Investigation of Cr Etch Chamber Seasoning

Pavel Nesladek[a], Guenther Ruhl[b], Marcel Kristlib[b]

[a]Advanced Mask Technology Center, Dresden, Germany,
[b]Infineon Technologies AG, Mask House, Munich, Germany

Abstract

One of the most critical steps for photomask CD off-target is the patterning of the mask. Here the instability of the dry etch process contributes directly to the stability of the CD value. The increasing demands on high-end masks cause a narrowing of both mask CD off-target and CD uniformity specifications, and accordingly the process stability has to be improved to fulfil these criteria.
In this work we investigated the correlation between hardware parameters, basic etch process parameters and the corresponding CD mean-to-target value. Correlations between CD mean-to-target and Cr etch rate as well as effects of chamber seasoning after wet cleans are discussed.

Keywords: Cr plasma etch, MTT stability, seasoning

1. Introduction

The increasing complexity of semiconductor technology and the scaling down of the feature size are the reasons for tightening the specifications for photomasks. In particular, the critical dimension uniformity (CDU) and mean-to-target (MTT) are the most critical parameters for mask manufacturing and are approaching physical limits of the processes used. Crucial steps for the usability of the mask are the patterning steps, in particular the Cr etch process and the MoSiN etch process for half-tone masks.

The decreasing range of the MTT approaches the natural scattering of the process, and so effects like changes of the MTT caused by the regular wet cleaning of the etch chamber are becoming more important.

Usually process monitoring is restricted to tracking of machine parameters of the etch system and process parameters like etch rates. In some cases these data help to find the root causes of process deviations. In contrast, there are some other cases where these data are not sufficient for root cause analysis. In this work we will show examples of both cases, which affect MTT deviations after etch chamber wet cleans.

2. Methodology

This analysis was done on a Cr etch process performed on an ETEC Tetra I ICP mask etch system. The etch chemistry utilized was Cl_2, O_2 and He, and the endpoint was detected by OES. The machine parameters were extracted using a company-customized software. Monitoring was done on stepper-exposed masks with iP3600 photoresist. The Cr etch rate was determined by dividing the nominal Cr thickness (stable by ± 1 nm) by the endpoint etch time. The photoresist etch rates were determined by thickness measurements performed with a Nanometrics Nanospec 6100 reflectometer. CD measurements were performed on a KLA 6100 CD-SEM.

3. Results

3.1 Mean-to-target stability

Due to particle and etch residue accumulation, plasma etch chambers have to be cleaned on a regular basis. The clean strategy of the current Cr etch system is based on the use of swap-kits consisting of a complete upper chamber (chamber body and ceramic ICP dome). The chamber is completely disassembled and replaced by a freshly cleaned chamber kit. The contaminated chamber kit is then wet-cleaned by external suppliers and thus serves as a swap-kit for the next chamber clean. The advantage of this procedure is the short chamber downtime and the lower risk of insufficient cleans under time-critical circumstances.

However, there is some risk that a difference in chamber hardware leads to shifts of the process characteristics. One event, which is further described in this paper, appeared as a Cr etch rate drift. At the same time the photoresist (PR) etch rate stayed unaffected, so there was a resultant shift in Cr / PR selectivity, which is inversely proportional to the clear etch bias [1]. This became evident as a shift in CD MTT of about 20 nm, whereas the CD uniformity was not affected. Figure 1 depicts the time to etch endpoint compared with MTT on dark structures. This figure clearly shows the correlation of both parameters during the event of a chamber change. Before this change the MTT was rather stable, then began increasing immediately after the chamber change.

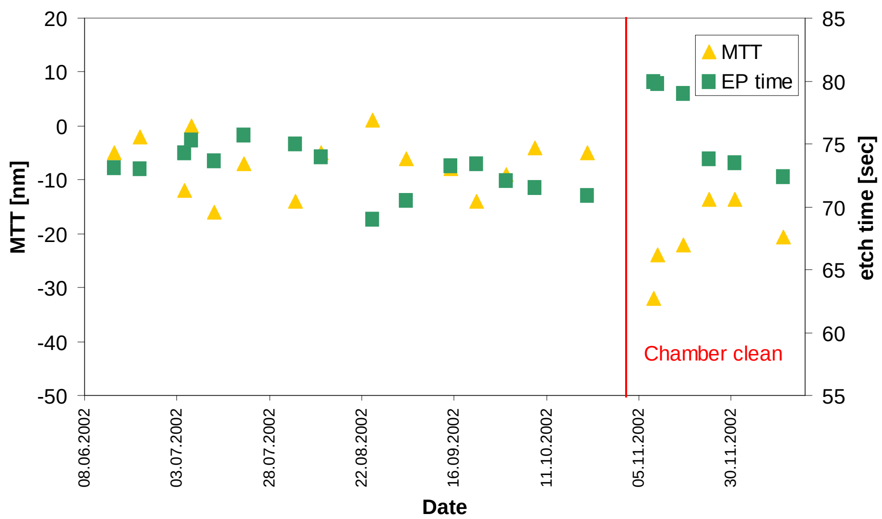

Figure 1: Cr etch rate and CD jump after chamber change due to wet clean

The etch rate monitor data in Figure 2 show that this phenomenon occurred several times (events 2 & 4), but there was also a chamber change without such an effect (event 3). Another event seems to show an inverse behavior (event 1).

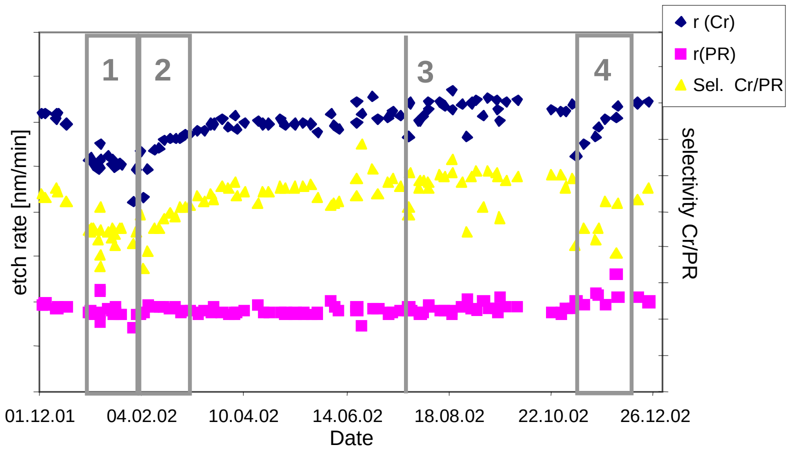

Figure 2: Data from Cr and PR etch rate monitor masks

To explain these phenomena different kinds of tracked data were analyzed. Since the tool process parameters are tracked automatically during etch of a biweekly monitor mask, this dataset was analyzed first.

3.2 Process Stability

From previous DoE data the process sensitivity to process parameters can be obtained by normalization of the parameter space as shown in Figure 3. Here the variation of the etch bias and thus of the CD value as a function of three different factors becomes obvious. The diagram shows the effect of O_2 concentration in active gas, source (ICP) power and pressure. Bias (RF) power does not have a significant impact on etch bias in the current process. The pressure shows the highest sensitivity; for example, a process pressure increase of 1 % decreases the CD value by about 3.5 nm. The O_2 concentration changes the CD about 2.2 nm per 1% in active gas and the influence of source power is only 0.5 nm per 1 % variation.

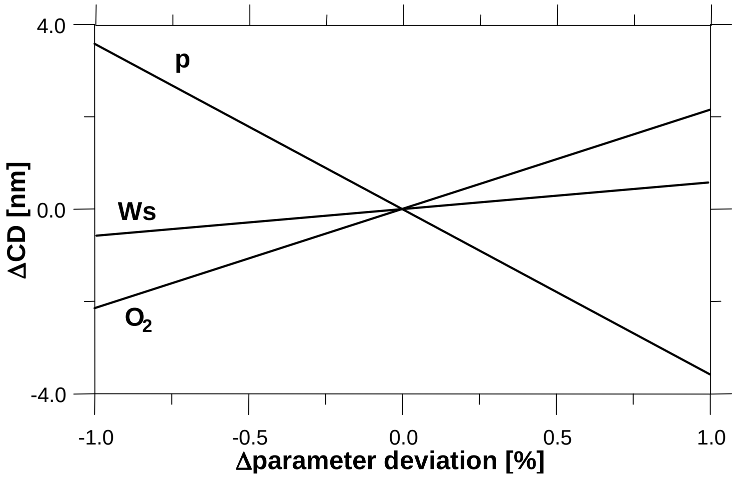

Figure 3: Perturbation plot for the CD value. The CD is function of the O_2 concentration in active gas (O_2), source power (W_s) and pressure (p) variation

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Unfortunately, this approach does not allow tracking and controlling of the changes in chamber seasoning, which could significantly affect Cr etch rate and hence the etch selectivity.

3.3 Process Monitoring

By observing the Cr etch process for a long period of time and comparing the data read out of the tool and the measured parameters of the etched mask, a set of monitoring parameters was found. This includes two kinds of parameters:

a) Process parameters, which can be set in tool recipes like pressure, power, reflected power, gas flows and temperatures.

Parameters in the first set can be identified from DoEs. The influence of these parameters on etch bias (and on MTT) or CD uniformity can be clearly resolved and described from experiments, as previously shown in figure 3.

b) Process parameters that cannot be tracked and influenced by tool parameter setting directly. In this group belong for example Cr and resist etch rate.

The second set contains parameters, which cannot be controlled by tool parameter settings, but nevertheless affect the final results to the same magnitude as the first set. They cannot be simply corrected and can depend on the "history" of the particular chamber, such as seasoning, polymer build-up on the chamber walls, etc.

For the Cr etch process monitoring we decided to track the following parameters:

Parameter which cannot be changed in the tool recipe	Parameter which can be changed in the tool recipe
• Cr etch rate • resist etch rate • selectivity • resist etch uniformity	• chamber pressure • -O_2 flow • -Cl_2 flow • -He flow • -forward source power • -reflected source power • -forward bias power • -reflected bias power • -settings of matchbox

From these parameters the Cr and photoresist etch rate and thus the selectivity are the most sensitive to the seasoning of the chamber and are used for process monitoring. To obtain the parameter in a significant frequency, twice a week a monitoring mask was etched to determine Cr and resist etch rate, resist uniformity, and selectivity. Parameters on the right hand side of the list were determined for these runs as well.

Figure 4 shows that the gas flows are very stable over time and the signal resolution is far beyond a significant contribution to CD variations as indicated in Figure 3. The missing data points are due to software problems. Pressure and throttle valve position (Figure 5) show a different picture. Whereas the pressure reading shows a constant value, the throttle valve position shows a strong increase during event 1. This indicates a problem with pressure control. The foreline pressure (Figure 6) supports this finding, showing an increase during the questionable time period. Actually, the chamber manometer could be identified as defective and was replaced. Unfortunately, there is no hint on the causes for the other events. Chamber wall and cathode temperature also do not show any excursions. Looking on the RF generator parameters (Figure 7) forward and reflected of bias (RF1) and source (RF2) power indicates some features. Bias power does not show any indication of a process drift. After event 1 occurred reflected source power (and thus also forward source power) exhibited a significant drop, which came back to its normal level after the Cr etch rate stabilization caused by a chamber change (event 2). The same behavior is seen after the other Cr etch rate drift due to another chamber change (event 4). The chamber change without a Cr etch rate drift (event 3) only showed a slight increase of the reflected source power. As mentioned earlier (Figure 3) the variation of source power has only a very small effect on etch bias, this cannot be the root cause for the observed CD drift. As reflected power is a function of the chamber impedance this effect only reflects the reaction on a process change, which is not directly tracked by the machine parameter monitoring.

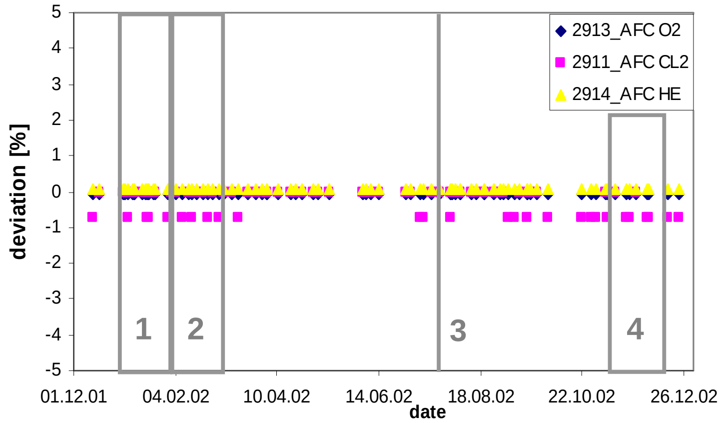

Figure 4: Monitoring data obtained from the Cr etch chamber by tracking machine data: mass flow controller readouts of O_2 (AFC O_2), Cl_2 (AFC Cl_2) and He (AFC He)

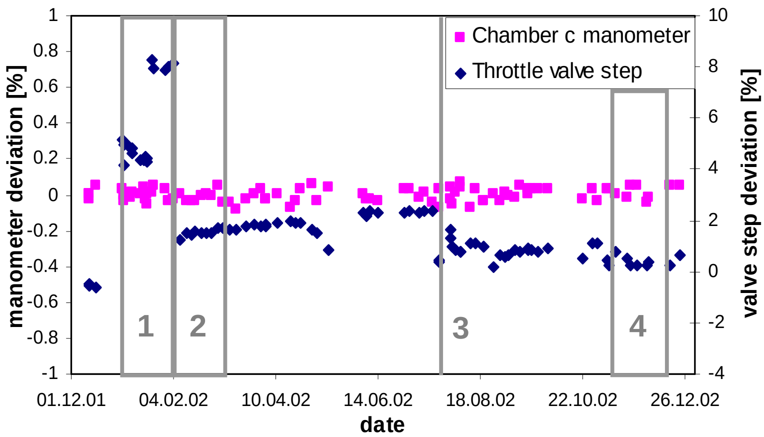

Figure 5: Monitoring data obtained from the Cr etch chamber by tracking machine data: pressure (Chamber c manometer) and throttle valve position (Throttle valve step)

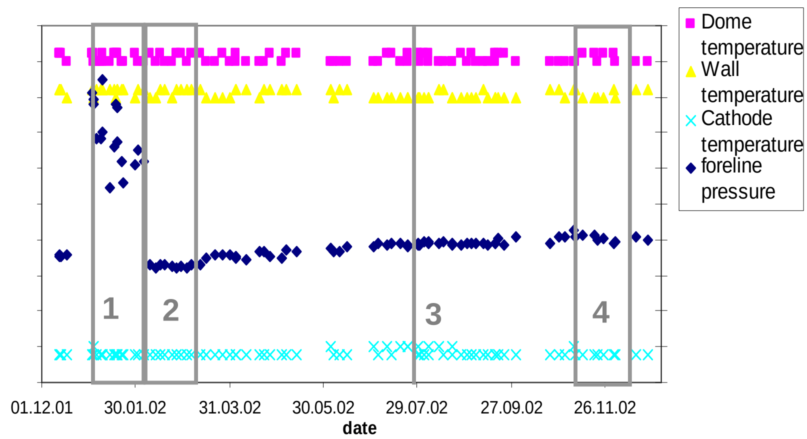

Figure 6: Monitoring data obtained from the Cr etch chamber by tracking machine data: foreline pressure, chamber wall/dome temperature and cathode temperature

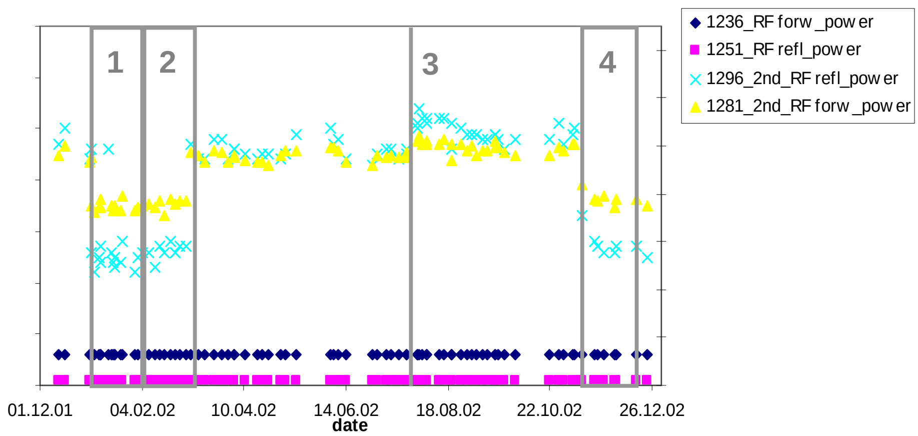

Figure 7: Monitoring data obtained from the Cr etch chamber by tracking machine data: bias power (RF forw/refl_power) and source power (RF2 forw/refl_power)

3.4 Chamber seasoning

In order to identify the effect of wet clean and thus the new chamber condition on the CD MTT performance, the effect of chamber seasoning was studied. The drifts of the Cr etch rate found in event 2 and 4 were estimated to occur during 1.5 plasma hours until reaching a stable level.

One explanation of the effect could be the possible deposition of etch products on the chamber walls. Since the etch products, like CrO_2Cl_2 and CO_2, are highly volatile, this scenario appears to be unlikely. In order to clarify the effect an experiment was designed to observe the Cr and photoresist etch rates as well as etch bias. First, baseline data were obtained using a freshly cleaned chamber. Then a typical etch process was run for 5 hours on a quartz blank to analyze the effect of the plasma changing the internal chamber wall surfaces. After this treatment the chamber was cooled down for 1 hour and the Cr and PR etch rates and etch bias were obtained again. Finally an etch process was run using Cr foil as a substrate for 1.5 hours. After this, the etch rates and etch bias were determined again. Neither the changes in PR and Cr etch rates, nor in MTT were significant as depicted in Figure 8. This result is consistent with the findings of J. Clevenger et al. [2] using XPS analysis of ceramic coupons positioned on the internal chamber surface. The analysis is consistent with the fact that this process drift did not occur after all performed chamber changes.

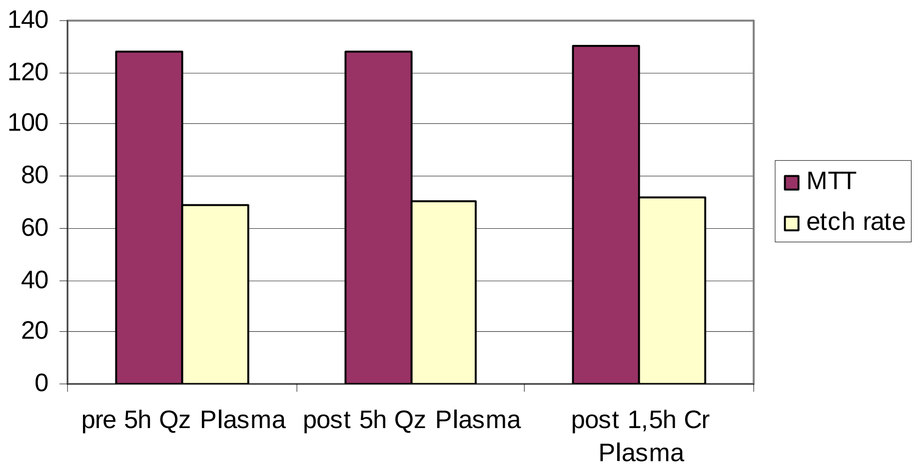

Figure 8: Cr etch rate and MTT at different chamber conditions.

This behavior could also be confirmed on regular product masks (Figure 9).

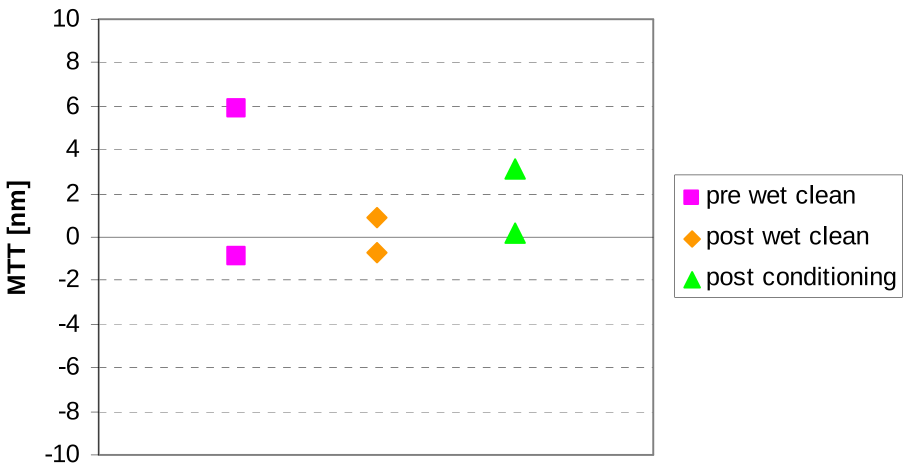

Figure 9: MTT stability of product masks at different chamber conditions.

This result disproves the hypothesis of chamber seasoning effects, so another explanation for the root cause of the CD shift effect has to be found.

3.5 Chamber wet cleaning method

According to the cleaning protocol the chambers were completely disassembled and the parts consisting of ceramic and anodized aluminum parts were sent to an external cleaning supplier. The wet cleaning procedure itself was a combination of physical and chemical treatments followed by enhanced temperature drying and vacuum sealing in polyethylene film.

During the life of the chambers the cleaning supplier was changed. This also meant that the wet cleaning procedures were slightly different at different times. This led us to do a comparison of the behavior of the same chambers after the cleans by different suppliers on both of two etch systems. Table 1 now clearly shows the dependency of the etch rate and CD jump to correlate with the cleaning supplier. The explanation for this effect is probably a formation of a specific residual surface layer after the cleaning procedure of supplier A. The removal of this surface layer then needs a longer plasma treatment leading to the Cr etch rate drift we observed.

	Supplier A	Supplier B
Chamber #1	2x MTT instable	MTT stable
Chamber #2		MTT stable

Table 1: MTT stability of different chambers

4. Conclusion

Although monitoring of the machine parameters of an etch system is very valuable to find process excursions, their use for analyzing root causes of process deviations is restricted. In this work we found Cr etch rate and thus MTT drifts after Cr etch chamber wet cleans, which could be assigned to a certain wet clean supplier. After changing the supplier the process stability could be maintained. We also could show that there is no significant effect of Cr etch chamber seasoning on the MTT performance of the process.

Acknowledgments

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References

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