PHOTOMASK

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New type of haze formation on masks fabricated with Mo-Si blanks

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ABSTRACT

In our paper we make an analysis of conditions for the haze development on photomask fabricated on Mo-Si containing substrates. We bring in focus cases of haze formation on masks with intrinsically very low contaminants level and being exposed in very well controlled atmosphere. There are clear indications that this new type of haze formation deviates from the generally accepted models not only with respect to the formation mechanisms but also with regard to the chemical composition of the haze products. In our analysis we speculate that the new haze type formation is closely related to the earlier reported CD degradation observed on Mo-Si masks. We also analyze the hypothesis that the ingredients for the haze formation are not only airborne contaminants and/or traces on the mask surface, but are also provided by the substrate material. Finally we present and discuss experimental data in the view of the advanced models.

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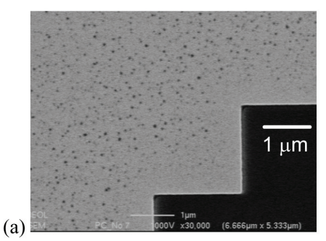

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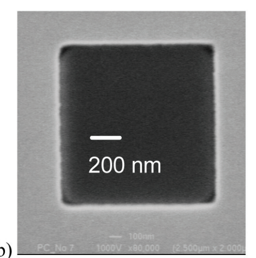

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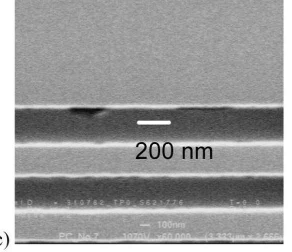

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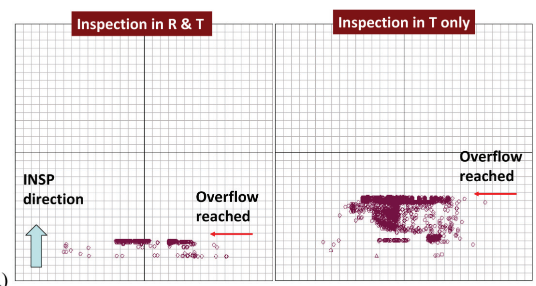

(d)

Figure 1. Haze can be found on top of MoSi material (a), but it also occurs on the structures' side walls: (b) contact hole with haze (c) haze occurring on the side wall of a line and space structure. Inspection maps of inspected masks with haze in R&T and in T only (d).

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EDITORIAL

Will Mask Writer Throughput Limit Optical Lithography?

By **Thomas B. Faure,** IBM Corp.

While the semiconductor industry waits for EUV lithography to be ready, as some expect, by 2015, optical lithography continues to try to meet the needs down to 15nm technology nodes. To be successful in this mission, more aggressive forms of computational lithography such as inverse lithography (ILT) and source mask optimization (SMO) are required. This will not only increase mask data volume, but it can lead to a dramatic increase in mask writer e-beam shot count that could cause mask print times of 48 hours or longer. This write time is not sustainable in a mask manufacturing environment which limits the use of ILT or SMO solutions to date.

Unfortunately, the lack of significant improvements in the core optical resolution of scanners makes techniques such as SMO and ILT a requirement for acceptable process windows at smaller feature sizes. Early industry assessments of the potential impact of SMO and ILT techniques on e-beam shot count indicated a 2x-10x increase in e-beam shot count versus traditional OPC. The 45 nm critical level masks have total shot counts ranging from 22-100 gigashots. It is expected that shot count numbers will increase to 180-200 gigashots for 32 nm masks without the application of ILT or SMO. As we approach 20 nm node, this number is likely to double again to 400 gigashots. But if we apply a 5x multiplier to shot count for SMO or ILT, we are facing shot counts of 2000 gigashots. Another factor that could aggravate this situation is a potential move to 4 pass e-beam print instead of the current 2 pass print, required for low sensitivity e-beam resists (high doses of 30-40 uC/cm2) which have lower LER (line edge roughness), better CD uniformity and pattern fidelity performance. Moving to four pass write would increase the total e-beam shot count and the mask write time by at least 2x.

The current e-beam tool manufacturers are offering some throughput relief in the form of higher current densities of up to 200 amps/cm2 which has the potential to reduce write times by 25-35% vs. the 70 amp/cm2 e-beam systems. But this change alone is not enough to allow the use of full SMO or ILT solutions required to extend optical lithography.

Additional methods to improve mask e-beam writer throughput will require coordination and cooperation of the entire industry. ILT and SMO algorithms will need to be optimized to take into account e-beam shot count to provide a more reasonable multiplication factor with respect to the shot count of traditional OPC solutions. Furthermore, improved methods of mask data fracture to minimize shot count need to be developed. One new approach called Model-Based Mask Data Prep shared at Photomask Japan 2010 Conference involves the use of overlapping shots to form images on the mask. This has the potential to dramatically reduce shot count and e-beam write time by 50%, but it requires industry support to technically validate and commercialize the approach. In addition, support for this and other new fracture approaches is required in OASIS and by the e-beam tool manufacturers. Development of a new multi-beam writer for mask making is also worth pursuing. Unfortunately, no multi-beam platforms for mask making are currently available, and industry funding will be needed. It is estimated that development of a production worthy multi-beam writer will take 3 years after funding is secured.

Lack of serious action will jeopardize the extension of optical lithography. Simply purchasing many additional e-beam writers to try to have reasonable mask write times will result in uncompetitive mask cost. Mask makers, equipment suppliers, mask data prep software vendors, ILT/SMO software companies, and semiconductor device manufacturers need to work together to develop solutions for optical lithography that we can all live with while we wait for EUV.

N • E • W • S

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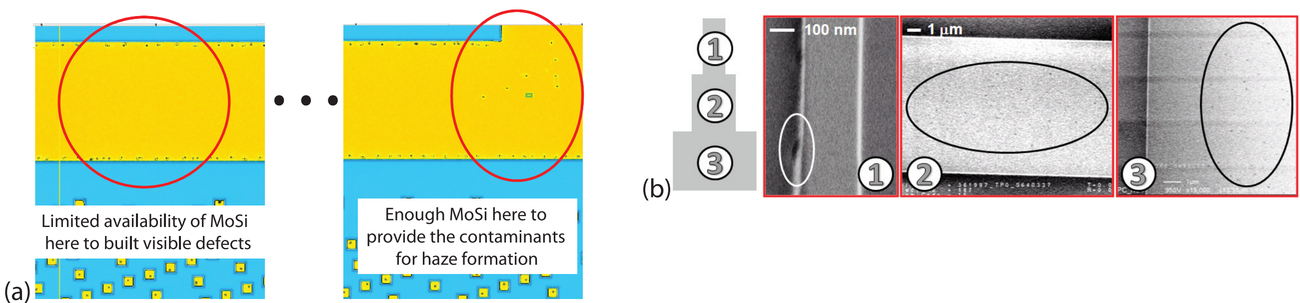

Figure 2. Visible haze defects on MoSi can be formed only if enough MoSi area is available. Bent structure where haze can be seen only where large MoSi area is present (a). Schematics of a structure which consists of MoSi blocks of different areas. SEM snapshots taken on the respective structure from areas with different MoSi coverage (b).

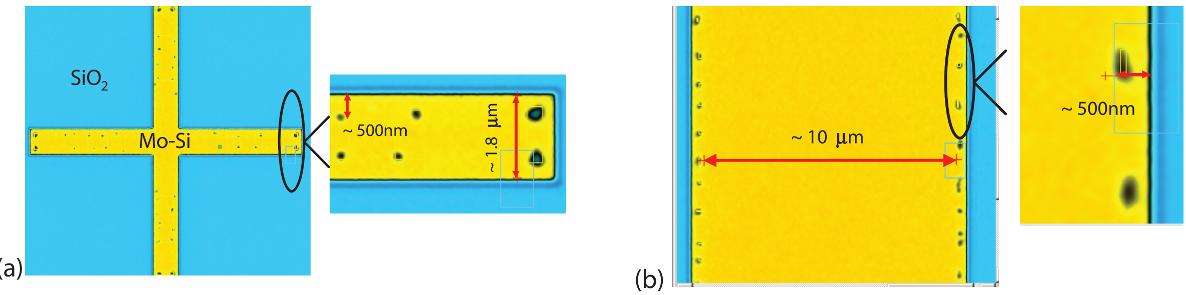

Figure 3. Haze occurrences at fixed distance from the feature edge: structure consisting of 1.8 µm line (a) is similarly affected as large bulky lines of 10 µm (b).

1. Introduction

Haze formation remains one of the main root causes for mask failure in the wafer fab. This is also one of the most investigated mask degradation topics (compare e.g. to the amount of reports on CD degradation of the masks). Despite considerable research and investigations conducted by industry and research laboratories the ultimate mechanisms of haze formation remain unclear. Different reaction chains were proposed which lead to haze formation.[1,2] In most of the cases, however, the argumentation is limited to the analysis of the possible spontaneous chemical reactions and their thermodynamical stability. It is only seldom that material related aspects are involved in the definition of the mechanisms for haze formation.[1, 3]

Although any kind of mask can be affected by haze, the most enticing haze formation mechanisms and properties are encountered on Mo-Si based materials (MoSi from now on) under the illumination with 193 nm light. This is not only because the radiation energy is high enough to promote all kind of interesting chemical and physical phenomena (e.g. O_2 or H_2 ionization, complex modes of surface diffusion), but also because typically the masks for this type of technology are very clean, i.e. exhibit a low amount of contaminants upon leaving the mask house.

In our paper we report on the inorganic haze formation which takes place under extremely clean conditions, i.e. low contamination level on the mask and in the wafer fab. We focus on MoSi based materials and masks illuminated with 193 nm light. Based on our detailed data analysis of the recent report we present a phenomenological analysis of the haze formation and also propose possible haze formation mechanisms.

2. Haze Description

The typical inorganic haze defects do usually show quite large structures, sometimes in the order of µm and very often with well defined crystallographic facets.[4] By contrast, the type of the haze we investigate in this paper exhibits defects which are usually very small – largest structures are < 300 nm, but most of them do show sizes in the range of 50 – 100 nm, see Figure 1. This type of haze occurs on 2 distinct places: top of MoSi material (see Figure 1a) and side walls of the structures (see Figure 1b-c). The defects seldom grow in size up to a few microns and they never build well defined crystallographic facets irrespective of their final size.

In general, when inspected with the maximum available sensitivity, the affected masks show a significant number of defects, which have no lithographic relevance when the reticle is printed: the inspection tool would trigger each defect spot, see Figure 1a. Hence with 100% sensitivity the inspection of the masks cannot be properly terminated and the tool reports an overflow after only a few inspected swaths. The inspection progress is dependent on the inspection mode though, (see Figure 1d). The magenta dots indicate defect distribution on the plate. If the mask is inspected in Transmission and Reflection mode then an overflow is encountered much earlier than if the mask is inspected in Transmission only, see Figure 1d. This is because the defects on the side walls are extremely small and often hidden by the structure itself or stretch along the feature with not so much growth into the clear (as shown in Figure 1c). It is important to mention though that very often the masks show haze on the structures sidewalls only and nothing can be found on the areas covered with MoSi. In such cases a typical starlight inspection will even not detect any haze defects and the mask will be reported as clean.

One can speculate that the clustering of very small defects, occurring on the side walls and top (where available), might lead to the formation of larger defects. In majority of the cases the defects occur only on the side walls of the structures or would have a varicella-like distribution on top of MoSi as shown in Figure 1a. If exposed to an energetic bombardment with electrons the defect will "evaporate" and completely disappear. We consider this as a confirmation of their aqueous state.

An interesting observation was made with respect to the position on the mask where haze0 is usually found. While there is no

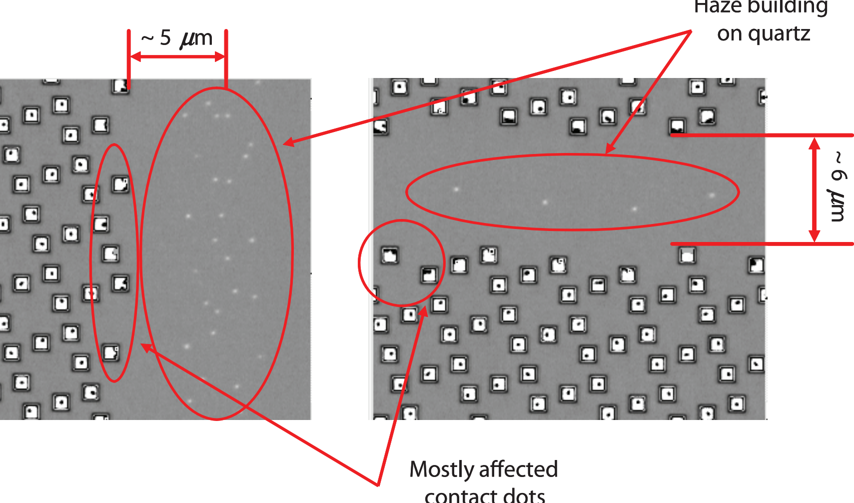

Figure 4. Haze on quartz (gray area with small whitish dots) and contact dots (large white square pads). (Haze on quartz is hardly visible in the printed versions) It can be hardly detected with SEM. Dots facing large quartz areas are heavily affected by haze.

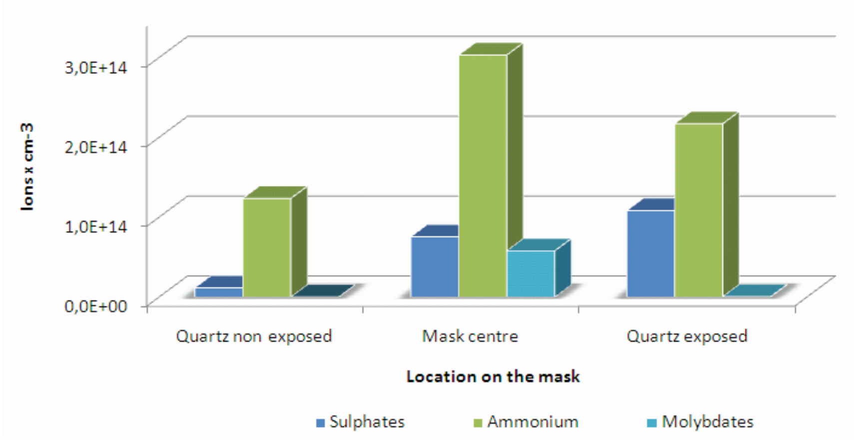

Figure 5. Main components detected on a mask which shows haze formation. Different areas on a mask are shown.

preferential structure type triggering the haze formation, its occurrence is found to be a direct function of MoSi coverage. This can be easily seen in Figure 2. It shows the schematics of a certain design features composed of three distinct blocks of increasing MoSi coverage. It can be seen that if the dark area is large enough one can find haze defects. The defect density will decrease once the MoSi coverage is reduced and there will be almost no haze product found for features which have small CD (e.g. below 1 um in Figure 2b SEM 1).

The SEM snapshot from the thin structure in Figure 3 shows no visible black dots on the top, but there can be clearly seen a defect at the features' side. Since the height of a structure is less than 70 nm while, in this particular case, the CD ~ 200 nm it can be easily concluded that haze occurrence on the features side is not only determined by the availability of the MoSi surface: this is an indication that the mechanisms of haze nucleation and growth on structures top and their side walls are distinct.

Figure 3 shows a very enticing property of the haze discussed here. While not easily found on each hazed masks, very often the haze occurs at a fixed distance from the feature edge. This typical range is ~ 500 nm and it stays constant on all features within an affected mask. Also this 500 nm scale is constant over the mask and from mask to mask. This edge haze can be barely visible in SEM pictures since 500 nm from the features edge is where the electron emission in SEM is highest and no contrasts can be distinguished. That is why it can be captured only in the inspection pictures as are the ones in Figure 3 made with NPI 5000 + inspection tool which proved to be exceptionally sensitive to this kind of defects.

Until now we focused on presenting haze defects on MoSi structures. Indeed in all cases the inspection tools trigger the defects only on the absorber or feature side walls. The small defects on quartz, if any at all, are invisible with SEM. However, after a detailed review of the defect images generated by the inspection tool, one could find cases when haze is visible on quartz as well. Figure 4 shows large quartz areas affected by haze. Note also that the contact dots will be differently attacked depending on their position with respect to the large quartz areas: the dots in immediate proximity will have large defects whereas dots which are far off the large quartz area will be less affected. The significance of this observation will be further elaborated in the discussion part.

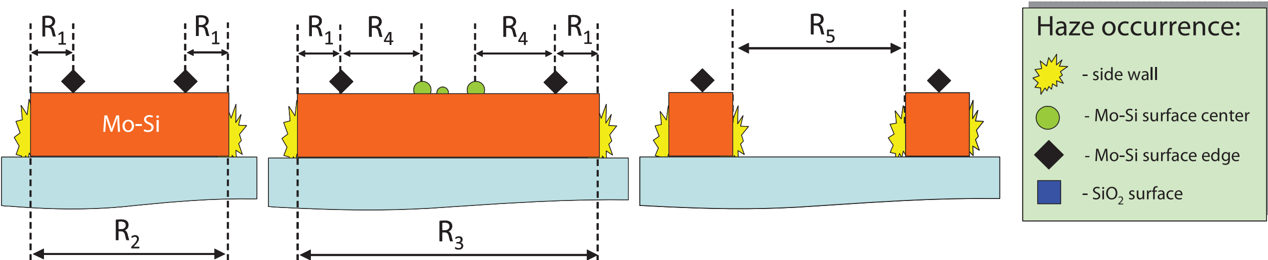

Figure 6. A schematics of where haze can be found on masks. The results are expressed in five length scales characteristic for the defects formation.

3. Material Analysis

Since most analytical tools have a spot size around 1 um a chemical compositional analysis of such defects is rather difficult. For large enough defects Raman spectroscopy proved to be successful and deliver good data. However for the defect size shown here the main problem is not even the analytical spot size, but that the defects cannot be located via standard alignment techniques and hence the spot cannot be directed on the structure to be analyzed.

Alternatively, especially for the case shown in Figure 1a one could analyze a large population of such defects and if a good signal to noise ratio is available an indication of the nature of the defects can be obtained. In such cases FTIR or Ion Chromatography can be used. The latter was applied in our case.

The used approach was local estimation of the ionic composition. Droplets of water were used to wash out different areas on mask with ulterior analysis for the ion composition. Thus we analyzed the ionic content of the pure quartz in the non exposed area, mask centre which encompasses solid features and clear and quartz only in the exposed area. The results are shown in Figure 5. Overall there is an increased level of ammonia which is higher in the illuminated area. A different picture can be observed for the sulphates: while very low in the non illuminated area their amount increases for the mask parts which are under exposure. Interestingly enough, the ammonium amounts less on quartz than on the centre of the mask, but an inverse trend is observed for the sulphates. This is a clear indication that the type of defects present on quartz are actually different (or at least can be treated so) than the centre of the mask (which is a mixture of MoSi and quartz).

The ionic analysis reveals a high concentration of molybdates detected in the mask centre. Compared to non exposed masks, their concentration was found to be a factor of 9 higher (data not shown here). Note that the presence of molybdates and their relation to haze formation saw a scarce treatment in the literature and hence most of the formation models omit their presence. In our discussion part we dedicate a detailed analysis of possible contribution of the molybdates to the haze formation.

4. Discussion

Summarizing the results one can conclude the following:

- Haze occurs at preferential sites on the mask: on MoSi area, on side walls of the structures and on large quartz areas;
- Defects larger than a few hundred nanometers form seldomly;
- Several length scales of haze occurrence could be identified;
- While always present on the structures side walls, the top of large MoSi structures or quartz areas are selectively affected;
- Defect analysis revealed that ammonium and sulphates show increased values in the exposed area, but an opposite trend is observed for the exposed mask or quartz only;
- Molybdates are detected.

Based on these facts we will try to elaborate on possible haze formation mechanisms below.

4. 1 Length scales and occurrences

Figure 6 summarizes the haze occurrence on MoSi films which could be observed on nearly all affected masks. Generally five length scales can be defined.

At the distance R_1 from the edge haze will be always found. On our masks this magnitude never exceeded 500 nm, but could be lower than this. At the same time this magnitude stayed constant within a mask. We think that this magnitude is electromagnetic field (i.e. illumination) related. The ingredients necessary for building this haze structure might have a similar source as the defects occurring on the side walls, since only these two types of defects are always found on the mask, even when no haze is detected in the open MoSi areas.

As already mentioned and confirmed by numerous images in the previous section, for the haze on large MoSi structures a critical amount of MoSi area is necessary in order to form defects which are detectable by inspection tools or SEM. One can only speculate that haze forms always, independent on the available MoSi amount, but it is simply not always large enough to be visible. The later may be true or not, but on structures smaller than a size range R_2 – no haze is detected (besides haze close to the edge and on the side walls) and if the structures are larger than R_2 – visible haze will always form. These magnitudes vary for different masks, but remain always constant within one mask. R_2 is usually in the range of micrometers.

A fourth magnitude is R_4 which we postulate to be a function of R_2 and R_3. It indicates a haze free zone on those structures which are large enough to provide conditions for haze formation. This magnitude is clearly visible in Figure 1a and Figure 2. It is also in µm range, usually below 5 µm, and can vary between the masks, but remains constant within one mask. It is tempting to consider R_4 field related. If this is true, possible justification for the haze free zones would be some surface waves destroying the haze defects. This would, however, imply that (i) no defects form at R_1 distance and (ii) this magnitude is constant for all affected masks. Both statements do not hold for our masks, which is an indication that fields do not play a role here. Instead, the existence of R_4 is an evidence of a critical amount of MoSi required in order to form visible defects; the surface availability toward feature end becomes scarce and hence no formation of defects is possible.

Haze formation on the side wall of the structures is an exciting phenomenon as well. First, it forms always and much faster than on any other mask location. No constrain to the amount of MoSi seems to be necessary. If the haze is only material promoted, then there is no explanation why micrometers of MoSi are required to form visible haze on the top of the structures and only a few nm (~ 70 nm thick are most of the MoSi layers) are enough for large and dense haze defects to be formed on the side walls and hence no photoeffects are expected. Second, assuming the light has a promoting effect (e.g. photochemical reaction) then the electromagnetic field intensity is actually lowest at the structures walls. The only remaining explanation is that haze on the side walls is

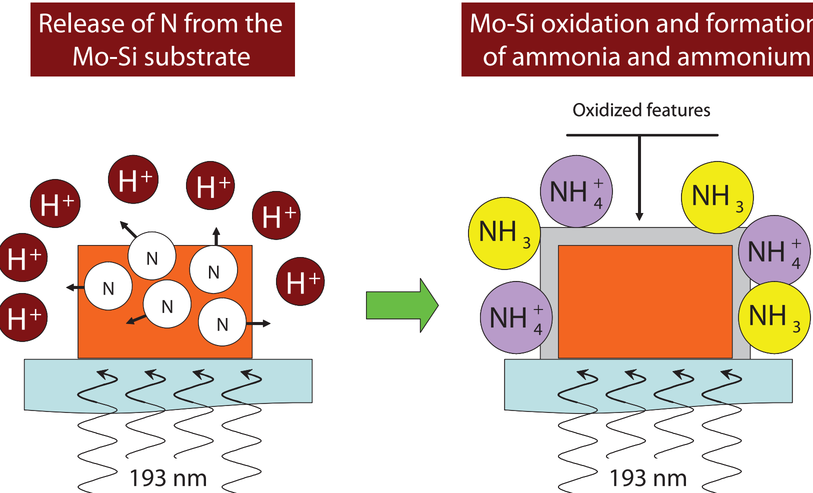

Figure 7. Alternative source of ammonium than air. Nitrogen release from the substrate, under extensive illumination with 193 nm.

always present because a large reservoir of contaminants is available and beneficial conditions favour defect growth.

Before elaborating on this hypothesis we would like to refer to the defects which are found on quartz. A detailed analysis, as for the defects on MoSi, is difficult since the defects on quartz are almost impossible to detect; the inspection tools will not trigger them. Nevertheless, it seems that another typical scale R_5 exists here too, which is the minimum amount of quartz needed for "visible" haze to be formed. From our images this scale is in micrometer range as well and is comparable to R_2. Still, obviously the structures which face different amount of quartz area are distinctly affected by haze too. A very fortunate example was shown in Figure 4 where contact dots are placed adjacent to quartz areas of different sizes: those dots which face large quartz areas are heavily affected by haze and it is clearly seen that dots facing reduced quartz areas are less affected. Again, the light might play a role, but it is most probably an indication that quartz participates directly in the supply of contaminants needed for haze building and this is independent where the defects finally occur: MoSi or quartz itself.

4.2 Reactants sources for haze

Interestingly enough, Figure 5 shows that ammonium concentration in the centre of the mask is considerably higher than on quartz (both exposed areas). This leads to the conclusion that the presence of MoSi favours the retention or catalytic reaction leading to NH_4^+ formation. The substrate itself can be envisioned as an additional source for these ions.

MoSi layers do usually contain a high amount of nitrogen. The ratio of this element in the bulk will strongly depend on the blank type. MoSi layers are usually non stoichiometric. It is expected that under illumination the nitrogen will be released from the substrate and will diffuse towards the surface. Also under the action of the illumination H_2 can be easily ionized (dissociation energy is ~ 4.5 eV which is well below the photon energy of the 193 nm). Nitrogen from the substrate and ionized hydrogen from the atmosphere will build ammonia and ammonium ions and most part of it will be found on the surface. The schematic of this process is represented in Figure 7. A similar mechanism was proposed by Yang et al.[5] In their paper the authors experimentally confirmed the loss of nitrogen from the MoSi layers. The authors in Ref. 5 claim the oxygen concentration on the absorber layer increases upon illumination, i.e. a feature oxidation will take place. Similar observation was made by Faure et al.[6] The authors showed TEM images of Xsections of MoSi features after long exposures. Indeed the features had a thick film of oxide which encapsulated the whole structure. All these facts confirm that MoSi layers are an important source of ammonia which directly contributes to the haze formation.

Detected sulphates can be found in a higher concentration on quartz than mask centre and non-illuminated quartz, as Figure 5 shows. Since the substrate cannot be considered a source for sulphates, these ions are provided by the environment.

The retention rate of ammonium and sulphates ions seems to be strongly dependent on the substrate. Indeed in Figure 5 it could be seen that the sulphate level is higher on the (non) illuminated quartz than the mask centre and the opposite holds for ammonium ions. If we assume the following relation between the areas:

$$\frac{\text{centre}}{A_{SiO_2}} = \frac{A_{MoSi} + A_{walls} + A_{clear}}{A_{SiO_2}} \quad (1)$$

where we consider that the contributors to the centre of the (structured) mask area are: MoSi features, their side walls and clears (i.e. quartz after MoSi etch) then one can easily conclude that the retention rate is not area determined, but correlates well with the substrate type. Taking Eq. 1 into account the following relation of the ions concentration can be obtained:

$$\begin{aligned} \left[SO_4^{2-}\right]_{SiO_2} &> \left[SO_4^{2-}\right]_{MoSi} \\ \left[NH_4^+\right]_{SiO_2} &< \left[NH_4^+\right]_{MoSi} \end{aligned} \quad (2)$$

A separate discussion must be dedicated to the presence of molybdates. Akutsu et al.[1] mentioned the presence of molybdates on hazed MoSi masks too. In their work several haze formation mechanisms leading to end products involving molybdates were proposed. While this is a relatively new subject we would like to address it in more detail.

4.3 Formation mechanisms

We start our reasoning from two premises: (i) masks are clean (or at least contaminants from mask manufacturing are not enough to build large defects) and (ii) the only sources of contaminants are mask substratea and the environment (storage, pellicle, etc.). Independent of the contaminants source the total amount of reactants is generally low and there should be an efficient surface migration mechanism which facilitates the formation of defects of detectable size. This is only possible in the presence of a water film on the

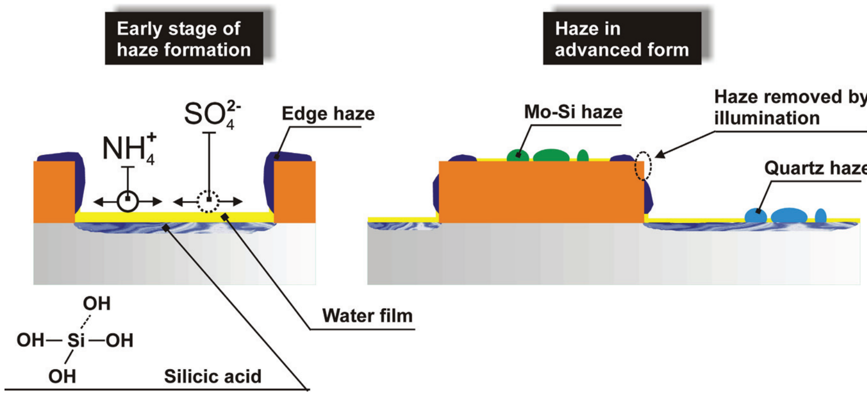

Figure 8. Stages of haze formation. In the early stage quartz is affected as well as sides of the features. Illumination plays a crucial role in re-arranging the defects on the mask. (Layers, structures and ions are not at true scale; only schematic representation to guide the reader!)

mask which in turn is possible in humid environments. The water presence is mirrored in the morphology of the haze products too: they are destroyed during illumination, i.e. their nature is aqueous.

Figure 8 depicts what we think the haze formation path is. We distinguish 2 main phases: early and advanced stage of haze growth. Kishkovich et al.[2] proposed that SiO_2 is transformed into silicic acid upon cleaning during mask manufacturing. In the early stage this silicic acid plays a crucial role in attracting and trapping ammonium and sulphates from the atmosphere. Enhanced by humidity the surface migration of these contaminants and their consumption in reactions leading to formation of ammonium sulphates is easily possible.

In the early stage haze will form on quartz and features side walls including migration to the features top. Vigorous illumination will however efficiently destroy the haze defects on quartz. Additionally the defects on the features will be also attacked. We think the analysis of the electromagnetic (EM) near field intensity distribution in illuminated structures has to be considered in order to explain final distribution of the haze on the structures. Indeed for specific polarizations and incident angles, the EM field components are all zero at metallic interfaces and hence the EM field intensity is low at the side walls, see [7] pages 553-587. The opposite holds for sharp features: EM intensity increases drastically there. This is a potential explanation for the fact that haze at the sidewalls is not (or considerably less) affected compared to the corners where large EM field intensity destroys any type of existing haze. In this case a periodic distribution of the defects will follow: haze always present on the features side and on the features top (short before their edge), but never found on the sharp corners of the structures.

The migration of the contaminants from quartz is not able to explain the haze growth on MoSi, however. We think different mechanisms should be invoked. In the following section haze formation on MoSi will be discussed in conjunction with the presence of molybdates.

We consider the possibility that MoSi thin films are an important source of ammonium. In general the presence of ammonium on the film surface will stabilize the formation of molybdates, e.g. MoO_4^{2-}, $Mo_7O_{24}^{6-}$.[8] In our measurements we could detect up to 9 timeshigher concentration of MoO_4^{2-} on a hazed mask compared to a mask without haze. The role of molybdates can be viewed as follows: (i) they come from the oxidized MoSi features or (ii) are part of the haze defects. We analyze these possibilities in more details.

4.3.1 Molybdates: MoSi film oxidation only

An exact form of the oxide found on MoSi structures could not be identified (always too small).[6] It was generically named as MoSiON[5] which in any case will deliver a strong signal for molybdates if analyzed with Ion Chromatography. Since oxidation was related to the depletion of nitrogen which in turn leads to the formation of ammonium on MoSi surface, obviously the haze defects will be mainly ammonium sulphates with high water content. In this case there is no difference in haze composition between locations: on quartz, features side wall and edge. In this particular case one can speculate that the observed CD degradation (see [6] on MoSi materials is always followed by the haze formation.

4.3.2 Molybdates: part of the haze defects

In this case two possible mechanisms can be invoked: clustering of protonated (or not) molybdates or the formation of ammonia molybdates salts. The general equation of molybdates clustering is shown in Eq. 1. One can see that an acidic environment is required. In Eq. 1 p - amount of protons, q - amount of molybdate monomers. The number r indicates how many molybdates stick into a cluster. For the case when non protonated molybdates have to be treated $r=p/2$

$$pH^+ + qMoO_4^{2-} \leftrightarrow \left[H_{p-2r}Mo_qO_{4q-r}\right]^{(2q-p)-} + rH_2O \qquad (3)$$

The literature reports that clusters of $q=7$ ((p,q)=(8,7), (9,7), (10,7) or (11,7)) and $q=8$ ((p,q)=(12,8), (13,8)) exist and are thermodynamically stable.[9] Clusters can be also built if $q=12$, $q=18$ or $q=36$. The (local) acidic environment is expected to be caused by the formation of H_2SO_4 during the mask illumination.[10]

Alternatively the molybdates, as charged ions, can undergo ionic bonds with available ammonium. In this case we expect that a salt similar in structure to $nH_2O\bullet(NH_4)_2MoO_4$. Certainly this represents only a possible product in which case Molybdenum (VI) is involved. However, there are plenty of other molybdates types which could undergo the formation of such salts.[11] Again water (and hence humidity) is involved.

The exact role of illumination in the haze formation mechanism (not its distribution) remains unclear. It suffices to mention that haze could not be found in the large open MoSi areas or on features side walls or on quartz in non illuminated areas. At least to what haze formation on MoSi is concerned, due to partial (or complete) absorption of light in MoSi the heating of the absorber might play a role. The Tammann temperature of molybdenum oxides was reported to be around 250°C[12] at which enhanced migration

mechanisms on MoSiON surface would be expected. However, meaningful data about the temperature a mask reaches during the illumination are missing.

5. Conclusions

In our article we have analyzed a very enticing form of haze formation which takes place under extremely clean conditions: low ionic contamination on the mask and in the environment. Due to small sizes it was not possible to obtain a detailed material analysis of the haze defects. This leaves a plethora of open questions with respect to haze formation. Particularly the role of the detected molybdates is not clear, but it can be speculated that they are either an indication of early stage of classical haze formation or represent a new type of haze: clusters or salts.

Similarly to other authors we could confirm that water plays a crucial role: it is decisive in any surface diffusion mechanisms which proved to be essential for haze formation, but it also participates in any kind of haze products treated in this paper. The role of illumination in the haze formation mechanism was not analyzed. It might contribute to the substrate heating and hence migration mechanism related herewith.

Finally we tried to show that the race for reducing sulphates and ammonium on the mask surface might be counter-productive. As Nesladek et al. showed there exist numerous methods for contaminants reduction on the mask surface.[13] Each of these methods would work at the expense of strong mask surface modifications. Although showing low contaminants level on the masks while leaving the mask shop, their surface might be brought in such a state that later during the mask use the formation of haze is strongly promoted with airborne contaminants or supplied by the stack. The surface condition and material plays a crucial role in formation of small defects which are meanwhile easily detected by advanced inspection tools. In this particular case the amount of sulphates and ammonium might not be significant but rather the condition of the mask surface at the delivery from the mask shop.

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Industry Briefs

The potential explosion of e-beam shot count caused by ILT and SMO coupled with the normal increase in complexity at each node could make e-beam write times exceed 48 hours. Thus, there seems to be the need for the industry to work together on solutions to improve the situation. Fabtech, in a May 12 article reported on:

"Sematech mulling multi-beam mask writer effort": Mask write times are getting uncomfortably long, and a potential solution is to employ the multi-electron-beam approach for mask writers. Sematech CEO Dan Armbrust, in a keynote speech at the 2010 Sematech Litho Forum week, said the consortium may form a multi-beam mask writer program late this year.

At least six companies are developing multi-beam direct-write systems for maskless wafer patterning. One or more of those companies may attempt to direct their multi-beam capabilities to the mask writing space, with Vistec Electron Beam GmbH (Jena, Germany) expressing interest in joining the proposed multi-beam mask writer (MBMW) consortium. The two leading mask writer vendors, JEOL and Nuflare, both based in Japan, also may join the planned Sematech program. Other multi-beam direct write companies, such as Mapper Lithography NV (Delft, Netherlands) and IMS Nanofabrication AG (Vienna, Austria) have indicated that they will continue to focus on the opportunities in maskless lithography, or ML2, the Sematech manager said.

A related article delves deeper into the ML2 thrust: "E-Beam Lithography Seeks Investment Boost." With zero mask costs and the ability to create ultra-dense patterns, what's not to like about electron beam lithography?

Since there are lingering major concerns that the mask and source infrastructure for EUV lithography may be lagging, Direct-write e-beam (DWEB) is receiving continuing interest. Several companies are making serious direct write e-beam development efforts, and the technology is relatively mature and low-cost, so companies can create workable DWEB systems at far less cost than, say, EUV lithography.

Developing a low-throughput DWEB system is old hat: IBM and many other companies have used them for years to develop prototypes. The challenge is scaling up to the thousands of e-beams required to achieve high throughputs in semiconductor manufacturing factories. The fundamental challenge facing DWEB is data handling. Taking a full-field chip, 26 mm wide, and dividing the patterns by many thousands of e-beams, requires data path handling based on computational power and storage capabilities. TSMC's Burn Lin's argues, that DWEB will be aided by the very transistor scaling it will help support. "Compute power and storage is getting very cheap," Lin said.

Beginning at last year's SEMICON West and continuing at two lithography forums this year, Intel's Yan Borodovsky has been saying that DWEB might be used to delineate the ends of patterns created by high-throughput immersion scanners. By combining DWEB and 193i scanners, the industry could manage to continue Moore's Law scaling while the EUV scanners achieve the "affordable and available" criteria that Intel demands of its lithography tools.

Nanowerk News also reported that D2S™, an emerging design and software company, announced a partnership with fellow eBeam Initiative member JEOL Ltd. to provide a new mask data preparation (MDP) infrastructure that is optimized for JEOL's new mask writing system. As the semiconductor industry migrates to the 22-nm node, the depth of focus of the contacts and vias become a large issue. Curvilinear assist features on photomasks aid in producing higher depth of focus. In addition, circular main features as the contacts and vias, instead of squares, helps with critical dimension uniformity

Together, JEOL's system hardware and D2S DFEB mask technology will enable the use of circular main features and curvilinear assist features on advanced photomasks—essentially extending the use of optical lithography for 22-nanometer-and-below integrated circuit (IC) processing.

Together, photomasks with circular main features and curvilinear assist features can be shot efficiently. This allows masks of reasonable cost and yield to produce the best yielding wafers for the 22-nm logic node.

"This announcement is an example of how a fruitful partnership between design and manufacturing can advance the state of the art for mask-writing technology," stated Aki Fujimura, president and CEO of D2S. "To break down the barrier to using circles, it required both manufacturing and design working together."

BACUS' Photomask10 is devoting a full-day Special Session to the above topics on Wed, Sept 25th, in Monterey.

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About the BACUS Group

Founded in 1980 by a group of chrome blank users wanting a single voice to interact with suppliers, BACUS has grown to become the largest and most widely known forum for the exchange of technical information of interest to photomask and reticle makers. BACUS joined SPIE in January of 1991 to expand the exchange of information with mask makers around the world.

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Late submissions will be considered by Chairs.

2011

SPIE Advanced Lithography

27 February-4 March
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