Pellicle dimensions for high NA photomasks

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ABSTRACT

At photomask manufacturing, post pellicle inspection suffers from an interference of pellicle size and height dimensions with the inspection equipment requirements. This pellicle shadow causes non-reliable inspection results. The evolution of this effect as well as similar potentially upcoming effects during other lithography processes need to be understood in order to identify potential problems ahead of time and guide the industry accordingly. The study recommends standardizing pellicle size and height dimensions in order to coordinate the required changes at scanner, mask inspection, mask metrology and pellicle vendors in the near and long term. Since frequent changes in other pellicle properties are expected over time to fulfill the requirements for high NA lithography and haze reduction, a standard in pellicle dimensions will also help controlling the complexity of pellicle variations.

Keywords: pellicle, inspection, shadowing, pellicle height, pellicle size, high NA lithography, 193nm lithography

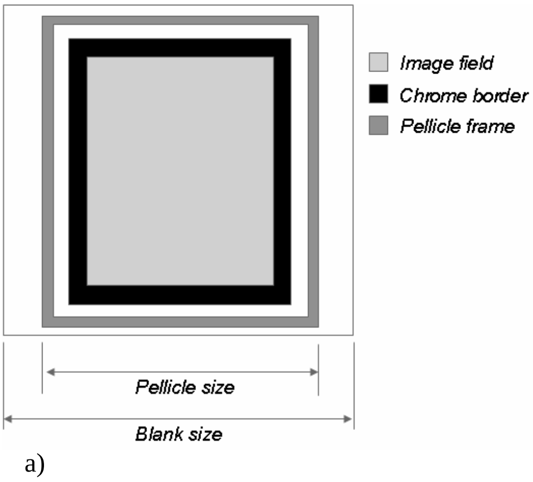
1. INTRODUCTION

With the extension of optical 193nm lithography by high NA immersion and double patterning techniques, the pellicle will remain an important part of the IC manufacturing chain for the foreseeable future. Requirements for future pellicles are investigated today, resulting in pellicle property specifications mainly to reduce registration distortion[1)] and transmission loss[2), 3)] at high NA exposure and to reduce the probability to support haze growth[4)].

Still, requirements for basic pellicle properties like size and height are mainly defined by the scanner tool requirements and are not standardized. As a result of those different scanner requirements and the above mentioned specifications, a variety of pellicles with different combinations of specifications and dimensions exists today. Some of these pellicles interfere with requirements coming from mask manufacturing equipment causing potential quality issues. Pellicle shadowing appears during mask through pellicle inspection in cases where pellicle size and height dimensions for a given image field size are not in line with mask inspection equipment requirements resulting in non-reliable inspection results in these areas. Evaluation of reduced pellicle height has started to eliminate the issue since changes in scanners and mask manufacturing equipment can earliest be expected with upcoming tool generations.

When choosing the optimum pellicle height, other influencing properties on pellicle shadowing and interactions with other properties should be considered for optimum solution. The optimum solution should be as robust as possible against future equipment changes and varying field sizes in order to reduce complexity and cost. Influences on other photomask and lithography properties as well as pellicle shadowing effects during other processes need to be considered.

This study is to present potential shadowing effects during scanner exposure, mask through pellicle inspection and mask through pellicle registration measurement and the resulting conclusions for future pellicle dimensions and equipment requirements.



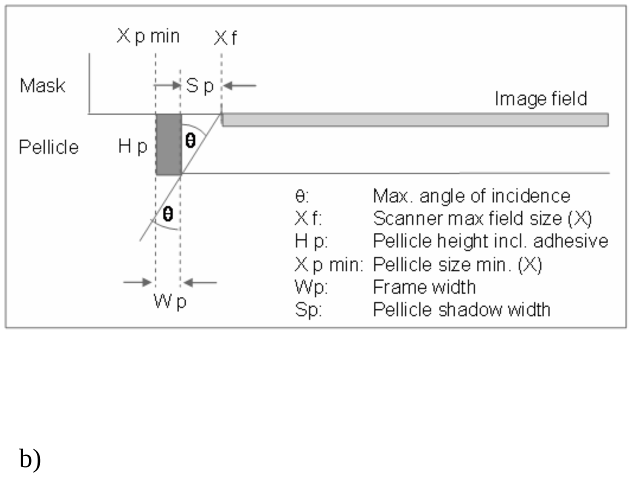
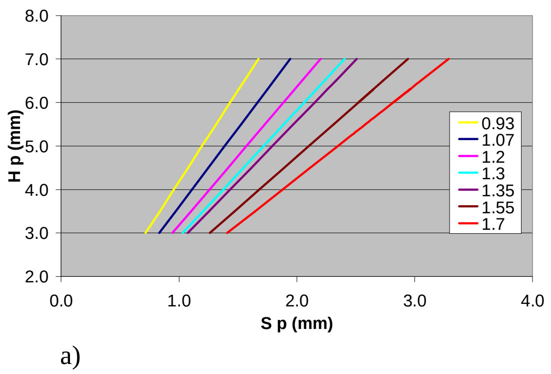


Fig. 1: a) Schematic of pelliclized mask (drawings not to scale) b) Pellicle shadow Sp and minimum pellicle size Xmin to avoid shadow and their main influencing parameters (Chrome border not shown)

2. PELLICLE SHADOWING

Any process that uses optical imaging of pelliclized photomasks can potentially suffer from pellicle shadowing affecting the image field of the mask. The range of this effect and the impact on the active image field respectively the minimum pellicle size to avoid impact on active image field for a given image field size mainly depends on the parameters as described in fig.1.

The maximum angle of incident light (θ) is defined by the numerical aperture (NA) of the imaging equipment. For a scanner exposure system with 4x magnification θ is defined by $\theta = \arcsin(NA/4)$. For an optical mask measurement system, θ is defined by $\theta = \arcsin(NA)$. Applying a pellicle of a certain height Hp, the resulting pellicle shadow is $Sp = Hp \times \tan\theta$. Fig. 2 shows the dimensions of pellicle shadow for exposure apertures between 0.93 and 1.7 NA and for optical mask measurement apertures between 0.5 and 0.9 NA in dependence of the pellicle height Hp.



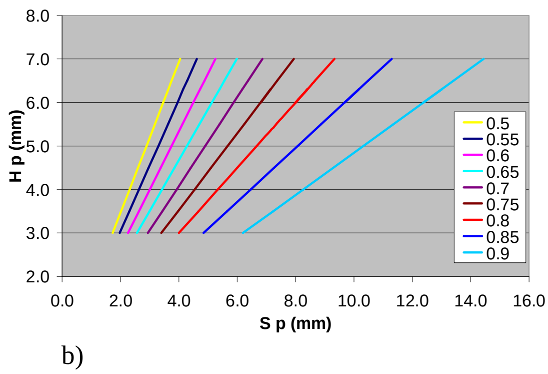


Fig. 2: Pellicle shadow during a) exposure, b) optical mask measurement for varying NA values

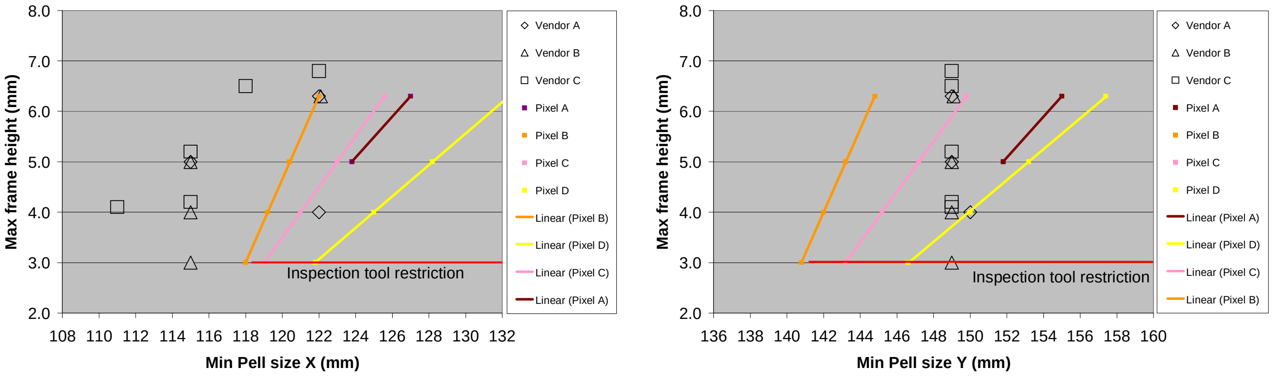
For typical NAs between 0.5 and 0.8 used in current optical mask measurement equipment, the resulting pellicle shadow is in the range of 1.7mm to 4.0mm for a pellicle height of 3mm and up to 3.5mm to almost 9.0mm for a pellicle height of 6.5mm.
For today's typical NAs between 0.93 and 1.35 of scanner generations, the resulting pellicle shadow is in the range of 0.7mm to 1.1mm for a pellicle height of 3mm and rises slightly to a range of 1.0mm to 1.4mm for a pellicle height of 6.5mm.
Current ArF pellicle height typically varies between 4.0mm to 6.8mm, 3.0mm is starting to be available.
As a result, optical mask measurement systems are much more sensitive to pellicle shadowing induced by pellicle height variations.

3. IMPACT ON IMAGE FIELD

The impact of the shadow on the active image field depends on the size of the pellicle Xp, Yp, the pellicle frame width Wp and the size of the image field Xf, Yf (see Fig.1 b). As mentioned above, pellicle sizes vary depending on the type of scanner that is intended to be used for a specific reticle. The pellicle frame width is currently fix at 2mm for all pellicles, whereas reduction is considered by the industry as possible solution (add bevel at top of frame). The image field varies by product, but maximum is standardized to 26mmx33mm for all scanner types. Additional contributor is the accuracy error of pellicle mounting with respect to the image field. Assuming a worst case of uncorrelated error contributors, this mounting accuracy can be described as $\sigma_{Mask} = \sigma_{PellM} + \sigma_{Centr} + \sigma_{Blank} / 2$, where σMask is the maximum Mask error, σBlank the maximum Blank size error, σCentr the maximum Centrality error and σPellM the maximum error of Pellicle Mounting. Assuming typical error contributors from current mask making equipment and blank vendors, this error can range up to ~1.1mm.
The resulting minimum pellicle size needed to avoid shadowing that affects the image field can be described as: $Xp\min = Xf + 2\times Sp + 2\times Wp + 2\times \sigma_{Mask}$ and $Yp\min = Yf + 2\times Sp + 2\times Wp + 2\times \sigma_{Mask}$.

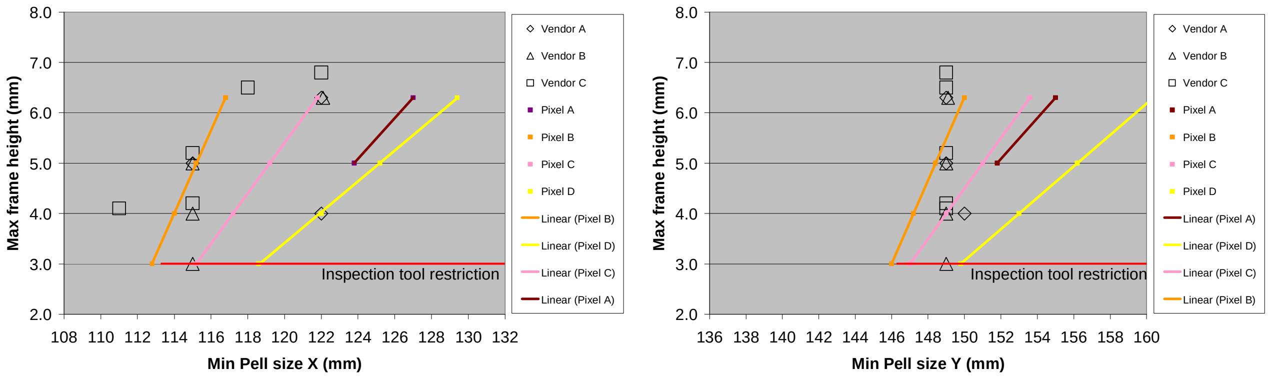
4. PELLICLE SHADOWING DURING POST PELLICLE INSPECTION

To study the impact of pellicle shadowing on the image field during mask post pellicle inspection, we have used the maximum possible image field of 26mmx33mm to represent the worst case assuming that IC manufacturers try to fully utilize these dimensions on their product. We have also assumed maximum error for σ_{Mask}. Instead of calculating the pellicle shadow Sp by the NA of the inspection equipment, the mask inspection vendors specify Sp by Pixel size in their equipment manuals. These values differ from the calculated values and are different in X and Y due to additional contributors coming mainly from the auto focus system of the tool. With these data, the minimum pellicle size needed to avoid shadowing within the image field is calculated and compared to a variety of currently used pellicles and their size and height dimensions. This is done for mask inspections in 0° (fig.3) and in 90° orientation (fig.4).



a) b)

Fig. 3: Minimum pellicle size in a) X and b) in Y depending on pellicle frame height for different mask inspection pixels at 0° mask inspection and current pellicle dimensions



a) b)

Fig. 4: Minimum pellicle size in a) X and b) in Y depending on pellicle frame height for different mask inspection pixels at 90° mask inspection and current pellicle dimensions

The comparisons show that most of the current pellicle dimensions are below the minimum pellicle size needed for a certain pellicle height at maximum image field depending on what pixel is used for inspection. For the most advanced pixel, none of the pellicles fulfills the minimum size either in X or in Y, therefore generating pellicle shadow into the image field of the customer if maximum field is used. The charts also show that currently there is a wide variety of pellicle sizes in X dimension existing, whereas the Y dimension is more or less fix at 149mm. Furthermore, a minimum pellicle height of 3mm is required for post pellicle inspection driven by the pellicle detection sensors of the tools, as well as a maximum pellicle size of 149,6mm in Y (129.0mm in X) (not shown in graphs) due to the loading mechanics of the tools.
As a conclusion, the only working point for pellicle dimensions for all of the current pixels in use allowing maximum image field sizes of 26mmx33mm without generating pellicle shadowing is 122x149x3mm (Xp, Yp, Hp) at 0° mask inspection (at 90° inspection, Yp is borderline for the most advanced pixel).

Reaching those dimensions in order to eliminate the problem of pellicle shadowing with current equipment is not easily possible. Pellicle size dimensions are restricted by the type and therefore design of scanners and to go to larger sizes would require changes in the scanner reticle system. Reducing the offset between mask inspection requirements for shadowing zones and the theoretical limits defined by the NA of the tool would require significant changes to the mask inspection system. The mask error has only limited potential for improvement and the resulting decrease in shadow would be small, but any improvement would require involvement of equipment as well as blank vendors. Reducing frame width or adding a bevel to the top of the frame to reduce width on the top only would be a challenging change to pellicle vendors and potentially the pellicle mounting processes. Customers have focused on reaching the required pellicle height to reduce the problem. Changes in pellicle height on the other hand may require changes at the pellicle vendors manufacturing, mask manufacturing or scanner equipment. Reducing pellicle height may also require simultaneous changes in other properties that are interacting with changes in height. So, in order to implement only as many changes as necessary to avoid further complexity especially considering the combinations with other pellicle properties including high NA and therefore to judge, if the change to the above working point is robust enough, it is necessary to understand the needs cc. pellicle height coming from other optical imaging processes and future equipment as well as the impacts of changes in pellicle height to other mask quality or lithography properties. Out of these inputs, the best working point can be defined.

Standardizing pellicle dimensions to a best working point would allow to jointly study the possibilities and impacts and align on solutions for the near and the long term that can be implemented in a synchronized way.

5. PELLICLE PROPERTIES AND INFLUENCE MATRIX

The pellicle shadowing problem during mask post pellicle inspection has shown that there is more than one influencing parameter. Currently, the approach to reduce the problem is to change the pellicle height.
As mentioned in section 2, any process, that uses optical imaging of pelliclized photomasks can potentially suffer from pellicle shadowing affecting the image field of the mask. So, processes like mask exposure and mask through pellicle registration measurement could be affected as well. Also, changing the height of the pellicle may have negative effect on other properties of the mask or the mask printing behavior. The matrix in fig.5 summarizes the main pellicle properties and their influence on lithography properties as well as lithography and mask making processes that influence those lithography properties.

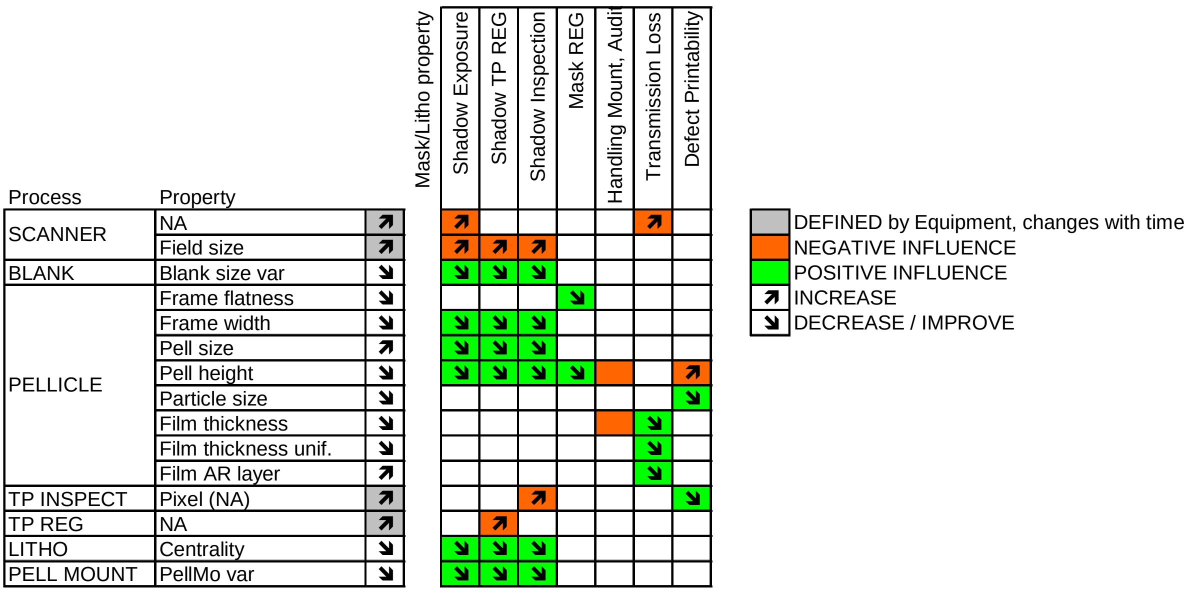
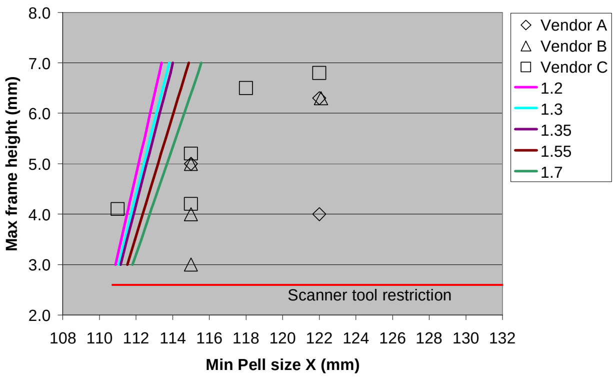


Fig. 5: Pellicle properties and influence matrix

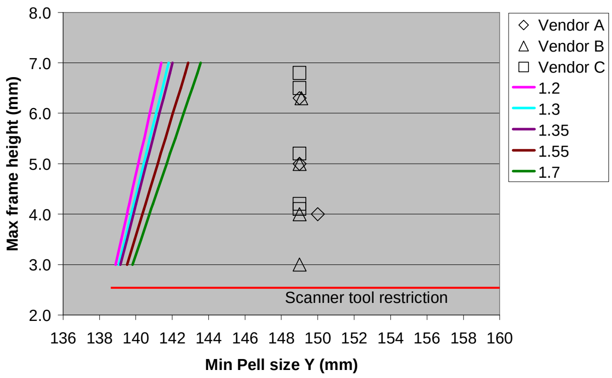
The influence parameters on pellicle shadowing during mask post pellicle inspection are described as discussed in section 1.-4. The dependencies are identical for the processes mask exposure and mask through pellicle registration measurement. It is obvious, that some of those parameters, which are defined by the equipment vendors, will change with new generations of equipment and therefore their contribution to pellicle shadowing as well as the required pellicle dimensions to eliminate the problem will change. When looking at the current approach to decrease pellicle height for reduced pellicle shadowing during inspection, it can be seen, that this generally has positive influence on mask through pellicle registration, but also negative influence on the robustness of the pellicle mounting process as well as on the defect printability of particles on the pellicle. In addition, interactions between the properties have to be considered. A change in pellicle height will require a change in the pellicle case and maybe also in the design of venting holes and filters which are needed for pressure equalization. To understand the optimum working point for pellicle dimensions for all processes and for future tool generations, we first studied the pellicle shadowing effect during mask exposure and during mask through pellicle registration measurement.

6. PELLICLE SHADOWING DURING EXPOSURE

When looking into the impact of pellicle shadowing on the image field during mask exposure, we again have used the maximum possible image field of 26mmx33mm and a maximum error for σ_{Mask} as in section 4. For calculation of the pellicle shadow Sp we have used NAs ranging from 0.93 up to 1.7 to cover future potential scanner NAs. With these data, the minimum pellicle size needed to avoid shadowing within the image field is calculated and compared to the currently used pellicles and their size and height dimensions. Fig. 6 shows the minimum pellicle size to avoid shadowing in dependence of pellicle frame height for different scanner NAs and current pellicle dimensions.



a)



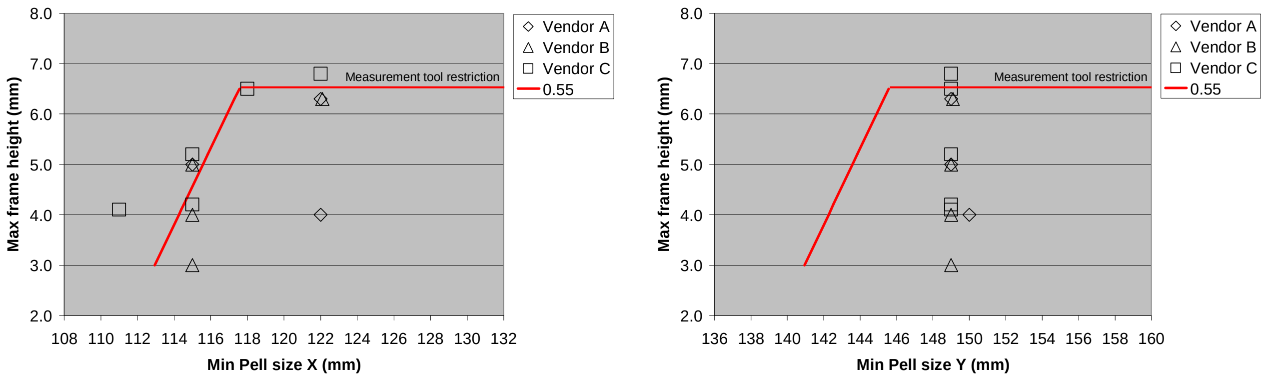
b)

Fig. 6: Minimum pellicle size in a) X and b) in Y for different scanner NAs and current pellicle dimensions

As a result, almost all (for all Xp>=115mm) of the current pellicle dimensions are above the minimum pellicle size needed for a certain pellicle height at maximum image field for all NAs up to even 1.7. Like with mask inspection equipment, also the scanner tools have specified a minimum pellicle height due to their detection sensors that does not allow pellicle heights below 2.5mm.
As a conclusion, there is no pellicle shadowing issue expected during exposure even up to scanner NAs up to 1.7 at maximum image field size.

7. PELLICLE SHADOWING DURING THROUGH PELL REGISTRATION

The impact of pellicle shadowing on the image field during mask through pellicle registration measurement is derived using the same assumptions and method as in section 6., for calculation of the pellicle shadow Sp we have used NAs of 0.55. Fig. 7 shows the minimum pellicle size to avoid shadowing in dependence of pellicle frame height for a NA of 0.55 and current pellicle dimensions.



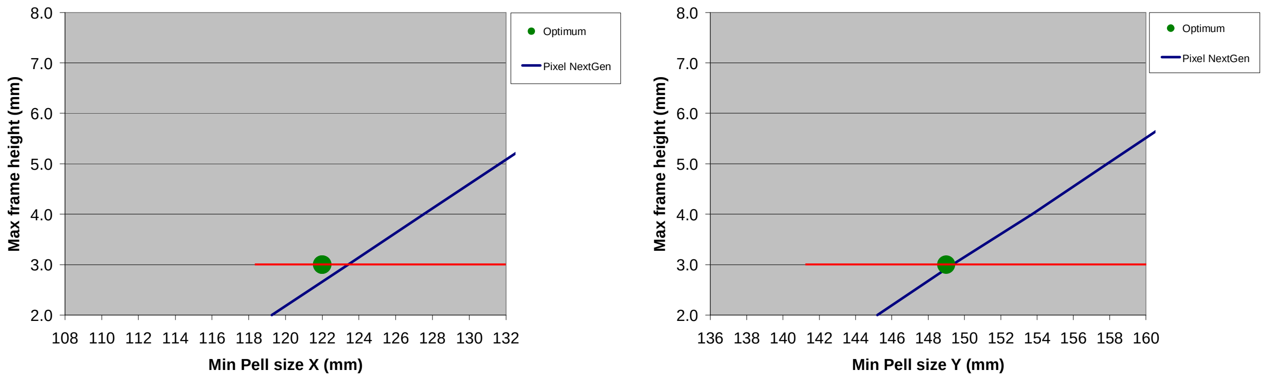
a) b)

Fig. 7: Minimum pellicle size in a) X and b) in Y for NA of 0.55 used during through pellicle registration measurement and current pellicle dimensions

Most of the current pellicle dimensions are above the minimum pellicle size needed for a certain pellicle height at maximum image field to avoid shadowing during measurement. The registration tool vendor in this case specifies a maximum pellicle height of 6.5mm driven by the working distance between objective lens and mask. Some pellicles existing today already violate that specification and could not be used during through pellicle registration measurement. Some pellicles with dimensions Xp<=115mm could cause pellicle shadowing and therefore need attention in case measurement structures are intended to be placed in the outer area of the image field.

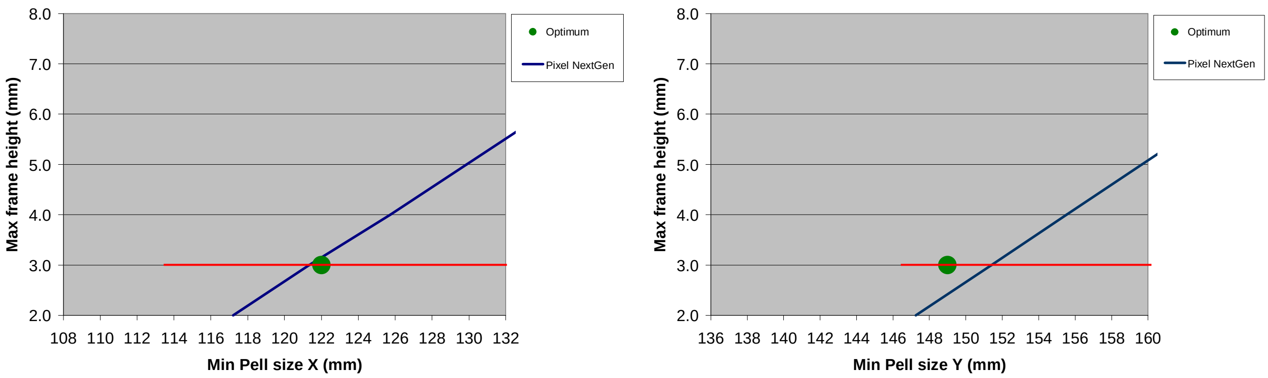
8. PELLICLE SHADOWING USING FUTURE POST PELLICLE INSPECTION TOOL

After analyzing potential pellicle shadowing effects today and in the future during other optical imaging processes than mask inspection, we want to understand how the critical effect during mask inspection evolves with new inspection tool generations. If we assume that in the coming generations of HighNA exposure techniques there will be at least one more mask inspection system with requirements for larger distances between the pellicle frame and the image field to avoid pellicle shadowing driven by higher NAs used in the systems, we can assess if the optimum working point 122x149x3mm for pellicle dimensions defined in section 4 is also suitable for next generation inspection tools. We have used the mask inspection vendors' specifications for extrapolating to an arbitrary next generation pixel. The extrapolation is done linearly, even though exponential extrapolation would give a better fit to the data. The result of using linear instead of exponential fit is a less aggressive increase in pellicle shadowing zone. If we find that the optimum dimensions for pellicle size and height are not suitable with already this "best case" extrapolation, it can be concluded, that it will probably not be suitable for the real next generation pixel. Fig.8 and fig.9 show the optimum working point 122x149x3mm in comparison with the required pellicle dimensions for an arbitrary next generation inspection pixel.



a) b)

Fig. 8: Minimum pellicle size in a) X and b) in Y depending on pellicle frame height for an extrapolated arbitrary next generation mask inspection pixel at 0° mask inspection compared to pellicle with dimensions of 122x149x3mm



a) b)

Fig. 9: Minimum pellicle size in a) X and b) in Y depending on pellicle frame height for an extrapolated arbitrary next generation mask inspection pixel at 90° mask inspection compared to pellicle with dimensions of 122x149x3mm

The result is, even with a less aggressive extrapolation of pellicle shadowing to an arbitrary next generation mask post pellicle inspection tool, the optimum dimensions for pellicles in combination with current inspection systems as derived in section 4. will not be suitable in combination with a next generation inspection tool. This holds true for 0° as well as for 90° orientations for mask inspection. Under the assumption, that a change in the auto focus system of inspection tool is not possible for future generations in order to reduce the offset between the theoretical shadowing values calculated from the NA and the inspection tool specifications, a new working point for pellicle dimensions needs to be defined. To avoid shadowing, either the pellicle size in X has to be increased to at least 124mm, which would need significant changes at the scanner manufacturers, or the pellicle height needs to be reduced even further to 2mm, which would need changes also at the scanner manufacturers (detection sensors), the inspection tool manufacturer (detection sensors), the mask manufacturer (pellicle mount) and at the pellicle vendor (manufacturing equipment).
The best working point including a future inspection generation would be either 122x149x2mm or 124x149x3mm.

9. PELLICLE HEIGHT INFLUENCES ON MASK, LITHOGRAPHY AND HIGH NA PROPERTIES

It has been shown in other studies that reduced pellicle height results in a positive influence on registration distortion after pellicle mounting. It can be estimated, that a decrease in pellicle height from Hp1 to Hp2 reduces the allowable particle size to Hp2/Hp1. Printability studies on particles on the pellicle are currently in works especially with respect to application of polarized illumination with high NA. The results of those studies will have to show, what pellicle height is still acceptable. To reduce haze growth, pellicle vendors have implemented several changes that may be affected when changing pellicle height. Also potential transportation issues when using low pellicle heights need to be considered. On the mask making side, automated pellicle mounting needs to be modified for low pellicle heights, in addition – where this holds true for any of the solution possibilities for pellicle shadowing as mentioned in section 4. – increased complexity causes higher risk for unstable processes resulting in decreased pellicle yield.

10. SUMMARY

A study on the impact of pellicle dimensions on pellicle shadow within the active image field during optical imaging processes of pelliclized photomasks has been done. It has been shown, that when using maximum image field, there are severe problems during mask inspection with almost all currently available pellicles. Recommendation to eliminate pellicle shadowing in current mask manufacturing is to standardize the pellicle dimensions to 149x122x3mm. For future generation inspection equipment, this problem will increase assuming there will be no substantial changes to the inspection systems reducing the required distance between pellicle and image field. Under this assumption, the recommended pellicle dimensions would be 122x149x2mm or 124x149x3mm. Establishing a solution will require the cooperation and alignment between pellicle, scanner, mask equipment and blank vendors as well as mask manufacturers. Standardization of pellicle dimensions is recommended to ensure coordinated and few changes in order to control complexity and to guide the industry. Further studies have to be carried out to find a best working point considering all relevant aspects of the potential solutions.

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