Correcting Image Placement Errors Using Registration Control (RegC®) Technology In The Photomask Periphery

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1. ABSTRACT

The ITRS roadmap specifies wafer overlay control as one of the major tasks for the sub 40 nm nodes in addition to CD control and defect control. Wafer overlay is strongly dependent on mask image placement error (registration errors or Reg errors)¹. The specifications for registration or mask placement accuracy are significantly tighter in some of the double patterning techniques (DPT). This puts a heavy challenge on mask manufacturers (mask shops) to comply with advanced node registration specifications. The conventional methods of feeding back the systematic registration error to the E-beam writer and re-writing the mask are becoming difficult, expensive and not sufficient for the advanced nodes especially for double patterning technologies.

Six production masks were measured on a standard registration metrology tool and the registration errors were calculated and plotted. Specially developed algorithm along with the RegC Wizard (dedicated software) was used to compute a correction lateral strain field that would minimize the registration errors. This strain field was then implemented in the photomask bulk material using an ultra short pulse laser based system. Finally the post process registration error maps were measured and the resulting residual registration error field with and without scale and orthogonal errors removal was calculated.

In this paper we present a robust process flow in the mask shop which leads up to 32% registration 3sigma improvement, bringing some out-of-spec masks into spec, utilizing the RegC® process in the photomask periphery while leaving the exposure field optically unaffected.

Key words: Image Placement, Registration, Wafer Overlay, Photomask, Laser, RegC®, RegC Wizard.
2. INTRODUCTION

For the advanced nodes and double patterning photomasks manufacturing is becoming more and more demanding. The E-beam writers are pushed to their limits regarding image placement performance. Currently, if a mask is rejected because of image placement is out of specification, there is no way to correct for it. The mask has to be scrapped and must be rewritten again.

Carl Zeiss SMS has developed a new technology named RegC® which enables the user (mask shop) correcting the global registration errors and improving the image placement of a manufactured mask. The process is based on a fs laser technology similar to the technology used in the CDC tools of Carl Zeiss for CD Uniformity correction²³.

The RegC® (Registration Control) process enables the mask maker to improve the registration performance of a mask or to bring a mask which is out of specification into specification. As a result the mask manufacturing yield is increased. Figure 1 shows the basic Registration Control process flow in the mask shop.

Figure 2 shows the RegC® block diagram. The system has two main optical sub systems. The first sub system is used to generate the deformation elements (pixels) utilizing an optical setup that includes the following main components: Pulse laser, beam delivery path, beam steering device and a focusing optics. The second sub system is a metrology system that is used to measure and characterize the properties of the generated deformation element, so-called “Mode Signature” (MS). The Mode signature will be then used as one of the inputs for the RegC® job computation by the dedicated software named RegC Wizard. Figure 3 shows the basic inputs and outputs utilizing this supporting software.

In this paper "fused silica", "quartz (Qz)" and mask "blank substrate" are used interchangeably.

Figure 1.RegC® process flow
3. THE REGISTRATION CONTROL (REGC) PRINCIPLES

Intra volume laser writing at certain conditions creates a predictable deformation element in the quartz (Qz) material. This deformation can be described by a physical-mathematical model that well represents the deformation caused by RegC® element.

The deformed zone inside the Qz bulk is a 3 dimensional volume of fused silica which has a slightly different morphological organization of the atoms with a slightly less dense packing, or lower density. The zone with lower density expands and pushes away the adjacent atoms and thus deforms the whole bulk of the Qz piece. Due to the elastic amorphous property of fused silica this deformation behaves almost truly elastically without critical breakage (cracks).
In other words, when considering very small deformations in the order of ppb and even ppm, fused silica behaves practically like rubber, elastically.

The special model that was developed to describe the accumulative effect of multitude pixels generated inside the Qz substrate takes into account the physical properties of fused silica such as its Young Modulus, its Poisson ratio etc. The model has been verified experimentally and provides a laser-material associated parameter, called the Mode Signature (MS). The MS defines the magnitude and angle/direction of the deformation induced by writing a laser pixel at given conditions.

The Mode Signature can be used first to calculate and predict the deformation and hence the affect on registration by writing a given array of pixels. Second and relevant for the RegC® process the MS can be used to calculate a set of pixels needed to compensate for a given registration error map.

The current RegC® process can only induce expansion pixels. This means that the average mask dimension after the RegC® process will always be larger than before the process. This also means that the absolute value of registration after RegC® will typically be higher than the absolute registration error before the process, except for rare cases where the whole mask error was contracted relative to the target. However this is not a limitation since the target of the RegC® process is not to compensate for the absolute registration errors, but rather to remove only the non compensable errors as it is well known to the mask and litho industry that the scanners have the ability to compensate for all systematic linear errors which have rotational, orthogonal and scale components (in short "Scale and Ortho"). The main issue with registration errors of masks is the non compensable residuals, the registration errors which are left over after the scanner has done its job. These residuals are typically 6-8 nm 3S in advanced 40nm nodes and below. However the specs at these nodes are 4-8 nm and in sub 20 nm nodes can go down to < 4nm, especially in double patterning technologies. Therefore the task of the RegC® process is to decrease these non compensable residuals from ~8 nm to ~4 nm, or about 50% improvement in the 2X and 1X nodes.

Because of the importance of the scanner ability to compensate for scale and ortho, all registration metrology tools report in addition to raw registration errors also the scale and ortho (S/O) removed residual errors. These are the values which typically interest mask makers and their fab customers who are interested eventually at mask to mask overlay in the scanner.

The capability of the scanner to remove specific registration errors is shown in Figure 4 as an example.

**Example of registration compensation capabilities by scanner**

(4a) Registration error - Raw

<table>
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<th>X_{Min}</th>
<th>X_{Max}</th>
<th>X_{3S}</th>
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<td>7.25</td>
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<table>
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<th>Y_{Min}</th>
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<td>-0.99</td>
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<td>1.51</td>
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(4b) Registration error – S/O

<table>
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<td>6.33</td>
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<table>
<thead>
<tr>
<th>Y_{Min}</th>
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<td>-0.55</td>
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<td>1.01</td>
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</table>

Figure 4a shows the raw registration error while Figure 4b shows the registration error after S/O removal. Note that the large vectors on the top left have been reduced in magnitude but not significantly.
The basic principle of RegC® is to take the registration error (“the problem”) shown in Figure (5a) and apply the required registration change shown in Figure (5b). The vector summation of those two will result in a new state shown in Figure (5c) that will enable higher capabilities of the scanner to remove residual errors by applying S/O as shown in Figure (5d).

![Diagram showing initial registration error, required registration change, and resulting state](image)

Figure 5a shows the initial registration error (raw) while Figure 5b shows the required registration change in order to bring all the errors to a correctable field. The post process registration error shown in Figure 5c is the vector summation of the initial error and the induced change. Figure 5d shows very low residual error after S/O removal by scanner.

### 4. EXPERIMENTAL RESULTS

Six OMOG (Opaque MoSi On Glass, binary photomask material developed by Shin-Etsu, IBM and Toppan) production plates (28nm) were measured by a registration tool as an input for the RegC® job computation. The registration measurement error was estimated as 0.8 nm (long term and short term error components). Then a pre-calculated RegC® process was applied and the plates were measured again for "Post" process registration errors.

In order to maximize the process capabilities, the actual processing was divided into two steps; each step had its own mode signature (deformation properties). Figure 6 shows the generated RegC® jobs for mask number 1 along with schematic drawing of the associated deformation direction due to the given mode utilization. Referring to the mask's Z direction, all the six masks were processed (creating pixels) at the quartz plate center while the spoken deformation or registration change was pre-calculated and targeted to the mask absorber level.
This experiment examined two main aspects related to the RegC® technology; the first aspect is how accurate the physical-mathematical model is and can it predict the registration change prior to the mask processing? The second is how efficient will the process be considering the constraint of processing the mask utilizing less then 42% out of the quartz area, keeping the exposure field optically unaffected. It is important to mention that in this test we were utilizing a system which is not a dedicated RegC® system for the actual processing step.

As for the accuracy of the model, Figure 7 shows on one plot the actual measured and the predicted change in registration due to the RegC® process for mask number 1. High agreement can be visually seen and it's been quantified by coefficient of determination $R^2 = 0.94$. Moreover, Table 1 summarizes the 3 Sigma differences between the actual measured registration errors post process and the predicted ones by the RegC wizard where less then 0.75 nm deviation can be seen.
Figure 7. The actual versus predicted registration change due to the RegC® process

Very good agreement; $R^2 = 0.94$

<table>
<thead>
<tr>
<th>Mask Number</th>
<th>Actual Measured Post</th>
<th>Predicted Post</th>
<th>Difference</th>
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<td></td>
<td>X</td>
<td>Y</td>
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</tr>
<tr>
<td>5</td>
<td>5.30</td>
<td>5.50</td>
<td>5.04</td>
</tr>
</tbody>
</table>

Table 1: Differences between the measured and predicted registration error 3 Sigma’s

As for the process efficiency, Figure 8 shows mask number 1 registration errors before and after the RegC® process. 32% improvement in X axis and 14% improvement in Y axis 3 sigma were observed, bringing an out of spec mask into spec. Table 2 summarizes the improvements achieved after the 5 masks processing. An 8% -32% improvement was seen.
5. CONCLUSIONS

It was proven that a registration correction strain field can be computed using a special algorithm and that a laser based correction method can be used to effectively reduce the registration error in the mask without affecting any other mask properties.

The above reported experiments have shown that a mask which was rejected based on its registration problem can be saved and brought into spec by treating the non active area. It is recognized that a better improvement in the order of 50% could be achieved by applying the RegC® process in the whole mask area. For this purpose Carl Zeiss has developed a new process where the whole mask area is treated. In addition, more and more chip manufacturers are now specifying not only the mask registration error but also mask to mask overlay error, which adds even more challenge to the mask maker.
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7. REFERENCES