

Approaching Zero Etch Bias at Cr Etch Process

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ABSTRACT

Increasing demand for high end lithography mask especially phase shift masks and narrowing the specification, lead to development of etch processes with minimum critical dimension uniformity (CDU) and very low etch bias. The etch bias becomes one of the limiting parameters for the Cr etch process, due to strong cross links between etch bias and other etch characteristics like linearity and loading effect, thus contributing strongly to the CDU for masks with non uniform pattern distribution. The goal was to develop a Cr etch process with very low etch bias, keeping the other parameters at the same level and providing a wider process window for further optimization of the CDU, loading effect and linearity. As proposed by Faure *et al.* one possible way seems to be the limitation of the ion energy and the ion density by using plasma pulsing or after glow discharge etch conditions.⁵ In the paper we want to present a feasibility study of one specific approach to the mentioned methods and compare different ways for measurement of the CDU and etch bias. The work presented was done on the Applied Materials Tetra II Mask Etch system.

Keywords: Cr dry etch, etch bias reduction, CD Uniformity, linearity, loading effect

INTRODUCTION

Reduction of the etch bias becomes one of the major tasks for each technology node process development, since the SRAF feature size is more or less comparable to the etch bias. Small etch bias is one of prerequisites for reaching the resolution of clear assist features, good pattern fidelity and last but not least good critical dimension (CD) linearity as shown further down. One can easily reduce the etch bias by reduction of the over etch time or the plasma power, but this reduction is connected to an increase of the CD uniformity and degradation of the sidewall slope. Due to this trade off between CD uniformity and sidewall slope on one side and the etch bias on the other one, no simple reduction is possible, without principal change of the etch parameters.

The Cr etch rate is driven by radicals only, whereas the photo resist etch rate depends mainly on the ion density and so the ratio seems to be a way leading to etch bias reduction.⁴

This hypothesis was tested experimentally during the process development for the “Andromeda” technology node and the results are presented and discussed in this paper.

EXPERIMENT

The experiments were performed at Applied Materials Tetra II mask etcher. To be able to judge the results, data of the new developed “Andromeda” etch process was compared to the previously available process for identical mask type. All experiments were done on Hoya NTAR7 Cr material coated with FEP171 positive CAR resist.

Evaluating the new “Andromeda” etch process, four different mask designs were used in order to check CD uniformity for evenly and unevenly distributed pattern with different global pattern density. With this approach, contributions of the etch process to following parameters can be judged independently:

- Etch bias
- Radial CD uniformity
- Linear CD uniformity
- Pattern density dependent etch loading effect
- CD linearity

The measurement sites are equally spaced across the mask area of 132x132 mm², which corresponds well to the quality area of the blank material. For evaluation the 280 nm clear feature was used.

ETCH BIAS MEASUREMENT

The etch bias is defined as widening of the clear or narrowing of the dark structure due to the etch process and determined by comparing the opening before and after Cr etch in resist and Cr layer. The pre measurement is done on 300 nm thick FEP171 resist layer, showing the typical CAR resist footing and in worst case also T- topping. The post measurement is done on approx. 70 nm thick CrOx/Cr layer with well-defined edge and steep sidewall slope.

Two different methods are typically used for estimation of etch bias. Most commonly used are optical or CD SEM measurement, which allows one to compare the CD variation for a huge number of points and almost any feature size. An alternative method is AFM, which is typically measured on less measurements sites and the feature size is restricted by the shape and size of the measurement tip. The biggest advantage for AFM, is the independency of the material in contrasts to the CD SEM. Comparing both methods, several differences were identified:

- 1, The CD SEM evaluates the CD using a 2 dimensional picture, so the result is an average over certain structure length. The AFM measurement contains several scans shifted each by a couple of nm, but the result is not averaged over that many data points as at CDSEM.
- 2, Feature width measured by CD SEM depends on the material and shape of the sidewall of the structure, which is often different for resist and Cr measurement. AFM measurement is material independent and width can be estimated at any height of the feature.

Figure 1 shows comparison of the CD post etch measurement and etch bias measured by CD SEM and an AFM tool.

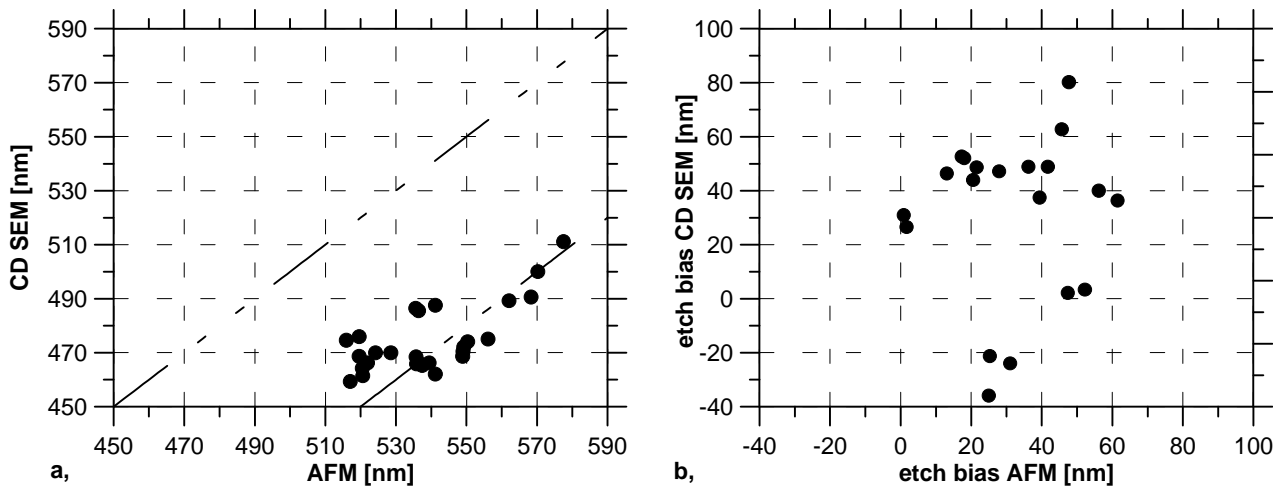


Fig.1 - **a**, Correlation between the CD in Cr measured by means of AFM and CD SEM. **b**, Correlation between etch bias measured by CD SEM and AFM

The measurement in Cr correlates quite well most probably because of the material contrast and excellent sidewall shape, whereas both measurement methods provide different values for etch bias even for the same feature. One obvious reason for the missing etch bias correlation is the variation of the CD in CD SEM measurement in resist. Other parameter, that affect the etch bias are resist type and litho process. They can potentially lead to variation in resist sidewall shape and cause an increase of the uncertainty of etch bias determination.

To better understand the details we have to clarify, what is the “right“ etch bias and estimate the etch bias at different height in the photo resist and Cr as shown in Fig.2..

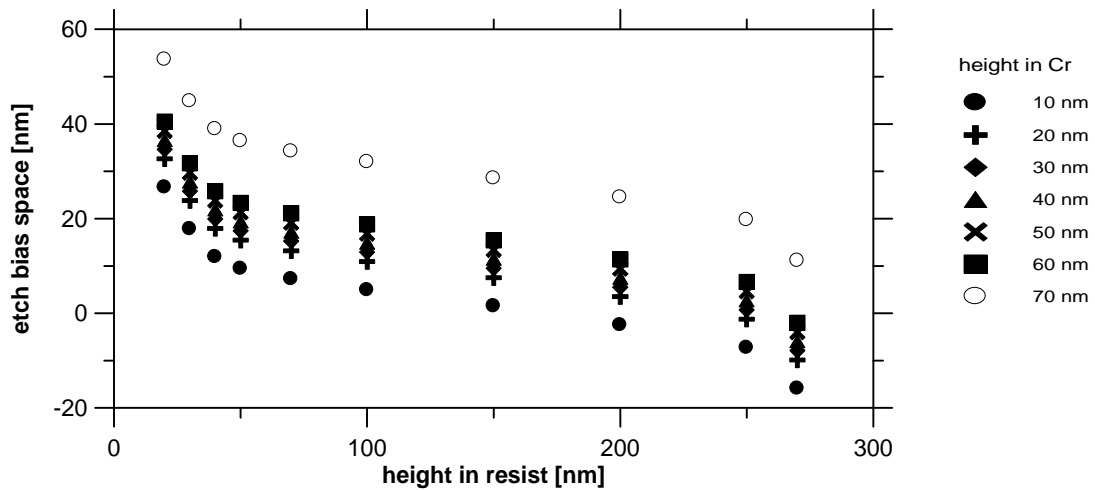


Fig.2 - Etch bias measured on space by means of AFM as a function of the height of the measurement point in resist and Cr. The varying height of measurement point in Cr is represented by different symbols.

The graph illustrates the dependence of the etch bias with respect to the position of the measurement point in resist and in Cr. This variation is caused by the difference in the sidewall angle and shape and cannot easily be avoided during the measurement. E.g. for a perfect 90° sidewall angle in Cr all points for given height in resist would be identical. This investigation proved that no generic method is valid for etch bias estimation, and comparison of two different processes is possible only using masks with the same litho process and measurement method.

ETCH BIAS

In order to determine the etch bias of the new “Andromeda” etch process, we decided to use the preceding “Galaxy” etch process as reference for etch bias and in parallel compare “Andromeda” and “Galaxy” processes using both CD SEM and AFM methods. Keeping the sidewall slopes as similar as possible (see Fig.3) the direct comparisons of etch bias values show the benefit of the “Andromeda” process. (Fig.4)

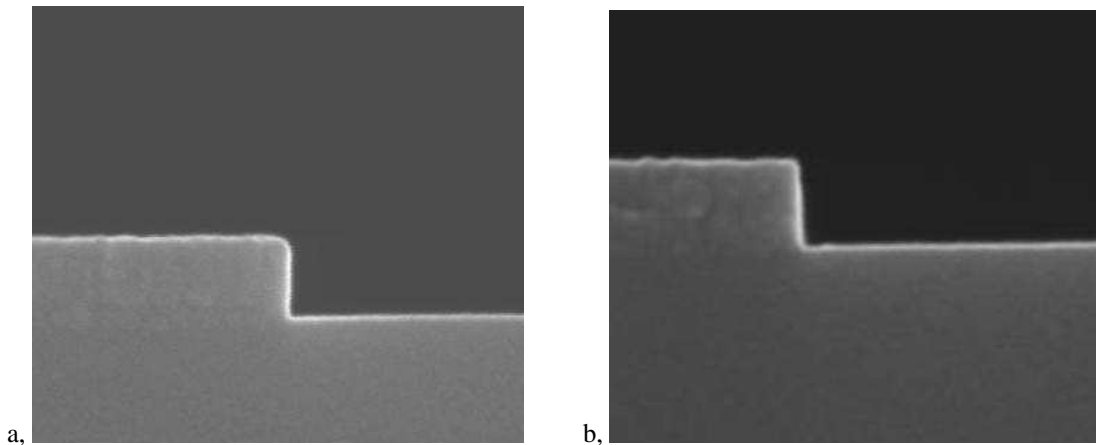


Fig.3 - Cr sidewall slope for **a**, “Galaxy” and **b**, “Andromeda” etch process

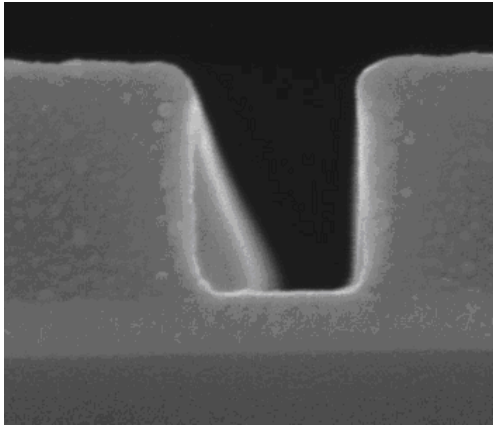


Fig.3c - resist sidewall slope

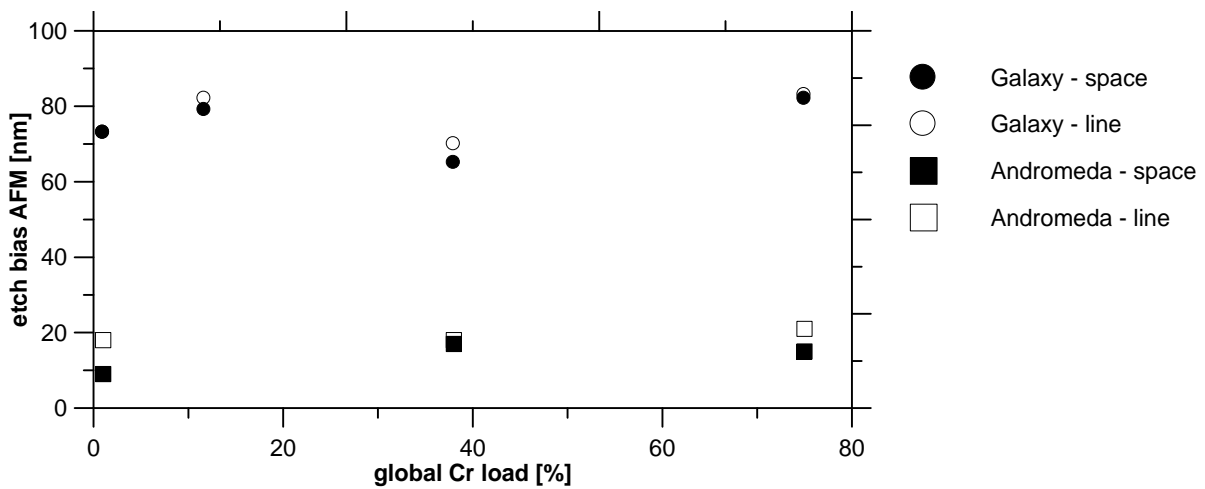


Fig.4 - Etch bias comparison at 4 different global pattern densities for low and high radical / ion processes. The etch bias was estimated using AFM and measured as widening of the space and narrowing of the line structure.

From the SEM cross-section of photo resist sidewall (Fig. 3c) one can estimate the photo resist pull back needed to achieve steep sidewall in Cr and to estimate the minimum lateral resist etch rate. Comparing these values for both processes another result becomes obvious. The “Galaxy” process removes laterally more resist than the estimated minimum resist pull back, whereas the “Andromeda” process approaches very well the minimum lateral resist pull back. As mentioned before, the etch bias has significant impact on the pattern fidelity. The lower the etch bias, the better the pattern fidelity. Since the pattern fidelity is one of the important factors especially for sub resolution assist features (SRAF’s), one can determine – at least qualitatively – the capability of an etch process simply by comparing SRAF’s. Fig. 5 shows the comparison between SRAF’s for the Galaxy and Andromeda processes.

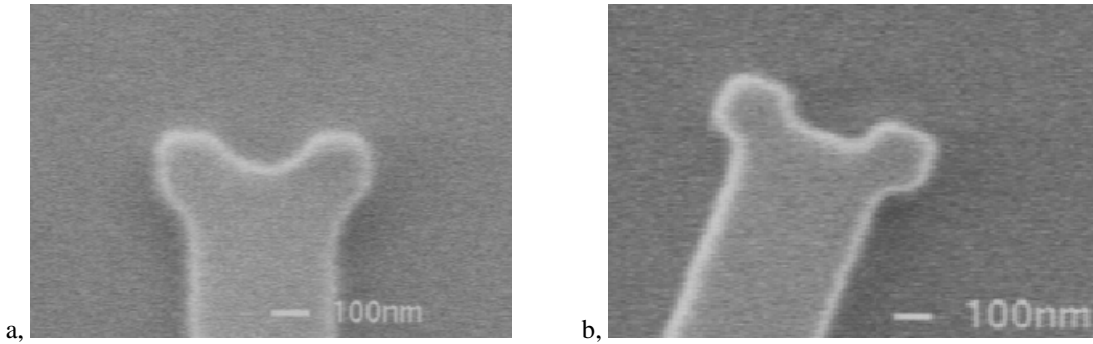


Fig.5 - Pattern fidelity of SRAF feature for **a**, Galaxy and **b**, Andromeda process. Courtesy of KLA Tencor Corp.

CD UNIFORMITY

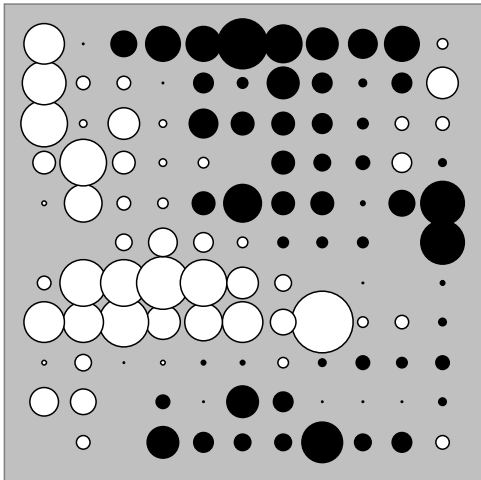
As mentioned at the beginning, one of the major tasks was to optimize the Cr etch process for different global Cr loads and minimize the systematic contributions to the radial CD Uniformity and loading effect.

The radial CD uniformity contribution was estimated at masks with uniformly distributed pattern at global Cr load of 1%, 38% and 75%. The loading effect was estimated using a mask with high Cr load in upper left quarter and very low Cr load in the remaining area of the mask.

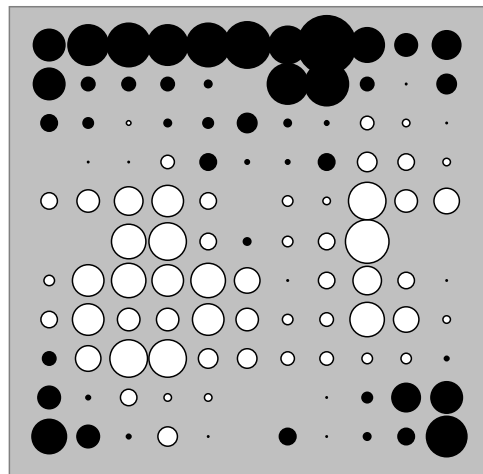
The final CD uniformity and the contribution of the Cr etch process are shown for both processes in Fig.6.

Figure 6 shows very clearly that the “Andromeda” process provides good CD uniformity results for masks with uniform distributed pattern density, similar to the “Galaxy” process, which shows good performance too.

The strength of the new process shows Figure 6d, where the loading effect plays an important role. Here the loading effect of the “Andromeda” process is almost negligible in comparison to the old process. The improvement of the CD uniformity due to the reduced loading effect is even more pronounced for the product masks. The loading effect on non-uniform distributed pattern as well as the loading effect at the border of the chip area is improved. This loading effect at the chip border is frequently not recognized as loading effect, but added to the radial CD uniformity footprint due to missing capability to differentiate between both effects for product masks.

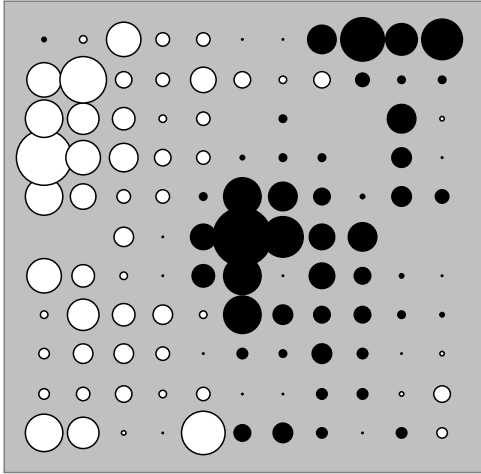


a, Galaxy CD Uniformity= 5.3 nm

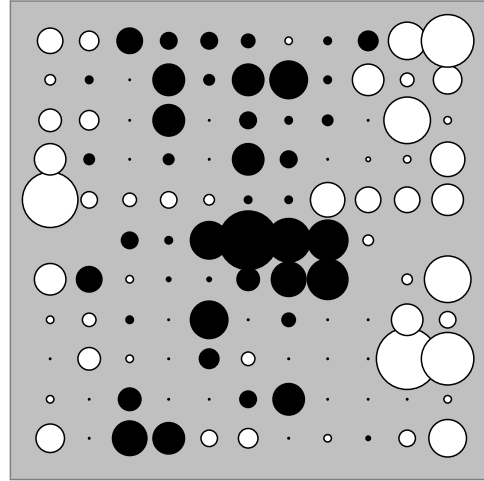


Andromeda CD Uniformity= 5.1 nm

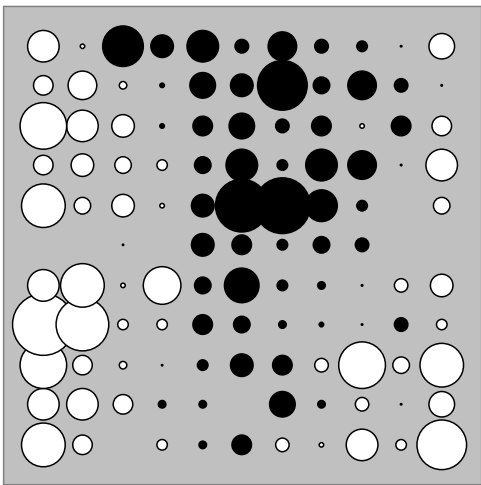
Fig.6a - Comparison of the final CD uniformity for “Andromeda” and “Galaxy” processes demonstrated at **a**, 1% mask



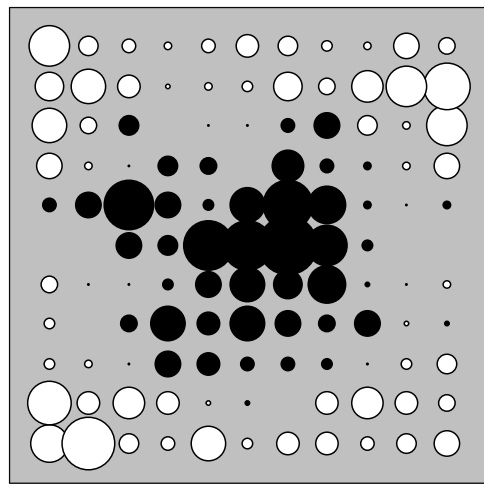
b, Galaxy CD Uniformity= 6.9 nm



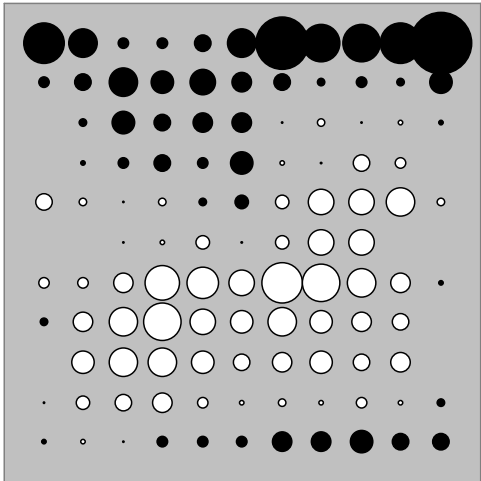
Andromeda CD Uniformity= 6.5 nm



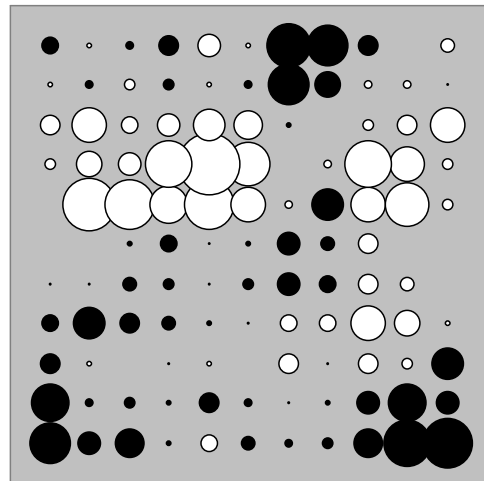
c, Galaxy CD Uniformity= 8.8 nm



Andromeda CD Uniformity= 5.2 nm



d, Galaxy CD Uniformity= 9.6 nm



Andromeda CD Uniformity= 4.3 nm

Fig.6 - Comparison of the final CD uniformity for “Andromeda” and “Galaxy” processes demonstrated at **b**, 38% mask **c**, 75% mask **d**, quarter quadrant mask (unevenly distributed Cr load)

Since the plots in Fig.6 show the “worst case” for CD uniformity at area of 132 x 132 mm², we decided to show CD uniformity plot for a product similar mask with a chip area of about 100 x 120 mm² to provide better idea about what the customer will see on products.

The CD uniformity data was fitted to obtain linear and radial footprint on the mask. The residual portion of the CDU is basically the contribution of e.g. metrology and pattern generation. Fig.7 shows the final CD uniformity plot for this product like mask.

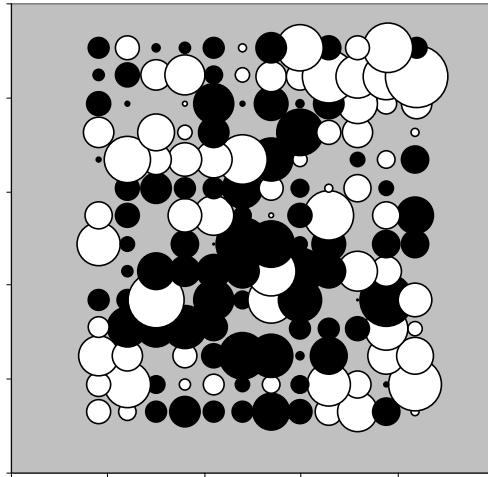


Fig.7- Final CD uniformity plot for product like mask with chip area of about 100x120mm² CDU =3.3 nm

CONCLUSION

The etch bias measurement is not only tool and method dependent, but depends also on feature size and sidewall shape in resist and Cr. Specifically the feature size and the sidewall shape contribute up to 20 nm and approx. 60 nm to the etch bias, respectively.

The new “Andromeda” process proves the hypothesis, that the etch bias of Cr etch process can be influenced by changing the process parameters. Etch bias was confirmed to be one of the most important factors influencing the linearity and pattern fidelity.

The performance of the “Andromeda” process exceeds performance of the former “Galaxy” process in all criteria:

Optimization of the etch process resulted in a reduction of approx. 80 down to ca. 20 nm etch bias.

The CD linearity for isolated clear, dense clear and dense dark structure improved significantly and is below 6 nm, CD linearity for isolated dark structure was slightly improved from ca. 12 nm down to 8 nm.

The CD uniformity for evenly loaded masks is comparable to the “Galaxy” process, however the CD uniformity for unevenly loaded masks was improved by more than 50% mainly due to reduction of the loading effect.

Last but not least the pattern fidelity was improved significantly as can be seen qualitatively in Fig. 5.

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