Development of a state-of-the-art nm-measurement system for square meter sized lithography masks

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Abstract

The demands and solutions for ultra-precision metrology in the manufacturing of lithography masks for the display industry are indeed challenging. Specification demands to be overcome are a measurement repeatability of 10 nm (3σ) and an absolute accuracy of better than 100 nm (3σ) on a scale of more than 1.5 m in the X and Y directions. The design of a measurement system that meets these requirements calls for careful selections of materials such as metal, ceramic composites, quartz or glass as they at this precision level are highly affected by the surrounding temperature. Also the fact that the refractive index of air in the interferometers measuring absolute distances is affected by temperature, pressure, humidity and CO_2 content make the reference measurements really challenging [1].

As in many other areas in the industry high quality metrology is the key for success in developing high accuracy production tools. This paper will therefore start by introducing the metrology requirements of mask making for display screens and end with the state-of-the-art results we have achieved.

1 Background

Several photo masks are used in the manufacturing of a Liquid Crystal Displays (LCD) or Organic Light Emitting Diode (OLED) displays. Specialized companies located in Asia make the photo masks which they deliver to manufactures as Samsung, LGD, Sharp or others that produce the display panels [2]. The absolute placement accuracy of features on the photo masks is 200-300 nm (3σ) over a maximum area of 1.6 x 1.8 m^2. The starting point of the photo mask process is the mask blank, an 8-16 mm thick soda lime or quartz glass plate covered with a 100 nm thick sputtered chromium layer. On top of that a 0.8-1.0 µm thick photo resist (PR) layer is deposited. The PR is exposed by a laser based large area pattern generator. The result after development and etching defines one of the patterned masks. Up do 4-7 different photo masks are needed to define a complete transistor layer backplane for an LCD or OLED display. Each of the photo masks are rigorously checked during the process in several ways. Besides ordinary defect inspection also high precision metrology is needed to verify the specifications of absolute accuracy and overlay i.e. how well the different masks fit together.

1.1 Development approach

The state-of-the-art lithography metrology tool MMS15000 is the result of an intense development by a small group of specialists during nine months in 2005 and it is still the world standard tool used for verification of large area photo masks [3]. The ultimate challenge for this small team (about 10 people) was to develop a 2D-metrology system capable to verify absolute accuracy at uncertainty levels < 90 nm (3σ) and having a measurement repeatability better than 50 nm (3σ) over an area of 1.3 x 1.5 m^2. Besides the extremely tough specifications we also had to develop a new self calibration method since there is no other system in the world good enough for verifying these kinds of specifications on such a large area.

By experience from the previously developed pattern generators we already knew the importance of understanding how materials behave under different environmental circumstances like temperature, pressure, humidity etc. to achieve stability in the sub-micron range. An example worth to mention here is that the stage is made of a special glass composite material, Zerodur, that can be tuned to have a zero temperature expansion in the temperature range 20-23 degrees. An important aspect that we needed to consider was the effect from gravity when the mask blank was placed on the stage. The state-of-the-art mask blanks used today in the industry has a long wave surface flatness within ±20 μm. This together with the fact that unwanted particles sometimes will be present under the blank is enough to have the blank being bent by gravity. This tiny bending is enough to distort the pattern at a nm-scale on the top surface. A special algorithm developed by us, Z-correction, is used to compensate for this effect in a measurement (or when the pattern is written in the photo resist) [5]. Throughout the development process of the MMS15000 several different image processing algorithms were developed in parallel with different hardware solutions.

Algorithms based on random sampling [5] where images were formed by events in the time domain could thus be compared to more conventional image processing techniques where pixel information was grabbed in the spatial domain. This approach was very successful since we could then choose different optimized methods for different measurement situations. Measurements of absolute accuracy showed e.g. better performance if it was done in the time domain while measurements of line widths, i.e. critical dimension (CD), yielded better results using pixel data in the spatial domain. In figure 1 the principle design of the MMS15000 metrology tool is shown.

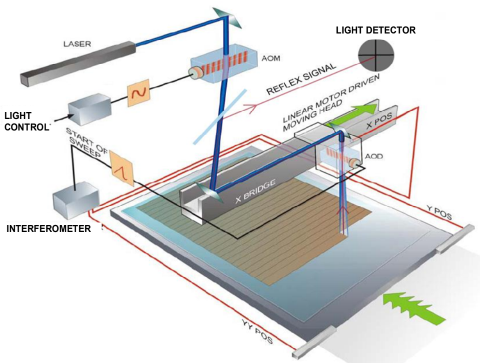
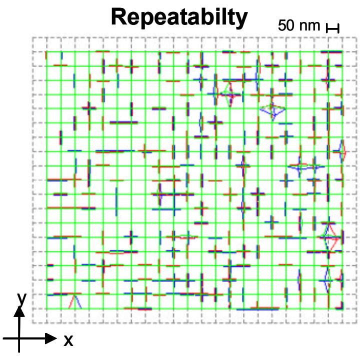


Figure 1: The principle design of the MMS15000 with the ultra precision laser beam deflection controlled by an acousto optic modulator (AOM) [4]. The reflected signal from a scanning blue laser beam (λ=448 nm) is picked up by a light detector. The output from the detector is processed by a specially developed image processing unit. The position of the Zerodur stage is controlled by interferometers. The whole stage is placed in a temperature controlled chamber with a maximum temperature variation of ± 0.01 °C.

2 Results

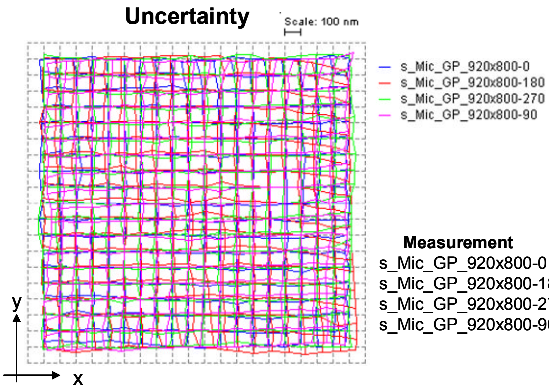
A special artifact called Golden Plate (GP) is used for calibration of the MMS15000. This is a quartz plate filled with a matrix of chromium measurement marks. The calibration procedure of the MMS15000 involves a very large number of measurements and takes several days to finalize. To achieve a good absolute accuracy it is extremely important to first establish a good measurement repeatability. [6] This is achieved by putting the GP on the stage for a sufficient amount of time for stabilization. During this so called soaking time a Z-height map is recorded that is later used by the Z-correction function. Depending on the actual area of the stage that needs to be calibrated a special placement scheme is used to optimize the measurements in order to acquire sufficient information for self-calibration of the stage using the Golden Plate. In each placement of the GP on the stage, several measurements are used for verifying the repeatability. In figure 2 an example of the measurement repeatability of three measurements is shown.



Meas.	X (3σ) nm	Y (3σ) nm
1	11	9
2	10	8
3	9	8

Figure 2: A demonstration of measurement repeatability in a dual scale graph and the obtained 3σ repeatability in X and Y in the table. The distance between two neighboring marks is represented by the dashed grid with 42 mm pitch while the local deviation around each mark is displayed within 50 x 50 nm^2 boxes. The results of three complete measurements, each taking 45 minutes to perform, are shown in the graph. The deviation in the table is shown relative the average position obtained from all three measurements of the respective mark.

After a finishing the self-calibration a compensation table is calculated and used for correction of the stage so the machine reflects a Cartesian coordinate system as good as possible. A verification of the calibration is then done by using the Golden Plate for re-measurement at four different rotations of the GP on the stage. By comparing the back-rotated (to zero degree) measurements we achieve a good estimate of the absolute accuracy of the calibration. In figure 3 a final verification of the stage is presented. The specification of the absolute accuracy is <90 nm (3σ).



Measurement	X nm (3σ)	Y nm (3σ)
s_Mic_GP_920x800-0	38	40
s_Mic_GP_920x800-180	60	74
s_Mic_GP_920x800-270	44	47
s_Mic_GP_920x800-90	59	53

Figure 3: An example of the verified absolute measurement uncertainty at 3σ in X and Y relative the Cartesian gridpoints obtained from the measurement of 390 marks on the GP after a self-calibration.
The covered area corresponds to 798 x 756 mm^2.

3 Conclusion

We have shown that it is possible to build a large area 2D measurement tool with a repeatability of around 10 nm (3σ) and an uncertainty in X and Y of better than 90 nm (3σ) over an area of 798 x 756 mm^2. The development was a success and the target of 90 nm uncertainty was achieved by the small project team. We believe that the tremendous force of this small group of dedicated people, where everyone felt a very high personal responsibility, was the reason for this success.

4 Acknowledgements

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