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In-Die Registration Measurement Using Novel Model-Based Approach for Advanced Technology Masks

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ABSTRACT

In recent years, 193nm immersion lithography has been extended instead of adopting EUV lithography. And multi-patterning technology is now widely applied, which requires tighter specification as the pattern size gets smaller on advanced semiconductor devices. Regarding the mask registration metrology, it is necessary to consider some difficult challenges like tight repeatability and complex In-Die pattern measurement.

In this study, the registration measurement capability was investigated on new registration metrology tool IPRO5+, and new measurement method called Model-Based measurement was

	IPRO4	IPRO5	IPRO5+
Tool Overview			
Wavelength[nm]/NA	360-410 / 0.55	266 / 0.8	266 / 0.8
Minimum Dense Pattern	1.0	0.50	0.41
Repeatability	1.0	0.60	0.43
Measurement Algorithm	Edge Threshold	Edge Threshold	Model Based
In-Die Measurement			

Figure 1. Overview of IPRO5+ and conventional tools.

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Editorial

"The Last Cinema in Paradise"

Naoya Hayashi, Dai Nippon Printing Co., Ltd.

The 22nd Photomask Japan (PMJ 2015) Meeting took place in April 20th to 22nd 2015 at Pacifico Yokohama International Convention Center, Yokohama, Japan. During the 2.5 day conference, we had 71 presentations, including 15 papers from the universities and academia. There were over 340 attendees, which exceeded last year's record by about 20%, and it was the best in the 4 years since the cancellation at 2011 due to the earthquake disaster. Is this a good sign of revitalizing the photomask industry? Or, did other factors work on it? May be the attractive entertainment programs?!

Well, DNP provided the 10th anniversary short movie at the banquet of this year's PMJ, titled "The Grand Kamifukuoka Plant". The motif is the movie titled "The Grand Budapest Hotel" by Wes Anderson released in 2014, which won 4 Oscar Awards. I mostly used the motif of Japanese movies in the past, but this time I selected this one because of a funny and interesting screenplay.

The original story is describing the life, adventure, and the bonds of the veteran concierge and a new lobby boy at the former famous hotel, named Grand Budapest. There is a secret society of the concierge to help each other when they have problems. However, this kind of independent, luxury hotel has been getting old, and getting pressure from the worldwide large hotel chains, then getting antiquated. This situation reminded me of the movie industry, where many large cinema complexes have been pushing good small independent theatres into trouble. Similarly, in our mask industry, huge captive maskshops have been pushing merchant maskshops into business challenges. So I described such story with an old fellow (me) and a new mask engineer in our Kamifukuoka Plant.

Let me explain the movie theatre world in a little bit more detail. Do you know the Honokaa People's Theatre in Big Island of Hawaii? The theatre was built by a Japanese immigrant named Mr. Tanimoto in 1930, and still on business by NPO, surviving the recession along with sugar cane business decline. In 2009, I learned about this theatre by a Japanese movie titled "Honokaa Boy", which was filmed at the theatre with a mostly Japanese cast, and made a strong impression on me. So, when I attended EIPBN 2012 conference in Big Island, I visited the theatre to watch a movie, and got a nostalgic and fantastic time at there. In 2014, the theatre raised a cloud funding to install the digital projector to continue to show new movies, no more provided with old 35mm film format, and I contributed. The funding was successfully closed with three times the money than was the target. The New York Times made a video article of this story, and you can watch in YouTube, titled "The Last Cinema in Paradise".

In Japan, the situation is about same. I also contributed to the cloud funding for the installation of digital projectors at Kawagoe La Scala, the only independent movie theatre in my town, and at Cinema Onomichi in Hiroshima. In addition, I knew the 101 years old theatre in Fukushima, named Motomiya Cinema Theatre, by coincidence. I made locations for my movie at those theatres, with their cheerful consent. I also found that there are very strong bonds between those independent theatres to share the information and resources to search for the way to survive. I am aware that such small movie theatres are very important place to gather, enjoy events, and communicate with the neighbors, similarly to what BACUS, PMJ, and EMLC do for our industry.

One more remarkable thing was that the managers of those independent theatres, including the one in Hawaii, are all women. They are excellent in managing local cultural activities. We should refer to their example to keep up our mask industry!

I believe that we have also very strong bonds across the mask industry as I described in my movie. The mask industry is niche, containing high business risk, but essential to the semiconductor industry. So then, we should preserve the bonds and try to maintain our mask industry for next generations. Photomask Forever!

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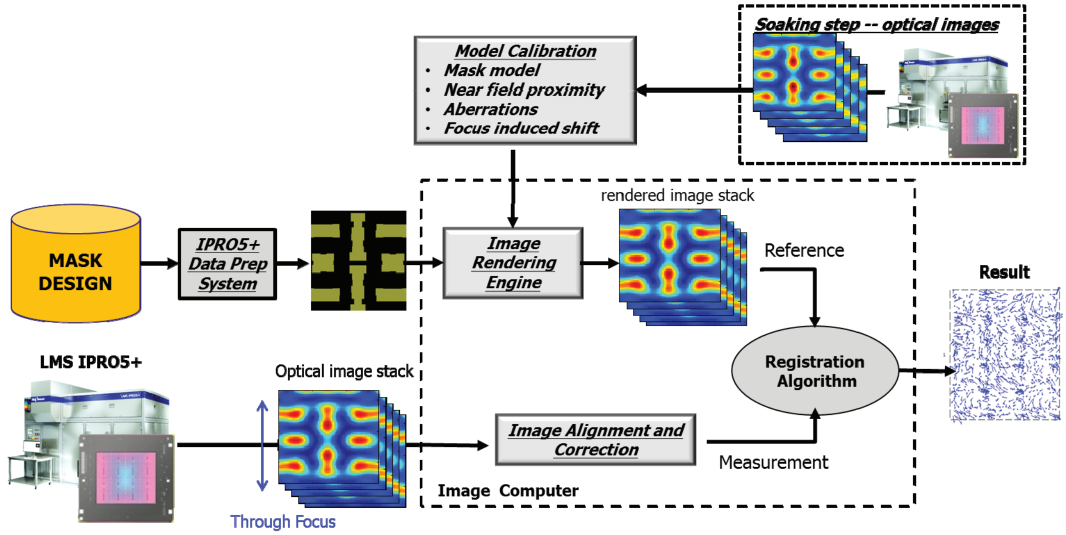

Figure 2. In-Die measurement flow with Model-Based algorithm.

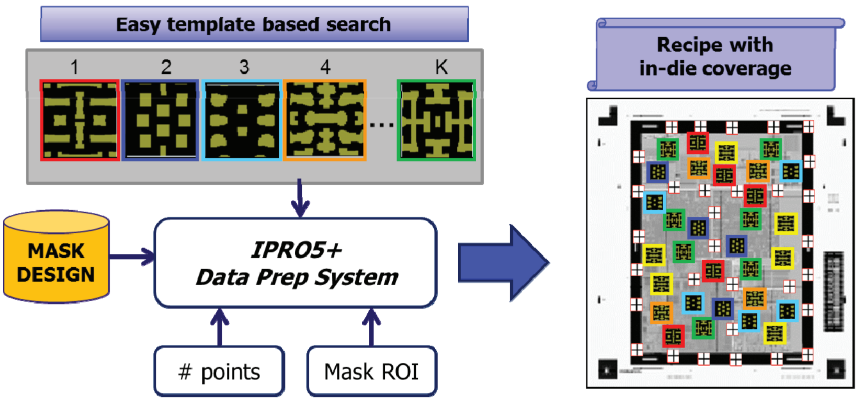

Figure 3. Recipe creation for a large number of In-Die measurements.

Table 1. Excerpt from ITRS Roadmap updated in 2012.

Year of Production	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
MPU gate in resist (nm)	47	41	35	31	28	25	22	20	18	16
DRAM/ MPU/ ASIC (M1) ½ pitch (nm) (contacted)	52	45	40	36	32	28	25	23	20	18
Image placement (nm, multi-point) [F]	6.2	5.4	4.8	4.3	3.8	3.4	3.0	2.7	2.4	2.1
Dual Patterning image Placement (nm) [F]	1.8	1.6	1.4	1.2	1.1	1.0	0.9	0.8	0.7	0.6
Mask image placement metrology uncertainty, P/T=0.1	0.62	0.54	0.48	0.43	0.38					

evaluated. And the performance and the prospect for advanced technology masks of the IPRO5+ were discussed based on the evaluation results.

1. Introduction

Technical demands for the scaling of semiconductor devices have been consistently tough. Recently, expectations of 193nm ArF immersion lithography extension has been increased as the release of EUV exposure tool delays. Therefore multiple patterning technique has become a mainstream at advanced technology node such as 14nm and 10nm logic devices. This multiple lithography requires a numerous challenges on mask registration. The image placement error needs to be below 4nm for each mask as represented in ITRS roadmap[1](Table 1).

Then, registration metrology will be also difficult to accomplish a precision-to-tolerance (P/T) ratio below 0.1. Moreover, mask registration is required to be measured on not only a simple monitor pattern but also more complex in-die pattern features. However, enough arguments about real In-Die registration signature haven't been considered. A presented paper advocated mask registration error can be divided into noise and systematic components including pattern dependent error.[2] And the other paper also indicated that there are different shift between monitor mark and In-Die mark.[3] This pattern dependency is one of the error factors which degrades wafer overlay. So it is essential to find registration tendency of intra-field by pattern dependency and to measure In-Die pattern more accurately. Furthermore, a method to set up a large number of measurement sites is expected to find whole mask registration trend.[4] For the problems to be solved, we will show some evaluation results and findings for Toppan's solutions using IPRO5+ and Model-Based approach in this work.

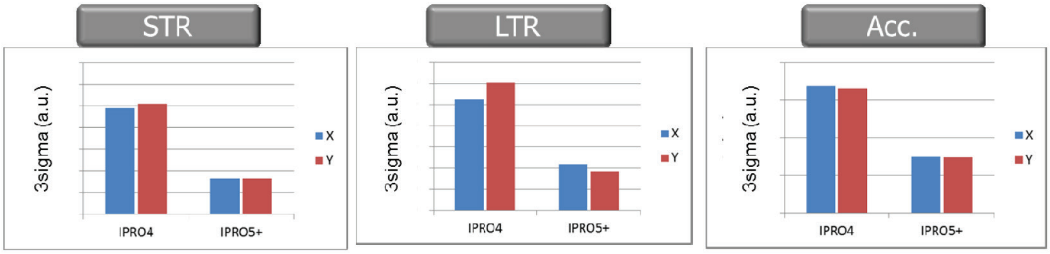

Figure 4. Repeatability and Accuracy at cross mark.

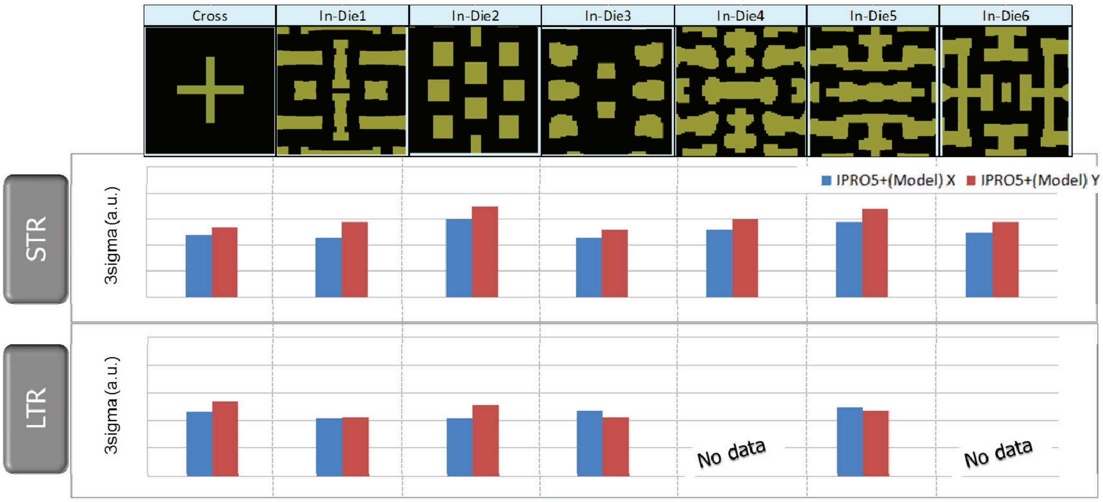

Figure 5. Repeatability of cross and In-Die features measured with Model-Based method.

At first, repeatability and accuracy performance of IPRO5+ were compared with old generation tool. Then, it was investigated whether the performance of Model-Based measurement would satisfy enough precision by measurements of several In-Die features. Furthermore, measurable feature size was investigated by several test pattern features. Finally, registration measurement was conducted to confirm if the registration signature differences exist between monitor pattern and In-Die pattern by production mask measurements, then a potential risk which may affect a wafer overlay was investigated.

2. Overview of IPRO5+

IPRO5+ developed by KLA-Tencor is new mask registration measurement tool, and the tool is targeting 20nm or 14nm node devices. The remarkable improvements on IPRO5+ from old generation tool IPRO4 are repeatability and accuracy as shown in Figure 1. 266nm Ar laser and high NA lens contribute progress of resolution limit. The minimum dense pattern size was 0.41 if we normalize IPRO4 value to 1. Compared with IPRO5, IPRO5+ is about 20% better due to measurement algorithm improvement. As for the repeatability performance, IPRO5+ is over 50% better than IPRO4 and 30% better than IPRO5.

Model-based measurements are unique feature of IPRO5+. This approach allows for measuring actual In-Die pattern in the intra-field area accurately. Figure 2 shows In-Die measurement flow by Model-Based algorithm which shares components with Die-to-Database mask inspection algorithms. The Data Prep system in IPRO5+ processes the mask data in various formats to find and clip appropriate in-die measurement sites from the design. Once the measurement recipe is prepared, the reticle is loaded in the tool. And while the plate is acclimating to the chamber temperature during soaking time, through-focus optical measurements are done on a small subset of measurement sites. This optical data is the processed in an image computer to train a model that can describe the optical behavior of mask as well as the tool itself. Once models are calibrated, the actual registration measurement begins and the expected image of the tool at each measurement site is computed by the appropriately calibrated imaging model. The image placement error for each site is calculated on the image computer in parallel to the data acquisition by the tool to deliver a fast and scalable architecture. It's an advantage for the Model-Based algorithm that arbitrarily complex features can be measured with flexible Region of Interest (ROI).

To apply the In-Die measurement method, there are 2 things which need to be considered. One is how to set up a large number of measurement sites, and the other is how to generate the measurement recipe. As explained above, there is the demand to get more measurement sites. Then, IPRO5+ provides the functionality to easily search for the measurement sites. Concept of this function was shown in Figure 3.

If the user chooses the measurement features as template from mask design, a number of measurement points, and Region of Interest, IPRO5+ Data Prep automatically selects adequate measurement sites from a whole mask. Moreover, Data Prep can

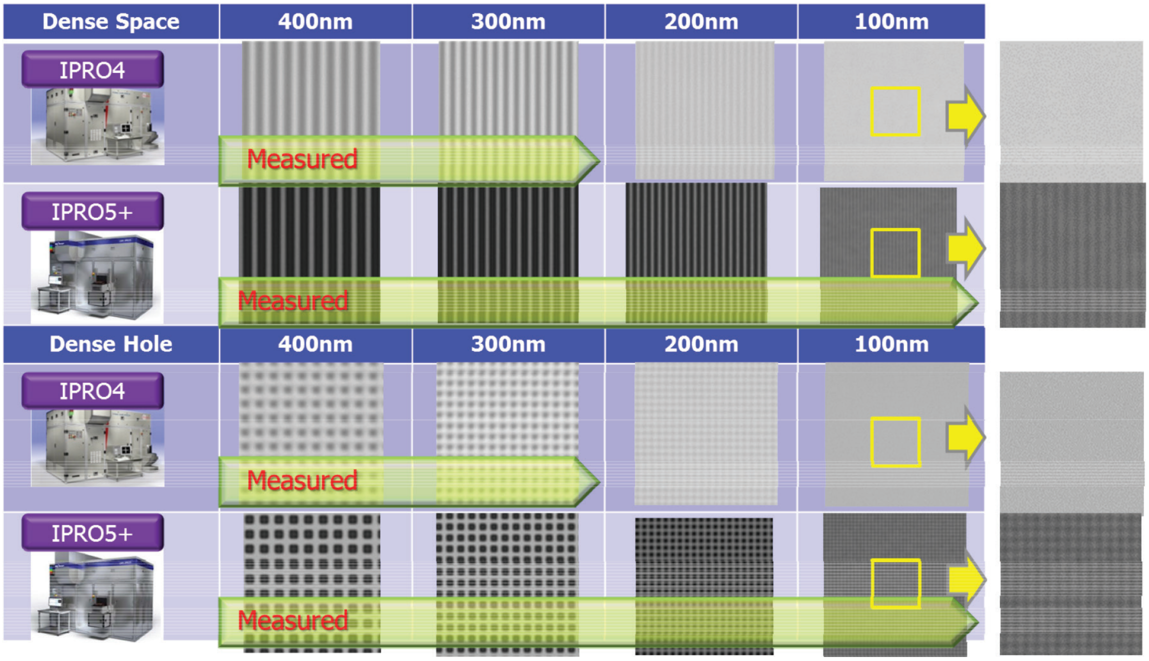

Figure 6. Captured images and measurable size.

create measurement recipes linked with template images. So these functions made it possible to generate In-Die measurement recipe very easily.

3. Experimental Results as Solution

3.1 Repeatability and Accuracy

First of all, basic tool capability of IPRO5+ was shown in Figure 4 using simple cross mark. The performance was compared to previous generation tools. Measurement conditions of this task are;

- Short Term Repeatability (STR) : 11x11 grid, 20 loops,
- Long Term Repeatability (LTR) : 11x11 grid, 10 loops x 2 days
- Accuracy (Acc.): 11x11 grid, 10 loops x 4 rotations

Then, edge threshold method has been used with conventional tools. In this task, though IPRO5+ has both edge and Model-Based algorithm, the edge threshold algorithm of IPRO5+ was applied in order to definitely compare with IPRO4. Vertical axis of Figure 4 shows 3 sigma value represented by arbitral unit. The graph of blue bar is X and red one is Y, respectively. From these results, the repeatability and accuracy performance of IPRO5+ were improved, 55~75%. Especially, STR performance is 3 times better than IPRO4. These results can be expected to satisfy the advanced technology demands.

Then, In-Die registration measurement capability was investigated by using Model-Based method. Figure 5 shows the designs which were applied for measurement test. Cross mark is a very common pattern which is historically applied for registration measurement. In-Die 1 and 2 are similar to SRAM pattern of metal and contact, respectively. In-Die 3 to 6 are designed feature like Source Mask Optimization (SMO) logic pattern. Upper graph illustrates short term repeatability and lower one is long term. From these results, it is clear that Model-Based method could measure on all In-Die patterns even if the target pattern has very complex shape. Regarding In-Die 4 and 6 results in LTR, the measurement was not conducted.

From these results, no STR and LTR performance difference were confirmed between cross mark measurement and In-Die features measurement. Therefore, the results means that Model-Based of IPRO5+ has great capability for In-Die measurement.

3.2 Resolution

As a next evaluation task, pattern resolution was compared between IPRO4 and IPRO5+, and measurable feature size was investigated based on the contrast of the captured images. For this evaluation, 1:1 two different patterns like dense line/space and dense hole with several size variations were tested. The results were shown in Figure 6.

Upper row is IPRO4 and lower row is IPRO5+ for each features. From these images, IPRO5+ images are clearer and more contract than that of IPRO4. The expanded images of 100nm size were shown in the right side of Figure 6, IPRO5+ can resolve the pattern in spite of 100nm feature size. Furthermore, the green bars in Figure 6 are illustrated as measurable feature size. In fact, although IPRO4 could not measure smaller than 300nm, IPRO5+ could do down to 100nm without any problem. Therefore, IPRO5+ has enough resolution capability of measuring such a small pattern size.

3.3 Overlay

At the last part of evaluation, we present a mask-to-mask overlay measurement using real production plates was conducted. In this work we chose two layers from advanced node logic plates, contact and metal. Figure 7 shows the registration signatures of these 2 masks and also overlay between them. The measurement target patterns are monitor pattern and three different shapes of In-Die patterns. All maps shows image placement error of X direction to compare the whole mask trend. The positive values of image placement error were indicated as red, and negative ones were blue, gradationally. And black dots represent measurement sites on each feature. In terms of sampling number, 140 sites were set up for each In-Die patterns. It means the registration measurement on 420 In-Die patterns was successfully conducted. This number of the measurement sites is much larger than the number of monitor

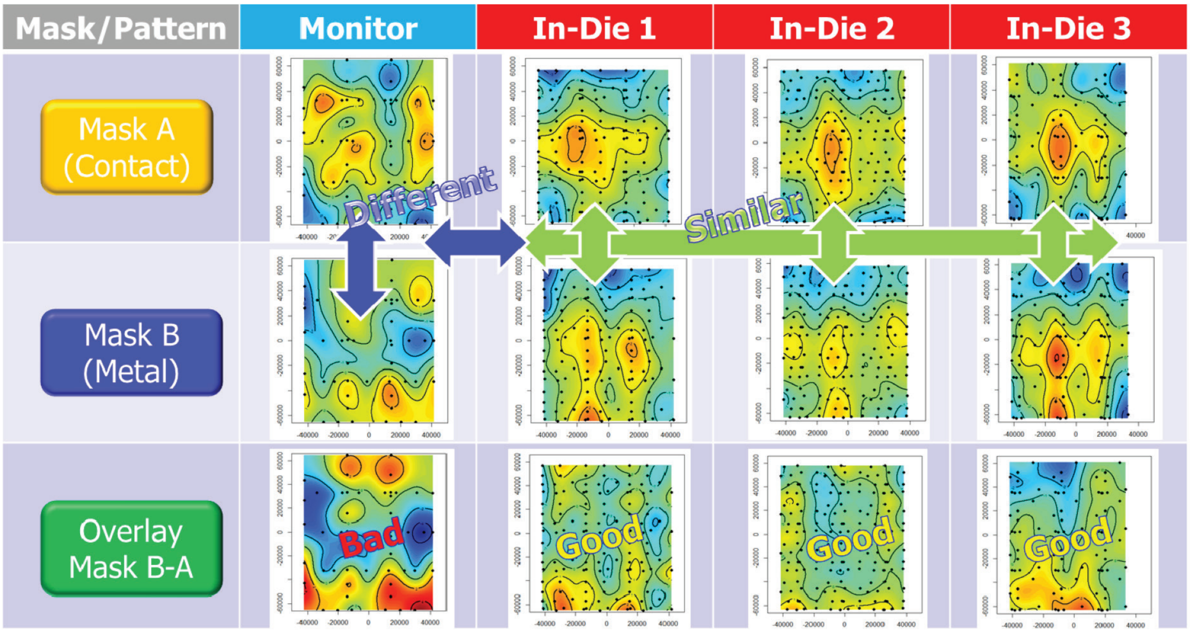

Figure 7. Registration signatures extracted image placement error of X direction.

mark which is only 50. Therefore, it was found that a large number of measurement sites to know whole mask trend could be achieved by applying In-Die pattern measurement. Furthermore, several facts were observed from these results.

This figure indicates that registration maps of monitor marks are different between two layers. It follows that overlay map of monitor mark seems to be bad. On the other hand, registration maps of In-Die patterns are similar not only among the measured pattern types of each layer, but also between layers. This makes In-Die pattern overlay maps to be significantly better than that of monitor marks. From the result, it is assumed that the historical measurement method which measures only monitor marks may lead wrong assessment of mask image placement quality.

Finally, all results above were analyzed. Figure 8 shows statistical values of Figure 7. In the top row, yellow and blue bars represent mean shift from design on each layer, if aligned to the monitor marks. The green bars represent mean shift of overlay. Using monitor marks to match wafer overlay is supposed to be identical to what wafer fabs are doing today. Hence, it can be seen from green bar value, mean value differences were found between monitor and In-Die patterns. This brings on an overlay quality issue in the real device features.

Now, what happens if you adopt the average of mean shift values among three In-Die overlay results as alignment? It may be presumed that the wafer overlay will be dramatically improved as purple bars. In other words, the result indicates wafer fabs can reduce a mean shift of In-Die feature by finding mean difference.

Then, in respect to 3 sigma values on the next row, the overlay result of Monitor pattern is worse than that of In-Die pattern due to the signature difference between contact mask and metal mask. On the other hand, the overlay results of In-Die patterns are good due to similar signature between 2 masks as shown in Figure 7. Comparing 3 sigma of In-Die with that of monitor, it was found In-Die overlay were about 40% better than monitor overlay. As a result, it was confirmed that the Model-Based In-Die measurement could reveal real overlay signature. Regarding registration error budget, a presented paper indicated that mask registration error can be divided into several factors.[2] One of them is a global signature error which consists mostly of mask registration error. And other paper showed that high order correction function of scanner was effective way to improve wafer registration.[5] Therefore, it is expected that wafer overlay can be improved by the correction function of scanner if the signature difference between monitor mark measurement and In-Die pattern measurement is utilized by a similar way to mean shift calculation. This is quite an eye-opening discovery.

4. Summary and Conclusion

In this paper, we showed several experimental results as Toppan solution using IPRO5+ and Model-Based approach. Regarding precision, we found the performance of IPRO5+ is 3 times better than IPRO4 about STR at simple cross pattern. Moreover Model-Based measurement could measure registration on any complex In-Die features with same accuracy as simple cross mark in terms of STR and LTR. As for sampling solution, Data Prep enables users to easily search for several In-Die patterns from mask design without any difficulties. As a result, high sampling In-Die pattern measurement was achieved by using this function.

In addition, these results clarified that the real In-Die registration signature is different from the signature of monitor marks. Furthermore, the overlay 3 sigmas of In-Die patterns were 40% better than monitor pattern's overlay. It seems reasonable to consider that applying In-Die registration signature for scanner correction will make wafer overlay improved. In conclusion, it is highly expected In-Die measurement with IPRO5+ has potential to help wafer fabs to improve wafer overlay.

5. Acknowledgement

The authors would like to appreciate strong support of Dr. Kokoro Kato, closed collaboration of KLA-Tencor members, and hard work of Toppan Asaka team in this evaluation.

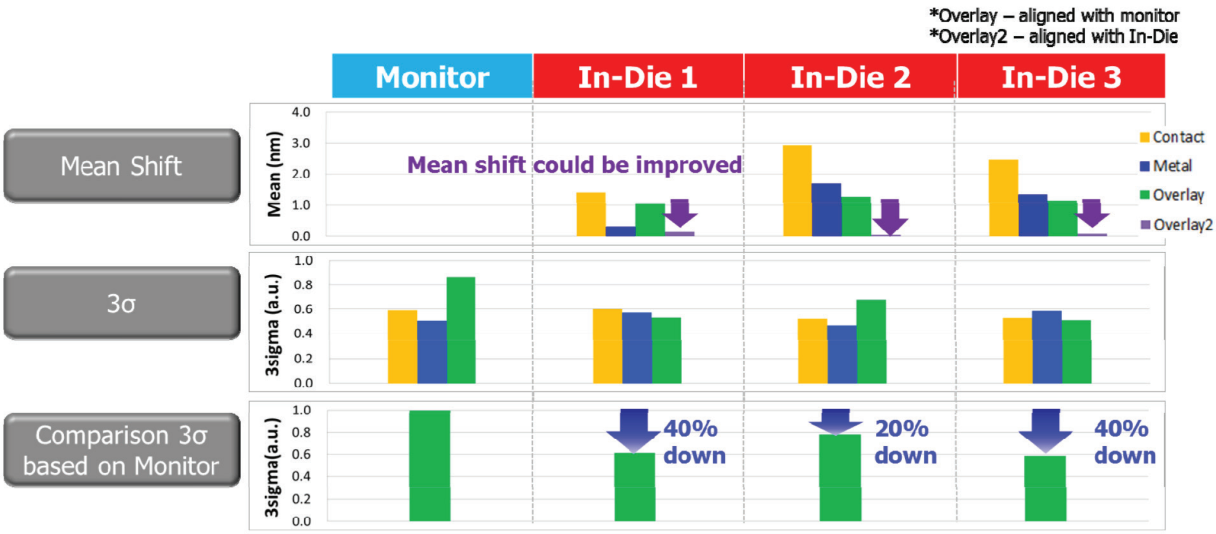

Figure 8. Statistics values of registration result.

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Industry Briefs

Semi Industry is Now Mature

By: **Dick James,** *Senior Technology Analyst, Chipworks,* Solid-State Technology, June 2015

The Confab, an industry get-together organized by Solid State Technology as the “Semiconductor Manufacturing & Design Industry’s Premier Conference and Networking Event”, in its panel discussion indicated that in the major segments we’re now down to three players. That’s a sign that those segments have probably consolidated as much as they can, in the same way as the auto industry has consisted of three significant players in each continental market (three in North America, three in Europe, etc). So in DRAM we have Samsung, Micron, and SK-Hynix; in flash we have Samsung, Micron, SK-Hynix, and Toshiba/Sandisk: and in leading-edge logic we have Samsung+GLOBALFOUNDRIES, Intel, and TSMC.

This point continues that now we are a mature industry and the business will tend to follow the world economic cycle rather than the capacity-based boom/bust cycles that we have seen in the first few decades. This makes sense from the mile-high perspective – we have all seen the changes in the customer base from the defense and computer industries, through the PC era, to a largely consumer-driven set of products – Apple is now the largest buyer of silicon chips in the world, after all.

In the final presentation – “Are IC industry cycles dead or just sleeping?” the conclusion was that they are likely sleeping, but the trigger has changed from chip-making overcapacity or shortage, to whether world GDP goes positive or negative. The correlation between worldwide GDP and IC market growth is now better than 0.9, compared with 0.35 back in the eighties. This trend is likely a result of the consolidation of companies, combined with the move to fabless and fab-lite, and its consequent tighter control over Capex; and, last but not least, the lack of disruptive new entrants to build mega-fabs and add over-capacity. China has had its play, India does not seem to want to get into that end of the business, and the Russian economy doesn’t seem to be up to it.

So, while we will see periods of growth and recession, likely amplified for our business since we are now so tied to consumer cycles, hopefully we won’t see the disruptive/destructive ups and downs that old-stagers like me have seen every three – five years in the last four and a half decades. There will be challenges, and it’s hard to see beyond 2020. We are now in the 14nm era in logic processes, and in five years (assuming a two-three year gap between generations) we will be ramping up seven-nm and heading for five.

In DRAM, Samsung has three 1x-nm nodes in their roadmap, possibly spread over five years, and flash is already at 14 – 16nm and moving to vertical – but how long will that last? Theoretically, v-NAND could shrink from its current ~40nm node down to ~15nm, with more layers stacked together.

All this might indicate that the technology is going to run out of steam. We’ve had these thoughts before, mostly due to mis-perceived lithography limits, but now we’re getting to the point where there may not be enough atoms or electrons to do what we want to do. Of course the research consortia are busy looking at ways of getting past this apparent impasse, it’s just that there seem to be quite a few options and no clear winner. And all the above doesn’t even consider the possible introduction of EUV and/or 450mm wafers.

Time will tell, but we do live in interesting times, and it’s not going to change.

IC Manufacturers Close or Repurpose 83 Wafer Fabs from 2009-2014

Solid-State Technology, June 2015

Since the global economic recession of 2008-2009, the IC industry has been on a mission to pare down older capacity (i.e., ≤200mm wafers) in order to produce devices more cost-effectively on larger wafers. From 2009-2014, semi manufacturers have closed or repurposed 83 wafer fabs, according to data in IC Insights’ *Global Wafer Capacity 2015-2019* report.

41 percent of fab closures since 2009 have been 150mm fabs and 27 percent have been 200mm fabs. Qimonda was the first company to close a 300mm wafer fab after it went out of business in early 2009. More recently, ProMOS and Powerchip closed their respective 300mm wafer fabs in 2013.

Semi suppliers in Japan have closed 34 wafer fabs since 2009, more than any other country/region over the past six years. In the 2009-2014 timeframe, 25 fabs were closed in North America and 17 were shuttered in Europe. Fab closures surged in 2009 and 2010 partly as a result of the severe economic recession. A total of 25 fabs were closed in 2009, followed by 24 being shut down in 2010. Ten fabs closed in 2012 and 12 were removed from service in 2013. Six fabs were closed in both 2011 and in 2014, the fewest number of closures per year during the 2009-2014 time span.

Calendar

2015

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29 September-1 October 2015
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