THE MASK ERROR FACTOR: CAUSES AND IMPLICATIONS FOR PROCESS LATITUDE

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ABSTRACT

In this paper, a broader understanding of the so called Mask Error Factor (MEF) will be described. MEF is defined as the ratio of the measured CD range on the wafer and the expected CD range due to the reticle. As a result, the MEF plays a very important role in the final CD range as observed on the wafer. It will be shown that the MEF can be controlled by Numerical Aperture (NA), illuminator settings, process conditions and resist type. Since the optimum conditions for Depth of Focus (DoF) will usually be found at different settings than the optimum for MEF, DoF has to be balanced with MEF in order to achieve a minimized CD uniformity over a required focus range.

We will show experimental results for different illumination settings (e.g. quadrupole versus annular illumination). Results for contact holes, isolated lines and dense lines and spaces will be presented. Smaller resolutions, especially line widths below the exposure wavelength, will yield a higher MEF. In turn, decreasing reticle CD's yield reticles where CD uniformity is judged to have worse reticle quality. This stresses the importance of understanding and being able to control the MEF.

1. Introduction

In general, lithographers try to extend the life of a generation of exposure tools by pushing them to print the smallest possible resolutions. The price is that lithography becomes harder. A common way to express this is the k₁-factor:

\[ k_1 = \frac{CD \cdot NA}{\lambda} \]  \hspace{1cm} (1)

As a rule of thumb, when k₁ becomes smaller than 0.5, conventional lithography does not yield enough process latitude. Resolution enhancement techniques like off axis illumination and phase shift masks are needed.

Although k₁ by simplicity is a very practical measure, it does not give us an insight into the real difficulties associated with lithography at these small resolutions. Two measures have been used for many years to provide this insight:

- Depth of Focus (DoF)
- Exposure Latitude (EL)

Recently, an important measure has been added [1][2][3][4][5][6]:

- Mask Error Factor (MEF)

The MEF shows how reticle CD errors are translated into wafer CD errors.

The MEF is expressed in the following way:

\[ MEF = m \cdot \frac{\partial CD_{\text{wafer}}}{\partial CD_{\text{reticle}}} \]  \hspace{1cm} (2)

where m is the reduction ratio of the lens, usually 4 or 5.

If the MEF = 1, a 40nm CD error on the reticle implies that the CD error on the wafer equals 10nm in the case of a 4x reduction lens. However, in the case where the MEF is larger, the CD error on the wafer will increase. In practical situations, the MEF can easily become larger than 2, hence more than doubling the observed CD range on the wafer. This shows the importance of understanding the fundamentals of the associated Mask Error Factor.

In the next section, a simple model is proposed which makes it possible to understand the concept of MEF. The two main implications of this model will be given. In section 3, the experimental conditions as used throughout this paper are given as well as a method for the determination of the MEF. In section 4, a number of examples will be given. All these examples can be understood based on the model as proposed in section 2. The examples give rise to a new approach in NA, illumination and process optimization. Finally, in section 5 some conclusions will be drawn.
2. THEORY

If light is projected onto a reticle with a dense line pattern, multiple diffraction orders are generated. Near the resolution limit of the lens, only the lowest orders are captured by the lens (diffraction limited case). This is shown in Figure 1.

Figure 2 shows what happens in the pupil plane of the lens. Note that even the first orders are not captured completely. The resulting aerial image in the focal plane has a sinusoidal shape because the Fourier back transform only contains the first order information. This aerial image is transformed into a resist pattern. This process can be envisioned in a simplified way as a threshold function as shown in Figure 3. Areas in the resist that receive a larger dose than the threshold level are developed away, the other areas will stay on the wafer.

In the case of coherent illumination, the aerial image can be expressed as:

\[
I(x) \propto \left[ 1 - \frac{A \cdot \sin(\frac{\pi \cdot CD_{ret}}{p_{ret}} \cdot \cos) \cdot \frac{2\pi \cdot x}{m \cdot p_{ret}}}{\pi \cdot CD_{ret} \cdot p_{ret}} \right]^2
\]

where \( A \leq 1 \) is the fraction of the first order that is captured by the lens. Higher orders are assumed not to be captured by the lens. If the reticle CD (CD_{ret}) is close to half the pitch (p_{ret}/2), the “Sin” term in equation 3 will be close to 1 and hence insensitive to small variations in CD_{ret}.

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**Figure 1** The diffracted orders originating from a lines-space pattern are partially captured by the projection lens.

**Figure 2** The diffracted orders as captured by the lens, observation of the pupil plane.

**Figure 3** Transformation of the aerial image into a resist pattern.

**Figure 4** A change in reticle CD gives rise to a change of the DC component of the aerial image only. The picture shows how this reticle CD change is translated into a wafer CD variation.
This is contrary to the first (constant, so called DC) term, which is proportional to $\text{CD}_{\text{ret}}$. As a result, CD errors only change the mean value of the aerial image, and not the amplitude or spatial frequency. What happens to the wafer CD is shown in Figure 4.

From Figure 4 it can be seen that the CD variation at wafer level changes proportional to the slope of the aerial image at the cross section with the resist threshold. This leads to two propositions:

**Contrast:**

A higher aerial image contrast (image log slope [7]) yields a smaller MEF.

**Threshold:**

The choice of the resist threshold with respect to the aerial image strongly influences the MEF. This can be achieved both by changing the threshold level and by changing the exposure dose.

The following remarks should be made:

- The slope as shown in Figure 4 is only constant in the case of CD variations small compared to the actual CD. Larger variations will shift the peaks or valleys of the aerial image close to the resist threshold value, hence lowering the slope. This leads to an increased MEF. Note that in the case of large CD variations the “Sin” term in equation 3 will also deviate considerably from 1.

- For dense lines, MEF and size linearity are two different quantities. In the case of size linearity both the line and the space are changed by the same proportion. In the case of MEF, the line is varied while keeping the pitch constant, hence reducing the space. Another way of expressing size linearity is that the zero order is kept constant and the first order is varied. When measuring MEF, this is the other way round. The zero order is varied and the first order is kept constant.

This will reduce the amplitude of the aerial image and increase the MEF even more. See Figure 5 and Figure 6.

- In the case where higher order terms are captured by the projection lens, the aerial image contrast will increase. This yields a low MEF value. In the case of isolated lines, an infinite number of orders is captured by the lens. Usually MEF values close to 1 are observed for isolated lines.

Note that the MEF as depicted in Figure 6 is only true when printing 1:1 target CD’s. If the line to pitch ratio decreases, MEF increases because the resist threshold is lying in a shallow region of the aerial image. When the target line to pitch ratio is small, the first step is to lower the exposure dose in such a way that the MEF reaches its minimum value for the requested pitch.

![Figure 5](image1.png) Aerial image simulation assuming $A=1$ in equation 3. For dense lines, when the reticle CD differs much from half the pitch, wafer errors increase in a non linear way.

![Figure 6](image2.png) An alternative way of representing the result from Figure 5 is a varying MEF over the reticle CD range.
3. EXPERIMENTAL

All experiments are performed on a PAS 5500/500 Step and Scan system with a maximum NA of 0.63 [3][8]. Three different types of photoresists have been used according to the process conditions given in Table 1. The photo resists were processed using FSI Polaris wafer tracks. The system is purged with activated charcoal filtered air to prevent adverse process results due to airborne base contamination.

<table>
<thead>
<tr>
<th>Description</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photo resist</td>
<td>APEX-E AZ DX-3301P TOK DP015</td>
</tr>
<tr>
<td>Thickness</td>
<td>0.63µm or 0.50µm 0.608µm</td>
</tr>
<tr>
<td>Softbake Temp.</td>
<td>95°C 90°C 80°C</td>
</tr>
<tr>
<td>SoftbakeTime</td>
<td>110s 60s 90s</td>
</tr>
<tr>
<td>PEB Temp.</td>
<td>90°C 110°C 110°C</td>
</tr>
<tr>
<td>PEB time</td>
<td>90s 90s 90s</td>
</tr>
<tr>
<td>Developer</td>
<td>MF-702 OPD-262</td>
</tr>
<tr>
<td>Develop Time</td>
<td>60s 60s 60s</td>
</tr>
</tbody>
</table>

Table 1 Processing conditions.

The process tracks and the exposure tools are not interfaced, therefore the time between coating, exposing and developing was kept below 15 minutes. SEM analysis was done with AMAT OPAL 7830-SI and Hitachi S-8C40 CD-SEMs.

For the experimental determination of the MEF, a reticle has been designed with 35 modules across the full 26mm*33mm field. Each module contains dense (1:1) and isolated features of both horizontal and vertical orientations. Each feature is printed 9 times in the module, where the line size is varied with targeted 12nm increments at reticle level. For the dense lines, the pitch is kept constant.

The same reticle is used for the CD uniformity measurements, benefiting from the so called “picked CD technique” [9]. This is done to limit the reticle CD range to values below 25nm. This 25nm will contribute to the CD range on the wafer according to equation 1, so even with a MEF of 1 (ideal case) a range at wafer level due to the reticle is about 6nm. The module is schematically shown in Figure 7.

The reticle CD’s for all of the various features are measured with a LWM200 which has a repeatability 3σ < 6nm. The wafer CD’s are measured with a top-down CD-SEM. The results are plotted in a scatter diagram against the reticle data. The MEF is calculated by fitting a linear function to the data points as shown in Figure 8.

![Figure 7](image1.png)

Figure 7 Schematic of the module used for determination of the MEF.

![Figure 8](image2.png)

Figure 8 Determination of MEF as the slope of reticle data versus the wafer data.
4. EXAMPLES

In order to obtain a smaller MEF, one can increase the aerial image contrast and optimize the level of the resist threshold with respect to the aerial image. In section 4.1 an example is given where the aerial image contrast is enhanced by Quadrupole illumination. A consequence of the Contrast Proposition is that the MEF will increase when going out of focus. The Threshold Proposition expresses the same about exposure dose. In section 4.2 we will show an example where the aerial image contrast is optimized by tuning the diffracted light as captured by the pupil. Changing the NA and the partial coherence will lead to a change in MEF. In section 4.3 the MEF is studied over the entire Exposure Defocus window. Finally in section 4.4, the influence of the process on the MEF is described.

4.1 Quadrupole illumination

The MEF depends significantly on the illumination setting. The basics of this illumination dependency can be theoretically explained comparing annular and quadrupole illumination.

In Figure 9a, the filling of the projection pupil in DUV lithography (NA=0.6) using annular illumination ($\sigma_{\text{outer}}=0.8/\sigma_{\text{inner}}=0.5$) is shown for 180nm dense lines. The zero order diffraction signal is fully captured. This mode does not contain any information about the reticle periodicity. In the case of a binary reticle containing a line/space pattern, the power carried by the zero order is just the average transmitted intensity level ($\frac{P_{\text{ret}}-CD_{\text{ret}}}{P_{\text{ret}}}$) and is often referred to as the DC-component. The aerial image is formed by two-beam interference of the zero order and one of the first order beams. However, both first order diffraction modes which carry the modulation information from the reticle, partially lie outside the entrance pupil. In this way, a significant part of the modulation signal is lost when using annular illumination. By using quadrupole illumination (round poles with $\sigma_{\text{outer}}=0.8$ and $\sigma_{\text{inner}}=0.5$), the amount of first order signal captured by the lens increases as depicted in Figure 9b. In this way, quadrupole illumination enhances the ratio of first to zero order.

It can be easily demonstrated that the higher the ratio of first to zero order, the higher the contrast of the aerial image. Therefore, the exposure latitude should be higher in the case of quadrupole illumination.

The impact of reticle errors on the diffraction pattern for dense lines is shown in Figure 10. For a binary intensity mask with equal lines and spaces, the even diffraction modes (2,4,..) are symmetrically restricted. Most common errors, induced during processing (e.g. during chrome etch) of the reticle will lead to a local variation across the reticle of the line width ($CD_{\text{ret}}$), whereas the pitch ($P_{\text{ret}}$) is constant. This change in duty cycle will cause changes in the aerial image:

- The even order diffraction modes are no longer restricted
- The power in the zero order diffraction mode (DC component) changes linearly with the reticle error $DCD_{\text{ret}}/P_{\text{ret}}$
- Changes in the intensity of the first order mode are very small (~1%)
- For the odd modes: the higher the diffraction order, the larger the impact on reticle errors.

![Figure 9a](image1.png) Filling of the projection pupil for 180nm dense lines with $\lambda=248$nm, annular illumination, $\sigma_{\text{outer}}=0.8$, $\sigma_{\text{inner}}=0.5$.

![Figure 9b](image2.png) Filling of the projection pupil for 180nm dense lines with $\lambda=248$nm, quadrupole illumination, round poles $\sigma_{\text{outer}}=0.8$, $\sigma_{\text{inner}}=0.5$. 
For small features, only the zero and first order modes have to be considered. The impact of a 10% reticle error on a shallow aerial image (e.g. annular) and a higher contrast aerial image (e.g. quadrupole) is shown in Figure 11. Neglecting the minor change of the first order, a 10% change in reticle CD will lead to 10% change of the zero order diffraction mode. Both aerial images will be lifted by 10%. Depending on the threshold level, a CD error will be introduced. However, for high-contrast aerial images this error will be much smaller than for low contrast aerial images. In this way, exposure latitude (shift of threshold) and MEF (shift of aerial image) are closely linked [10]. Both depend on the aerial image contrast which is directly dependent on the ratio of captured first order to zero order diffraction mode.

We experimentally verified the difference between the two different illumination settings (Annular and Quadrupole) with respect to the MEF. For both illumination settings, we observed an excellent correlation between the wafer CD and the reticle CD on the reticle as depicted in Figure 13.

To study this correlation we made use of our “Picked CD” approach. This approach allows us to reduce the CD range on the reticle to values below 25nm for every position in the field the reticle CD was varied. CD uniformity at best focus is 21nm. Taking into account a reticle CD range of 25nm (NA=0.63) and a MEF of 2.1, this indicates that 60% of the CD variation on the wafer is due to reticle variations. This reticle contribution is reduced when going to quadrupole illumination, because of the lower MEF. For all illumination settings, the fingerprint of the reticle CD variations is found back in the fingerprint of the across field CD variation on the wafer.

This MEF reduction should have a significant impact on the achieved across field line width variation, also known as CD uniformity. CD uniformity values at best focus and over a focus range of 0.4mm are listed in Table 2 for the two illumination settings. The CD uniformity is determined for 20 positions in the scanner exposure field using both horizontal and vertical features. For annular illumination, the CD uniformity at best focus is 21nm. Taking into account a reticle CD range of 25nm (NA=0.63) and a MEF of 2.1, this indicates that 60% of the CD variation on the wafer is due to reticle variations. This reticle contribution is reduced when going to quadrupole illumination, because of the lower MEF. For all illumination settings, the fingerprint of the reticle CD variations is found back in the fingerprint of the across field CD variation on the wafer.

To illustrate this, the CD distributions at best focus for annular and quadrupole illumination are compared in Figure 12. The correlation slope of 0.5 reflects the difference in MEF which is almost twice as large in the case of annular illumination.

<table>
<thead>
<tr>
<th>Focus Range</th>
<th>Annular CD</th>
<th>Quadrupole CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best Focus</td>
<td>21 nm</td>
<td>14 nm</td>
</tr>
<tr>
<td>0.4μm</td>
<td>29 nm</td>
<td>18 nm</td>
</tr>
</tbody>
</table>

Table 2 CD range at wafer level for two different illumination modes. Annular: NA=0.63, σ=0.8/0.5, 180nm dense lines. Quadrupole: same settings, pole opening is 30 degrees.

Out of focus, the difference in CD uniformity for annular and quadrupole illumination is even more pronounced. This is due to the fact that the DoF is larger and that the change in MEF through focus is smaller in the case of quadrupole illumination.

Figure 10 Impact of 10% reticle errors on the diffraction pattern of dense lines (assuming coherent light).

Figure 11 Impact of 10% reticle CD error on a low- and high-contrast aerial image.
4.2 NA-partial coherence tuning

Changing NA and partial coherence (PC) will change the pupil filling and hence the aerial image contrast. In general, a larger NA lens captures more of the higher orders leading to a smaller MEF. Off-axis illumination can also be used to increase the aerial image contrast. Experimentally obtained MEF values for 180nm dense lines (1:1) are shown in Table 3.

<table>
<thead>
<tr>
<th>NA</th>
<th>σ</th>
<th>MEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.54</td>
<td>0.75/0.45 (annular)</td>
<td>2.4</td>
</tr>
<tr>
<td>0.63</td>
<td>0.70/0.40 (annular)</td>
<td>1.7</td>
</tr>
<tr>
<td>0.57</td>
<td>0.75 (conventional)</td>
<td>2.2</td>
</tr>
<tr>
<td>0.63</td>
<td>0.70 (conventional)</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Table 3 MEF values for 180nm dense lines with different NA and illuminator settings.

A detailed study was done determining the minimum MEF for 220nm dense contact holes.

Experimental and simulation results are shown in Figures 14 and 15. For the simulations a full resist model has been used with the following characteristics:

- Package: Solid-C 5.5 on a Sun Sparc 20 workstation
- Optical model: scaled defocus
- Resist model: calibrated to 0.25μm dense contact holes with 0.61μm TOK DP015.

The simulations are carried out using Solid C with a full resist model.

Also here, a larger NA yields the lowest MEF. Note that this is not necessarily the optimum condition for having the best CD uniformity. Due to image plane deviation, focussing errors, wafer unflatness/topology, dose errors etc., not all contacts over the full field are printed at best energy and best focus. As a result, a sufficiently large exposure latitude and DoF are required. Optimum values for EL and MEF will generally be found at the same NA-PC settings. DoF however usually increases when going towards a lower NA. As a result, a compromise yields the optimum CD uniformity where the actual process conditions (i.e. the focus consumption), determines the actual location of the optimum. If the focus budget is small (due to flat wafers, small topology, good BF determination, stable exposure tool), a smaller DoF is required, so a larger NA can be applied. As a result, the CD control will improve.
Two important parameters determining the quality of the resist image are focus and energy. Usually a Bossung plot is used for showing the CD dependency to energy and focus. A question that rises is how MEF behaves as a function of energy and focus. As already stated in section 2, the MEF depends both on the aerial image contrast and the chosen resist threshold. Defocusing will decrease the aerial image contrast, leading to a larger MEF. Changing the exposure dose will change the position of the aerial image with respect to the resist threshold which will also influence the MEF. For 220nm dense lines (1:1) the MEF has been determined both experimentally and with a simulator. Based on the model as presented in section 2, we expect an optimum for the MEF in best focus, at an energy level where the threshold is halfway the aerial image.

The experiments were done on a PAS 5500/500 at NA=0.57 and a conventional illumination setting, σ=0.75. The reticle consisted of dense lines with a target CD of 220nm. A 0.63µm APEX-E DUV photoresist has been used. The MEF had been determined within a focus-exposure matrix containing 16 focus steps and 5 energy levels. For the simulation, the settings were equal to the experiments. A full resist model had been used with the following characteristics:
- Package: Solid-C 5.5 on a Sun Sparc 20 workstation
- Optical model: scaled defocus
- Resist model: calibrated to 180nm isolated and dense lines with 0.63µm APEX-E with RTC.

The MEF has been calculated over the entire energy and focus range. This surface was put in the graph containing experimental MEF in focus-exposure space. Results are depicted in Figure 16. The surface is calculated with the simulator, the experimental data is shown with the white dots. As expected, a minimum MEF can be observed. It can be concluded that in the case an exposure is not performed at best energy and best focus, not only a wrong CD is printed, according to the Bossung plot, but also reticle errors are more severely impacting the CD error budget on the wafer.

Going half a micron out of focus, combined with an energy error of 5%, almost doubles the MEF in the case of 220nm dense lines.
4.4 Process influences on MEF

Because MEF plays a key factor determining intrafield CD uniformity, we also used it as one of the measures for the 180nm photoresist selection. Multiple photoresists were screened for MEF in best focus. As expected the higher contrast resists, the ones that are dedicated for dense line structures, yielded the lowest MEF values.

<table>
<thead>
<tr>
<th>Substrate</th>
<th>MEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>APEX-E</td>
<td>2.6</td>
</tr>
<tr>
<td>Resist B</td>
<td>3.1</td>
</tr>
<tr>
<td>AZ DX33-01P</td>
<td>2.4</td>
</tr>
<tr>
<td>BARC</td>
<td>2.1</td>
</tr>
<tr>
<td>Resist D</td>
<td>2.6</td>
</tr>
<tr>
<td>Resist E</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Table 4  MEF as function of resist type for NA=0.63, \( \sigma =0.8/0.5 \) annular illumination.

Based on ASML internal specifications, including MEF, the AZ-DX3301P photoresist from Clariant was selected for process optimization. A design of experiment was carried out in which softbake temperature, post exposure bake temperature and develop time were varied. The goal was to find the process with the best imaging performance for 180nm isolated and dense lines (i.e. intrafield CD uniformity), with sufficient process stability.

The MEF showed a clear minimum for a certain softbake and post exposure bake temperature. Longer develop times also reduced MEF. In order to understand these trends, the aerial image threshold model must be extended. The aerial image is transferred into a position dependent, acid catalyst concentration.

This concentration image is again translated into an image of deprotected groups. If the local concentration of deprotected groups is above a certain threshold, this region is dissolved in the developer. Areas with concentrations of deprotected groups which are below the threshold will remain on the wafer.

This process is depicted in Figure 18 for three different PEB temperatures. The figure shows the aerial image intensity on the top, the acid catalyst concentration in the middle, and the amount of deprotected groups with the developer threshold at the bottom.

For the AZ-DX3301P resist the deprotection reactions mainly take place during the PEB step, therefore the reaction rate is a function of PEB temperature. For low PEB temperature the lower reaction rate must be compensated by exposure dose. This leads to very high concentrations of acid catalyst that diffuse into the unexposed regions. As a result the base line of deprotected sites shifts up and contrast reduces.

For middle PEB temperature the deprotection reaction rate is higher so that lower exposure dose and acid catalyst concentrations are sufficient. The diffusion of acid catalyst into the unexposed regions is lower and as a result the obtained contrast is higher.

Even higher PEB temperature increases the diffusion length of the acid catalyst. The deprotection reaction is provoked over a longer distance, thus reducing contrast. Besides the diffusion, another effect lowers the contrast even more. The selectivity of the deprotection reaction decreases with too high PEB temperatures due to competitive reactions. Both effects explain the PEB temperature optimum for MEF.

![Figure 17](image-url)  MEF as function of SB and PEB temperature and develop time.
A lower MEF at longer developer times can be explained by a downward shift of the developer threshold to a steeper part of the slope enhancing the contrast.

An ASML internal prediction model for intrafield CD uniformity [11][12] for the PAS 5500/500 Step and Scan exposure tool was used. It is based on system and process related energy, focus and CD budgets, and predicts the scanner intrafield CD uniformity based on MEF and Bossung curves. The reticle CD budget is composed of 14nm (3σ) across the mask CD variation (reticle level) and 6nm (3σ) mask CD measurement error. Using these specifications and a MEF of 2 results in a CD error due to the reticle of 10 nm (3σ). This is more than 50% of the CD budget for 180nm dense lines.

Again the same set of process settings was used to calculate the predicted CD uniformity. Key factors determining this response are exposure latitude, DoF, isofocality and MEF. The latter becomes clear when fingerprints from the MEF in Figure 17 and predicted intrafield CD uniformity in Figure 19 are compared. This good correlation shows why MEF became an integral part of process optimizations for dense lines of 180nm and below.

Figure 18  Resist threshold model for low, middle and high PEB.

Figure 19  Predicted CD uniformity for 180nm dense lines against SB and PEB temperature and develop time.
5. CONCLUSIONS

In this paper a simple model is described that explains the origin of the Mask Error Factor (MEF). With this model it can be explained why changing the pupil filling leads to different MEF values. If a larger part of the first and higher order diffractions are captured in the entrance pupil, the aerial image contrast will increase. This gives rise to a lower MEF. In general, a lower MEF results in a better controlled CD distribution on the wafer.

It is shown how MEF can be measured. Measurements are presented that show that the MEF indeed depends strongly on the pupil filling. The resulting CD uniformity is analyzed for two different illumination modes. A main consequence is that if an NA-PC optimization is carried out, MEF should be taken into account. This approach results in a trade off between MEF and e.g. Depth of Focus (DoF), leading to different values for the optimum NA and PC.

It is also shown that resist type and process setup influence the MEF. In order to explain the observed effects, the described model is extended.

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7. REFERENCES
