CD forecasting in resist by means of scatterometry

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ABSTRACT

Critical dimension (CD) targeting is one of the key process parameters for the disposition of photomasks. The specifications are tightened at a constant rate over the years and are currently in the range of 3 nm for the most critical layers. Many efforts have been put in prediction of the critical dimension that is targeting the actual product based on data of previous products and also using resist data for further analysis and correction cycles. So far the tool of choice was the CD SEM (scanning electron microscope) with significant shortcomings due to altering the resist and its defect criticality during resist measurement.

Here we present data of long term resist CD monitoring on an n&k CDRT 5700 scatterometer system measuring standard mask patterns in the non-active field. Presented are results for one resist on two different photomask stack materials. The data is compared with the final CD measurement by CD SEM. The data is correlated accounting for tool variances in the manufacturing process and the mask clear field loading. The resulting model is still fairly simple with only 4 parameters for each process of record, one of them for the slope of CD values between CD SEM and n&k and three offsets for different process variables.

The data shows stable model behavior over close to one year including several resist lot changes and significant drifts in the front end process. The maximum forecast error is slightly above 2 nm and the process has a 95% capability to predict mean to target values better than 2 nm. Furthermore, the defect level has shown to be constant during that time frame with not a single incidence of particles due to the usage of the scatterometer. The total cycle time impact is minimal because only 4 points are recorded thus loading and unloading the mask to the tool is the actual cycle time adder. The described method is capable to significantly improve the CD targeting performance due to better partitioning of processes.

Key words: CD-measurement, cycle time, scatterometry, CD-SEM

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Introduction

Critical dimension mean to target is one of the rare mask house key process indicators that combines almost all single processes and extends even to blank and resist suppliers. It is such a fundamental parameter that it is mandatory to measure it with the best techniques available. While for the final product CD SEM is well established as tool of choice little progress has been made for measurements in resist. Here, CD SEM has the major drawbacks of being destructive to the resist and endangering the defect free status of the mask. Over the last years scatterometry has been described several times as one candidate as a fast, non-destructive optical technique.[1] However, lacking appropriate measurement sites in the mask design scatterometry has got a hard time to be introduced in production.

Recent studies suggest that many variables that seemed to influence scatterometer results are interdependent for cutting edge mask processes. Firstly, there is a high feature to feature correlation which enables to measure fixed reference structures and calculate the properties of other structures via measured correlations.[2] Secondly, modeling of scatterometer data was aiming for the perfect fit lately which prolonged calculation times and ended in highly sophisticated models hard to create. However, chasing reality is not necessary. A robust simple model that fails to give exact "real" values might be still good enough to give accurate correlations.[3,4] Thirdly, current etch processes have a very stable performance. This might not look like a prerequisite for a new technique, but correlations for the first two points can only be found when there is stable relationship.

Putting it all together, a simple scatterometer model measured on a single reference structure should be enough to determine the resist CD value and finally can be used to forecast the final mean to target value of a mask.

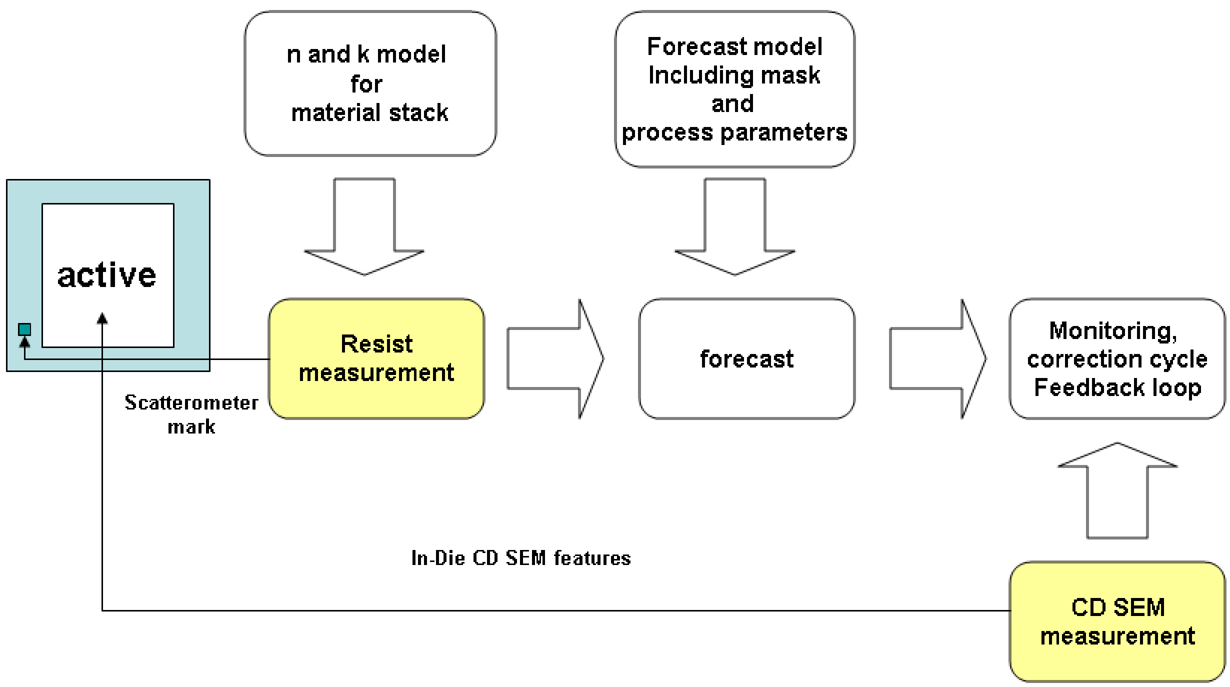
Experimental

We implemented the idea of a single reference measurement for part of our 4x nm production line. The pitch of the reference structure was chosen to be 520 nm and a 1:1 lines/space pattern was used. The pattern was placed well outside the active area of the mask. Our scatterometer (n&k CDRT 5700) enables that different sites with and without grating can be coupled. This has been used in such a way that on a non-patterned reference field only the resist thickness is measured. This resist thickness is then used as input parameter for CD evaluation on a field with grating. The n and k model consists of only 4 layers with two chrome layers for halftone material (MoSi, Chrome, Chrome oxide, resist) or 4 layers with two MoSi layers for binary material (opaque MoSi, coating MoSi, Chrome, resist). The side wall angle was fixed at 90 degrees. Only the resist thickness was allowed to vary. In all there are only two variables, resist thickness in the model without grating and CD in the model with grating (using the calculated resist thickness of the other model as input).

The process is then set up, that on every mask the reference measurement was done. In total this takes about 4 minutes including loading – unloading and alignment. The actual measurement takes only 10 seconds (RCWA approach without library).[5,6]

After measurement the result is correlated based on its known mask variables (A,B) and its process variables

(X,Y). This is an important step to get to nanometer precision. Many mask variables like local clear field, proximity, CD size … could result in different process biases. While the difference might be only a single or two nanometers neglecting these parameters will result in a failure of this approach. The same goes to the process variables, like different tools, process steps, set ups … An overview of the different parts of the process is given in sketch 1. It simplifies the data flow and depicts the major components to evaluate the resist data and calculate the forecast.



Sketch 1: Process flow for scatterometer measurement data. 1) Resist measurement on reference mark outside of active mask field. 2) evaluation of CD using an robust n and k model 3) Forecasting final mean to target by forecast model that includes variables for process and mask properties 4) Feeding data to monitoring, correction cycles and feedback loops including evaluation of how good the forecast matches the measured final CD mean to target by CD SEM.

We found that although the variable space seems to be quite large in the beginning it quickly boils down to a couple essentials parameters and all data shown later derive from a simple linear model. Here, the most important parameter is the slope. It describes how much of a nanometer in resist will be transferred to final CD. This parameter essentially describes the behavior of the very complicated resist profile during etch. Stable linear correlation could be found over a CD range of 15nm. For even larger input variances a linear model might not be sufficient. A single slope value was used for all material and process variables. Only for different resist types different slopes have been used. All other variables are constants and are very close to each other. The largest difference was found to be less than 5 nm, with usual differences of about 1-2 nm.

Results

Monitoring results of the forecast process are shown in figure 1. Depicted are product data of a single process of record over the time span of nine months. To simplify the calculations the MTT is the mean of all mean to target CD values measured with CD SEM once the mask is fully processed (excluding scatterbars). The difference between MTT and the forecast is then a measure for how good the resist measurement matches the final CD values.

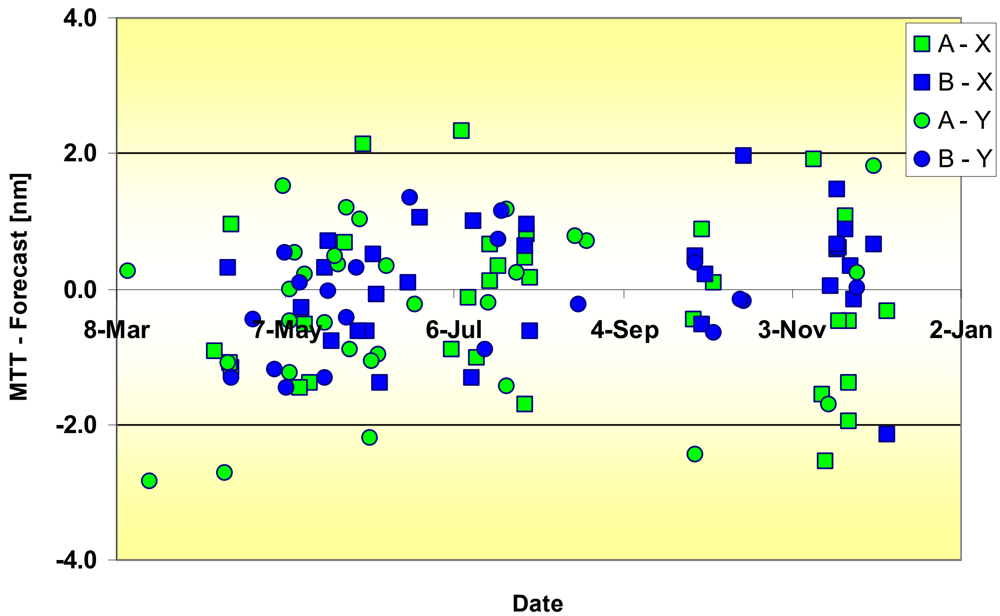


Figure 1: Monitoring data split for different mask variables A and B and process variables X and Y. While the capability is 2 nm in all cases, it can be seen that mask variable B enables a more precise forecast. Within the shown time frame neither the resist model nor the forecast model has been changed.

It is now interesting to investigate where the difference of MTT and the forecast derives from. Obviously, all processes between resist and final measurement contribute to the error. In our case this is chrome etch, Mosi etch, resist strip, tool matching of CD SEMs and long term stability of scatterometer and all CD SEMs. Furthermore, the simplification of the resist measurement to a single point of a lines/space pattern in horizontal direction leads to the inclusion of horizontal and vertical biases and also dependencies of how closely the CD SEM sites match the resist pattern sites. And finally, the correlation of the scatterometer marks in the outer rim of the photomasks to the in die measurements was assumed to be constant. In principle, all these parameters could be taken into account to refine the model accordingly. On the other hand, these 5 variables, one slope and four offsets (A-X, A-Y, B-X and B-Y) are enough for a forecast capability of around 2 nm. This emphasizes that our simple approach relying on stable processes and looking for correlations works outstandingly well.

One of the biggest concerns was the influence of the resist lot on the model itself. The resist lot determines the optical properties of the resist and with scatterometry being sensitive to such changes it could result in changes in the forecast. This is a crucial parameter for the whole approach. Only changes in the three-dimensional profile should influence the forecast not changes in the material properties.

In all we observed more than 10 changes on the resist lot without the necessity to adjust the forecast model (slope and the 4 constants are stable). On the contrary good and bad resist lots could be made visible (figure 2). Also process variables like post coat delay and resist age can now be monitored on every production mask. For many single processes this opens completely new monitoring concepts like resist thickness data for develop process monitoring. It also enables better correction cycles for process excursion and trouble shooting.

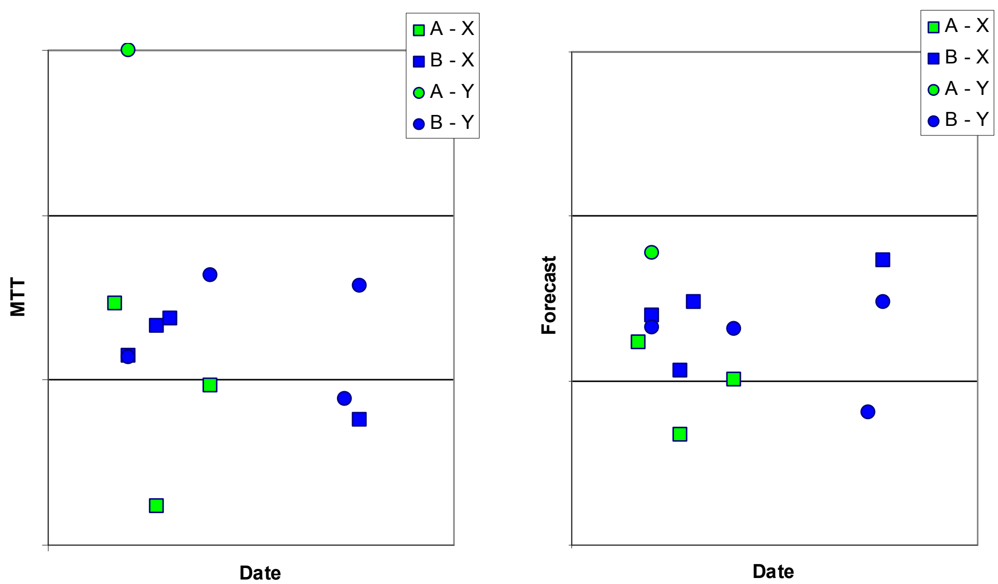


Figure 2: Snapshot of the data to show the equivalence of MTT performance and the forecast by scatterometry. In the depicted timeframe an elevated targeting behavior was observed. The good correlation between MTT and the forecast was clear evidence that the process excursion was already present in resist. The equal performance of the parameters A,B and X,Y excluded other key process parameters that left only the resist lot itself as possible root cause. After replacing the resist lot the targeting went back to normal.

Further work will be performed to understand the limitations of the current approach. In particular it is not clear when the assumption of good correlations will fail. Although not necessary at the present stage it would enable to determine which parameters have to be taken into account to gain higher precession for future developments.

Conclusion

This work demonstrates the capabilities of CD measurements in resist by scatterometry. Monitoring data reveal that the method reliably forecasts the mean to target value of the final photomask. The proven capability of around 2 nm enables accurate process partitioning which can be used for shorter feedback loops and separation of the pre-develop processes and etch. The applied scatterometer model proved stable versus different resist lots over a time interval of almost a year. That means that this method also permits resist quality assessment. Given that the reported 2 nm capability is to a significant extend due to correctable limitations in the applied approach, scatterometry finally seems to fulfill the promises surrounding it for years.

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