Endpoint Detection Development for 70 nm Technology Cr Etch Process

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Abstract

For the last few years several different photoresists and Cr layers were used for mask making:

- IP3600 resist for 363.8 nm laser writer
- ZEP 7000 resist suitable for E-beam writers
- CAR resists (PEK 130, FEP 171, NEB 022)

Introduction of a new resist into production has several risks associated with and requires process adjustments in litho and etch process likewise. This presentation will focus on the differences in the endpoint detection using optical emission spectroscopy (OES), especially at low Cr load, when using above mentioned photo resists.

Development of the OES endpoint detection starting from single wavelength is shortly discussed and methods for endpoint detection at low Cr concentration in the gas phase caused by decreasing plasma power and increasing volume of the etch chamber are shown.

An important factor for the practical use of the endpoint detection is the reliability, scalability for different Cr loads and dependence on the chamber seasoning. These factors will be discussed finally.

Keywords: Cr plasma etch, Endpoint detection, Optical emission spectroscopy

Introduction

Scaling down of the feature size in semiconductor technology and increasing complexity are reasons for tightening of the specifications for photomasks. Major drivers for the introduction of novel types of photo resists, which provide better performance, are the critical dimension uniformity, compatibility of resists with both laser as well as E-beam writers and - in some cases – reduced writing time. Today several types of photo resists for the I-line laser writer, classical E-beam resists and modern positive and negative chemically amplified resists are used to exploit the previously developed technology and tools on one hand and the production of high end masks on the other hand. The following resist types were used in this work: IP3600, ZEP7000, FEP171, NEB022 and PEK 130.

Their usage depends on the technology node, complexity and the specification of the particular mask. Nowadays the Cr layer of almost all masks are dry etched, which requires an etch process available for all these resist types. These requirements include endpoint detection, in this case optical emission spectroscopy endpoint. The process development showed that there are several differences between these types of resists causing difficulties, which have to be solved in order to achieve reliable endpoint detection for all of these resists. Formerly the endpoint was detected by a photomultiplier and monochromator set to 520 nm. This detection method can potentially result in misprocessing of the mask due to different slope of this line for different combination of Cr layer and resist type. Some of the differences between the photo resists mentioned above will be discussed as examples.

Methodology

The data used in this article was obtained from chrome etch process performed on an ETEC Tetra II® mask etch system equipped with EyeD® OES endpoint system manufactured by Verity Instruments Inc. The etch chemistry utilized was Cl_2 & O_2, with an excess of the Cl_2. The endpoint data was recorded in the range between 200–800nm with a sampling rate of 2 Hz. The intensity of the signal was adjusted by automatic gain control after plasma ignition by changing the integration time of the CCD array.

Three types of masks will be discussed in this paper i.e. photo resist blank and two different mask layouts with a global clear field of 0.23% and 11.7%. All experiments were performed on Hoya NTAR7 Cr blank for ZEP7000, FEP171 and Hoya AR8 Cr blank for IP3600 and PEK130 resists.

Endpoint time and Cr etch rate

There are several known factors influencing the endpoint time. The most important ones are thickness and composition of the Cr layer and the gas composition - mainly the ratio O_2/Cl_2 [1]. Another factor is the global Cr load that affects the endpoint time and etch rate [2],[3],[4]. The vertical Cr etch rate is influenced by the global as well as the local Cr load. This effect can be observed as "steps" in the endpoint signal, when etching masks, containing regions with strongly different Cr load. Each of the steps in Fig. 1 represent an endpoint for the particular region, starting with the low load areas and ending with the high load regions as proven by measurement of the vertical Cr etch rate. Also the average structure size seems to be a factor influencing the etch rate and causing differences in the endpoint time of masks with the same global Cr load and different layout.

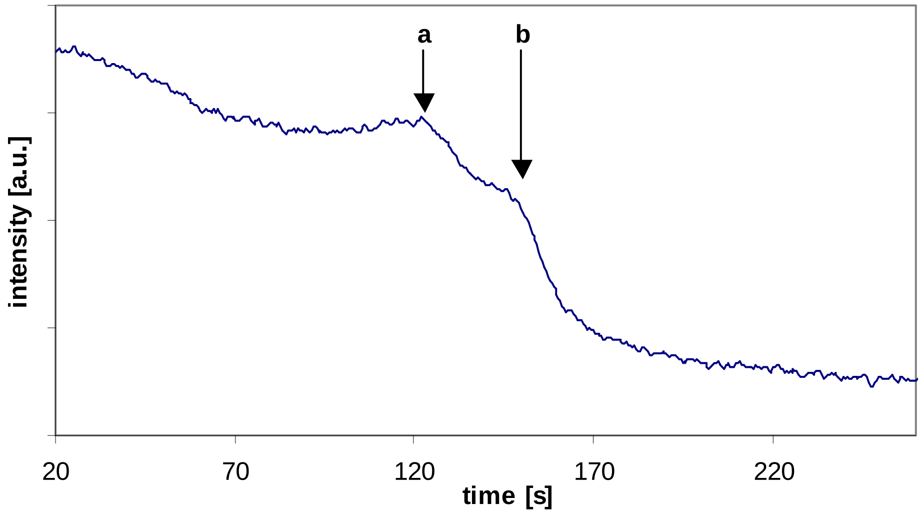

Figure 1: Endpoint trace (520 nm) of an FEP171 masks containing two different Cr loads: **a**, low load area (< 3%) **b**, high load area (> 40%)

Endpoint for low load masks

As shown in Figure 2, the endpoint traces at 520 nm dramatically differs when using FEP171, ZEP7000, IP3600 and PEK130 resists at extremely low Cr load masks.

The FEP171masks show well-pronounced endpoint with a plateau just before the endpoint down to about 0.1% global Cr load.

ZEP7000 coated masks show the same trend at Cr loads higher than ca. 0.5%. Below this limit the endpoint cannot be identified unequivocal. At lower Cr load the data has to be more precisely investigated, to obtain reliable endpoint as will be shown later.

Traces of the IP3600 and PEK130 coated masks show a falling trend where no endpoint signal at the 520 nm can be identified. There are several hypotheses explaining this effect.

A) The trend can be explained by slight decrease of the Cr etch rate, caused by sulfur content in the resist. Small amount of sulfur in the etch gas may decrease the Chromium etch rate dramatically, or stop the etching completely, depending on the O_2/Cl_2 gas ratio.

B) Varying composition of the vertical profile of the Hoya AR8 Cr layer is the root cause, which changes the Cr etch rate and thus the signal intensity.

C) The background intensity trend is the root cause for the intensity decrease for 520 nm.

Which of these hypotheses is correct can be answered by comparing the endpoint traces of the resist blanks and masks with both AR8 and NTAR7 Cr layers coated with the same resist.

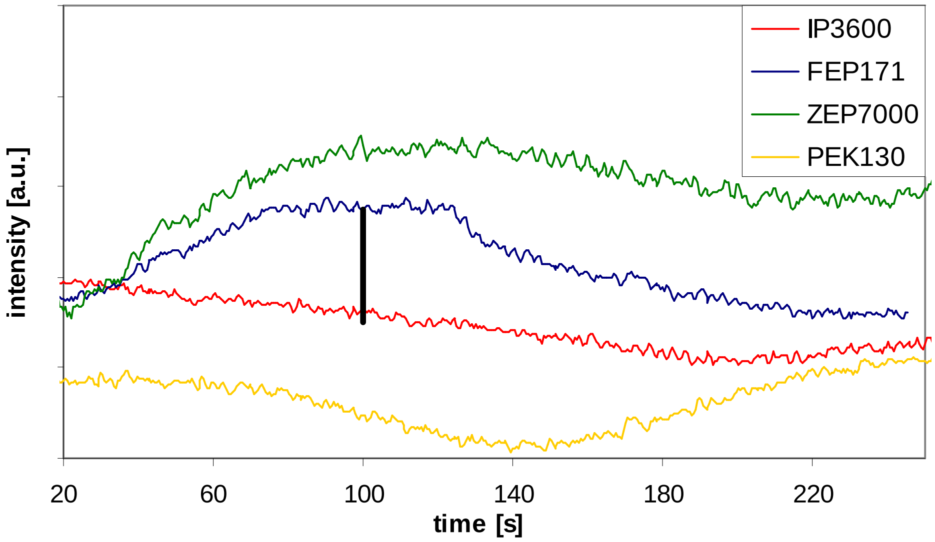

Figure 2: Intensity trend of 520 nm Cr line for uniformly distributed masks with 0.23% global Cr load coated with IP3600, FEP171, ZEP7000 and PEK130 resists. The expected endpoint time is about 130 s for FEP171 and ZEP7000 masks and about 170 s for the IP3600 and PEK130 masks.

Endpoint evolution for higher Cr load

As shown for very low Cr loads, each photo resist has its own characteristic but with decreasing resist percentage its contribution to the endpoint signal becomes less and less important. In contrast the amount of etched Cr in the gas phase increases and thus its impact on the endpoint signal increases. At the same time the endpoint time shifts to slightly higher values.

Figure 3 demonstrates that the differences between resists are already very small at 11.7% global Cr load. Typically one can use the same algorithm for high load masks. Please note the shape of the trend line before the endpoint, which corresponds well to the trend for very low load masks (cf. Figure 2).

The endpoint time for ZEP7000 and FEP171 resists differs by about 5 %. The higher endpoint time of the IP3600 and PEK130 coated mask is mainly due to the thicker Hoya AR8 Cr layer.

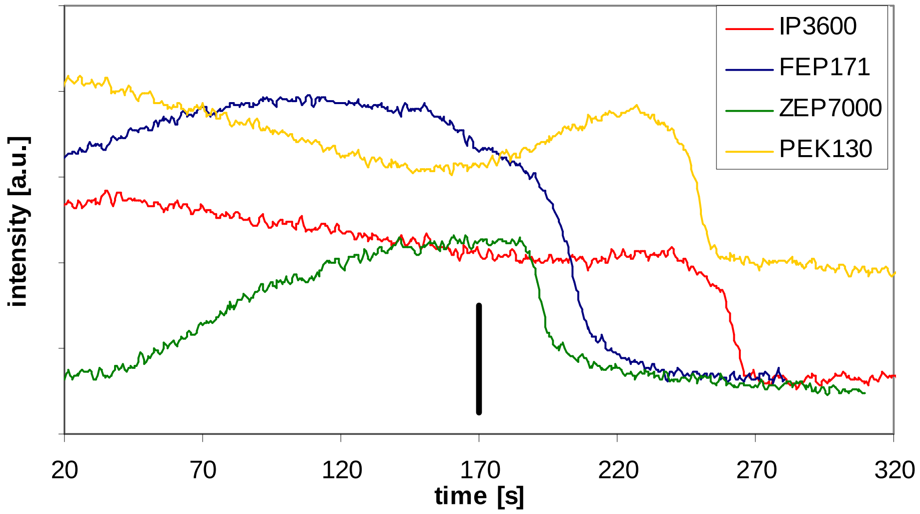

Figure 3: Intensity trend of the 520 nm Cr line for masks with 11.7% global Cr load coated with IP3600, FEP171, ZEP7000 and PEK130 resist. The endpoint is very well pronounced and the intensity prior to endpoint shows a similar trend as corresponding low load masks. The error bar indicates the intensity range of the low load FEP mask from Figure 2.

Resist contribution to the endpoint signal

In order to clarify the resist contribution intensity trends and spectra were collected for resist blanks. Figure 4 shows the intensity trends for FEP171, ZEP7000, IP3600 resist and - for reference - a Quartz blank. As expected the trend for quartz is nearly flat whereas the resist blanks show a decreasing signal at endpoint[1] after ca. 140s. These intensity trends do not contain any endpoint information instead their curvature corresponds to the intensity change of the neighboring lines, in most cases the Cl_2 lines. Their variation can be linked to the change of conditions in the gas phase, a change of the

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[1] In addition the FEP171 resist shows an intensity increase at the beginning.

resist etch rate because of surface passivation, variation of the resist composition across the film depth just to name a few. These processes affect the intensity trends but they steadily decrease with increasing Cr load of the mask. To amplify the contribution of the Cr layer, we have to subtract the blank resist data from the endpoint intensity data taken for the corresponding low load masks.

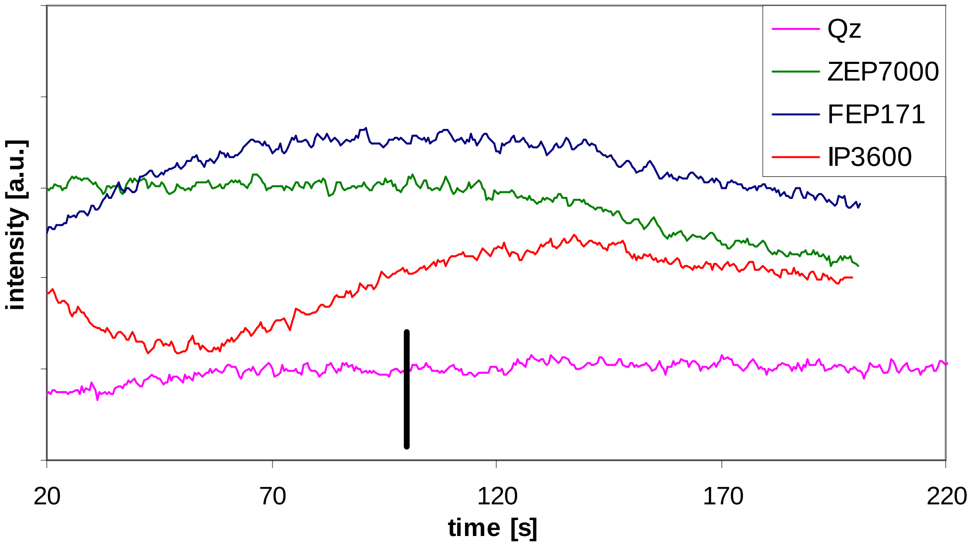


Figure 4: Intensity trend of 520 nm (Cr line) for Quartz, IP3600, ZEP7000 and FEP171 blanks. The error bar indicates the intensity range of the low load FEP mask from Figure 2. The Y scale is identical for both figures.

A rough estimate of the Cr etch contribution can be obtained by subtracting the background (Figure 4) from low load mask (Figure 2) for corresponding resist types.

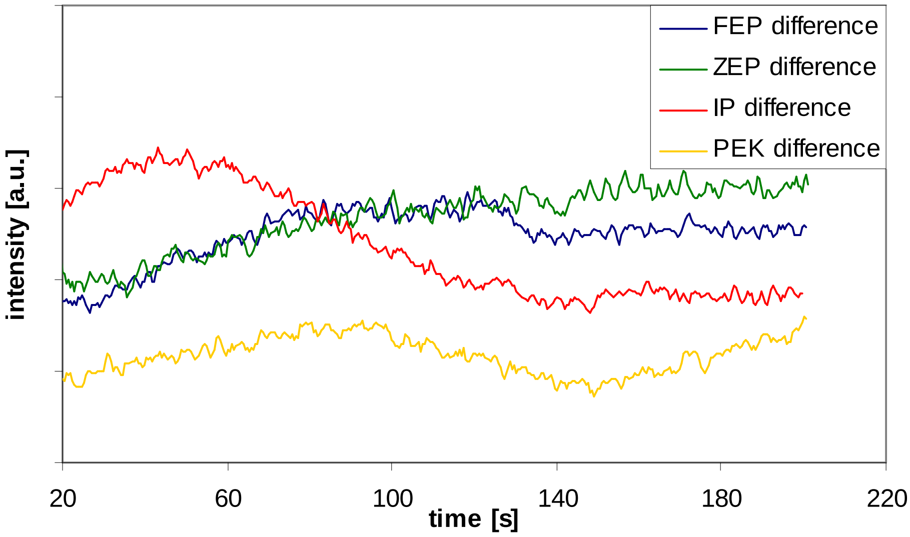


Figure 5: Resulting endpoint traces of the low load masks at 520 nm calculated by background subtraction (“Low Load – Resist Blank”).

Endpoint data analysis

Figure 6 shows the spectra for certain resist types between 500-540 nm normalized to the most intense chlorine line (256nm). The spectra was averaged for 5 seconds in timeframe 50-55s after the etch start to reduce the noise. The differences in both spectra do not seem to be significant but play a big role for the endpoint detection. Below the spectra, the endpoint signal of the 0.23% FEP mask is shown to give an indication for the intensity change we are looking for (mind the error bar indicating the intensity range for FEP171).

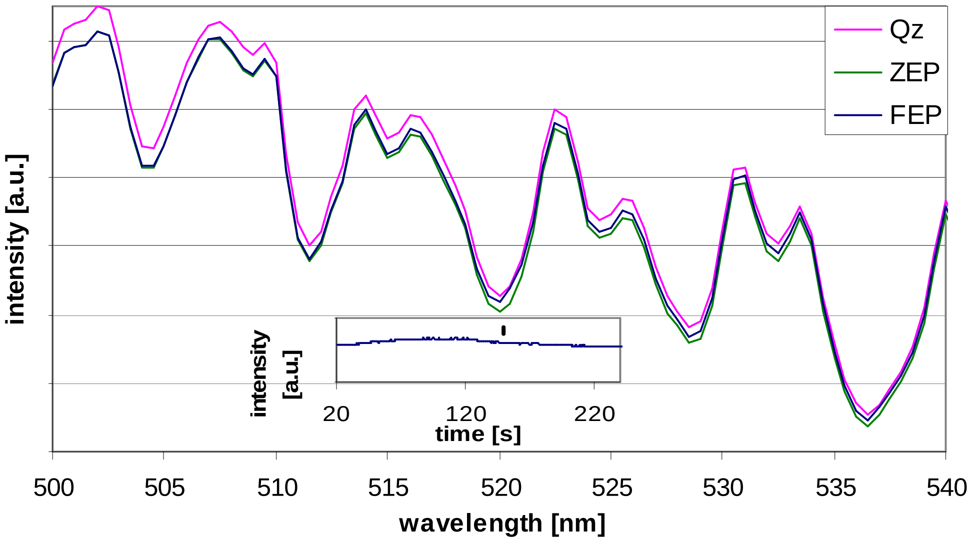


Figure 6: Spectra of the Cr-etch process performed for Quartz, ZEP7000 and FEP171 resists between 500-540 nm averaged for 5s. In order to provide an estimate for the intensity change, the endpoint trace of low load FEP mask is shown below the spectra.

Since there is no obvious endpoint in figure 5 for the ZEP coated mask at 520 nm, there has to be at least one parameter, which affects the intensity trend. To find the root cause for this trend, all remaining Cr lines at 205, 428 and 360 nm were investigated.

Figure 7a shows that all trends from the different Cr lines deviate from each other, indicating that the change of Cr amount in the gas phase during the etch process is not the root cause. After background subtraction trends are more prevalent in Figure 7c but nonetheless all 4 trends differ from each other. Only the trend for 360 nm shows an acceptable endpoint trace.

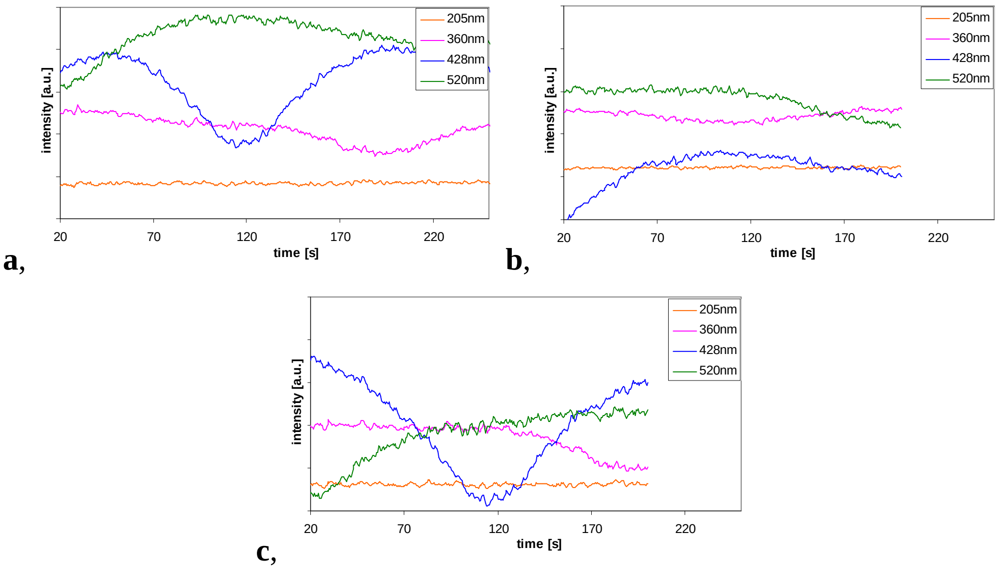
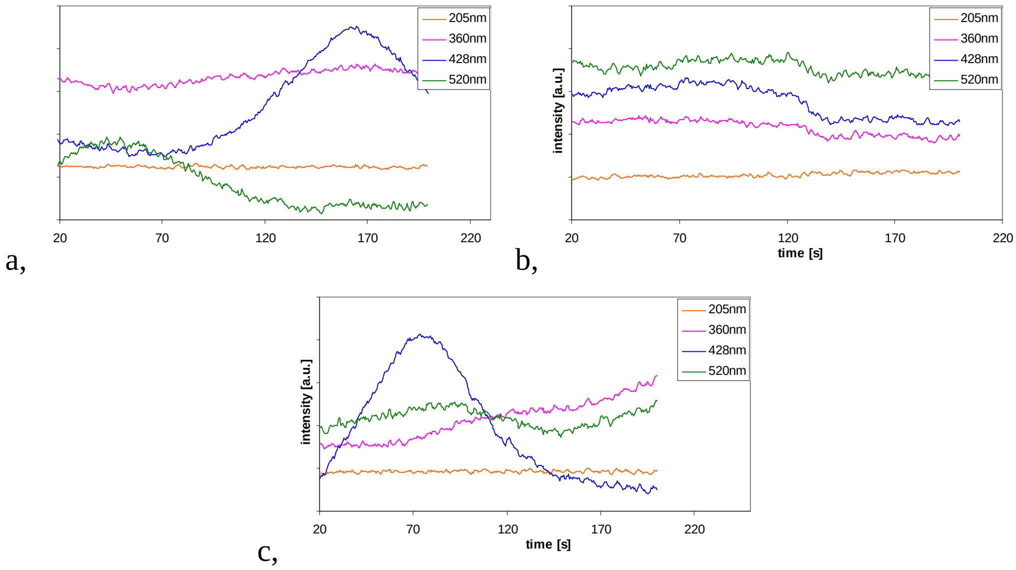


Figure 7: Intensity trend observed at Cr wavelengths 205, 360, 428 and 520 nm for ZEP resist. **a**, 0.23% Cr load mask **b**, Resist blank **c**, 0.23% load with background subtraction.

One would expect that all four Cr lines show a similar trend, even so the absolute magnitude and/or slight variation in the form are conceivable. This effect is not fully understood. Identical analyses for each of the other resist types (cf. Figures 8a- c) show, that there are preferable wavelengths, which are less affected by the background subtraction and show the “real” Cr endpoint trace. The optimal wavelength differs from resist to resist and endpoint signal strength (ratio of intensity change at the endpoint time vs. noise) is specific to the resist type too. In practice this determines the lowest limit for the Cr load at which a reliable and repeatable endpoint can be found. E.g. PEK130 resist in Figure 8c has no reliable endpoint conditions (expected endpoint time is approx. 170s) for any given wavelength, whereas the endpoint for FEP171 resist has multiple wavelengths with very reliable endpoint.



a, b, c,

Figure 8: Intensity trend observed at Cr wavelengths 205, 360, 428 and 520 nm 0.23% Cr load mask processed as in Figure 7 for different resist types at **a**, IP3600 mask **b**, FEP171 masks **c**, PEK130 mask.

A method frequently used for improving the signal-to-noise-ratio is the division of the intensity of the Cr line by one of the lines for the reactants, in our case Cl or O. This approach improves the signal, but introduces at the same time an additional factor, which may cover the real endpoint and lead to a shift of the endpoint time to higher numbers. A typical example for this case is shown in Figure 9.

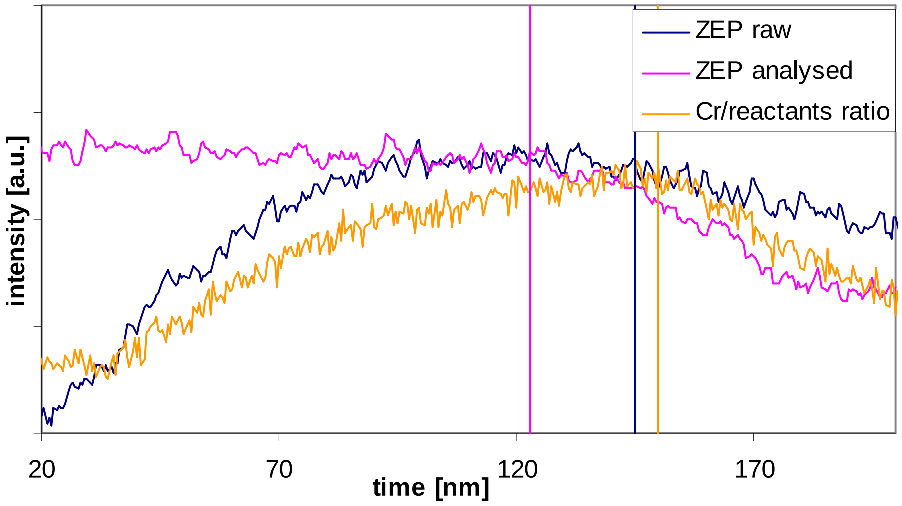


Figure 9: Endpoint comparison for ZEP coated mask for: 520 nm Cr line (ZEP raw), 360nm line with background subtraction (ZEP analyzed) and ratio of Cr 520 nm / Cl_2 258 nm line.

Conclusion

Using a single wavelength detector (e.g. 520 nm Cr) may result in wrong estimation of the endpoint time for (very) small Cr load to due to the background influence. This has an adverse effect on the Cp_k due to e.g. higher variance of the critical dimension as well as variations of the sidewall slope.

As we have shown in this paper the different resist types show reliable endpoint traces at different Cr lines. Table 1 summarizes these findings:

Resist type	**Suitable Cr line**
FEP171	428 ~ 520 > 360
ZEP7000	360
IP3600	428 > 360
PEK130	No wavelength available at given conditions at 0.23% Cr load

Table 1: Overview of photo resists investigated and corresponding Cr lines which show a reliable endpoint.

Last but not least the root cause for the decreasing intensity trend when using IP3600 resist in combination with Hoya AR8 Cr layer was investigated. The detailed analysis of the endpoint data from IP3600 blank as well as the 0.23% Cr load mask show, that the significant decrease of the intensity prior to endpoint is not caused by the resist itself, since the trace of resist blank shows a different trend. Comparison of the endpoint data of Hoya AR8 and Hoya NTAR7 material provide a strong hint that this trend is caused solely by the composition of the AR8 Cr layer.

References

[1] K.H.Kwon, S.Y.Kang, S.H.Park, H.K.Sung, D.K.Kim, J.H.Moon; J.of Mat.Sci.Lett.; 18(1999); p.1197

[2] Cr photomask etch performance and its modeling; Banqiu Wu, David Chan; Photronics Inc.

[3] K.H.Smith, J.R.Wasson and P.J.S.Mangat, W.J.Dauksher and D.J.Resnick; J.Vac.Sci.Technol; B 19 (6); 2001

[4] F.Chen, W.Tsai, S.Chegwidden, S.Yu, M.Kamna, J.Farnsworth, T.Coleman; SPIE Vol.3546; 1998