DEVELOPMENTS TO IMPROVE PROCESS STABILITY ON THE NEW MA200 GEN3

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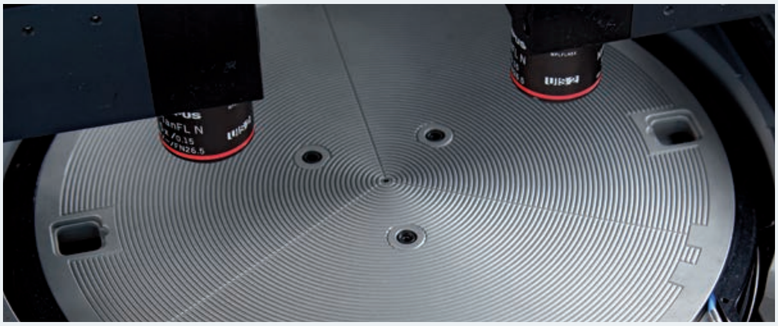
Scrap rate, rework rate and consequentially yield are decisive parameters for the cost of production processes. To achieve the constant reduction of production cost which is needed to stay competitive in semiconductor manufacturing, yield improvements are an important factor. Besides the improvements of the production processes themselves, ongoing development of the production tools support the efforts to bring down the cost of goods sold. Especially in the back end of line yield loss is painful, since source material is very costly. Improving the process stability and avoiding any wafer scrap are therefore desirable goals of any machine development.



With the advancement of 2.5- and 3D integration and the emerging of new bumping processes lithography in the back end saw a continuous shrink of feature sizes. This feature shrink also dictates an ever tightening requirement on the stability of the respective lithography processes. Especially when looking at feature size uniformity, line edge roughness and resist side wall angle, the specifications tightened significantly in the back end market.

Mask aligner lithography is typically thought of to be a mature production technology and to be lacking the capability for game changing development regarding its resolution capabilities. However, when looking at the process stability of the exposure the mask aligner still offers possibilities to improve. The stability of a mask aligner exposure process is defined by the accuracy and stability of the overlay and exposure. SUSS MicroTec has been putting significant effort in identifying those parameters that still are most promising to further improve the stability of mask aligner processes. From the results a long term improvement project is driven, which shall be outlined in this article and already partly found its realization in recent feature and product releases on the SUSS aligner platform.

OVERLAY ACCURACY

Overlay accuracy and its stability is a topic of high concern for all high volume manufacturers. The general functionalities to maintain good overlay accuracy in the mask aligner – high quality pattern recognition system, mechanical stability of the alignment stages and compensation of thermal effects – are already present in SUSS mask aligners. However, the complexity to train reliable alignment pattern, especially in production environments with heavily varying pattern quality demanded an improvement of the training system available on our mask aligners.

Therefore, starting with the MA200 Gen3 SUSS started to roll out the new VisionPro alignment editor software. The new software contains several new possibilities to train targets and has a clearer structure of the user interface. It offers two editors with different levels of com-

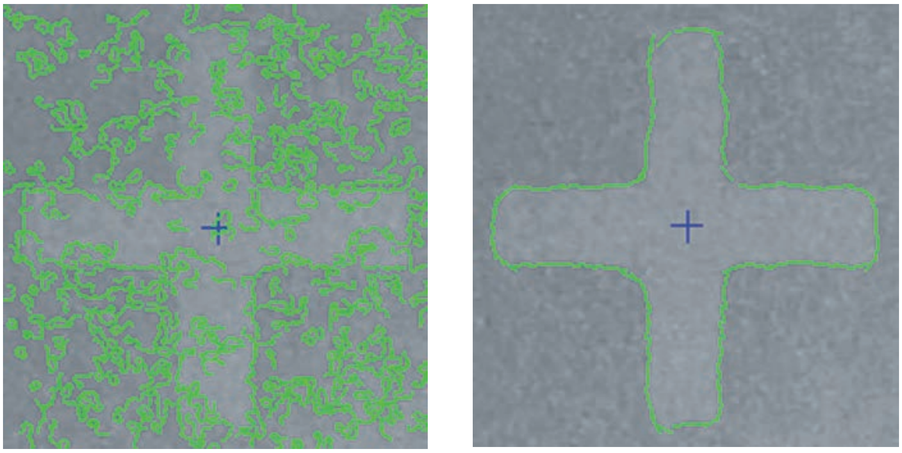


Figure 1: Model trained from real target. Proper usage of grain limits and contrast thresholds can improve the model quality from unusable (left) to stable (right). Direct visual feedback facilitates the understanding of the training results.

plexity allowing the process engineer to select the training tool of choice depending on the difficulty of the pattern training. The base editor gives quick access to the most important training tools and parameters like automated edge recognition and threshold adjustment. It will be sufficient for most training cases. For those cases, where the quality of the targets or the images require a more detailed access to the model creation the advanced training window comes with more powerful, but also more complex tools and parameters as synthetic target creation, model manipulation, masking or grain limit definition. These tools allow addressing even complex tasks where relevant feature information is disguised by e.g. excessive noise in the pattern images (for an example refer to Figure 1).

The also newly introduced direct visual feedback during model training and alignment together with the new image log provides a better understanding of the training results and of issues that might arise with the trained target model in a pilot production. The combination of the new features will support the process engineers to train more reliable target models at shorter times hence improving process accuracy, stability and throughput.

FEATURE SIZE UNIFORMITY

For almost all lithography layers feature size uniformity is the critical quality feature. The feature size uniformity directly influences functional parameters of the finished device as the conductivity of metallization layers in the packaging of ICs or mechanical properties of MEMS structures.

In a mask aligner the feature size is mainly influenced by two different process parameters, exposure dose and gap.

As commonly known, depending on the used material, changing doses have a substantial influence on the feature size. Especially absorbent, chemically non-amplified materials as standard DNQ resists are rather sensitive to dose changes due to their relatively flat resist profile.

Additionally the exposure gap has an important influence on the feature creation through its definition of the contrast in the created aerial image. A recent study performed by SUSS in cooperation with the FhG IZM showed as a side result, that the effect of gap and dose on the process result are

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quite different. While dose variation became mainly visible in the bottom feature size the variations of the gap resulted mainly in changes of the top feature size and, as a result, the side wall angle. The study also quantified the dependence between the exposure gap and the side wall angle for the tested processes. As can be seen from figure 2 the side wall angle decreases exponentially with increasing gap. Due to the exponential behavior, especially at small gaps any gap variation will result in significant variations of the process result.

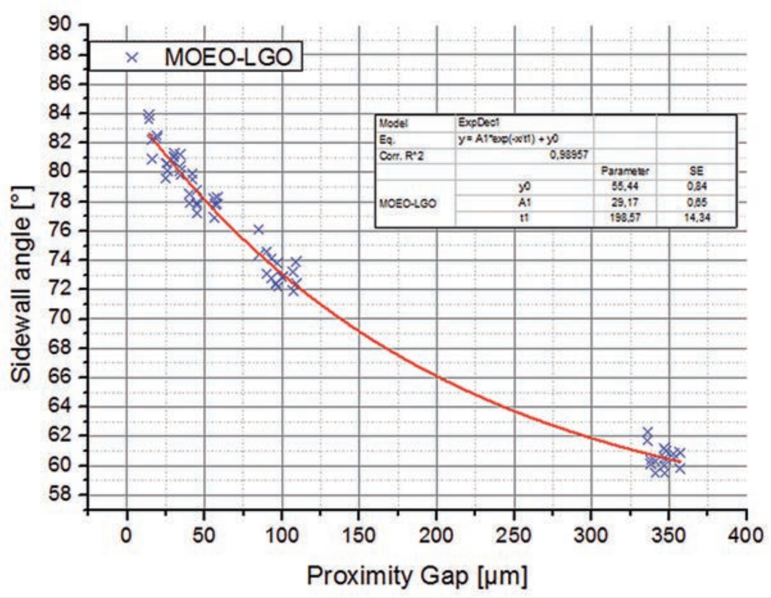

Figure 2: Dependence of the resist profile angle on the proximity gap. The experimental results can be fitted by an exponential curve. Especially for small gaps the dependence of the profile angle on the gap is substantial.

From: F. Windrich, FhG IZM-ASSID, internal project report: Determination of the Resist Sidewall Profile in Dependence on the Proximity Gap for 4 Optical Settings

The results of internal studies as the one quickly presented before, together with the observed development of the process requirements underline the need to further optimize the known good stability of the SUSS mask aligners in both, illumination and gap setting. The first steps of the improvement program focused on enhancing the optical performance of the SUSS mask aligners. At this end, the introduction and ongoing improvement of the constant dose functionality helps to improve the wafer to wafer stability of the processes. The electro-mechanical shutter that is introduced to the aligner platform with the MA200 Gen3 optimizes the accuracy of the dose control further.

To also improve the within wafer uniformity SUSS introduced the MO Exposure Optics®. The benefits of this optics on the process stability are manifold: through the high amount of lenses used to homogenize the light, the MO Exposure Optics® reaches superior illumination uniformity of better than ±2.5 %. Furthermore, the MO Exposure Optics® is capable to uncouple the illumination characteristics at the mask level from the light source. This means that no matter how the electrodes of the Hg-lamp and hence the shape of the short arc is changing, the intensity distribution on the mask and therefore also the intensity uniformity will stay the same during the life time of a bulb and even over a bulb exchange. These features are obviously reducing the portion the illumination is taking from the error budget in the lithographic process.

However, as discussed above, to translate the full effect of these improvements into the process stability it is needed to also reduce the exposure gap variation to a minimum.

A well-adjusted and well-maintained SUSS mask aligner already today offers a very high level of gap setting accuracy and gap uniformity. However, during large scale production machines are always prone to wear. With the traditional passive gap setting system the level to which this wear can be monitored and between maintenance cycles is limited. Silent malfunctions of heavily used motors as e.g. loss of single steps or damages on the proximity system as well as process related disturbances as sporadic presence of particles on wafers and masks can go unnoticed through the exposure process until they got recognized in the quality assurance later in the process chain. Through this, process variation can be increased and in the worst case even yield or scrap and rework rate can be affected. Consequentially this leads to lower

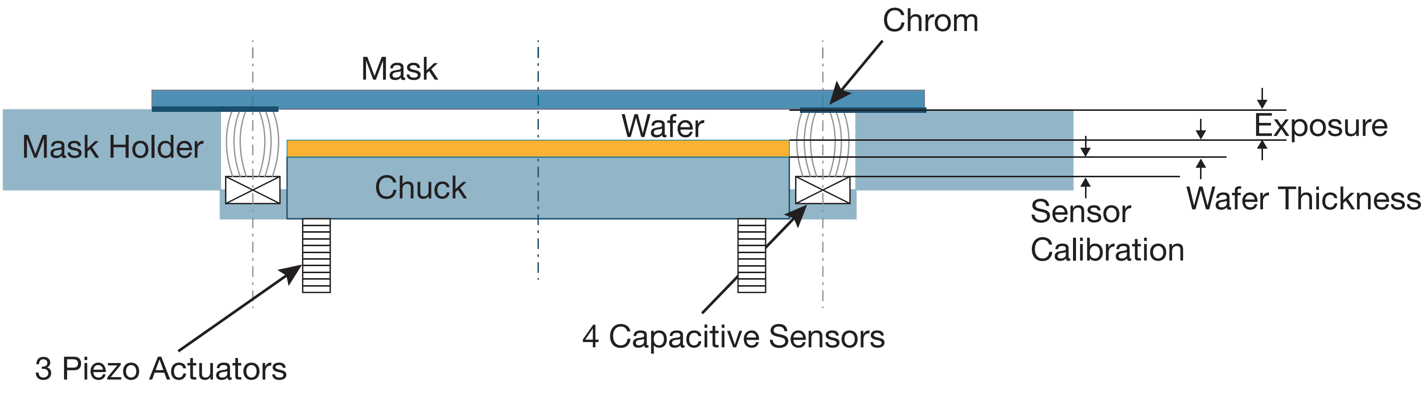

Figure 3: Schematics of the active gap setting. The system measures and controls the real time gap between chuck and mask. Due to the measurement principle the system combines the flexibility to process a wide range of different substrates, surfaces and coatings with a high sensitivity of any misplacements of toolings or materials.

effective throughput and higher cost. To mitigate these risks the next step of the improvement program is the development of a closed loop gap setting and control system for the MA200 Gen3. This system, which is currently in development, will comprise a tool for thickness measurement of the processed substrates as well as a real time measurement of the gap between the chuck and the mask based on capacitive measurement (see Figure 3). Through the direct measurement between chuck and mask the system is even sensitive to variations of the average mask thickness and placement accuracy of the chuck in its holder. Other systems that rely on the distance measurement between chuck holder and mask holder tooling are blind to these errors.

The idea to use optical distance measurement between mask and substrate itself was deliberately discarded to maintain the flexibility of the machine regarding processed substrates and surfaces as well as regarding resist materials. Additionally, optical measurement would require clear fields for the measurement which would reduce the usable area on the wafer and would limit the design flexibility of the litho layer.

Through the real time measurement the new system is capable to set the gap with repeatability in the submicrometer range. Since the feedback circuit also recognizes if fatal errors in the gap setting occur, the system warns and interrupts the process before corrupt exposures are performed.

The resulting cd uniformity within the wafer is of course also dependent on thickness variation and flatness of the used materials. Future development projects therefore are planned to also address the flatness issues of masks and wafers by enhancement of the tooling.

SUSS MicroTec is optimistic that the ongoing development on the tooling together with the presented improvements on alignment, illumination and gap setting will push the process stability on the SUSS mask aligner platforms even beyond the already known good performance.

THE AUTHORS

Dr. Marc Hennemeyer is Product Manager at SUSS MicroTec Lithography. He is responsible for the automatic mask aligner product group. After his graduation in Physics at University of Munich where he also received his PhD working on micro fluidic systems for biological applications he joined SUSS MicroTec in the Application Department before he proceeded to his current job. He authored and coauthored several papers on various topics, including micro imprinting and lithography.