Printability based mask inspection: 640 Dual-imaging mode

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Abstract – In a typical mask inspection at a mask-shop, discriminating between printable vs non-printable defects during mask inspection is key to improving sensitivity and controlling nuisance defects. Several layers at the 10nm node are employing patterns with complex OPCs to achieve the pattern fidelity and process windows needed during Lithography. These layers are a particular challenge to achieve the necessary sensitivity while controlling the number of nuisance defects using the two major inspection modes (low-NA and high-NA) available on current tools. The 640 team has developed a novel two pass data-base inspection scheme that operates simultaneously on the low-NA and high-NA images, called the Dual-imaging (DI) mode. DI mode has demonstrated that both increased sensitivity and low nuisance counts can be achieved to meet inspection needs at the 10nm node. Customer studies are indicating that the defect printability estimates from 640 have as good or better correlation to the Zeiss AIMS metrology tools.

I. Introduction

A. Challenges for established inspection modes

Customer mask shops making masks for the latest lithographic nodes use either High NA inspection (also called Reticle Plane Inspection (RPI)) or Low NA inspection (also known as Aerial plane inspection and other names). Reticle plane inspection is a high resolution inspection mode providing very high defect sensitivity. However, in the RPI mode, the optical images are quite different from the image projected onto the wafer on a Litho tool. As a result of this, ascertaining the printability impact of a given defect is difficult to do during the inspection. Over the years, several features have been incorporated into the RPI algorithms that help RAPID tools provide the needed sensitivity without suffering from too much nuisance defect counts. Typically these desense mechanisms rely on classifying defects based on where they are detected: either on their location relative to the base pattern on the mask (geometry based approach) or on their location relative to the intensity of the image (intensity band based approach). In some RPI implementations, we estimate the pattern defect by recovering the mask pattern and simulate that pattern down to the wafer plane and estimate the printability impact of a given defect. As the complexity of OPC decorations has increased, it is becoming more difficult to use the approaches developed in the past. The key goal for the 640 team was clear: develop a technique for assessing the printability of an imperfection on the mask that is always accurate. Several approaches were evaluated for their efficacy in estimating printing impact of defects/imperfections on a mask and the dual-imaging mode has been shown to be the most accurate. The team studied the mathematics and physics behind the approach and concluded that there is in fact some rigorous basis for concluding that the method is likely to work for all classes of defects that we are likely to encounter on a customer Mask.

B. Challenges for getting printability right

The Low NA inspection mode that has been used by some customers because the image captured by the system closely mimics the intensity image that is projected onto the wafer in a typical stepper. The imaging NA of the system in this mode is made to be identical to the imaging NA of a scanner. However, there are several notable differences in this imaging mode that make it difficult to achieve printability based inspections.

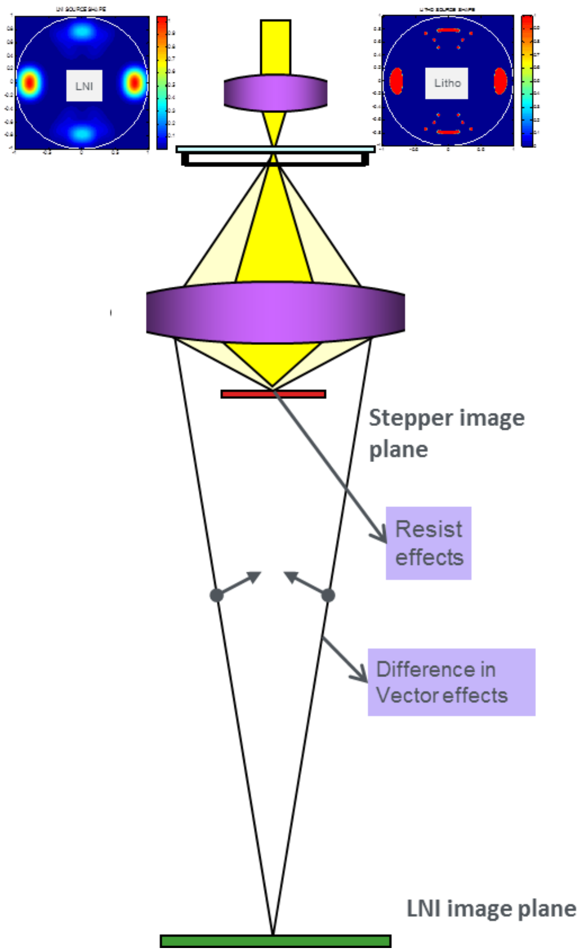

Fig. 1. Differences in optical condition between an inspection system and a litho system

The modulation of the components of the electric field in the imaging pupil that have a radial component to them are modulated quite differently because of "vector effect" difference between a scanner which demagnifies the image to our inspector where we magnify the image. The illumination pupils that we have used in LNI mode are quite different from the lithographic illumination pupils. Resist effects are not included in a purely intensity difference based inspections to find defects. Printability of a defect is a function of the slope of the image intensity at the resist threshold, this needs to be included in order to predict the correct printability. Additionally, effects of the 3D topology of the mask needs to be considered in data base modeling in order to render the reference database images correctly.

A further issue is that printable defects in LNI have a very low intensity delta in "High-MEEF" regions. When the defect delta-intensity is very low, it is very hard to distinguish it from noise thus limiting the efficacy by overwhelming the inspection with false defects.

II. Approach used by 640

A. Details of implementation

Figure 2. shows a block diagram of the 640 dual imaging mode. As mentioned earlier, this is a two pass inspection mode. The first scan is a high resolution RPI inspection. The scan is performed with a very high sensitivity. This ensures that all the areas on the mask with both printable and non-printable defects are found. RPI scan typically provides a very high SNR and most defects found are real variations on the mask. The key task then is to ensure that only the printable defects are kept after the second pass. As seen in figure 2., the candidate defects found during the RPI scan are stored on the image computer to be played back during the second scan. The system is sized to identify several million candidate defects during the first RPI inspection. Certain defects from the first scan are sent directly to the inspection report. Printability impact of these defects is not evaluated. If the defect is very large in either spatial extent or in defect residue, such defects may need to be repaired and they are not what causes nuisance defects and are kept. A second class of defects that are kept those that may not have any significant printability impact but indicate that there is contamination present on the mask or the mask writer has small shifts in where the patterns were written by the writer. These defects do not cause nuisance and customers

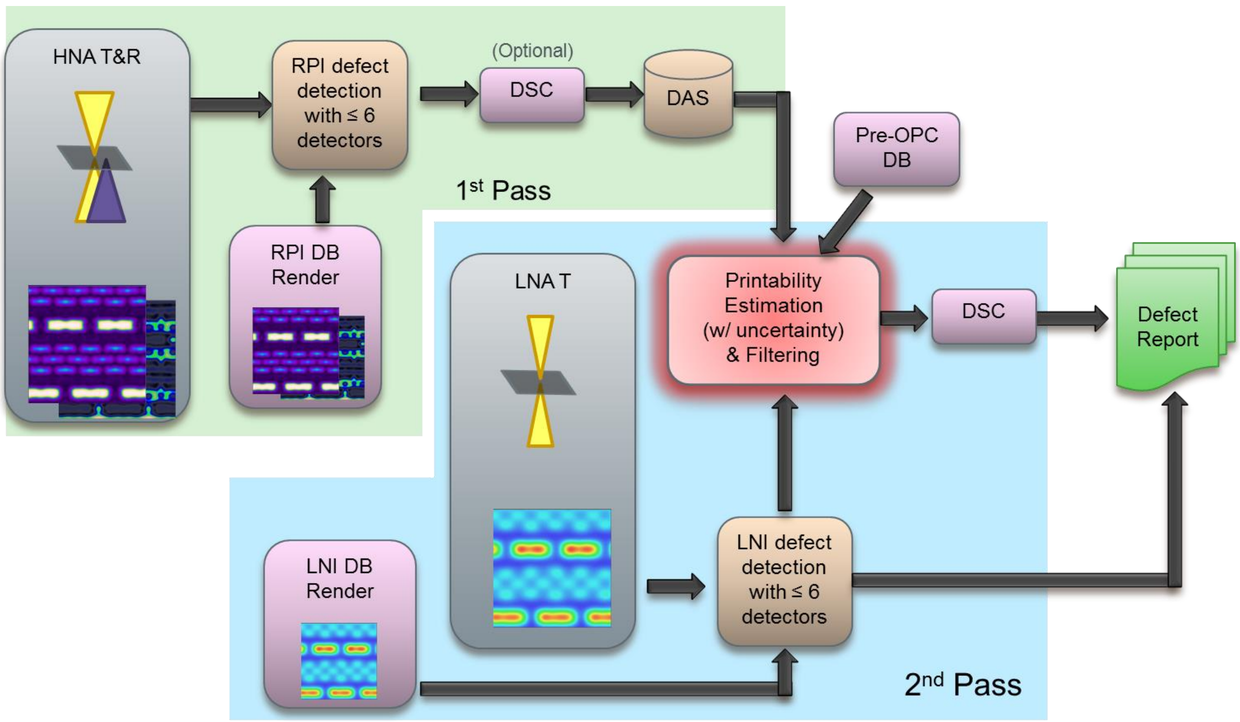

Fig. 2. Schematic block diagram of DI mode operation

want to see such defects.

During the second scan, the printability impact of all defects is evaluated by combining the LNI inspection images and algorithmic simulation of Litho plane test and reference images. Pre-OPC data base is used to estimate the proper resist threshold. The LNI mode is suitable for detecting certain class of defects such as "half-etch" phase defects. These are sent directly to the defect report without a printability estimation. For each of the RPI candidate defects, the corresponding LNI image clips (test and reference) are obtained. Various effects such as vector effects, illumination differences, mask 3D effects etc. are then algorithmically compensated for using the 640 algorithms. The printability impact of each RPI candidate defect is estimated. The uncertainty in the printability estimation is also estimated. If the nominal +/- uncertainty is larger than the defect detection threshold the defect is kept. If the defect printability is less than the threshold, the defect is discarded but a "defect light" packet is kept for process monitoring to track the performance of the mask manufacturing process.
The specific details of the algorithm are not presented here because the algorithm details are being kept as KLA-Tencor trade secret.

B. *Inspection results*

A 640 tool has been installed at TSMC and the DI mode has been activated on the tool. Several programmed defect masks and product masks have been inspected on this tool Figure 3. Shows the printability estimates obtained form the 640 algorithm on the programmed defects. The 640 data is plotted against the printability estimate obtained from the Zeiss AIMS metrology tool. It can be seen that the agreement between the two is fairly accurate.

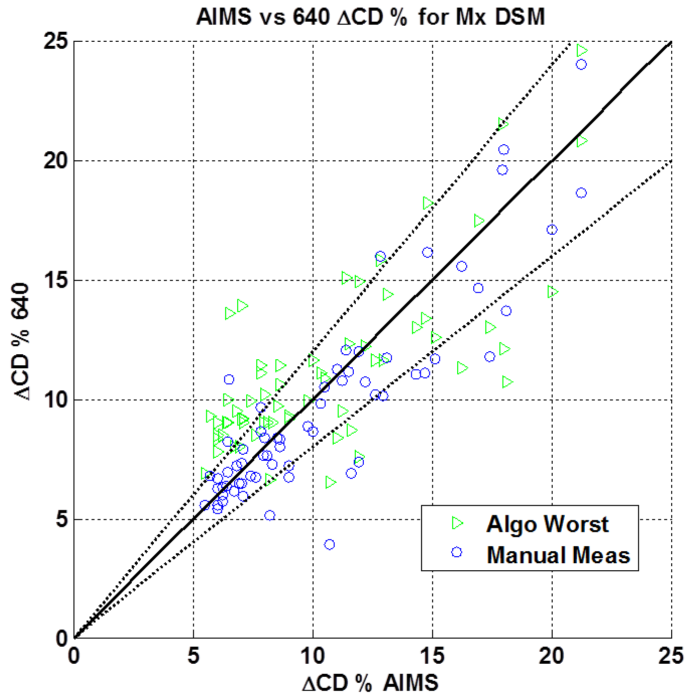

Figure 3. Mx Programmed Defect mask: printability of 640 vs Zeiss AIMS

Figure 4. shows that 528K RPI candidate defects can be printability arbitrated during the LNI scan only a handful of real printing defects are kept and the rest of the defects are discarded as non printing defects.

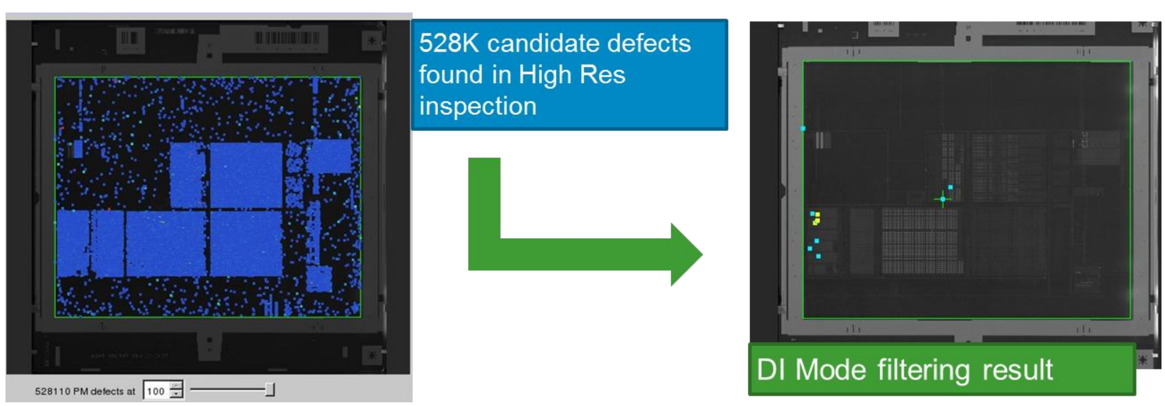

Figure 4. DI mode RPI candidates and final defects kept after DI mode filtering.

III. Conclusion

The 640 DI mode has been shown to successfully identify printable defects on masks with complex OPCs. This technology enables mask inspection for the 10nm node and beyond for immersion lithography.

Acknowledgment

The entire 640 product team worked diligently to bring this product to market. TSMC AMT has been working alongside with the RAPID team to study the performance of this mode.