accelerating voltage of 0.3 kV has been used for estimation of all patterned tests. Since the ultra low voltage enabled an inspection and a recording uncoated patterns it additionally improved the accuracy of the measurements. The results provided valuable data for the exposure optimization and the simulation work.

References

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