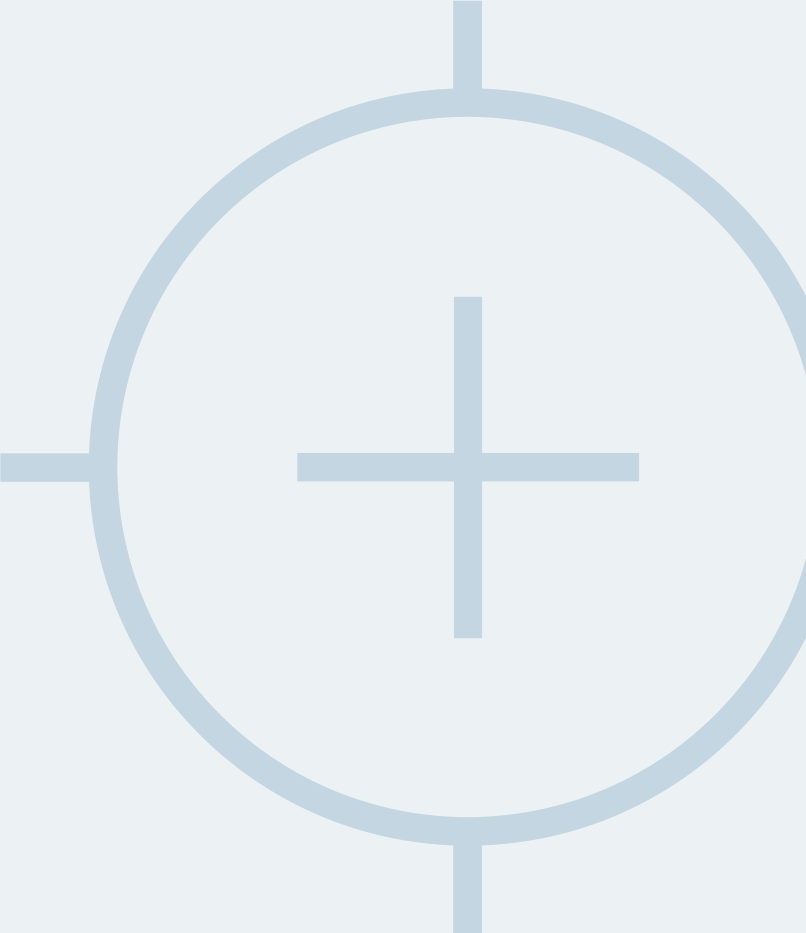
AUTO-ALIGNMENT INSIGHTS

Dr. Marc Hennemeyer, Dr. Thomas Hülsmann
SUSS MicroTec Lithography GmbH | Germany



Published in the SUSS report 01/2013

E-mail: info@suss.com

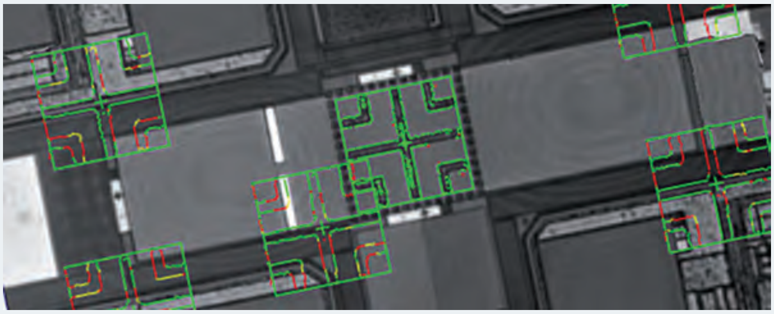
www.SUSS.com

SEQUENCE 1

AUTO-ALIGNMENT INSIGHTS

Dr. Marc Hennemeyer, Dr. Thomas Hülsmann, SUSS MicroTec Lithography GmbH, Schleissheimer Str. 90, 85748 Garching, Germany

This article is the first part of a short series of articles focusing on pattern recognition and alignment in SUSS mask aligners. It is meant as a guideline especially for beginners in the field of pattern recognition, but even more experienced users might find one or the other aspect about pattern recognition which is new to him or her.



Almost all production steps in the manufacturing of semiconductor and MEMS devices need some sort of alignment of the new features to structures already placed on the substrate earlier. This is especially true for back end of line processes which are the main field of application of SUSS mask aligners.

Since according to Moore's law also backend processes are targeting ever smaller feature sizes the requirement on alignment accuracy saw a constant tightening in the last years. Nowadays, required alignment accuracies of 1 µm or even smaller are common, where it used to be several micrometers just a couple of years ago. While measurement of the pattern position with submicron accuracy in principle is not an issue for modern pattern recognition systems – they are capable to find positions of structures with accuracies far smaller than the pixel resolution of the image capturing system, down to several tens of nanometers – as often the devil is in the details. While alignment systems in the front end processing rely on fixed target geometries, in backend processing target variation is a lot bigger and the target quality often much worse. This can be caused by countless reasons, substrate surface condition and covering by insufficiently transmitting materials just being two examples.

The following overview will try to give some insight into the complexity of the task of creating reliable and accurate alignment pattern models under varying surface and surrounding conditions. It can be used as a quick guideline when starting alignment target training. However, for more complex challenges in target model training the reader is pointed to the extensive trainings offered by the SUSS training center and which are noted at the end of this article.

The first part of the series will cover general information about the pattern recognition system used in SUSS mask aligners and how changing the conditions of the grabbed image is influencing the pattern recognition process. The following parts will focus on rules and processes how to setup and optimize pattern in order to achieve good accuracy and reliability in the alignment process as well as on some application examples more detailed.

COGNEX PATMAX® VERSUS CNL

The alignment system in SUSS MicroTec mask aligners is based on the standard solution in the semiconductor market: the PatMax® geometric pattern recognition algorithm of Cognex.

In contrast to cross-correlation methods like CNL which directly compare the grey levels of the acquired images, the PatMax® system extracts geometrical infor-mation from the images to create edge models of the structures found in the image. Although grey values are also used for the identification of the edges inside of the image, geometrical pattern matching has several advantages over correlation matching.

1. Due to the restriction of the used information on geometrical data, the system is less sensitive to changes in brightness and contrast between the trained model and the actual scene presented to the system during a pattern search.

2. It is up to the user to decide which edges carry the position information and which edges are ignored.

3. Furthermore, flexible transformations of geometrical data, like scaling and rotation allow automatic or manual adaption to changing process conditions.

4. The model's edges are dis-played giving the user feedback on the model and the position and quality of its match with the targets.

THE MODEL OR PATTERN AND ITS MATCH WITH THE TARGET

Pattern matching algorithms operate with a target "model" or "pattern". The most common way to define target models is the model creation from a part of an image of the real world target. In case of PatMax®, the model is an "edge model", some matches of such a model with an image are shown in the title figure on page 10. The match in the center is supposed to deliver the highest score. Mismatches are represented with red lines indicating missing edges.

It is obvious, that especially during the target model training a high expertise has to be put into selecting well suited real world structures. A bad choice of the structure used for training e.g. a very small area will result in a trained target model which gives multiple and thus unreliable recognition results.

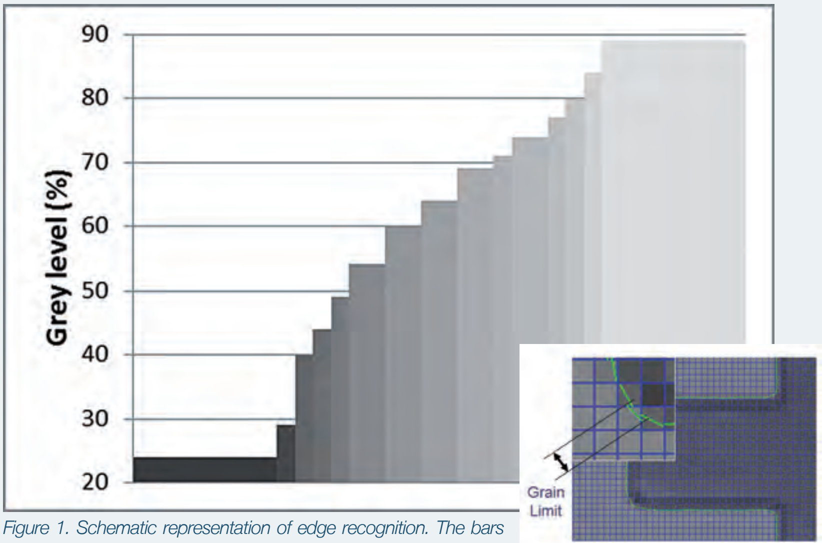


Figure 1. Schematic representation of edge recognition. The bars represent grey levels along a pixel line. By approximation, the discrete grey values are transferred into a continuous function. The position of the edge is found from a defined threshold level in the continuous data (here 50% of spanned grey range). Inlet: image of edges found in typcal mask aligner target

WHAT IS AN EDGE?

The extraction of geometries from the pixel images is performed by analyzing grey scale levels. If the grey level changes in a certain area surpass the limit "edge threshold" for the slope and "contrast threshold" for the height, then we have found an edge segment. For a schematic drawing see figure 1. The size of this vicinity is appointed by the grain limit control in the PatMax® software.

As the lateral position of the edge is determined from the approximated continuous data, it can be located with sub pixel accuracy. The direction of the edge segment is found using the grey levels of its neighborhood. This edge detection is performed on each scene during the actual pattern recognition, but also in case of pattern training from real world data.

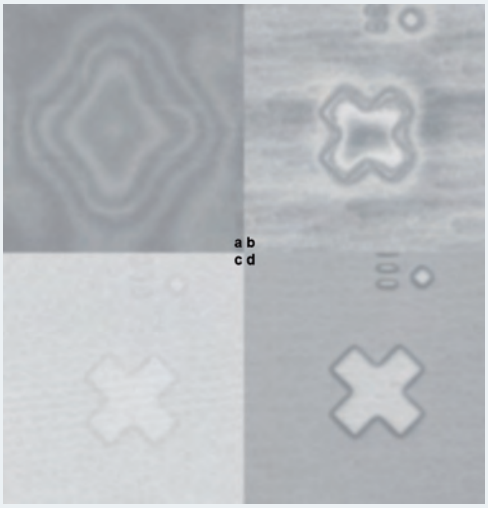


Figure 2. Influence of illumination on target visibility. Microscopic images acquired with different illumination settings. a) undefined customer illumination, b) red LED, c) yellow filtered white LED (6000K), d) yellow filtered white light halogen (3200K)

SUB-PIXEL ACCURACY

In tests we proved a sub-pixel accuracy of below 1/40 pixel. That can be explained: A target which measures 50 µm yields 200 edge segments, whose positions and directions are averaged.

The advantage is that low power objectives can be used.

Example: A 5x objective and a camera may result in 1 µm/pixel magnification. But although the objective has only a 2 µm L/S resolution, the systems yields a 25 nm position resolution. Besides granting a large field of view low power objectives contribute to machine stability with their high depth of focus.

ILLUMINATION: KEY TO SUCCESS

The art in setting up reliable pattern recognition and therefore reliable alignment processes lies in balancing the need for flexibility to recognize varying targets with the need for uniqueness to reduce the amount of wrong findings.

The most important parameter to improve the reliability of pattern recognition is a proper definition of the illumination conditions. The illumination of the scene should fulfill a whole set of requirements:

1. It must be bright enough to keep any detector noise at a low level and to insure that even in the darkest areas real features are still discernible.

2. On the other hand the illumination should be low enough not to overexpose bright image areas and crossfade important details.

3. It must not create artifacts.

4. The contrast between edge and environment must be high enough to distinguish them from each other.

5. Avoid exposure of the photo resist.

That can be seen exemplarily on the SiO2-substrate in figure 2. Here, changing the illumination setup created anything from hardly discernible substrate structures over strong shadow artifacts and very weak contrasts to crispy images with very good structure representation. Parameters that can be varied for this adjustment in the SUSS mask aligners are the illumination method (reflected or transmitted light), light sources (halogen/LED), color filtering and collimation angles of the incident light (ring illumination).

It is easy enough to understand, that having sufficient contrast in the images to be analyzed by the pattern recognition is of crucial importance. This is especially true if the image is used as a template for creating the target model, as lower contrast always increases the risk to train features in the scene that are actually not part of the real target.

However, as the images in figure 2a) and 2b) demonstrate, illumination can also create virtual edges within the scene that can heavily interfere with the pattern recognition and consequently with the complete alignment process. Common reasons for such ghost edges or artifacts are reflections from the substrate surface interfering with geometries on the mask, which can be suppressed or at least greatly reduced by choosing larger imaging gaps. A second reason is the presence of interference artifacts within transparent layers on top of the structures on the substrate. Figure 2a) is a good example of the effect these interference artifacts can have on the observed images.

PROCESS VARIATIONS

The second serious influence on the reliability of the pattern recognition is, of course, the repeatability of the structures presented in the individual scenes. Due to process fluctuations, the target structures on the wafer can drastically vary from wafer to wafer. Figure 3 presents examples of structure variation between wafers

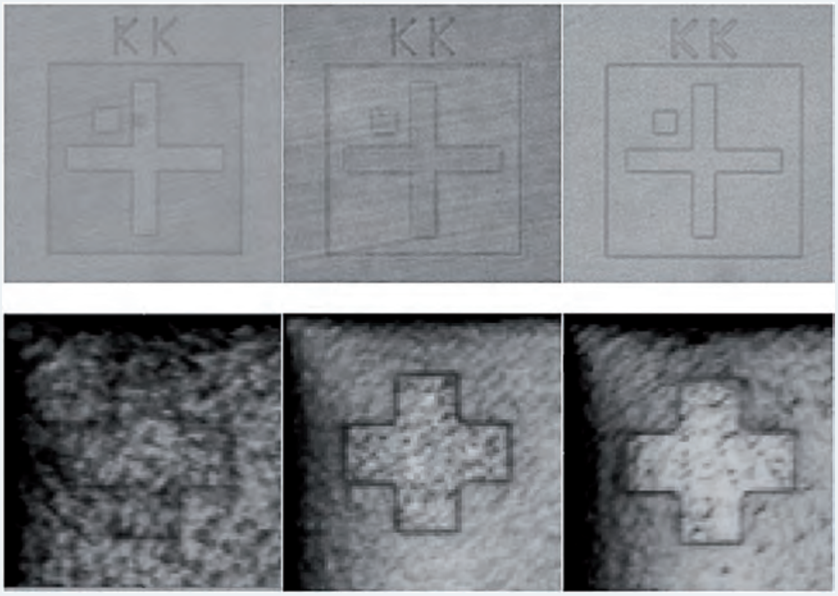


Figure 3. Two examples of screen shots of target variation in different scenes. Scrub marks (top row) and epilayers (bottom row) can introduce clutter and change contrast

caused by preceding process steps. The top row shows an example of back ground wafers. Here, due to the different degree of scrub marks, contrast and even polarity of the marks changes together with a varying level of clutter in the scenes. Also the bottom row, which shows targets on epilayers, presents a severe degree of variation. These variations are based on the varying reflectivity caused by the surface roughness. As can be seen in the image this even leads to reasonable changes in the identifiable edges.
As can be understood from these examples, the choice of suited scenes for the target training is of crucial importance. Selection of bad targets for the training (scenes with untypical information, bad contrast, untypical polarity and so on) will severely deteriorate the reliability of the pattern recognition process.

The next parts of the articles will therefore introduce guidelines on how to select good scenes for target training and procedures for testing and optimizing the trained target models.

Meanwhile, we would like to remind the reader of the extensive trainings that are offered by the SUSS MicroTec training department covering this subject. For information on trainings please be referred to the respective SUSS webpage: http://www.suss.com/en/customer-service/training.html and the contact information therein.

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 co-authored several papers on various topics, including micro imprinting and lithography.