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MASTER

Accelerated Wafer Z-map for layout independent leveling

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Accelerated Wafer Z-map for Layout Independent Leveling

Master Thesis

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Abstract

In this public version of my thesis you can read the results of the research on the Accelerated Wafer Z-map.
The big success of ASML in the photolithography market is mostly due to the TwinScan machine. This machine has two sides: a measure side and an expose side. That way, two wafers can be processed at the same time.
There are various specifications the TwinScan machines have to meet. Among other things, the processing speed and the preciseness of these machines have to agree to certain standards.
On the measure side of the TwinScan the wafer is measured to make sure that it is always in focus on the expose side. Currently, the wafer is only measured with constant speed, see Figure 1 (left). In my research, I investigate the possibility to measure and accelerate/decelerate at the same time, the so-called Accelerated Wafer Z-Map (AWZM), see Figure 1 (right).

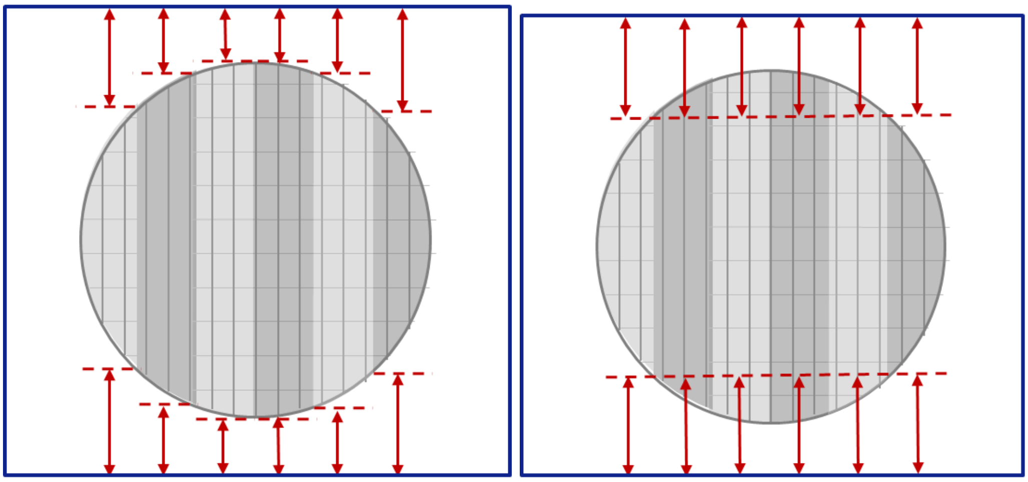

Figure 1: Velocities of the strokes during the wafer Z-Map in the normal way (left) and the accelerated way (right).

In my research I did some tests on a real TwinScan machine. During these tests, I gathered a lot of data, which I later analyzed through Matlab. The results of my research look very promising, and this gives rise to more possibilities to investigate the AWZM.

Keywords: ASML, UVLS, LIL, WZM

Preface

For the last 11.5 months I have been an intern in the Leveling group of ASML. During my internship I have learned a lot. Not much in the academic sense (the University has done a good job on that subject in the 5 years before that), but more in the work-related sense. Before I started to work at ASML, I never had a (side) job fitting to my mental capabilities. To be in such an intellectual working environment is really inspiring.

I found that everyone inside ASML wants to deliver a product that is as good as possible. To succeed in this, people have to work together. Whenever I had a question about anything at all, and someone had time to help me, they always wanted to help me. This has really helped me in many situations.

A special thanks goes out to my ASML supervisor, Doru Torumba. Doru has helped me a lot, even when he did not really have time to help me. Whenever I asked him something, I immediately got an answer, or he would look it up to come back to me later. I don't think my project would have been so successful without Doru.

There are two other people from ASML I want to thank. Maarten Voncken is the group leader of the Leveling group, and has helped me in many ways. He made sure I had everything I needed. Also, he helped me with the job search for after my internship. The other person I want to thank is Luc Bouten. As the project leader of the project team I was part of, we had a weekly meeting where we would talk about the progress. Luc was always interested in my research, and made sure I kept deadlines. Sometimes he was strict, but never unfair.

After all the thanks for ASML people, I want to thank my mentors from the TU/e. I thank Barry Koren for being my first supervisor. He was really happy when I got an internship inside ASML and chose him as my supervisor.
I thank Jos Maubach, who not only has been my second supervisor. I also worked together with him during the lectures of Calculus. He is a really nice person, and very pleasant to work with.
The final person I want to thank is Han Slot. He wanted to be part of my graduation committee, when I really needed someone.

I also want to thank my fellow interns, which were not only nice colleagues, but turned out to be good friends, too. Also outside ASML. Thank you very much John van Dijk, Arnoud Janssen, Tommie Koot and Nicole Pitre. Without you my time would have been way less exciting.

The final people I want to thank are my family. They have always been supportive for me. The times I came home from work really tired are countless, and my girlfriend was always a listening ear at the right moments. During the weekends, when I saw the rest of my family, they were always very interested, even though I could not tell them much about the project because of confidentiality.

Abbreviations

AWZM	Accelerated Wafer Z-Map
IC	Integrated Circuit
LDL	Layout Dependent Leveling
LIL	Layout Independent Leveling
LS	Level Sensor
NXT	New Generation TwinScan
SPM	Stage Position Measurement
UVLS	UV Level Sensor
vaj	Velocity, Acceleration and Jerk
VISLS	Visible Level Sensor
WS	Wafer Stage
WZM	Wafer Z-Map

Definitions

3σ	Three times the standard deviation. This indicates an interval in which 99.7% of the data is located.
6DOF	The six degrees of freedom: x, y and z, which is the location of the center of the object, and Rx, Ry and Rz, which is the amount of tilt around the axis, see Figure 2.
Chuck	A chuck carries the wafer, it is also called a wafer table.
Delta map	The difference between two Wafer Z-maps.
Field	Part of the wafer which is exposed in one move, the reticle pattern shines on this field once.
Focus	The preciseness in z-direction.
Imaging	The creation of a pattern on silicon wafers by shining light through a reticle. Needs good focus.
Overlay	The preciseness in x- and y-direction.
Reticle	The mask through which light shines during the expose phase.
Stroke	Part of the WZM, which consists of one column of fields for LDL, and multiple columns of fields for LIL.
Throughput	The amount of wafers processed in a certain time period.

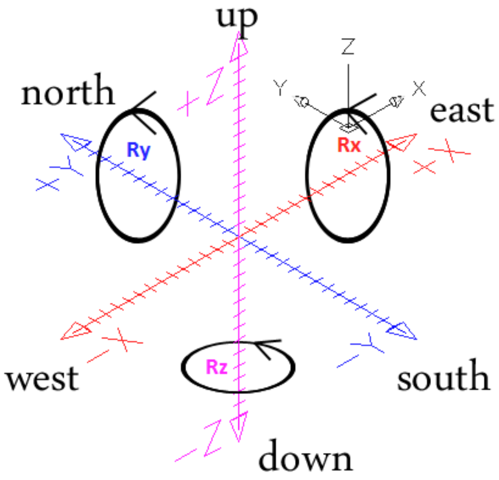

Figure 2: The six degrees of freedom x, y, z, Rx, Ry and Rz.

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Chapter 1

Introduction

In this introduction chapter, I will give some background information about ASML and one of its products, the TwinScan machine.

1.1 ASML

ASML is a world leader in the manufacturing of advanced technology systems for the Semiconductor industry.[2] The company offers an integrated portfolio for manufacturing complex Integrated circuits (also called ICs or chips). ASML designs, develops, integrates, markets and services advanced Photolithography systems used by customers - the major global semiconductor manufacturers - to create chips that power a wide array of electronic, communications and information technology products.

With every generation, the complexity of producing integrated circuits with more functionality increases. Semiconductor manufacturers need partners that provide technology and complete process solutions. ASML is committed to providing customers with leading edge technology that is production-ready at the earliest possible date. ASML technology is supported by process solutions, enabling customers to gain and sustain a competitive edge in the marketplace.

ASMLs corporate headquarters is in Veldhoven, the Netherlands. Manufacturing sites and research and development facilities are located in Connecticut, California and the Netherlands. Technology development centers and training facilities are located in Japan, Korea, the Netherlands, Taiwan and the United States. Additionally, ASML provides optimal service to its customers via over 60 sales and service organizations in 16 countries.

Founded in the Netherlands in 1984, the company is publicly traded on Euronext Amsterdam and NASDAQ under the symbol ASML.

1.1.1 Leveling group

My internship was done in the Leveling group. In the Leveling group currently consists of 44 group members from all over the world. The Leveling group researches the following topics.

- Measuring the wafer topology at specified productivity and accuracy
- Delivering focus set points (to be used during wafer exposure) that minimize defocus due to wafer properties and limitations of contributing subsystems
- Reporting relevant parameters to the user

These concepts will be further explained in the later chapters.

1.2 TwinScan

In this chapter, I will give some background information on the TwinScan machine, and specifically on the NXT machine.
The TwinScan machine is a photolithography machine manufactered by ASML. These are used in the production of computer chips. In Section 1.2.1, the production process of an IC can be seen, and the part the TwinScan plays a role in. With the TwinScan, ASML had over 80% of the worldwide sales of lithography machines in 2014. An example of the TwinScan machine can be seen in Figure 1.1.

Figure 1.1: A schematic representation of a TwinScan machine.

1.2.1 IC production process

In Figure 1.2 you can see the production process of an IC. We first begin with a silicon disk, and add a photosensitive resist. After that, this so called wafer is exposed to light, to create patterns on the resist. The resist's chemical structure changes when light shines on it. Then, the softened resist is washed off, and the etches are filled with a material such as metal or oxides. These are the first layer of the circuits. Now, another layer of photosensitive resist is added, and the steps are all repeated until the preferred setup is reached. Now, the wafer is cut into individual dies. These dies are put in a package, and are now ready to be used in all kinds of appliances, such as mobile phones and laptops.

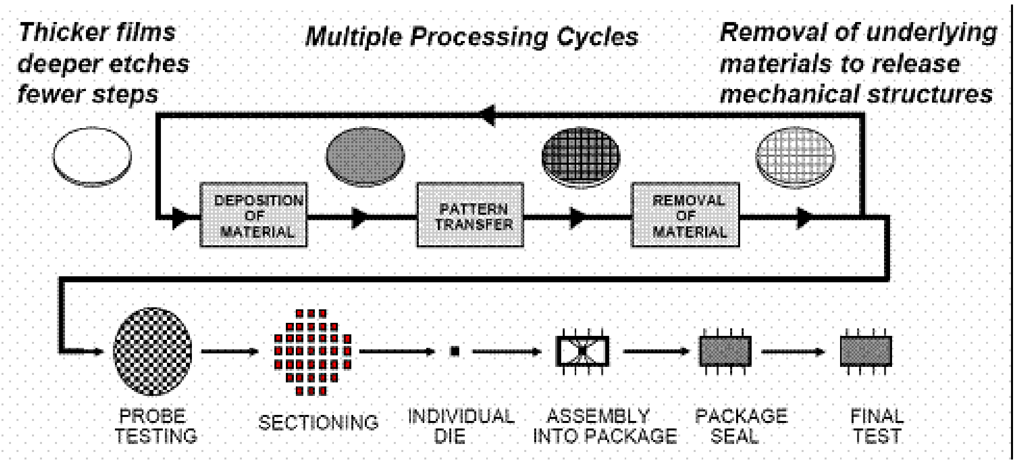

Figure 1.2: A schematic representation of the production process of an integrated circuit.

The TwinScan machine plays a role in the creation of the patterns on the resist. This is by far the hardest part of the process, and therefore these machines are very expensive.

1.2.2 Cycle of a wafer

In this section, I will give a summary of the road the wafer takes in the TwinScan machine.

1. Load the wafer on one of the two chucks, the one that is currently on the measure side.
2. Align the chuck and wafer, such that we have a reference for the alignment on the exposure side.
3. Use the UVLS to measure the topography of the wafer. This is done very precisely.
4. Do a chuck swap, such that the chuck the wafer is on goes to the expose side.
5. Align the reticle, chuck and wafer, such that everything is aligned perfectly.
6. Expose the wafer with a powerful light source. The chuck is tilted and shifted up and down constantly, to keep the wafer in focus according to the topography measured in step 3.
7. Do a chuck swap to the measure side.
8. Unload the wafer.

Because there are two chucks in the TwinScan machine, two wafers can be processed at the same time. One of these is in the expose side, and one of these is in the measure side. That means step 7. → 8. → 1. → 2. → 3. and 5. → 6. are done at the same time. This increases the throughput immensely, and is one of the biggest reasons of the success of the TwinScan machine.

1.2.3 Specifications

The TwinScan machine has to compete with various other companies. To keep the highest market share, tight specifications have to be met, regarding production speed and preciseness. These specifications can be divided in three main categories:

- Overlay: Preciseness in x- and y-direction. This is mainly achieved by aligning as good as possible.
- Focus: The preciseness in z-direction. Among other things this is achieved by doing the various LS measurements.
- Throughput: The amount of wafers processed in a certain amount of time (usually expressed per hour or per day). Among other things this is achieved by optimizing algorithms and moving the chuck faster.

You can imagine that it is possible to make a process faster (more throughput), but that this results in a worse preciseness (worse overlay and imaging). ASML is always busy increasing the throughput without changing the accuracy.

Chapter 2

UV Level Sensor

In this chapter, we will take a look at one of the most important sensors in the TwinScan machine, the UV Level Sensor. This UVLS is located at the measure side of the machine and is used to measure the topography of the wafer. As already seen in the name, the UVLS uses UV light to measure the topography.[1]
Before the UVLS, we had the VISLS (Visible Level Sensor), which used visible light to measure the topography of the wafer.

2.1 How does it work?

In Figure 2.1 you can see a schematic overview of the functionality of the UVLS.

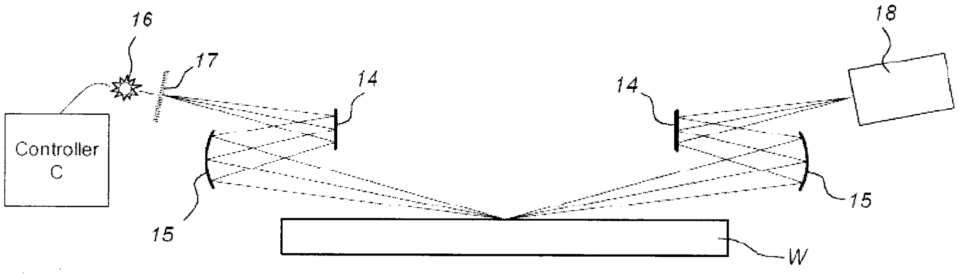

Figure 2.1: A schematic overview of the functionality of the UVLS.

I will explain the way this works. I will use the numbers as indicated in Figure 2.1. From the UV light source (16) light is emitted. This light first passes through the projection grating (17), which splits the light beam in two light beams. After this they are reflected on two mirrors (14 and 15), to control their path to the wafer (W) and to focus on that. Then, the light beams are reflected from the wafer (W) to two mirrors (15 and 14). Then, the light beams travel to the detectors (18). There are two detectors, the upper and the lower, to detect the two light beams. From the two signal strengths (U for upper, L for lower), the height $z = z(U, L)$ is calculated a formula.

2.1.1 Stage position measurement (SPM)

Stage position measurement is needed because the wafer stage and reticle stage are not always in the same position. There is a certain zero position, which the machine is calibrated to. This zero position indicates the position where the UVLS signal is correct. Because the system is not perfect, after a while the stages are not positioned to this zero position anymore. Therefore the position of the stages is measured. The UVLS signal can be corrected for this SPM signal.

2.2 Various LS scan types

With the UVLS various measurements (scan types) can be done. The most important ones for my research are discussed and explained. I will not provide a detailed description, because that would make it unnecessarily complicated. A general idea of the scan types is enough to understand the rest of the thesis.

2.2.1 Capture

A LS capture is a vertical scan, so it is done only in the z-direction. The WS does not move in x- or y-direction during this scan type. It is used to determine the correct z and Ry values at the current (x, y)-position. In my experiment, this is used to calculate the z- and Ry-values of the beginning and the end of the stroke.

2.2.2 Wafer Z-Map (WZM)

A WZM stroke is part of a WZM. The input for this scan type are the start and end coordinates of the stroke. All six degrees of freedom can be used as input, but in my experiment only x-, y-, z- and Ry-values are used. The y-value is different in the start and the end coordinates, the x-value does not change. The output is then the z-values at every data point.

2.3 UVLS driver steps

In this section, I would have explained the driver steps during a WZM, but because of the confidentiality this is removed.

Chapter 3

Accelerated Wafer Z-map

During the measurement phase, the wafer is measured by the UVLS. The chuck on the measure side accelerates in y-direction until the wafer is under the UVLS. After that, the UVLS starts measuring and the chuck moves with constant speed. When the wafer is not under the UVLS again, the chuck will decelerate, see Figure 3.1 (left).

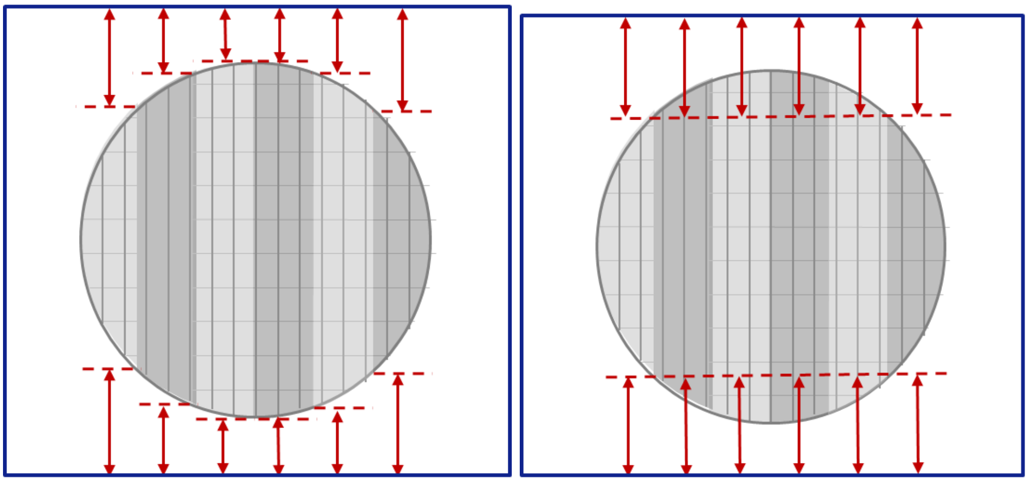

Figure 3.1: Velocities of the strokes during WZM in the normal way (left) and the accelerated way (right).

The reason why we don't accelerate on the wafer is that the chuck under the wafer deforms under force. Because this acceleration, there will be force exerted on the wafer and chuck. This leads to height errors in the wafer Z-map, eventually resulting in defocus in the exposure phase.

3.1 Goal of the investigation

In my investigation, I look into the possibility of accelerating while measuring, see Figure 3.1 (right). I will investigate the deformations to see whether they are both reproducible and stable over time. If they are, I will propose a calibration method. Also, I will look into the LS driver data processing steps, to see which can stay the same and which will need to change.

Chapter 4

Experiment

In this chapter, we look closer at the experiments done on the TwinScan machine to collect data. In Section 4.2, the way we measured the wafer will be discussed. In Section 4.3, the data results and analysis of this data will be presented.

4.1 Scripting

In this section, I told something about the scripting I did to make the experiment happen, but this is not included in the public version because of confidentiality reasons.

4.2 Experiment description

A description of the measuring process for every normal WZM is as follows.

1. Do captures on the edge of the wafer for every stroke x-position, both on the top and the bottom.
2. Do WZM scans between the two capture locations.

For the accelerated WZM, this is slightly different.

1. Do captures at a certain location for every stroke x-position. This location is where the chuck can reach maximum speed.
2. Do WZM scans between the two capture locations, and do controlled turns outside the wafer. The controlled moves are to prevent x-moves on the wafer.

We got two time slots of machine time, on 8 June 2015 and 15 June 2015.
During each of these time slots, we ran our test queue two times (two runs). Our test queue consists of 10 WZMs measured in the normal way and 10 WZMs measured in the accelerated way on chuck 1, and afterwards the same on chuck 2. This means that in total we have

$$10 \text{ (WZMs)} \cdot 2 \text{ (acc./nor.)} \cdot 2 \text{ (chucks)} \cdot 2 \text{ (runs)} \cdot 2 \text{ (days)} = 160 \text{ WZMs}.$$

We measured the same wafer each time.
The data we got with our script was raw LS and SPM data. With Matlab we postprocessed the data as it would normally be processed by the drivers in the machine.
All the data files can be found on the ASML shared drive, such that eventual future data analysis can be done.

4.3 Results and analysis

First we introduce some notation. We note the normal WZM by $N_{i,j}$, with i the chuck number ($i = 1, 2$) and j ($j = 1, \ldots, 40$) indicating the jth wafer map. We use the same notation for the accelerated WZM $A_{i,j}$. We define $\Delta_{i,j} := A_{i,j} - N_{i,j}$, the delta map of $A_{i,j}$ and $N_{i,j}$. This means that for $j = 1, \ldots, 10$, we talk about day 1 run 1, for $j = 11, \ldots, 20$, we talk about day 1 run 2, for $j = 21, \ldots, 30$, we talk about day 2 run 1 and for $j = 31, \ldots, 40$, we talk about day 2 run 2. We only look at the same i and j for the delta maps, because we saw in the analysis of the other maps that they had the same typical behavior.

We see in the WZMs that the difference between the normal and accelerated maps are not big, and are mostly in the accelerated region.

4.3.1 Reproducibility

We look at the reproducibility of the individual maps per run, for both the normal WZMs and the accelerated WZMs. Also, we calculate these numbers for the delta maps. The reproducibility numbers indicate how well the individual WZMs are alike. The lower the number, the more they are alike.

As we can see in these numbers, the reproducibility number of the normal maps and the reproducibility number of the accelerated maps are approximately the same. These numbers are within the population of the NXT3 systems.

4.3.2 Calibration methods

For the calibration, we have several possibilities. The basis of these possibilities is the same for all of them. The idea is to take the average of several WZMs, to remove some noise.

The statistics corresponding to this calibration method look very good. The reproducibility, drift and accuracy are all within boundaries.

Filtered calibration map

The second calibration method we tried was to take the standard calibration map, and apply a filter, to remove even more noise.

The statistics corresponding to this calibration method don't look very good. The reproducibility and drift are within boundaries, but the accuracy not.

Fitted filtered calibration map

The third calibration method we tried was to take the standard calibration map, subtract a fit, filter the data and add the fit.

The statistics corresponding to this calibration method don't look very good. The reproducibility and drift are within boundaries, but the accuracy not.

Best calibration

As we saw, for the reproducibility numbers and the drift analysis numbers, we get acceptable numbers for all three methods. However, for the most important number, the accuracy number, we see that the standard calibration map wins significantly. Therefore we conclude that the first calibration method, the standard calibration method, is the best considered calibration method.

There could be other calibration methods not considered that are better. These can be investigated in a later research.

Chapter 5

Changes in drivers

The measurements during the scan phase are done with constant temporal frequency. Because we now accelerate during the scan phase, unfortunately the measurements are not on an equidistant grid anymore. Some driver steps assume an equidistant grid, so these wont work optimally anymore when creating accelerated WZMs. We looked into this and proposed new, updated driver steps.

Chapter 6

Conclusions

As we saw in Chapter 4, the deformations are reproducible and stable over time. This is a good sign, because the investigation can now be continued, with a very good chance of success.

Various possibilities for the calibration method have been investigated:

1. Standard calibration map.
2. Filtered calibration map.
3. Fitted filtered calibration map.

Of these calibration methods, the standard calibration map performs the best.
Of the LS driver steps, some have to be updated. Various possibilities for updates have been investigated.

6.1 Recommendations

If more throughput is needed, the acceleration during measuring should be implemented.

Before being able to implement the accelerated Wafer Z-Map, more investigation is needed. We only got two time slots of machine time, which is not enough to draw final conclusions about the best calibration method and the best driver changes. We at least need data on other wafers before we can conclude something definite.

There could be other calibration methods not considered that are better. We have at various options for this.

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