CD-Signature evaluation Evaluation using Scatterometry

Jan Richter[a], Philipp Laube[a], John Lam[b]

[a]*Advanced Mask Technology Center GmbH & Co KG*
Rähnitzer Allee 9, 01109 Dresden, Germany
[b] *n&k Technology, Inc.*
4051 Burton Drive, Santa Clara, California 95054, USA

Abstract

The current abilities for active feedback loops to correct for various parameters challenge metrology groups to provide exact input data for these correction cycles. One of the most important feedback loops is the one that deals with the improvement of the CD (critical dimension) uniformity of structures. Here, several processes rely on exact metrology data to tackle systematic effects that either have to be overcome by finding better process conditions or compensated actively, for instance, by tuning the writer data.

Right now most of these processes tackle long range effects on the order of millimetres and do not vary a lot on the micrometer scale. On the other hand, CD measurements are usually performed with instruments that measure single points with dimensions of a couple of micrometers (such as the conventional CD-SEM). Thus noise from the micrometer scale is introduced in the global mapping of the uniformity.

Recently, numerical methods, such as the exponentially weighted penalty approach called TPS (thin plate splines) have been developed that separate between the true signatures on the millimetre scale from the noise of the micrometer measurements. In this paper, we will take one step further by showing that the acquired statistically stable CD signature of a CD-SEM measurement matches the CD data measured by a scatterometer. Furthermore, we will show that the residual of the CD data of the scatterometer measurement compared to the found TPS fit has a noise level of about 0.1 nm (3σ), which essentially equals the short-term reproducibility of the tool. This is of high importance since both methods do essentially the same - they average out micrometer noise with the only difference being that TPS does it theoretically and a scatterometer does experimentally. Thus, we have the extremely fortunate situation in which theory and experiment give the same results. Hence, two separate conclusions can be drawn: the scatterometer measures indeed stable macroscopic CD signatures and TPS is indeed the right method to extract these signatures from any given CD data.

Keywords: critical dimensions, metrology, reproducibility, cross-calibration, photolithographic masks, scatterometry

Introduction

In recent years the overall mask performance improved so dramatically that new effects can be detected that are not yet part of the roadmaps. One of these emerging parameters is the CD signature of the mask or, in other words, the distribution of the CD differences over the mask. This parameter is significantly influenced by the measurement results of a single point and thus statistically not stable since these influences are on the same order of magnitude. For applications that involve active feedback cycles with the writer, where CD signatures are corrected in the data, it is fundamentally important to obtain stable measurement results that only vary on a length scale that corresponds to the

physical parameters of the writer, otherwise the risk of trying to manage the noise is extremely high. Currently, CD-SEMs measure with boxes that are in the very low micrometer region. The length scale for some of the parameters of the writer is, unfortunately, rather large (for instance, fogging effects that can influence regions on centimetre scale). Even with multiple measurements it takes a tremendous effort to provide a stable signature within such large regions.

Recently, a statistical method called TPS has been introduced,[1] which is a thin plate spline method that weights neighbouring measurement points. It can be used to decrease the noise introduced by the measurement and to extract stable signatures. One remaining puzzle of these approaches is still whether the averaging has any physical meaning and do the averaged signatures of different methods match. Previously we have shown that the calculated CD signatures from different CD tools match even when the measurement accuracy of these tools is different.[2]

Additionally, scatterometry had been introduced in mask houses in the last couple of years. While the layer systems for photo lithographic masks are much easier to model than layer systems for wafers, the technique has a hard stand in the CD-SEM based metrology landscape. What is needed is a sound correlation with CD-SEM data[3] and robust calculation techniques that enable good results with a limited number of parameters.

In this work we would like to go one step in this direction and compare the TPS results of CD-SEM with the measurement results of a scatterometer, as well as the behaviour of the CD data of a scatterometer with its fitted values. This will demonstrate the potential of both techniques to characterize the CD variations on the mask on macroscopic length scales.

Experiment

The experimental data were obtained with a current generation CD-SEM (Holon EMU220A) and a scatterometer (n&k 5700-CDRT). The measured wavelength range was from 190 nm to 1000 nm in one-nanometer intervals. The data was collected in 500×500 µm dense line field that was repeated 20×20 times accross the mask.

For CD-SEM data we usually observe a noise level which is the difference between CD data and fitted CD data of slightly over 1 nm (3σ). The main reason for the noise is the nanoscopic variation of the line dimensions caused, most likely, by line edge roughness and e-beam shot stitching. To overcome this shortcoming we used 25 measurements in each dense line field and averaged them. As a result we obtained a very smooth CD signature and once a TPS fit was calculated the resultant 3σ noise level was on the order of 0.3 nm.

For the scatterometer we used reflected and transmitted light and two polarization modes. We The only parameters varied in the model were the CD and the thickness of the layers on top of quartz glass. The dispersion data of the films (spectra of *n* and *k*) were measured on the unpatterned areas, and we used a bi-layer model (Cr + CrO_xN_y) for the chrome layer. In total, we investigated three systems: Chrome etched and MoSi not yet etched, the same mask after MoSi etch and, finally, the signature after chrome removal. To ensure consistent orientation of the mask we included loading pads on the mask and used a loading dependent develop process. Figure 1 depicts the signatures we obtained for the different process steps.

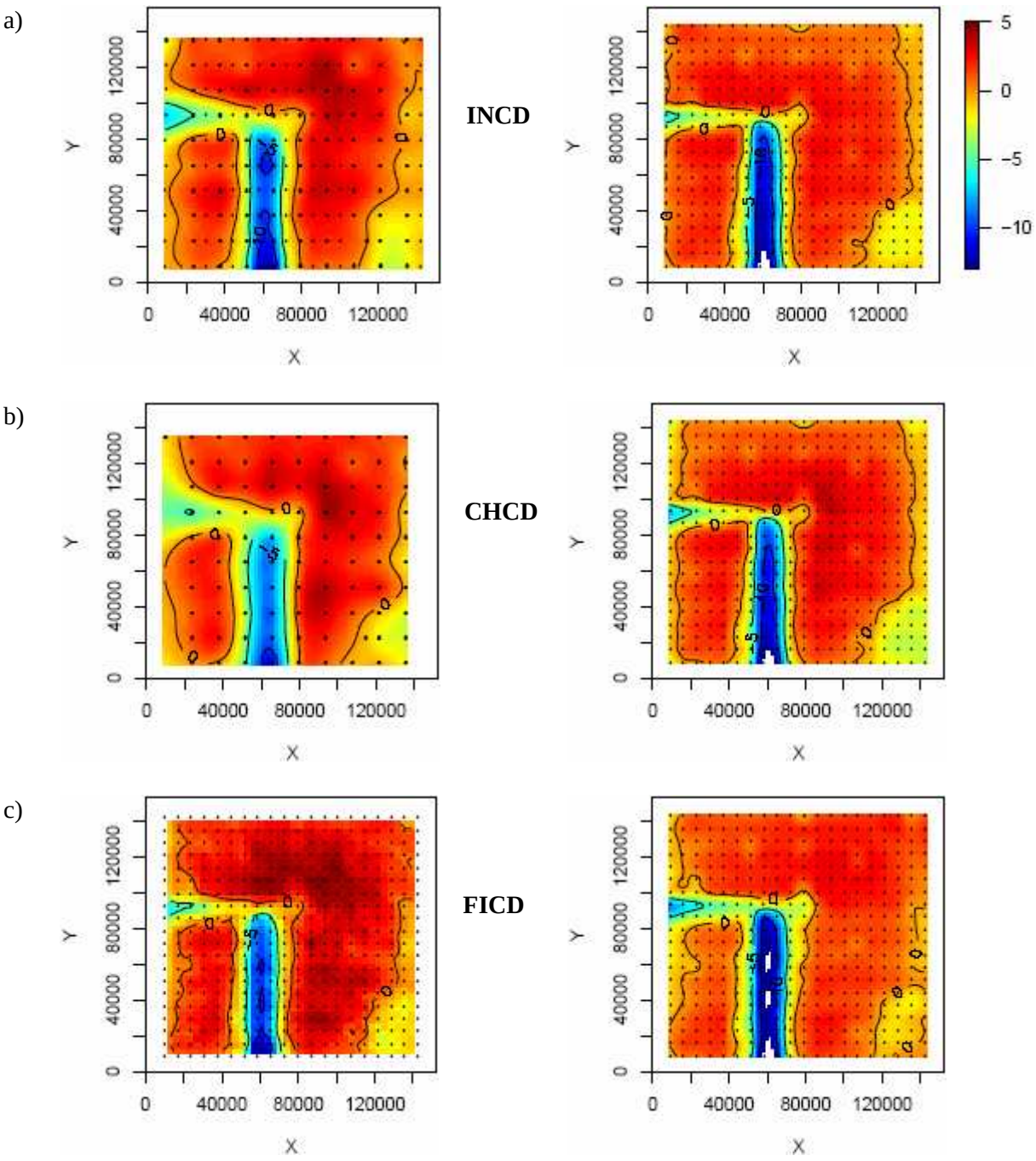

Figure 1: CD data obtained by means of CD-SEM (left) and scatterometer (right). 1a) depicts the CD signature at internal CD - Chrome etched, Mosi non etched, 1b) shows the same mask after MoSi etch and, finally, 1c) illustrates the signature after chrome removal. All dimensions are given in nm.

Figures 1a through 1c nicely guide through the production process of the mask, with the signature being transferred successively from one layer to the next. While its shape does only change slightly, the depth of the prominent finger signature changes measurably. All these changes are detected simultaneously by both methods.

A detailed comparison of the signature reveals a slight radial discrepancy with an unknown root cause. Apart from that, we obtain a very good correlation for the two methods of measuring the CD signature. The noise level for the scatterometer was with 0.1 nm (3σ) even lower than for the averaged 25 measurement points of the CD-SEM. This constitutes a powerful demonstration of the averaging

capabilities of the scatterometry. In Figure 2 the difference plot of raw data scatterometer and fitted data is shown with negligible differences in the order of 0.05nm.

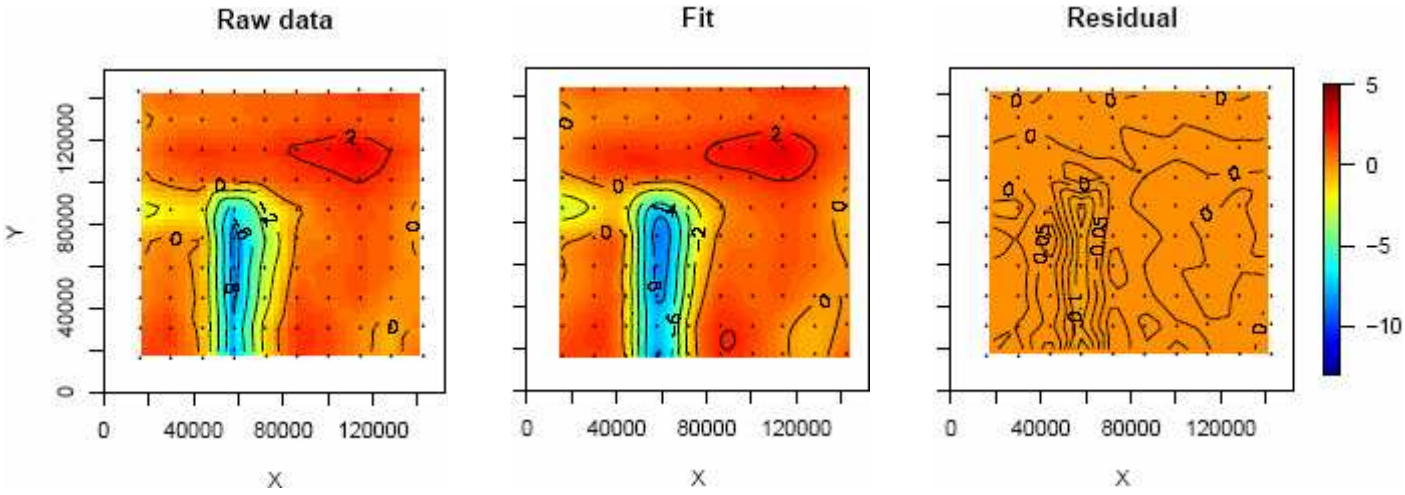

Figure 2: *left)* CD obtained using scatterometer for resist measurements, *middle)* TPS fit of the CD data, and *right)* difference plot from CD data and fitted CD data. Scale is in nm.

The residual of the scatterometer data shown in the right field of Figure 2 has a 3σ value of 0.1 nm. It is interesting to note that our daily process control shows a short term reproducibility of slightly less than 0.1 nm (3σ). Thus, it can be concluded that to some extend the residual distribution reflects the short-term measurement error of the tool. Some systematics can be seen for the very pronounced finger structure, which can be due to very slight fit artefacts once the signature changes dramatically.

To illustrate the potential of the method, calculated thickness of MoSi is depicted in Figure 3. Such thickness uniformity analysis can be utilized in process development and product characterization. CD and thickness (or depth) are the two first order parameters in the model and their signatures are robust against small changes in the model setup (e.g. changing dispersion starting points). Sidewall angle and surface roughness can also be determined using scatterometry. The accuracy of these parameters is not as good as for CD and thickness, nevertheless, scatterometry does detect slight changes between different photomasks. The origin of these changes, however, is sometimes hard to track down.

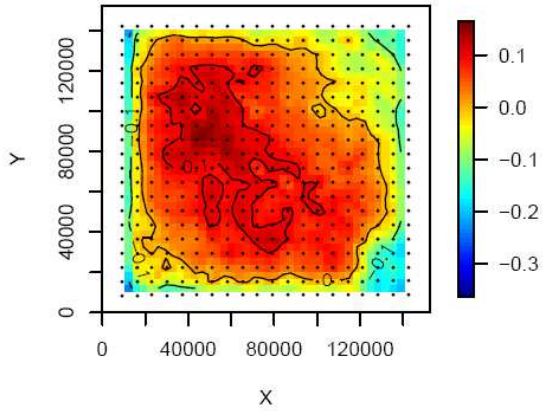

Figure 3: MoSi thickness as modelled from the scatterometer data. Scale is in nm.

Summary

We have demonstrated that scatterometry is a suitable method for the measurement of the signature profiles of photolithographic masks. It was found that the CD data of a scatterometer (n&k 5700-CDRT) are statistically stable on the micrometer scale and that there is no significant difference seen to theoretical averaging methods. We conclude that the experimental (scatterometry) and the theoretical (TPS) methods do essentially the same - they average out nanoscale noise. The results of this study can be interpreted two complimentary ways: the scatterometer measures stable macroscopic CD signatures and TPS is an appropriate method for extracting these signatures from any given CD data. This is an important prerequisite for the implementation of scatterometry in future development work and for benchmarking the obtained data to the traditional methods with the clear benefit for all applications that require averaging of data from larger areas. Furthermore, scatterometry allows to determine more parameters compared to standard CD-SEM. It is straightforward to use the thickness information for phase uniformity investigations and the sidewall angle variations for process development.

Acknowledgements

We would like to thank Alexander Gray (Physics Department, University of California, Davis) for his help in preparing the manuscript.

References

[1] Utzny, M. Rößiger, Determination of spatial CD signature on Photomasks, SPIE Microlithography Conference 2005, Proc. SPIE 6349 (2006)

[2] J. Richter, R. Liebe, F. Laske, J. Rudolf, T. Heins, Measurement tool influence on CD results on photolithographic masks, SPIE Microlithography Conference 2005, Proc. SPIE 6283 (2006)

[3] E.-M. Zerbe, T. Marschner, J. Richter, C. Utzny, Matching of different CD-metrology tools for global CD signature on photomasks, Proc. SPIE Vol. 6607 (2007)