Rapid and precise monitor of reticle haze

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1. ABSTRACT

Reticle Haze results from the deposition of a chemical residue of a reaction that is initiated by Deep Ultra Violet (DUV) or higher frequency actinic radiation. Haze can form on the backside of the reticle, on the chrome side and on the pellicle itself[1].

The most commonly reported effect of haze is a gradual loss in transmission of the reticle that results in a need to increase the exposure-dose in order to maintain properly sized features. Since haze formation is non-uniform across the reticle, transmission loss results in an increase in the Across Chip Linewidth Variation (ACLV) that is accompanied by a corresponding reduction in the manufacturing process window[2]. Haze continues to grow as the reticle is exposed to additional low wavelength radiation through repeated use.

Early haze formation is a small-area phenomenon in comparison to the total area of the reticle and may initiate simultaneously in separate areas. The early stages of reticle haze therefore results in a degradation of Best Focus, Depth of Focus and the Exposure latitude of individual features in the “hazed” area prior to any noticeable large area transmission loss. Production lots subject to reticle hazing on critical layers will experience a direct loss of lithographic yields, loss of capacity, an increase in rework rates and an ultimate loss in overall final-test yield long before the need for an overall image exposure-dose increase is detected.

Feature profiles and process response are degraded at the earliest stages of haze formation. While early hazing may occur in a small area of the reticle, the area influenced by the initial deposition is relatively large in comparison to the size of an individual circuit feature. A sampled metrological inspection of a regular array of points across the exposure field is therefore able to detect any form of reticle haze if the analysis monitors the feature-profile response rather than simply feature widths. A model-driven method for the early detection of reticle-haze using basic feature metrology is developed in this study. Application results from a production reticle are used to demonstrate validation of the technique that employs a highly accurate method of calculation of the uniformity of the reticle exposure-response for individual features across the exposure.

2. INTRODUCTION

Reticle haze is a problem that occurs in DUV and lower wavelength environments. Reticle haze was initially observed as a reticle back-side phenomenon but has recently been recognized as a contaminant that can appear on the chrome or 'object side of the reticle. Haze is a contaminant that is caused by mask-making chemicals, process residue, reticle-container out-gassing or through localized high-energy interactions with environmental gases in the exposure tool environment.

Reticle haze on DUV process tools is rising in significance as a significant source of yield and capacity loss in device manufacturing. Reticle front or back-side haze causes non-uniform transmission loss within and near the hazed-areas across the reticle. The extreme effects of haze-generation are observed as a gradual increase in the reticle exposure-dose needed to maintain proper feature size. Degradation increases with continued usage.

Most production facilities experiencing the reticle haze phenomenon overlook the more subtle but strong influence of the phenomenon on aerial-image feature profile uniformity and therefore device response and process yield. In these facilities, production usage of a hazed-reticle continues until lithographic re-work levels rise above tolerable limits or production capacity drops significantly. Here we highlight "capacity" because the larger doses caused by haze not only reduce yield by also reduce the wafer throughput of the exposure tool by requiring slower reticle-scan rates and through the increased lithographic rework-levels that result from the contaminant.

A similar degradation of process exposure-dose can be encountered with the onset of film depositions on the final lens of the exposure tool. Film deposition is created by photoresist or other chemical radical dissolution during latent image formation that results in a subsequent deposition of vapor-phase polymers on the lens-surface. Lens contaminant films are not uniform in thickness but are less localized in their appearance than the reticle-haze phenomenon.

Hardware-based offline reticle area inspection tools currently offer a direct method of reticle inspection that requires over 3 hours using a 90 nanometer (nm) pixel size. The scan process relies on the tool's ability to visually detect the presence of very thin films (the haze) at a different wavelength than production-device exposure. Influence of haze on the final image cannot be directly measured with this method and detection occurs only after significant haze deposition.

Therefore, long before direct reticle inspection successfully detects haze, device yield is lowered. Production yields slowly drop because haze growth is gradual, continuous with use and influences CD distributions in a non-uniform manner. As a result features are produced at the wrong size as the extent and full-field uniformity of the process window of multiple across-chip features slowly degrades. Tool-specific lens aberrations also interact differently with the haze and are dependant upon the specific aberration signature of the optics. This results in additional degradation of the CD uniformity and profiles as the reticle is used on multiple toolsets obfuscating engineering efforts to determine yield-loss sources.

To maintain process stability the impact of haze-degradation on production should be detected at the earliest stages of formation. Once the onset is noted, the process can become aware of the haze growth cycle and can plan for an orderly scheduling of the reticle for proper cleaning and repair. Fortunately haze can be easily monitored using standard metrology methods described in the following sections

3. HAZE INITIATION AND OPTICAL INFLUENCE

The major component of the haze constituent is known to be Ammonium sulfate. Ammonium sulfate is a residual of the cleaning process and the interaction of the actinic radiation encountered during exposure with the cleaning residue, as shown in figure 1[3]. Haze depositions are created from sources found within mask-making materials, process residues, the reticle storage container and the environment in which the reticle is used. An observation of the characteristic deposition signature of haze across the reticle, as shown in figure 2, is a good indicator of the source of the contamination. Note the relatively large reticle area covered by the advanced stages of haze in the illustration.

Since haze deposition is a chemical reaction it first forms on the high-energy areas of the reticle known as "seed-sites". Seed sites are not singularities that form at one or two isolated points on the reticle but can initiate in clusters over regions of the reticle surface. Seed-sites also do not necessarily correspond to the areas around a chrome feature-edge although these will be high potential areas because of the scanner and change of refractive index that occurs at these

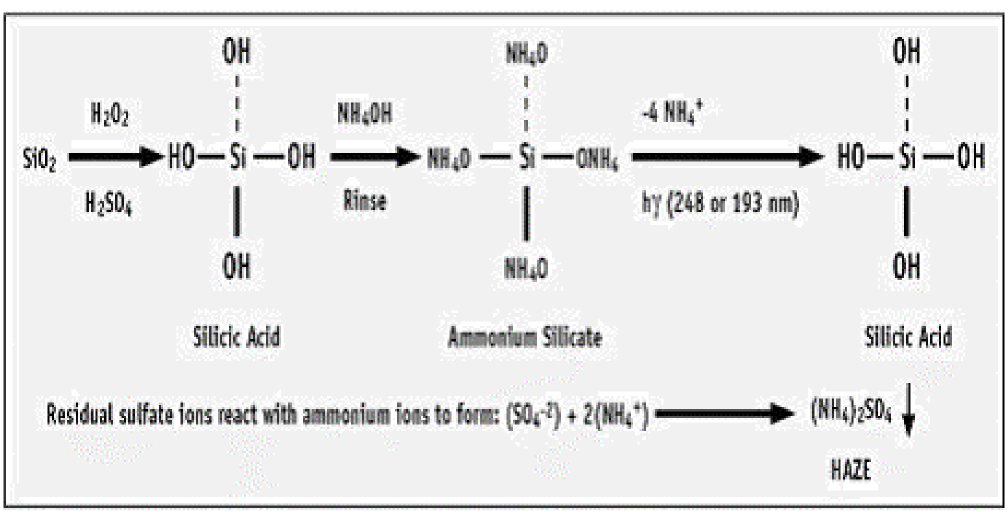

Figure 1: Haze deposition of Ammonium Sulfate (Courtesy Grenon Consulting, Inc.)

points. Reticle repair sites, glass imperfections, localized index of refraction areas on the glass (known as "color centers") and chrome undercut regions can all act as host areas for the start of haze deposition and growth.

Haze deposition will begin across an extended area of the reticle surface covering millimeters or centimeters in extent. Formation speed is a function of localized feature density, the localized optical wavefront characteristics (lens edge verses center), the wavelength of illumination. Phase Shift Mask (PSM) technology reticles can initiate haze formation in areas of unequal etch or film thickness that results in non-optimum wavefront extinction during phase shifting.

Haze influence on the wavefront extends beyond that of a neutral-density filter-type change in intensity. Aerial image wavefronts are distorted through aberration and scatter both directly above the hazed areas and for a significant extent adjacent to the areas. To understand these effects we will examine the behavior of a "grain" of haze located on three separate areas of the reticle.

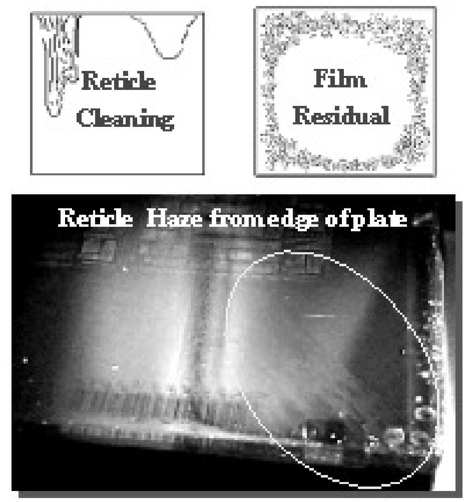

Figure 2: ***Lower*** **– Haze formations on lower right-side of reticle.** ***Upper*** **– Schematic of two characteristic sources of haze formation**

3.1 Knife-edge Optical Effects

To visualize the effects of haze formation at a chrome-feature edge, consider the Foucault knife-edge. The thin chrome of the reticle acts similar to a knife-edge discontinuity that results in a redirection by diffraction of a portion of the incident radiation around the back of the chrome as a phenomenon that is explained by Huygenes principal of diffraction.

Therefore the true intensity profile at the edge of the feature is not a pure Dirac step function in intensity as assumed in a Gibbs Phenomenon modeling of side-lobe formation. It is a complex intensity gradient that incorporates a strong variance caused by optics-limited distortions, scatter and localized changes in the effective numeric aperture caused by the finite edge that results in a portion of the wavefront propagation behind the chrome obscuration as shown in figure 3.

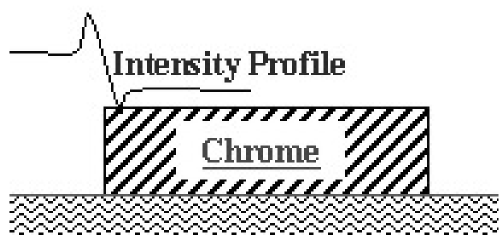

Figure 3: Intensity profile of wavefront at the edge of a chrome knife-edge.

These perturbations result in an intensity profile that behaves somewhat like a Gibb’s function but is actually stronger in intensity and results in a more extreme variant of feature profiles across the focus and exposure-dose ranges encountered in the process-space of semiconductor fabrication. The net effect of translucent obscurations, the chrome and quartz, interacting with feature edges is therefore greater than the Gibbs predicted, simple creation of intensity side-lobes in the image.

Chrome is not a true knife-edge in that it’s thickness is actually a significant fraction of the actinic wavelengths, approximately 900 Angstroms. The thickness therefore directly compounds profile changes by polarization and coherence perturbations. Chrome edge effects further amplify the aberrational influences present in the aerial image of the reticle.

3.2 Scatter Effects

The chrome feature image is further complicated in that it is supported by a quartz substrate. The wavefront at the feature edge encounters a change in the index of refraction (Quartz-to-Air) at the same time that it encounters the chrome feature obscuration as illustrated in figure 4. The index change at the edge results in scatter and this in turn reduces the edge resolution and contrast.

3.3 Open Area Haze Formation

Haze does not form randomly. It needs a high-energy seed-site. Seed-sites start in areas containing:

- Localized damaged from repair
- Chrome Undercut
- Impurities or localized stress in the quartz substrate

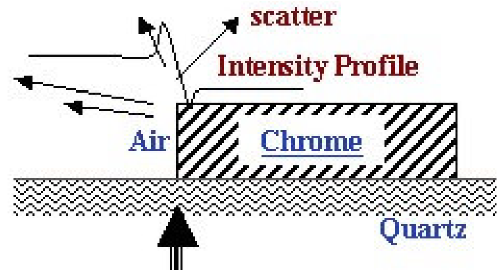

Figure 4: The influence of scatter and finite-chrome thickness on a wavefront.

The wavefront resulting from passage near a haze-area will be a convolution of the intensity profile across the hazed area PLUS the chrome edge, figure 5. The scatter added by the chrome edge, haze edge and internal haze phase boundaries, themselves exhibiting acrylic crystalline transitions, influence image intensity profiles of features as far distant as two or more microns. The translucent haze-area interacts as a micro-lens and will introduce refractive aberrations and diffraction that further interfere adding perturbations to the image wavefront.

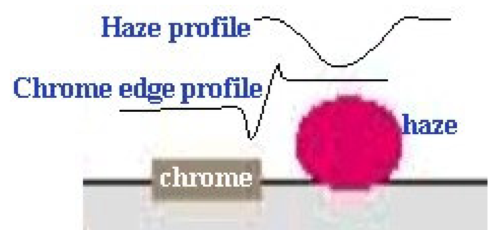

Figure 5: Haze initiation near a reticle feature edge.

3.4 Chrome-obscured haze

Chrome is not a complete obscuration of the wavefront. It's complex index of refraction results in a portion of the electromagnetic wave that penetrates the thin film and interacts with the overall image formation. Chrome is therefore mildly translucent even at deep-UV illumination since the wavefront amplitude and phase immediately above the chrome surface is not zero. A haze element will react with the chrome causing thinning, cracking and other localized physical reactions. Scatter from other parts of the imaging layer will interact with this wavefront and also be gathered by the lenticular behavior of the translucent haze. This results in localized aberrations of near feature-edge images not directly involved with the haze seed.

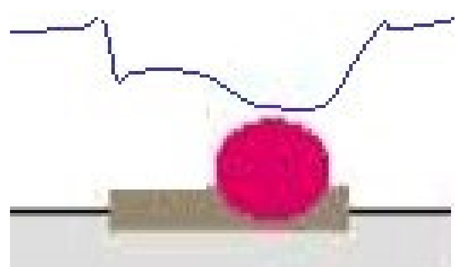

Figure 6: Intensity profile of small haze deposition on top of chrome feature

In summary, haze formation is a process phenomenon that initiates on high-energy areas of the reticle and influences regions of the aerial image significantly greater than the actual physical area of the contaminant. While the most widely recognized response associated with reticle-haze is a requirement to increase exposure-dose in order to restore proper feature size, the influence and degradation of the reticle image begins at a much earlier timeframe.

Early haze formation does not have to be intimately associated with a feature edge to influence overall image quality. Early seed-formation results in isolated haze segments that act as "micro-lens" or scatter elements placed directly on the object surface of the lens system. Even haze formation located directly on a chrome surface can influence the overall flare and dark-image formation of the optical train.

During image formation, the photomask-object is converted to a frequency spectrum at the entrance pupil of the lens. Scatter and aberrations from haze perturb this spectrum and also change the influence of the inherent lens aberrations on the image. The overall effect results in large-area image degradation. Since all lenses retain finite coma and spherical aberration as balanced aberrations tuned to the ideal photomask image, the optimized-tuning of the lens rapidly degrades over the entire image area.

Early haze formation results in an aberrational influence on the wavefront that negatively influences the shape and size of the individually affected features an in-turn results in a loss of contrast or profile slope as well as feature size. The feature-image also is further degraded by a corresponding response loss to defocus and substrate characteristics. As shown in the picture of figure 7, this degradation results in asymmetric response and degradation of the feature's Best Focus, Depth of Focus and the Exposure Latitude as wafers are exposed to normal production sequence variation. Normal process-space variation will therefore result in a direct loss of lithographic yields, an increase in rework rates and an ultimate loss in overall final-test yield long before the more extreme effects of dose-sensitive reticle-haze are observed.

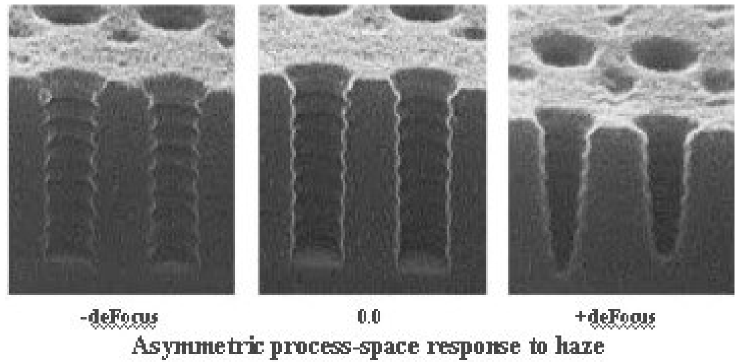

Figure 7: Haze response to defocus on a via mask

4. EXPERIMENTAL SETUP FOR RETICLE HAZE DETECTION

Haze Detection is reticle-specific and must be setup using the standard product reticle in question. The reticle is exposed onto a normal focus-dose (FEM) matrix wafer, the metrology data taken from which can also be used to setup and validate the current process window settings. The analyses performed for the normal critical dimension (CD) process window response on this matrix are not sufficient for haze detection since the phenomenon is more profile than feature-width sensitive and multiple feature-sites on the reticle must be tested. To detect the presence of early haze levels or lens surface contamination the data must be measured and analyzed as a dose-uniformity analysis, this technique was first described in an earlier paper by the author.[4]

Depending upon the cause of reticle haze formation, haze can form on arbitrary sections of the reticle as shown in figure 2. This does not mean that, as in an image-direct analysis, all sites on the reticle must be measured. Haze formation is not confined to only a single line or reticle site. Haze is a process phenomenon that will build up over areas of the reticle and at differing local rates. The difficulty in detection is that haze build-up is gradual so unless it is continuously monitored OR compared against a dose-uniformity standard it's influence cannot be seen until the effects of the dose-reduction are great enough to significantly influence process yields or the overall feature ACLV population.

Weir PW software from TEA Systems was used for haze-modeling of the process window and dose-uniformity in the following analyses. Commercial ellipsometric optical critical dimension (OCD) tool from Nanometrics as well as an Hitach CD-SEM were used for CD and profile response in the focus-dose matrices performed on an ASML DUV scanner.

A typical Process Window analysis that can be employed for haze detection uses Optical Critical Dimension (OCD) or CD-SEM Metrology to measure a total of nine (9) sites on the reticle and fifteen (15) exposures on the focus-dose matrix wafer for a total of 135 measurements.

A CD SEM is the slowest and least appropriate for haze detection tool since it measures a small area on a single feature profile. A scatterometer or ellipsometer (i.e. OCD tool) is preferred since it measures a target that consists of a 50x50 micron square area of lines and spaces for each measurement. The probability of finding the early onset of haze with an OCD tool is thus greater because of the tool's area-averaging technology and diffraction sensitivity. The OCD tool is also faster than a CD-SEM since it measures at about 3 seconds per site with no vacuum pumpdown. So fullt-test metrology on an OCD tool requires (135 * 3 = 405) seconds = 6 to 10 minutes. The Weir PW analysis requires less than 2 additional minutes for data acquisition and analysis.

4.1 Test Wafer and Metrology Layout

The exposures on the test wafer should be performed using the same layout and recipe used for a process window analysis. Expose a focus-dose matrix of fields that cover the depth-of-focus and exposure latitude of the tool and process.

Metrology on the wafer can be performed using any metrology tool. An OCD tool is more effective since the area measured by the tool averages over the 50 micron square area of the target CD.

Unlike a process-window analysis, more than one site per exposure field must be measured in order to insure measurement in any area of the reticle susceptible to haze formation. We recommended a minimum of nine sites on the reticle, more measurements will add metrology time but they also increase accuracy and the probability of early haze detection. Ideally the minimal analysis should measure a 3 x 3 array with sites positioned on each exposure field similar to:

X	**X**	**X**
X	**X**	**X**
X	**X**	**X**

- Do not set all measurement sites around the edges or just in one corner.
- Exact placement is not critical but the metrology should sample near the field center and on the edges.
- If only **one site** on the reticle is measured, then the analysis cannot model dose uniformity across the whole area and detection accuracy will be diminished..
- If only the **edges** of the reticle are measured, then the analysis may miss haze that initiates on the center of the reticle.
- If only **one corner** is measured, then the model cannot assume the other corners will also respond the same so early detection will be reduced.

With nine-points as a minimum set of points on the reticle, the model can accurately determine if haze occurs between the points in each of the six regions of the reticle.

As the number of measurement sites increase, the confidence level in finding haze earlier in the cycle will increase. Even with only four points measured on the corners, this method will find haze before direct-inspection, light-scattering methods on the reticle because the technique directly measures the reticle feature image as influenced by the entire optical train and it's aberrations.

4.2 Influence of Sample-Size on Dose-Mapping Accuracy

The influence of sample-size is graphically shown in figure 8. This is a reticle exhibiting haze formation on the top and bottom edges resulting from cleaning depositions.

The left-plot shows the measurement location of 20 measured sites on the field with the corresponding dose-uniformity contour directly below it.

The center plots have reduced and offset the metrology sites. Even with only nine points measured on the exposure field, dose nonuniformity is clearly seen.

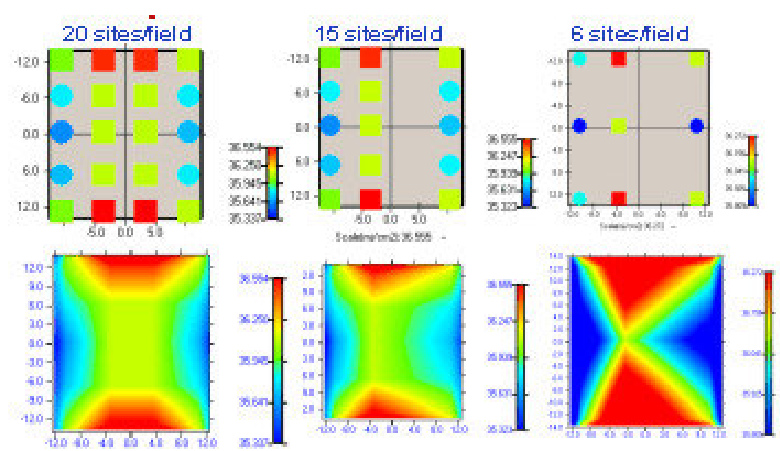

Figure 8: Hazed-reticle dose uniformity calculated at 20, 15 and 9 metrology sites per field.

5. DETECTION OF RETICLE HAZE

Reticle Haze deposition can be symmetric around the edges of a reticle or asymmetric radiating from a single edge of the plate as shown in figure 2.

- Radial-oriented signatures are typically exposure or process induced formations.
- Reticle cleaning operations tend to form edge-preferred orientations
- Equipment sources from contamination or damage to the reticle can initiate haze at random, scatter locations that cover a wide range of the plate's surface.

Testing for haze does not require an inspection of the entire plate. Haze will influence the across-reticle distributions of CD uniformity, Depth-of-Focus, IsoFocal Dose and Exposure-Dose uniformity. Of these variables, the Exposure-Dose needed to achieve a target-CD value will be the most sensitive indicator of early haze formation. Monitoring IsoFocal Dose characteristics for every site will also exhibit early haze sensitivity.

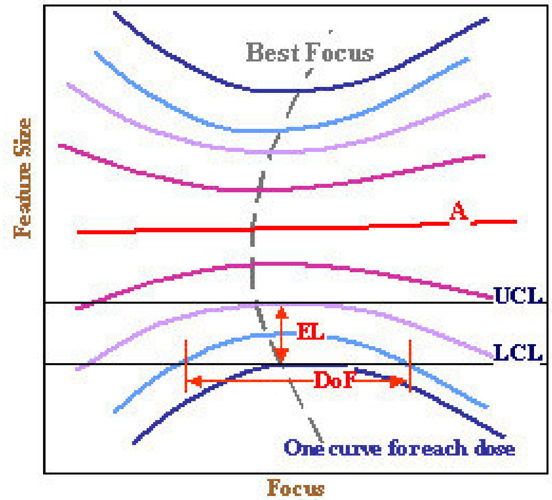

Figure 9: Schematic of Bossung Curve Response

The presence of Haze over any reticle feature-site can be seen through a Bossung analysis of the data, an idealized schematic of which is shown in figure 9[3]. As the exposure-dose moves away from the IsoFocal dose of curve "A", the influence of the exposure tool's focus setting has an increased influence on feature size. Feature size-change with focus is minimized at the 2nd order extremity of each dose-curve, shown in the figure as the "Best Focus" Curve.

An ideal exposure tool lens without aberrations will exhibit a "Best Focus" curve that is linear and orthogonal to the abscissa. That is, the value of best focus is unchanging with dose.

The presence of aberrations in the lens systems forces asymmetric response of the dose curves about the best focus point with a concurrent bending of the Best Focus response curve as exemplified in the illustration of the figure.

Weir PW performs the Bossung Analysis of figure 9 on every site located on the reticle field. Sites whose response curves are influenced by haze will suffer degraded feature profiles at the earliest stages. As an illustration, the plot of figure 10 shows the response of four sites on a hazed reticle to variations in exposure-dose. In this plot each feature's edge-slope response to variations in dose was measured on an OCD tool using a reticle that experienced a level of reticle-haze formation as shown on the inset. Profile-slope curves for four reticle sites, shown as sites "A thru "D", are then plotted.

Notice how the haze-influenced sites, curves A and D, lose response sensitivity and cannot achieve the higher slope, or feature contrast, values while the field-center slopes are not strongly influenced. The optimal first-order response of feature size to dose is stronger for the non-aberrated features in the center of the plate, B & C, while the hazed-feature response changes drastically and non-linearly.

As discussed in the previous section, the response of the feature will be influenced by the proximity of adjacent features in the area as well as by the increased absorption of the local hazing thereby even more strongly impacting the performance of enhanced reticle designs such as optical proximity correction.

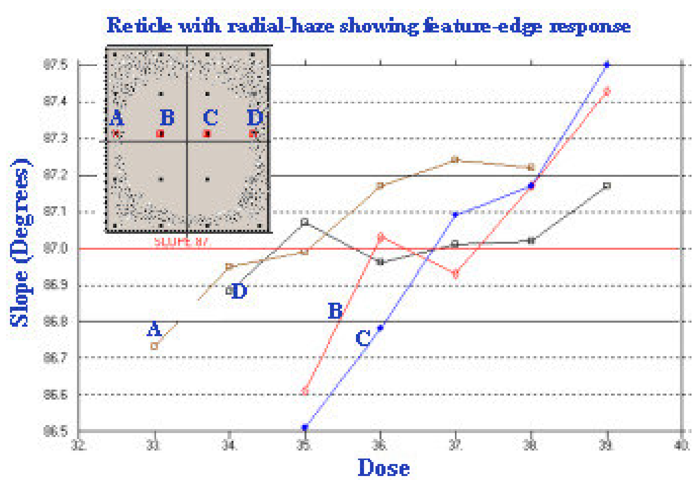

Figure 10: Profile edge-slope for four points on a hazed reticle

The strong interaction of reticle haze with the aberrations of the lens system of the exposure tools provides an opportunity to detect the presence of reticle haze very early in the deposition cycle. To detect reticle haze, expose the product reticle using a Focus-Dose matrix (FEM) setup in the same format as one used for a classic "Process Window" analysis. The metrology differs from the classic analysis in that more than one site is measured on each exposure field. The sites measured should include a regular area covering as much area of the reticle as possible particularly around the edges with at least one site near the center of the exposure field.

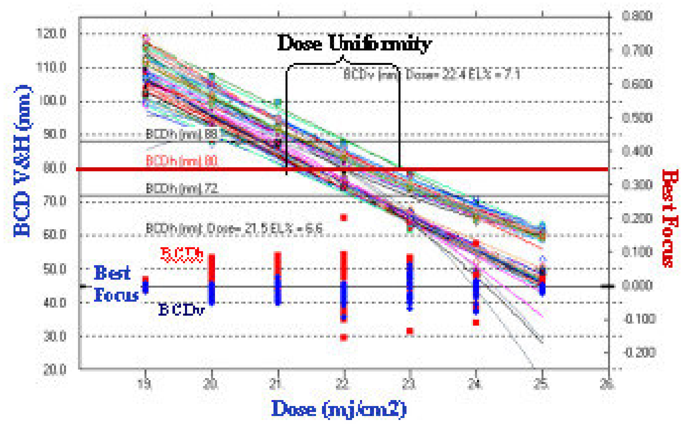

Figure 11: Dose Uniformity plot for a reticle with defocus removal of feature perturbations

A Weir PW analysis of the FEM data will yield the dose uniformity by calculating a Bossung-curve analysis of the response of each site to focus and dose as shown in figure 11. The feature size, in this case Bottom Critical Dimension (BCD) values for **V**ertical and **H**orizontal oriented features, are plotted against the Exposure-Dose. This curve differs from a common Bossung Analysis in that the across-field focus errors must be removed from the data to yield a more accurate analysis of reticle-to-wafer response[3].

The data points marked "Best Focus" on the bottom of the graph illustrate the optimal focus for each site at the exposure dose and their values are plotted against the ordinate axis on the right side of the abscissa. Weir PW then saves a Dose Report in the data workbook that details the calculated Dose, Focus and Exposure Latitude that will be experienced by each site when the feature is at the target feature size at each process.

Summary of Dose Response for Max Dose Latitude by Site					
		Best	Best	Dose	Dose
Feature	Site	Dose	Focus	Latitude	%Latitude
BCDv(nm)	1.0000	35.0000	-0.0270	1.9210	4.3000
BCDh(nm)	1.0000	28.4000	-0.0290	1.9210	4.3000
BCDv(nm)	2.0000	31.0000	-0.0310	1.9210	4.3000
BCDh(nm)	2.0000	28.5000	-0.0510	1.9210	4.3000
BCDv(nm)	3.0000	28.6000	-0.0470	1.9210	4.3000
BCDh(nm)	3.0000	27.5000	-0.0480	1.9210	4.3000
BCDv(nm)	4.0000	28.3000	-0.0530	1.9210	4.3000

The target feature size can be either the process specification or the projected feature size at the IsoFocal Dose.

5.1 Dose Uniformity Contour with/ without Haze

The contour plots of dose uniformity shown in figure 12 illustrate reticle dose response after haze has formed on the reticle (left contour) and after reticle cleaning (right image). The hazed-reticle image on the left contour has been obtained from a reticle-cleaning system that has deposited haze across the center of the plate requiring an average increase of 2.6 mj/cm2 exposure to achieve final image size. The right size depicts normal operation after haze removal.

These plots are not the uniformity of exposure dose as supplied by the scanner light-source but rather the dose-energy map that must be exposed on each portion of the reticle in order to achieve an on-target feature size. The responses therefore include the non-uniformity due systematic reticle feature-size variation as well as the scanner source and any reticle-absorption or scattering influence.

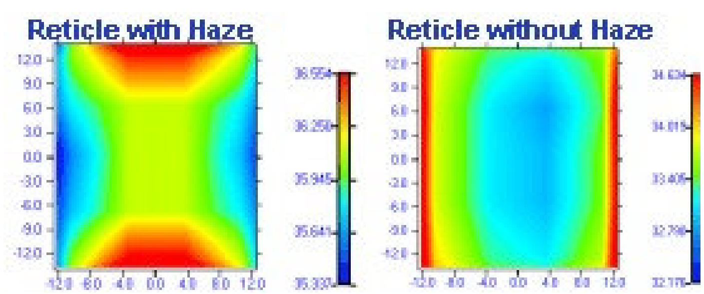

Figure 12: Dose uniformity for a reticle with (left) and without (right) haze contamination.

The haze-free reticle image on the right of the figure shows an exposure that requires a lower dose to achieve target feature size than the hazed reticle on the left. This field also exhibits greater uniformity of the center-scan area with higher field-edge requirements; a characteristic exposure contour for a scanner. The response of the haze-free reticle on the right is typical for a scanner and the loss of exposure on the left and right sides of the reticle are an artifact of the intensity profile of the scanner lens-slit. The vertical uniformity of the exposure is an artifact of the scan of the slit up or down the field by the reticle-stage during exposure.

As a commonly observed aside; high or low bands of dose-change at the top and bottom of the reticle would indicate non-optimal reticle scan-stage acceleration at the end or start of exposure resulting in a corresponding loss in feature uniformity at these reticle edges.

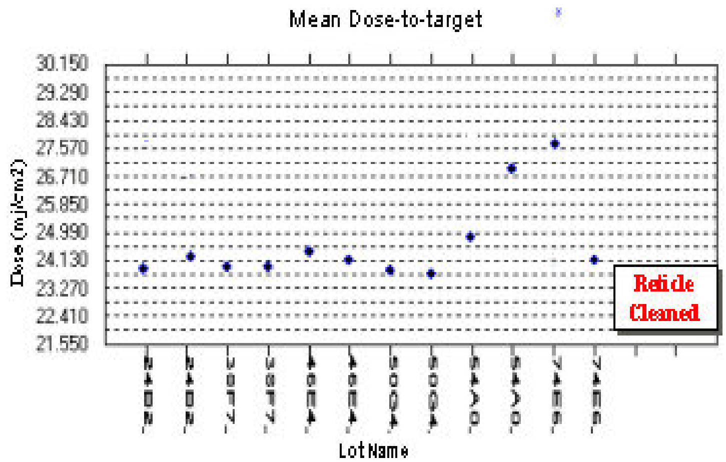

Figure 13: Trend-plot of the average dose required for feature uniformity on a reticle that exhibited hazing and was subsequently cleaned.

The hazed-reticle contour on the left of the figure exhibits significant haze attenuation at the top and bottom edges of the field as well as within the field center. This is not due to scanning but to reticle haze. The overall required dosage for proper feature size is also greater than the haze-free contour on the right. Cleaning of this reticle will result in the lower-exposure, more uniform response of the right-side image.

This methodology results in a highly accurate calculation of the reticle and optical system response as long as feature-response due to focus errors of the exposure-tool have been removed from the analysis. A small amount of haze formation on the reticle will change the required exposure-dose.

Haze detection is therefore noted as a change in the dose-uniformity contour with usage. Reticle usage on a specific process or exposure tool should be monitored on a recurring basis to trend either the required average dose or, with more sensitivity, the dose-uniformity range across the exposure. The onset of reticle haze or lens-film depositions will respond as a gradual increase in the required dose needed for proper feature-size and uniformity as shown in figure 13. This figure illustrates the onset, growth and correction of a hazed reticle. Haze removal will return the reticle exposure response to normal levels unless extensive plate damage has occurred from processing.

5.2 Validation of Dose Uniformity Method

The method of calculation of the required dose uniformity for a reticle-process workspace is critical to monitoring the early levels of reticle haze formation. To validate the concept we compared the calculate against direct measurement of the reticle's features and the inherent bias each feature exhibited when imaged on the wafer.

A recent study reported the results of the direct measurement of reticle feature sizes using an optical ellipsometer (OCD) metrology tool. The natural reticle-to-wafer bias of this reticle was then measured at the IsoFocal Dose and it's response was calculated by subtracting the size of each feature's adjusted measurement on the reticle from the Bottom Critical Dimension (BCD) value measured on a wafer exposed

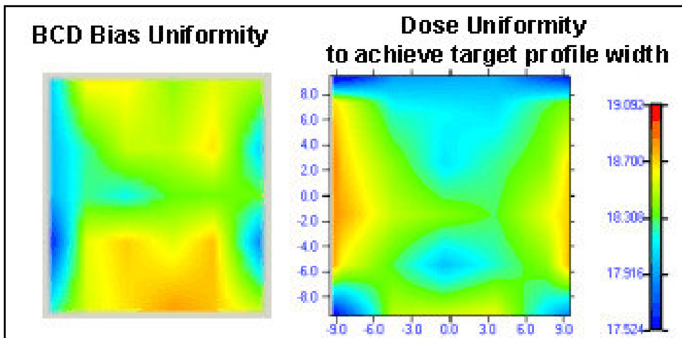

Figure 14: BCD Reticle-to-Wafer Bias Uniformity (left) compared with the Dose Uniformity needed to achieve the on-size feature target (right).

in a focus-dose matrix[5].

The reticle-to-wafer feature-bias contour plot is shown on the left-side of figure 14 and illustrates the natural bias uniformity across the exposed field at the IsoFocal Dose.

The contour plot on the right side of the figure is the calculated dose-uniformity needed to achieve a 70 nanometer (nm) target size on the same exposure tool and with the same reticle. This data was taken three months earlier than that of the left-plot using the same reticle but without knowledge of the actual reticle size measurements. The reticle and exposure-tool used for both datasets were identical.

The Bias Uniformity contour on the left of figure 14 is highly correlated to, but inversely related to the Dose Uniformity plot on the right side. That is, a high-bias point, i.e. oversize feature, on the reticle field correlates to a low-Dose requirement on the wafer as would be expected from the definition of each plot. This correlation is greater than 87% and presents independent confirmation of the validity of the Dose Uniformity calculation.

6. DETECTION OF RETICLE HAZE SUMMARY

Reticle haze results from the deposition of an Ammonium Sulfate film on the reticle surfaces that is chemically initiated by the chemicals and environments encountered by the reticle and their reaction to DUV illumination. Heavy levels of hazing behave similar to a neutral-density filter or absorber being placed within the optical train in that a noticeable increase in the exposure-dose necessary to achieve the proper feature size is required.

Since haze directly influences the optical response of the optics of the exposure tool. Even in the early stages of deposition its presence strongly degrades the quality of the overall lithographic imaging process. Significant process response degradation occurs long before noticeable increases in exposure-dose occur.

Reticle haze is a local-area phenomenon that initiates deposition in high-energy sites on the reticle rather than occurring uniformly across the photomask. This behavior means that it can be detected very early in the formation sequence as a change in the reticle-specific process dose-uniformity requirements of the photomask.

Metrology for haze detection requires a minimum of nine points on the field to be measured in a focus-dose matrix of exposures. More points per field will increase the accuracy and timeliness of haze discovery. Fewer points will suffice with an increased potential of detection occurring at a later stage of haze development.

A periodic monitor of the dose-uniformity requirement of each reticle in production allows reticle haze to be detected early in the contamination cycle and a cleaning of the reticle to be scheduled prior to any actual impact on production yields.

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