Reticle CDU improvement by Zeiss CDC and the impact on real circuit pattern

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ABSTRACT

The excellent control of the critical dimension (CD) is an essential pre-requisite for a defect free patterning at advanced technology nodes. The overall CD variation budget in lithography can be separated into wafer mean, across wafer and across reticle field variation. In our paper we will concentrate on methods how to improve the across reticle CD variation. In a first section, we will compare scanner dose control and correction techniques with the Zeiss CDC technique done at reticle level. We will touch inherent challenges for both techniques in the logic application space where multiple different patterns have to be controlled accurately. The more the MEEF to dose sensitivity ratio matches for different features, the feature dependent correction becomes more accurate. We will discuss several applications from the 28nm and 22nm process node. Figure 1 shows this MEEF to dose sensitivity ratio out of S-Litho simulations for selected features for a 28nm metal application. As we can see, the deviations to a linear fit are acceptable and thus enabling a good correction for a wide variety of features. Please note that the features with negative dose sensitivity and MEEF are dark features whereas the others are bright features.

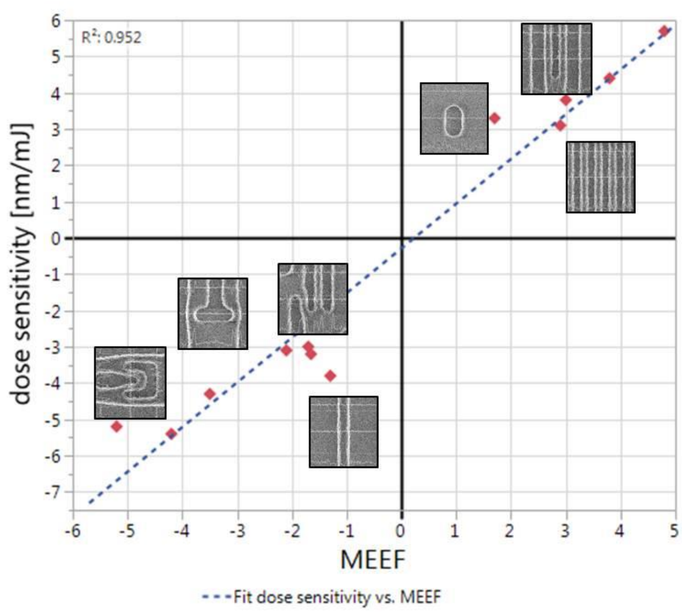

Figure 1. Dose sensitivity versus MEEF simulated for different features of a 28nm metal application.

In a second section we will discuss the CDC technique in more detail. This technique uses an ultra-short pulse laser technology, which generates a micro-level Shade-In-Element (also known as "Pixels") into the mask quartz bulk material. These pixels are used to selectively attenuate certain areas of the reticle in high resolution compared to any other method and thus excellent CDU improvements on reticle field level can be achieved. If we want to describe that principle in more detail, we need to consider both, the pure dose effect due to attenuation and the effect of the scattered light. A small part of that forward scattered light can enter the lens pupil thus creates some source blur. The amount of source blur is very small. However, in particular for illumination settings with extremely small pupil fill ratio, the impact on CD through pitch and on different patterning hotspots can be sensitive regarding the occurring source blur. The impact of the dose and the source part will be characterized based on measurements on scanner and wafer level. Further on wafer measurements are supported by simulations. With the help of specific scanner test masks that got different levels of CDC pixel density, both the impact on the illumination source and the dose transfer can be measured. To check the feature specific impact on the CDU correction, we show a correction of a “virtual” mask with an estimated CD-error of 2nm at mask level to be corrected. Figure 2 shows the on wafer CD deviation from target for 5 pitches for that mask, separated into three cases: the pre correction error (MEEF related), the dose-only correction (like we have at scanner dose correction) and the combined dose correction and source blur effect which occurs by using CDC correction. The result is somewhat surprising: The CDC sample with the combined effect shows a lower deviation for the 5 selected pitches than the pure dose based correction. This effect will be discussed in more detail.

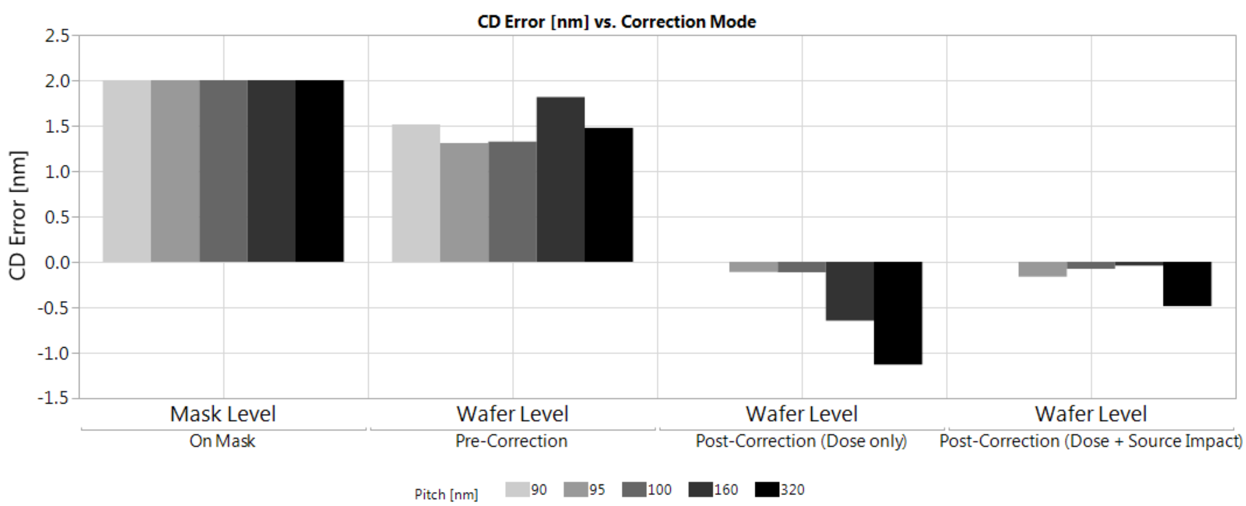

Figure 2. Simulated CD error at wafer level at an estimated 2nm mask error for different pitches. Comparison of pure dose correction result versus correction result including the combined dose and source effect.

Finally, we will discuss electrical verification results. For that experiment, two masks got programmed CD offsets on part of the reticle that resulted in a bad CDU. Afterwards, these masks got CDC treatment with the result of a “perfect” CDU. The CDC treated sample shows a significantly increased robustness of the product yield against disturbances as focus and dose variation. In a second step of that electrical verification test the CDC treated, originally “bad” masks are compared to two golden masks with inherently good CDU. No yield difference is observed. These results show that the CDC technique can be used to repair masks with a borderline CDU without any negative impact on patterning and yield.

Keywords: CDC, Critical Dimension Uniformity (CDU), simulation, yield, reticle, MEEF, hotspots