Detection of Progressive Transmission Loss Due to Haze with Galileo^{TM} Mask DUV Transmittance Mapping Based on Non Imaging Optics

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Keywords: Transmission, DUV, Blank, Fused Silica, Haze, Photomask, Non imaging optics

ABSTRACT

In this paper, we expand on our earlier work[1,2] reporting the use of high sensitivity DUV transmission metrology as a means for detection of progressive transmission loss on mask and pellicle surfaces. We also report a use case for incoming reticle qualification based on DUV transmission uniformity.

Traditional inspection systems rely on algorithms to locate discrete defects greater than a threshold size (typically > 100nm), or printing a wafer and then looking for repeating defects using wafer inspection and SEM review. These types of defect inspection do not have the ability to detect transmission degradation at the low levels where it begins to impact yield. There are numerous mechanisms for transmission degradation, including haze in its early, thin film form, electric-field induced field migration, and pellicle degradation.

During the early development of haze, it behaves as a surface film which reduces 193nm transmission and requires compensation by scanner dose. The film forms in a non-uniform fashion, resulting from non-uniformity of exposure on the pattern side due to varying dose passing through the attenuating layers. As this non-uniformity evolves, there is a gradual loss of wafer critical dimension uniformity (CDU) due to a degradation of the exposure dose homogeneity. Electric-field induced migration also appears to manifest as a non-uniform transmission loss, typically presenting with a radial signature.

In this paper we present evidence that a DUV transmission measurement system, Galileo™, is capable of detecting low levels of transmission loss, prior to CDU related yield loss or the appearance of printing defects. Galileo is an advanced DUV transmission metrology system which utilizes a wide-band, incoherent light source and non-imaging optics to achieve sensitivities to transmission changes of less than 0.1%. Due to its very high SNR, it has a fast MAM time of less than 1 sec per point, measuring a full field mask in as little as 30 minutes. A flexible user interface enables users to easily define measurement recipes, threshold sensitivities, and time-based tracking of transmission degradation. The system measures through pellicle under better than class 1 clean air conditions.

Keywords: Transmission, DUV, 193nm, Haze, Electric-field induced migration (EFM), Photomask, Non imaging optics, Dose, CDU

INTRODUCTION

A key feature of a photomask is the transmission property of its many surfaces. Typical advanced 6" masks have 4 surfaces: back side quartz, front side pattern, inside pellicle and outside pellicle. In addition to the surfaces themselves the bulk of the transparent materials- fused silica which is the material out of which the blank quartz is made and fluoropolymer out of which the pellicle is made, have specific optical transmission properties which contribute to the total Tr properties of the mask. Also surface coating materials like Cr, MoSi and anti-reflective (AR) coatings have their specific transmission contributions. Figure 1 shows a schematic drawing with all the different contributors to transmission loss in a photomask exposure system.

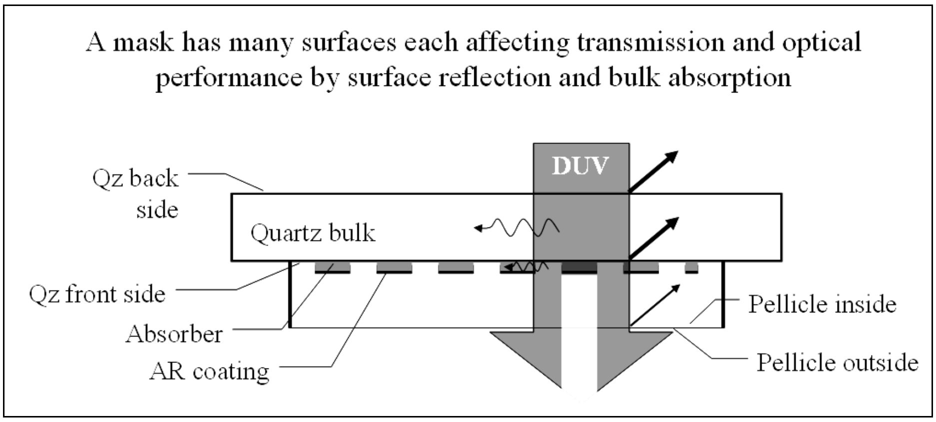


Figure 1: Transmission loss contributors in the photomask system are shown. Back and front side reflection from the quartz, reflection from the pellicle and absorption in the quartz bulk and in the absorber.

Overall the wafer printed pattern fidelity to the design depends both on the physical size of the etched lines and spaces and on the transmission properties of the spaces and of the coating material in the lines.

Factors which may contribute to transmission deviations may be:

1. Quartz raw material non homogeneity[1]
2. MoSi absorber layer non-uniformity
3. Contamination by metal and oxide ions absorbed in the Quartz and adsorbed on the Quartz surface during mask manufacturing[3]
4. Contamination by haze growth on any of the surfaces (Quartz, absorber, pellicle)
5. Electric-field induced migration (EFM) of the absorber layer (also commonly referred to as the “Sun Effect”)[4]
6. Photochemical degradation of the pellicle and fused silica substrates
7. Degradation of absorber thickness, particularly of MoSi, due to clean processes
8. Other factors

Accumulated contributions of all those factors can give rise to transmission variations of several percent. Every percent of exposure dose change may result in 1-2 nm CD change on wafer depending on exposure and process conditions. All the above raise the need for an advanced, in-line transmission measurement system that will be able to measure transmission at the exposure wavelength with sensitivities better than 0.1%, preferably better than 0.01% (100 ppm). With the ability to monitor changes in transmission uniformity to this sensitivity, CDU related yield loss can be monitored more efficiently than through the use of CD metrology and more effectively than traditional reticle requalification techniques.

In this paper we report significant findings in the use of DUV transmission metrology for both incoming qualification of new masks and detection of progressive changes in transmission. We also discuss the significance of these findings for wafer CDU and the potential impact on CD yield. The capability to detect these transmission non-uniformities is critical to wafer fabs, allowing them to verify new mask quality and periodically monitor mask transmission in order to detect progressive changes as in the case of haze.

EXPERIMENTAL

Galileo system description

The Galileo tool has two optical systems. An optical path in the visible range uses transmitted light for alignment and auto focusing. A DUV Tr measurement path is used for measurement of transmission. The mask is mounted pellicle down on an open frame XY stage with the help of an autoloader. The whole process area and the autoloader are enclosed in a minienvironment with < Class 1 clean air conditions. The system is sufficiently clean to allow measurement of production masks and return them to production without need to repell and clean.

Pixer methods for detecting transmission change

Galileo can be used to both evaluate transmission uniformity and to detect transmission change over time. There are two effective approaches to this goal. The first is the creation of transmission uniformity maps through the use of a die-to-die type analysis. Uniformity maps of multi-die reticles eliminate the transmission variations due to varying pattern density seen in the raw data, instead enabling easy visualization of uniformity trends on the mask as seen in Figure 2. This use case can be employed at both incoming qual and as a means to detect changes in the uniformity signature over time.

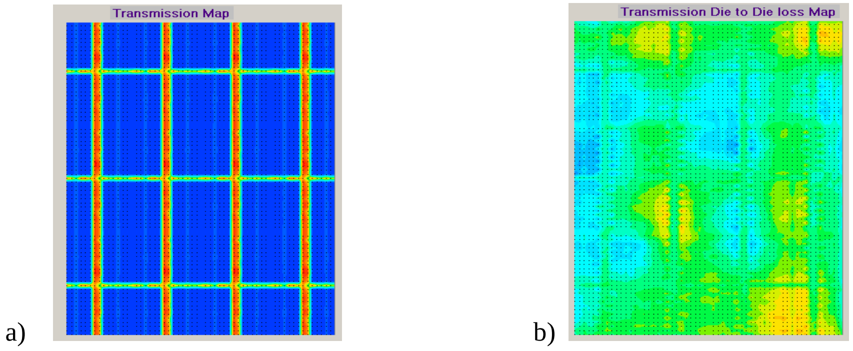


Figure 2: a) The raw transmission data for the mask. The red areas indicate high transmission (low pattern density)of the periphery. B) The transmission uniformity plot shows 2 vertical areas of transmission non-uniformity with ~5nm expected CDU error.

The second approach is to monitor transmission over time, comparing the new transmission data to a baseline data set. The Galileo tool has a special software package for monitoring and data logging the transmission maps of every mask from time zero (before first exposure) and through multiple repeat exposures. The software allows the user to preset threshold values for Tr loss and Tr uniformity loss from the Tr map at time zero and each progressive map.

In either use case, monitoring is performed at regular intervals, based on either time or cumulative exposure. As a fab gains experience with understanding the relationship of CD with transmission change in their process, they will be able to set appropriate thresholds to prevent transmission/CDU related yield losses by optimizing when to return masks for clean and repell at the mask shop.

RESULTS

Blank qualification

We received a 6% MoSi coated blank for transmission uniformity measurement. The blank had not been coated with Cr nor had it been patterned, so it is expected that the results reflect the transmission signature of the MoSi and quartz substrate. The blank was measured on Galileo and the uniformity map is shown in Figure 3. The measured of 12.8% deviates from the 6% transmission at 193 due because the Galileo DUV and 193nm scanner lights sources. The Galileo DUV system utilizes a wide band (~20nm range) source with a central wavelength of 210nm. In this range of wavelengths, MoSi becomes more transparent than 193nm with increasing wavelength. The relative transmission variation correlates well with 193nm however. More significantly our findings show a relative transmission variation of 2.5%, with a strong radial and tilt signature. This variation may induce a CDU variation of up to 0.75nm on the wafer. It is believed that the source of this signature is non-uniformity of the MoSi thickness, which although not measured, would also result in an approximate phase error of 3.5 degrees.

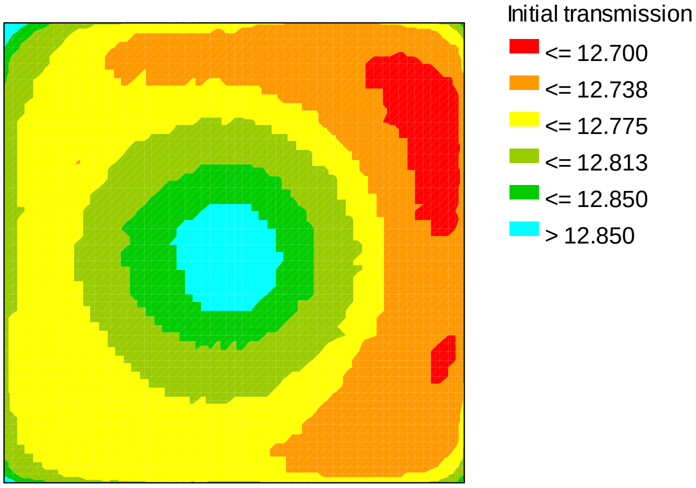


Figure 3: Transmission profile of MoSi coated blank. The relative transmission range is 2.5% with a strong radial signature and pronounced tilt.

Incoming mask qualification

In the following case, extensive DUV measurements were made on an incoming mask as both incoming mask qualification as well as creating a baseline for monitoring of transmission over time and cumulative exposure. A dense map of 8000 points was created for a measurement time of approximately 2 hours. The recipe was created to allow for transmission uniformity mapping as well, since the mask had 6 identical die. In figure 5, we can see the transmission map is slightly more transmissive (red) in the upper right die. This deviation is more easily visualized in the scatter plot on the right, which indicates the die in questions is approximately 5% more transmissive than the other 5 die. This error would result in a potential CDU error of 5-10nm on the wafer depending on the exposure conditions. In this case, the fab opted not to print the mask but rather return it to the mask shop for additional analysis with a Zeiss AIMS-193 tool.

Map Scaling
Min: 0.00097
Max: 0.07737
☐ Tr. Measured min Threshold 0.3

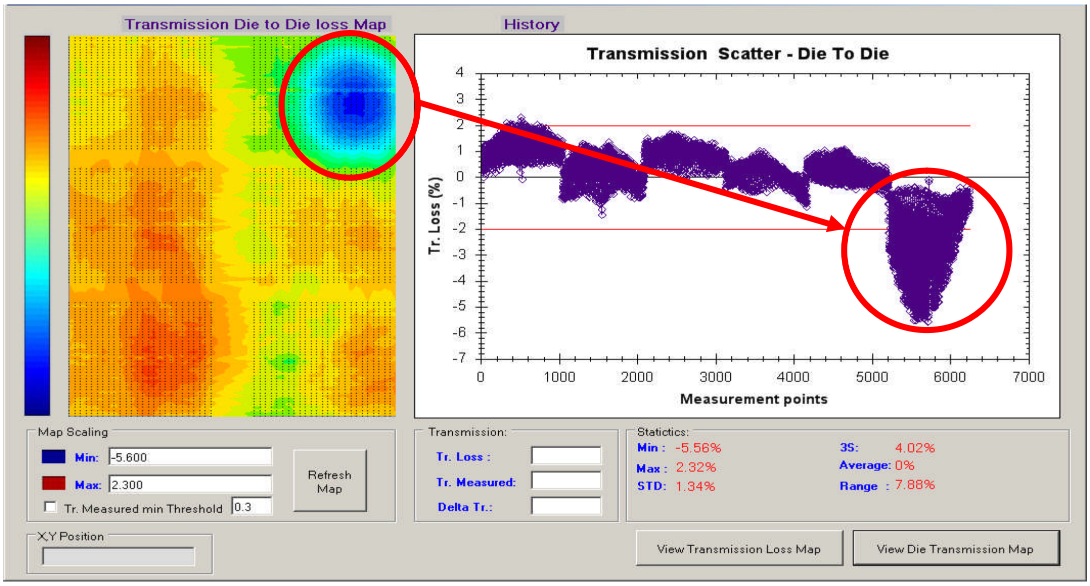
Transmission:
Tr. Loss :
Tr. Measured:
Delta Tr.:

Statictics:
Min : 0.10%
Max : 7.74%
STD: 2.80%
3S: 8.40%
Average: 5.23%
Range : 7.64%

X,Y Position

Figure 4: Transmission map generated at incoming mask qualification indicates a potentially bad die due to increased transmission.

In order to better visualize the impact of this die, and eliminate the pattern density effects on the map in Figure 4, a transmission uniformity plot can be created in the Galileo analysis software. This die-to-die type analysis shown in Figure 5. The upper right die now clearly stands out as having a different transmission profile from the other die. A circular area in that die stands out from the rest of the die, and it is expected that dense CD sampling would result in a similar CDU map.



Min: -5.600

Max: 2.300

☐ Tr. Measured min Threshold 0.3

Statictics:

Min : -5.56%

Max : 2.32%

STD: 1.34%

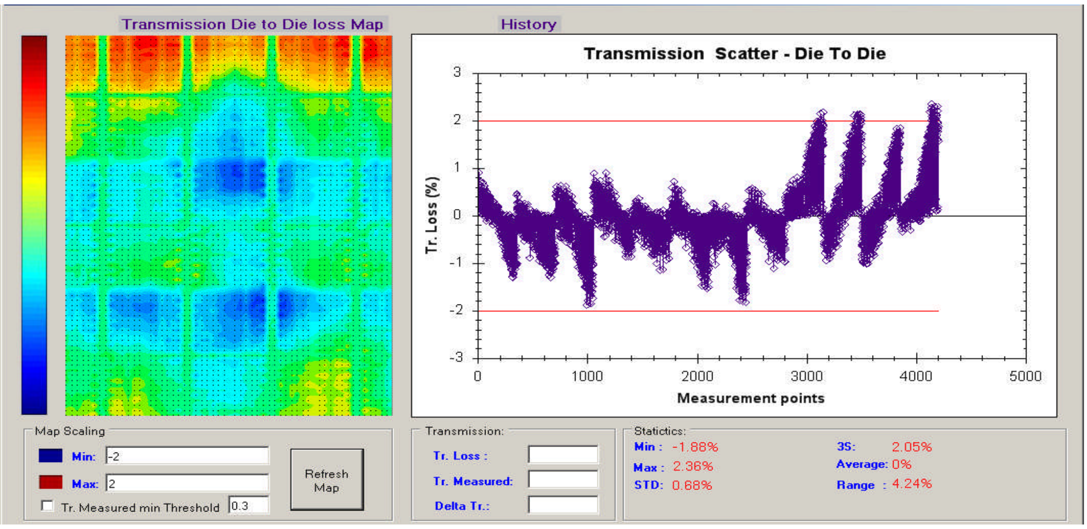
3S: 4.02%

Average: 0%

Range : 7.88%

Figure 5: Transmission uniformity map generated at incoming mask qualification more easily identifies a potentially bad die due to increased transmission.

A final example of the incoming qualification use case shows a DRAM mask that was printed prior to measurement. Print testing showed significant CD errors in the top die row. The mask was sent to Pixer's Taiwan Process Center for analysis on the CDC200 tool with the Galileo option, where the measurements revealed a transmission range of 4.24% as shown in Figure 6. This transmission range should result in an approximate CD error of 8.5nm in the top die row. The fab reported that in fact the error was 8nm, demonstrating excellent correlation between transmission uniformity as measured with Galileo and wafer CDU.



Min: -2

Max: 2

☐ Tr. Measured min Threshold 0.3

Statictics:

Min : -1.88%

Max : 2.36%

STD: 0.68%

3S: 2.05%

Average: 0%

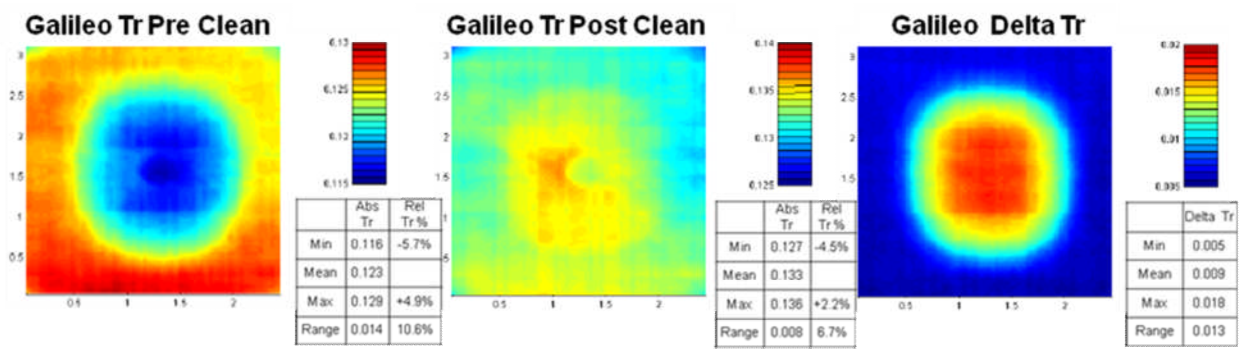
Range : 4.24%

Figure 6: Transmission uniformity map generated at incoming mask qualification identifies a substantial transmission uniformity error that correlates very well with the observed CDU problems at the wafer level.

Detection of haze, EFM, and other progressive degradation of transmission

An EPSM (MoSi) production mask (Mask A) which was described by users as suspected as hazed was measured by Galileo before and after cleaning.

This mask showed yield loss at the fab and was suspected to have haze. No killer defects were detected by mask inspection systems. CDU measurements showed quite large CDU non uniformity, larger than expected based on mask CDU data. The mask was sent to Pixer for measurement on the Galileo tool before cleaning. The mask was then sent for cleaning and repell at the mask shop. Next the mask was measured again on Galileo. Finally the mask was printed and wafer CDU was remeasured. Figure 7 shows the pre and post clean and the delta transmission calculation in terms of transmission gain as measured by Galileo. Figure 8 shows the corresponding CDU maps of the wafer before and after cleaning. Note that improvement of transmission uniformity and of CDU was a result of both mask cleaning and of pellicle replacement. It is believed that this progressive defect resulted from EFM.



	Abs Tr	Rel Tr%
Min	0.116	-5.7%
Mean	0.123	
Max	0.129	+4.9%
Range	0.014	10.6%

	Abs Tr	Rel Tr%
Min	0.127	-4.5%
Mean	0.133	
Max	0.136	+2.2%
Range	0.008	6.7%

	Delta Tr
Min	0.005
Mean	0.009
Max	0.018
Range	0.013

Figure 7: Galileo Tr pre and post clean and the transmission gain due to cleaning EFM damage.

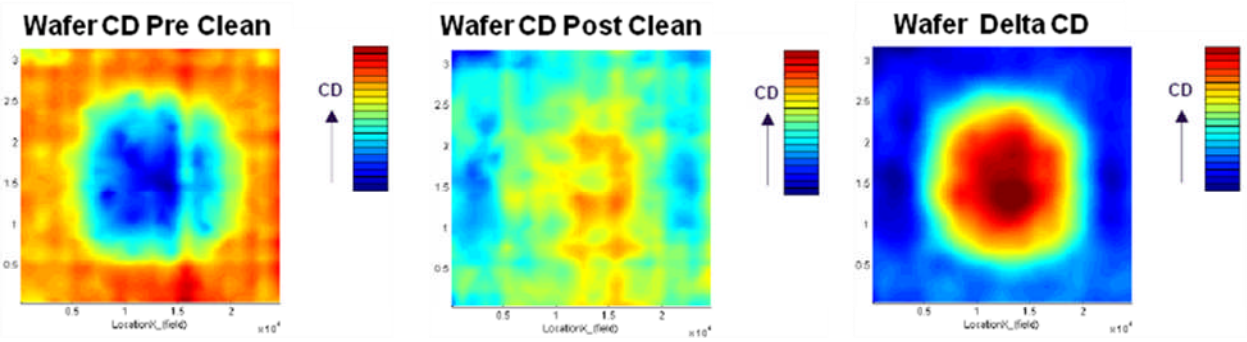


Figure 8: Wafer CDU pre and post clean and delta CD due to cleaning EFM damage. Actual CD data cannot be disclosed due to confidentiality. Total CD non uniformity (delta CD) due to the clean process was ~ 3 nm 3S on wafer.

As can be seen above the Galileo transmission maps and the wafer CDU maps show excellent correlation. Also the improvement in wafer CDU (wafer delta CD map) correlates very well with the EFM (delta transmission) reported by Galileo.

In another case, a flash memory mask returned to the mask shop for repelliclization showed a similar radial transmission signature that was removed after cleaning, and showed correlation to the limited inline CD sampling of both lines and spaces as shown in Figure 9. In this case, cleaning of the mask returned the transmission map to a flatter state, showing a radial transmission loss signature pre-clean, with a maximum loss of 5.3%. The pre-clean CD map showed a similar radial signature, and post-clean the CD map was substantially flatter, with CDU reported to be 60% improved, and back within the fab’s SPC limits.

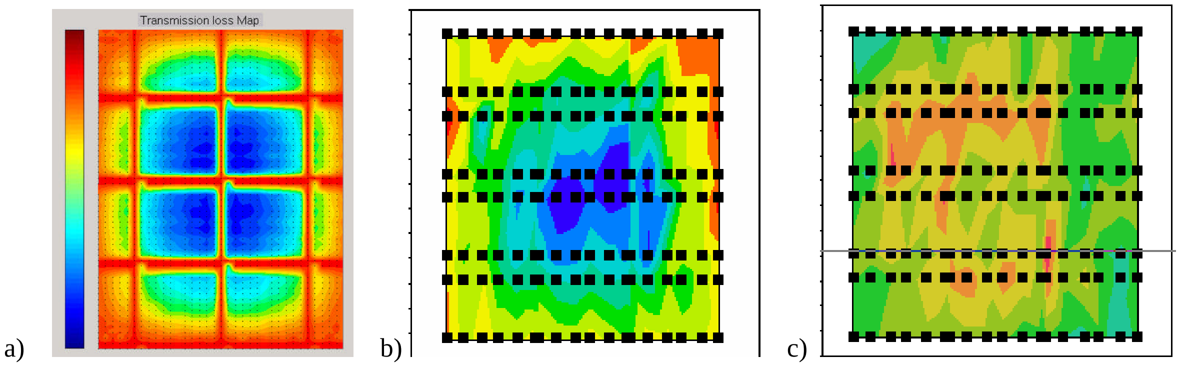
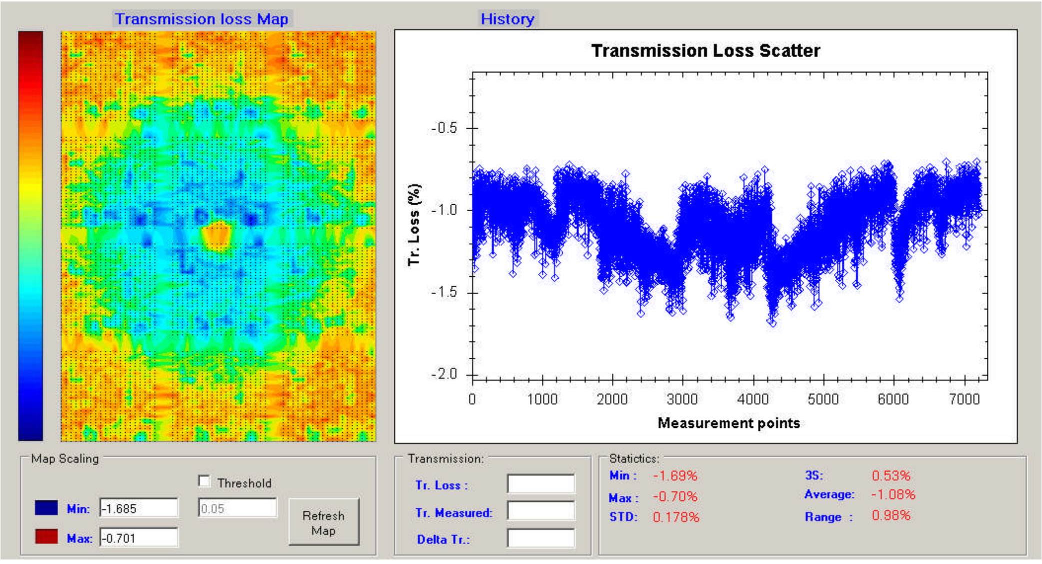


Figure 9: a) Post-clean transmission loss of ~5% with a radial signature. b) Pre-clean CDU map. C) Post-clean CDU map showing a 60% improvement in CDU> Note the correlation between the transmission loss map and the pre-clean CDU map.

A more common signature often observed in the case of haze is a gradually increasing transmission loss in the corners and scribelines of the mask, working inwards into the active area. Several examples of this phenomenon are shown below. In Figure 3, we showed a case where there was transmission change signature that indicated a possible yield problem in vertical columns. Further information from the fab indicated that the issue was in the peripheral circuitry of the device, and that the mask was not failing reticle requalification using their standard mask inspection techniques. A high resolution scan of the 4 vertical regions of periphery was performed. Analysis of the data showed that column 3 showed a 1.67% absolute difference in transmission from the other 3 columns, indicating a potentially significant CDU error condition in the circuitry in that column. In actuality, this mask was pulled from production due to high densities of printing defects detected by wafer inspection in the third vertical column of the field. The mask was returned to the mask shop for additional analysis. Inline monitoring with Galileo would have allowed for identification of this yield loss mechanism prior to printing wafers.

Figure 10 shows another case where transmission loss is mapped over time. In this case, the mask has developed a strong radial signature, with an absolute change in transmission of almost 1% radially, with the heaviest transmission loss in the corners. The transmission loss in the center of mask is as of yet unexplained.



Map Scaling

☐ Threshold 0.05

Min: -1.685

Max: -0.701

Transmission:

Tr. Loss :

Tr. Measured:

Delta Tr.:

Statictics:

Min : -1.69%

Max : -0.70%

STD: 0.178%

3S: 0.53%

Average: -1.08%

Range : 0.98%

Figure 10: a) Post-clean transmission loss of 1% with a radial signature of 1%.

DISCUSSION

Blank qualification

In addition to the quartz blank grading use case presented at EMLC 2008, we have demonstrated that Galileo also has the ability to characterize the non-uniformity of transmission in MoSi coated blanks. This offers blank manufactures the ability to both characterize their quartz and MoSi deposition processes and grade blanks as being high or low transmission uniformity. This enables customers to specify and purchase higher uniformity blanks for critical layer patterning, and enables blank manufacturers to generate additional income by selling those high uniformity grade blanks for a premium over standard grade blanks.

Incoming qualification

Two cases were presented where Galileo effectively identified transmission non-uniformities at incoming qualification. In the case of the DRAM mask shown in Figure 7, Galileo DUV transmission metrology correlated strongly with CDU on the wafer print, predicting the CD impact within 1 nm. Using Galileo as an inline qualification technique allows for full field qualification without the need for wafer print. While inspection techniques still serve a purpose looking for discrete defects and particles, Galileo adds to the suite of qualification tools that can be employed to protect line yield. In both cases presented, Galileo highlighted issues that are not found using traditional inspection techniques, and can be detected in fast and cost-effective manner.

Detection of transmission change

In the several cases presented, Galileo was able to identify significant transmission non-uniformities over time and cumulative exposure. In two cases, the transmission loss was identified via a simple pre/post-clean comparison. With these masks, both the transmission and CD uniformity improved significantly after clean, and the two indicators were well correlated. In a third case, a specific yield signature was identified with DUV transmission metrology after other in-line monitoring techniques failed to identify the problem before wafer printing. Finally, a mask was presented that shows a more classical “haze” signature developing over time, providing a complementary means of identifying early haze with traditional inspection techniques. In all of these cases, Galileo has demonstrated capability for in-line monitoring to protect fab yields.

CONCLUSIONS

1. The total CDU signature of a mask is made of all the different contributions for transmission non-uniformities such as:
    a. Blank transmission uniformity
    b. Coating process uniformities (especially MoSi)
    c. Pattern etching affect on transmission uniformity
    d. Pellicle transmission uniformity
    e. Transmission/transmission uniformity degradation in the fab as the result of haze, EFM and other processes
    f. Haze cleaning efficiency in the mask shop
2. Galileo has proven capable of detecting all these effects, and the detected effects have been correlated to CDU and defect yield.
3. Galileo as an inline monitoring technique enables fabs to detect these non-uniformities before yields are impacted.
4. Galileo is an effective addition to the suite of techniques employed to protect yield at incoming reticle qualification and as for in-line reticle requalification.

FUTURE DEVELOPMENTS

Several evaluations of Galileo in production environments are ongoing as well as R&D on the various applications of high sensitivity transmission measurements. We will continue to report the results of these evaluations in the coming months.

ACKNOWLEDGMENTS

We would like to thank the Intel Mask Operation and their assistance in generating data early in the development of Galileo. We also appreciate the feedback we have received from those who are currently evaluating Galileo in their fabs.

REFERENCES

1. Ben-Zvi, et al, “Very High Sensitivity Mask DUV Transmittance Mapping and Measurements Based on Non Imaging Optics European Mask and Lithography Conference, 2008
2. Ben-Zvi, et al, “Very High Sensitivity Mask DUV Transmittance Mapping and Measurements Based on Non Imaging Opticswith Galileo™,” Photomask Japan, 2008
3. B. Grenon, “Molecular Contamination and its Potential Impact on and Below Photomask Surface,” Sematech 5th Annual Mask Cleaning Workshop, 2008.
4. Rider and Kalkurm “Experimental quantification of reticle electrostatic damage below the threshold for ESD”. SPIE Advanced Lithography, 2008.