WAMA™ - a method of optimizing reticle/die placement to increase litho cell productivity.

Created by: Amos Dor, Yoram Schwarz

Rev number: 1.0

ABSTRACT

This paper focuses on reticle/field placement methodology issues, the disadvantages of typical methods used in the industry, and the innovative way that the WAMA software solution achieves optimized placement. Typical wafer placement methodologies used in the semiconductor industry considers a very limited number of parameters, like placing the maximum amount of die on the wafer circle and manually modifying die placement to minimize edge yield degradation. This paper describes how WAMA software takes into account process characteristics, manufacturing constraints and business objectives to optimize placement for maximum stepper productivity and maximum good die (yield) on the wafer.

Keywords: yield improvement, lithography, throughput, productivity, placement, reticle, shotmap, scanner and stepper.

1. INTRODUCTION

If we could predict the yield potential of every point on the wafer, we could skip printing die in locations that have very low yield prediction, and decrease production time. WAMA methodology consists of using the minimum number of shots to produce the optimum number of devices on the wafer. (Device is similar to product, in this context.) This achieves the best productivity and/or maximum number of good yielding die per minute. WAMA also places fewer die in low yield hot spots, and increases the total die yield on the wafer. WAMA places alignment marks and blading (mark shielding) in areas that have low yield prediction, saving better areas for good die. The bottom line is that WAMA can save money and increase productivity if it can predict the process systematic yield on each point on a wafer, and if it can find the placement that minimizes the time it takes the stepper to flash all reticle shots.

1.1 Definitions

a) **WAMA:** PDF Solutions software tool to optimize shot maps. The name *WAMA* is an acronym for Wafer Mapping.

b) **Systematic yield failures:** Area on the wafer that has low yield and low deviation.

c) **Wafer Objects:** Equipment in the FAB that interacts with the wafer or has yield impact on the wafer. An example of a wafer object might be a clamp that holds the wafer in one of the manufacturing stages.

d) **Configuration file:** WAMA Data file that describes the yield distribution across the wafer, the placement methodologies and the impact different manufacturing processes have on yield.

e) **EBR:** Area on the edge of the wafer where yield is zero, typically three mm from the edge.

f) **Gross Die**: Number of complete die on the wafer in radius of radial exclusion, exclude dies on defined zero Good Dies regions (Flat, ID area, Mark shielding, Blading).

g) **Good Die:** Average of good die per wafer. Counted as the sum of yield on the wafer.

h) **Blading**: Partial blocking of reticle area during exposure, to protect alignment marks.

2. GENERAL

The WAMA toolset by PDF Solutions, Inc. is designed to optimize wafer placement by understanding the real yield map, using process object location, yield modeling for each object and mature products yield data to predict yield potential at each point on the wafer.

Recent evaluations performed by PDF Solutions utilizing the WAMA optimization tool, demonstrated that by taking into consideration parameters like known areas with low or zero yield (clamps, crowns, alignment marks, blading), and by considering the existing yield data of the process (yield on each point on the wafer), it is possible to find a placement which can increase the fab productivity by an average of 5%, and also increase the total good die produced by an average of 2%. Typically, yield improvement was 1%-3%, but in some cases it reached 16%.

This evaluation demonstrated that productivity (die per minute) is greatly improved by the optimized placement (by taking in to consideration the overhead of printing low yielding die, and by minimizing stepper shots). Typically, yield improvement was 3%-5%, but in some cases it reached 17%.

On 8” wafers with a total 1,000 of yielding die, it was common to get about 7% improvements in productivity or 5% improvement while keeping the same number of gross die. This can be translated to more die shipped, with no added equipment costs.

It also was demonstrated that in some cases, Fabs are losing time and money by printing reticles that provide negative return on investment.

The WAMA evaluations demonstrated that current wafer placement methodologies common in most semiconductor fabs fail to take full advantage of the wafer.

3. WAMA BENIFITS

WAMA benefits vary, depending on the type of optimization you run. They include five main areas the customer can use to increase profit, productivity and savings.

3.1 Benefits

a. **Stepper Time** - Reduce overall stepper time per wafer (all layers) while keeping the same number of good die.

   Typical results: 3% to 5 % improvement in litho cell productivity. Best results on small die yet if depends on how good of a job was done to place that product. Greater advantages can be achieved with small sacrifices in good die per wafer (less than 0.5%).

b. **Good Die** - Increase potential good die per wafer without sacrifice to litho cell throughput.

   Typical results: 1% to 3 % improvement in good die per wafer. Greater advantages can be achieved with small sacrifice in stepper time.

c. **Gross Die** - Maximize gross die per wafer

   Typical results: 1% to 3 % improvement.

d. **Test Time** - Reduce test time per wafer – higher prober throughput

   Typical results: 4% to 6 % improvement. Applies to multi-site probe heads. Best results when flexibility allowed in probe head configuration.

e. **Profit** - Increase overall Fab profitability both for litho cells and test cells.

   Typical results: 3% to 4 % improvement.

4. **WAMA YIELD MODEL**

The WAMA Optimization can be prioritized and divided for maximized productivity, gross die, average good die, stepper/scanner time and stepper shots. WAMA optimizes the prober for minimum touchdowns and optimal probe head configuration. The first step to optimize your placement will be to understand your current yield map per process. To do so, we can use two methods: construct a yield map based on a process object such as clamps, EBR, etc.; or use sort data from a number of products per process. WAMA allows you to use these methods or to load a pre construct yield profile for various process technologies.

4.1 WAMA Map Editor

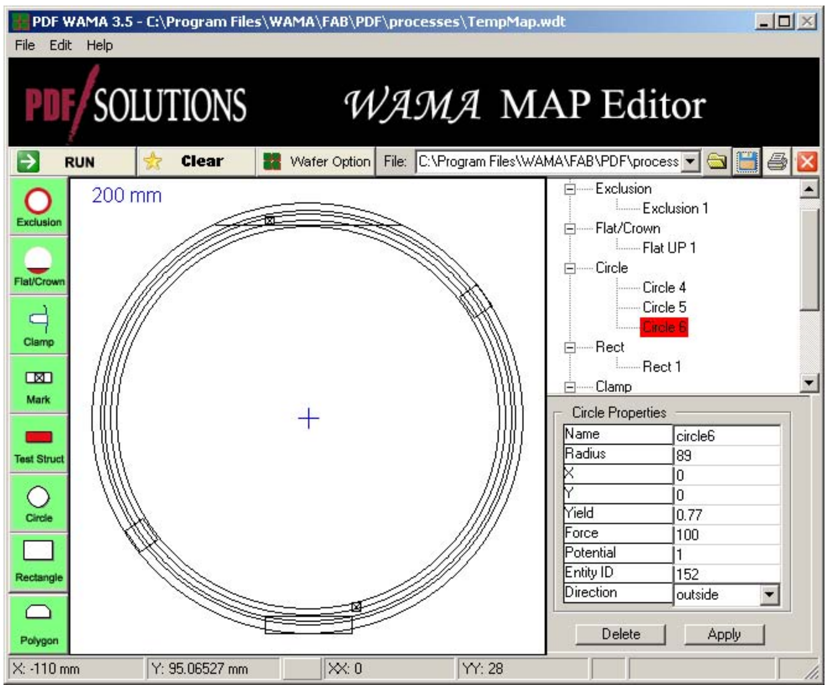

Figure 1: MAP Editor is used to build a good yielding area map.

WAMA Map editor is used to characterize and simulate process yield maps. You can use the editor to create the following objects:

(1) Flat – Flat or crown object on the top, bottom, left or right of the wafer
(2) Wafer ID – usually a rectangle in which the scribe number is printed
(3) Alignment marks – static alignment mark locations
(4) Backup marks – dynamic alignment mark areas in which WAMA will find the best place for those marks.
(5) Clamps – Clamps can be in the EBR or inside the "good" wafer area
(6) Exclusion areas – typically the EBR or some hot spot with yield degradation.
(7) Test structures – test structure location
(8) CMP rules – Rules on areas and when to put partial shots
(9) Blading rules – Rules on blade type and when to blade

Once you position all objects and rules, you can compile the process file. You can also use the system to import SORT data from *data*POWER or from predefine yield profiles. Each yield profile represents the average yield distribution per process, using the vast experience of WAMA, more than 30 fabs and hundreds of products.

4.2 WAMA Yield Model

To get a more accurate model of a customer process yield map, WAMA uses a method of composite mapping. With this method, WAMA collects sort data of mature products and superimposes the data on a fine pixel wafer map (Fig. 2)

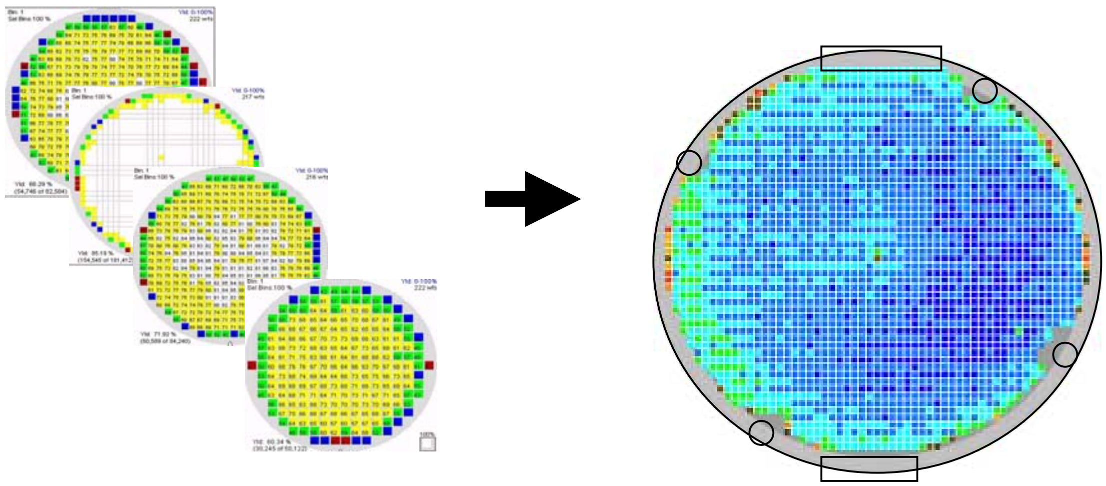

Figure 2: Wafer process map, stacked map of multiple products of the same process.

The composite map is merged with wafer object data (clamps, crowns, test structures, alignment marks, halo effect) coming from the map editor. WAMA uses its predefined predicted yield potential to optimize the placement for maximum productivity or any other optimization that considers increasing the number of good die. Process methods like blading, penumbra effect, CMP dummy prints and stage limitations are also imposed on the process map for best optimization.

WAMA builds a composite map per each process and saves it for later product optimization. Once a product is loaded or a new product is created, it is decided to which process this product belongs.

The WAMA optimization can be prioritized and divided for maximized productivity, gross die, average good die, stepper/scanner time and stepper shots. WAMA optimizes the prober for minimum touchdowns and optimal probe head configuration.

WAMA libraries include set of world-class yield profiles for most technology nodes. *data*POWER w/WAMA enables customers to generate a more accurate yield map. Once the yield map is loaded WAMA can generate a shot maps based on selected minimum yield thresholds. The threshold methodology is also applicable for products that use speed binning or other yields correlated factors.

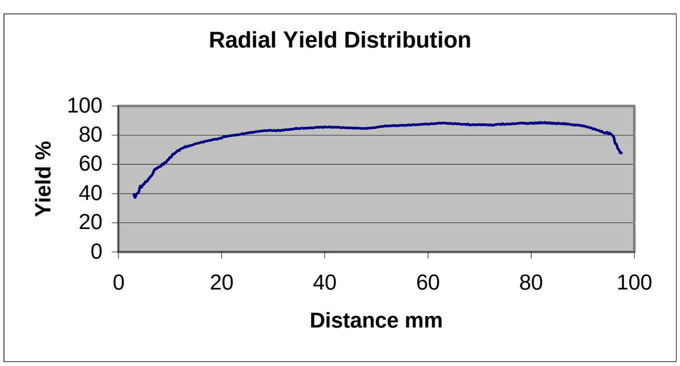

Figure 3: This graph represents the average radial yield from the edge of the wafer.

5. RUNNING WAMA

When running WAMA Optimization, the user can choose to run different type of optimizations. The most common optimizations are: maximum productivity, maximum gross die and maximum good yielding die. Advanced users can optimize the placement for any of the above, while adding targets for other parameters. For example, users can optimize for productivity, while not allowing the number of gross die to fall below a set value.

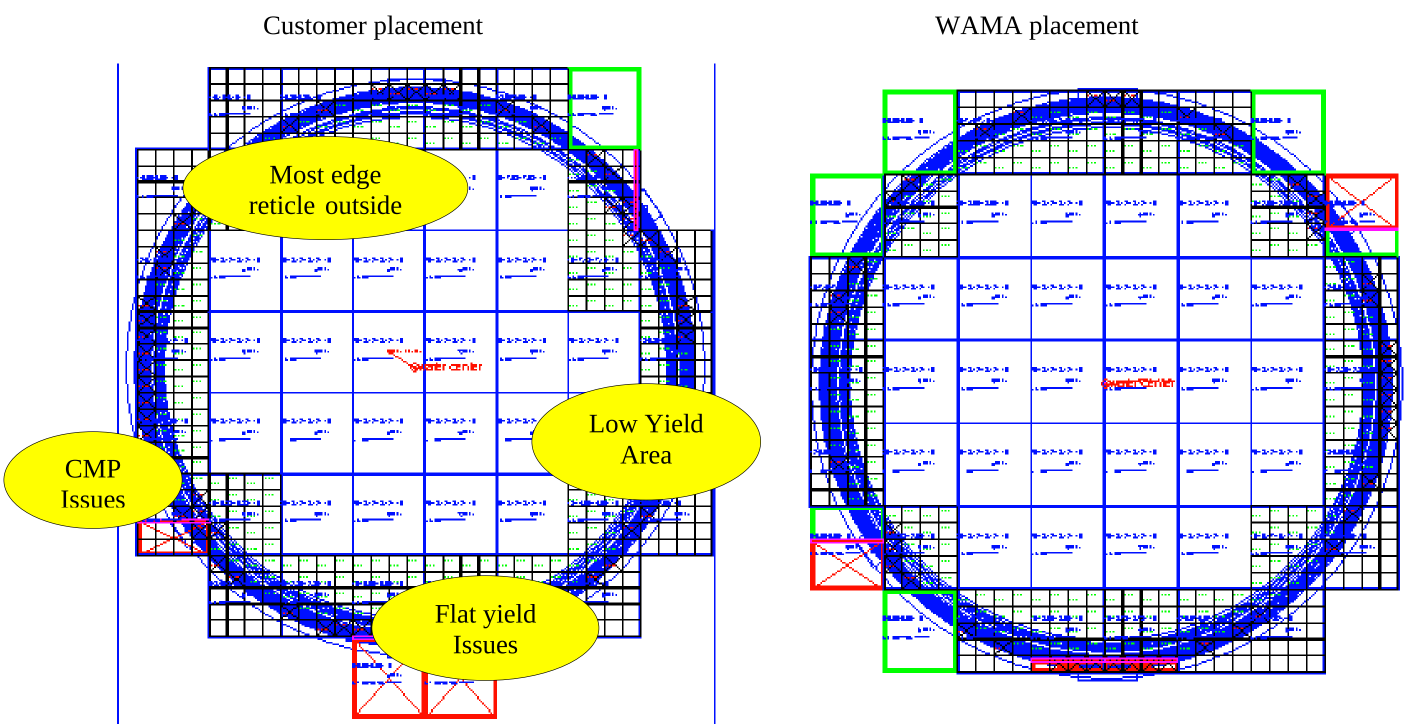

Figure 4: Side-by-side placement before and after WAMA optimization. This example shows an improvement of more than 5% in the number of die-per-minute that the fab can generate for this product.

Recent evaluations performed by PDF Solutions utilizing the WAMA optimization tool demonstrated that by taking into consideration parameters like known areas with low or zero yield (clamps, crowns, alignment marks, blading) and existing yield data of the process (yield on each point on the wafer), it is possible to find a placement which can increase the fab productivity and the total good die.

3.1 How much should you except to improve using WAMA

Stepper Time - Average of 5% was measured on more than 30 evaluations. WAMA optimization reduced the overall stepper time per wafer (all layers) while keeping the same number of good die.

Good Die - 1% to 3 % improvement in good die per wafer. Greater advantages can be achieved with small sacrifices in stepper time. WAMA predicted the yield for each device using the multi dimension yield model.

Gross Die – Average of 2% improvement in gross die per wafer. Greater advantages can be achieved with small sacrifices in stepper time. WAMA optimizes for maximum die in all areas that don’t have wafer objects with zero yield.

6. ADVANCED FEATURES

Up to this point, the paper has focused on ways to use WAMA Optimization to maximize productivity, maximum gross die and maximum good yielding die. For most products these basic capabilities are good enough to increase fab profitability and to gain millions of dollars in revenue. Yet some customers are using the WAMA system for much more advanced features, such as mix and match, multi layer reticles, multi product reticles and bricking.

1) **Mix and Match** – When using a mix of different steppers/scanners to produce a product, matching different size reticles can be a very difficult problem. WAMA can help to avoid stage limit problems (see figure 5) by making sure that masks can be printed on all layers and can use any stepper/scanner as designate. More than this, WAMA can help you get the maximum die count and throughput for this product.

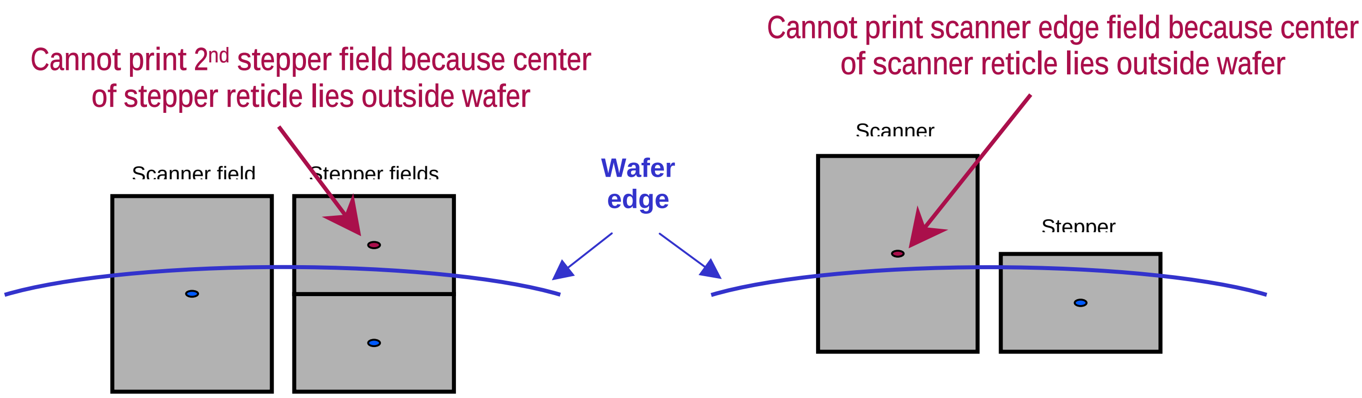

Figure 5: This chart shows the problems that can occur when optimizing the placement for one stepper only.

2) **Multi layer reticles (MLR) –** Today's mask costs are very high. To reduce costs, it is possible to decrease the number of masks and have one mask for several layers. When using this method, the same problems may be encountered as described in the mix and match method. WAMA can help create the stepper job for different layers quickly and without violating stage limits.

3) Multi product reticles – High mask costs can also be mitigated by decreasing the number of masks and using one mask for several products. This method is also called "Shuttle". When using this method, the same problems may be encountered as described in the mix and match. WAMA can help create the stepper job for different layers quickly and without violating stage limits.

4) **Bricking –** Bricking shifts some of the reticle columns or rows to allow more die on the wafer. It does work, yet it makes the metrology job creation much more complicated. The types of shifts that WAMA software supports are Brick, Marked and Edges

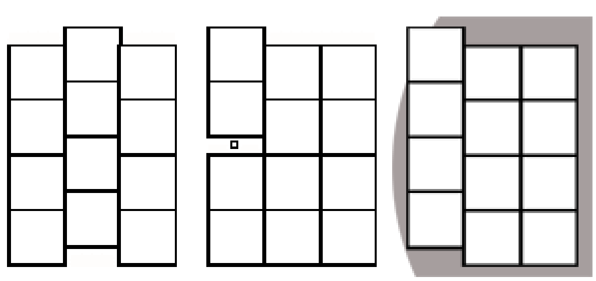

Figure 6: This chart shows the different shift methods allows using WAMA

7. ROI MODEL

To translate WAMA improvement to fab profit we took an example of an average fab producing 30,000 wafers a month. We assume that this fab will use WAMA only on 25% of its products and that out of those products only 25% of them are litho limited. So, when the stepper is the bottleneck, only those products will be optimized by WAMA and only those products will contribute to that improvement.. The table below shows that the average of WAMA improvement can be more than eight million dollars in the first year. Each year you should assume that more products would be using WAMA placement, so the benefits should increase.

This model takes into account that not all products will be optimized, not all product are litho limited and that there might be some gross die loss on a wafer when you optimize for productivity. The model also takes into account the cost of testing, the average yield in the fab, die price and the cost of wafers.

ROI Input:	
Number of wafers produced in a month	30000
Average # of die on a wafer	2000
Average Die Price	$10.00
Average yield	90.00%
Wafer processing cost	$1,500.00
Yearly product adoption rate	25.00%
Wama Productivity	
Average Productivity Increase	5.00%
Average good die reduction	0.00%
Wama Yield	
Average good die increase	2.00%
Average productivity reduction	1.00%
Test	
Cost of Test and packaging	$1.00
Constraint	
Manufacturing constraint - Litho	25.00%
Manufacturing constraint - (NOT Litho)	25.00%
Demand constraint	50.00%
First Year Predicted Profit Increase:	**$8,268,750.00**

Figure 7: Monthly savings per 5% of productivity improvement can translate to more than 8 million dollars in increased revenue in the first year of using WAMA. This profit should be greater in the following years as more products will use WAMA placement.

8. SUMMARY

Wafer placement techniques used in the semiconductor industry are basic and leave a wide gap for improvements. The WAMA optimization tool improves reticle/field/die placement, and demonstrates significant productivity and yield improvement by analyzing mature products yield maps combined with predefined yield regions, to predict future yield on new products. WAMA optimization is used on hundreds products all over the world in IDMs and foundries, It helps customer achieve an average of 5% productivity improvement, translating to millions of dollars every quarter.

8.1 Main WAMA Benefits:

- Stepper/scanner throughput increase without losing any die
- Maximize gross die per wafer and good die per wafer
- Compatible with all major stepper and prober brands
- Supports any wafer sizes
- Fast implementation with no changes to the manufacturing process
- Open architecture to enable centralized solutions
- Fast return on investment; WAMA value can be demonstrated in the first production run

Contact information

4.1 Authors

Name: Amos Dor
Company: PDF Solutions, Inc.
Address: 333 West San Carlos Street, Suite 700
San Jose, CA 95110 USA
Phone: 408 283-5605
Fax: 408 280-7915
E-mail: Amos.Dor@pdf.com

4.1

Name: Yoram Schwarz
Company: PDF Solutions, Inc.
Address: 333 West San Carlos Street, Suite 700
San Jose, CA 95110 USA
Phone: 408 283-5603
Fax: 408 280-7915
E-mail: Yoram.Schwarz@pdf.com

Conference Session(s):
Design and Process Integration for Microelectronic Manufacturing