A New Decision Paradigm for Comparing Patterned Wafer Inspectors

Justin Arrington, Paul Johnson – Micron Technology, Inc.,
Ali Salehpour, Andy Phillips, Gangadharan Sivaraman, Anthony Moore, Ray Campbell, Wade Jensen – KLA-Tencor Corporation

Today's optical patterned wafer inspectors cover a range of configurations, including brightfield, darkfield, and brightfield/darkfield combination tools. With so many choices, selecting a tool that meets a fab's yield-monitoring requirements can be a complex endeavor. How should fab management efficiently decide which tool provides the best overall return on investment in terms of cost, defect capture, and yield acceleration? A new decision methodology has been developed that creates a metric for this evaluation process: weighted average throughput in production (WATIP).

Inspection Tool Evaluation Methodologies

Many parameters are considered when evaluating optical patterned wafer inspection tools for a fab's particular yield-monitoring strategy. Some are economic factors, such as capital cost, cost of ownership, and platform extendibility. Others are implementation factors, such as ease of recipe setup and automated defect-binning capability. However, the most critical factor to consider is an inspector's effectiveness at detecting defects of interest for a range of inspection points, at the highest possible speed.

Most inspection tool manufacturers publish graphs of sensitivity (represented by pixel size) versus throughput (Figure 1). In general, higher-sensitivity modes run at lower throughputs. However, the ability of an inspection system to capture defects of interest on layers of interest is determined by more than just pixel size. Rather, inspector sensitivity is a complex entity affected by tool parameters such as peak wavelength, wavelength spectrum, numerical aperture, optical aperture, and detection algorithms. Inspector sensitivity also varies with layer, device, and design rule.

We have found through experimentation that published sensitivity and throughput specifications are not a reliable predictor of real-world performance when comparing different types of inspectors or inspectors from different suppliers. Sensitivity specifications are often based on pixel sizes, but pixel size alone is not a direct determinant of ultimate sensitivity. Furthermore, published throughput specifications are often based on a specific measurement methodology that can vary among inspector suppliers. These published throughputs also depend on factors such as inspected area, and may not represent the actual throughputs observed in the fab on production wafers. Hence, the use of published specifications for tool comparisons is often an inaccurate representation of actual tool performance.

A better tool comparison methodology uses data on actual production wafers from a supplier demonstration or an on-site evaluation. This allows for a more accurate determination of

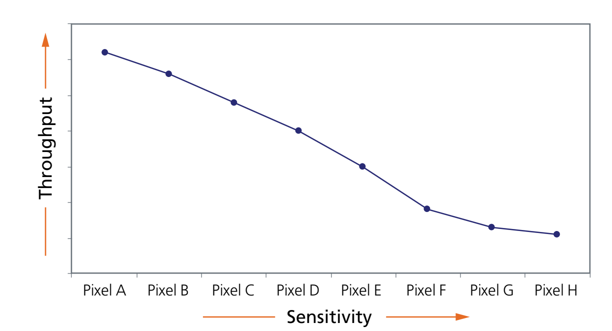

Figure 1: Data demonstrating the inverse relationship between sensitivity—represented as a pixel size—and throughput for an optical patterned wafer inspector. Higher-sensitivity pixels have a lower throughput.

the pixel sizes necessary to meet specific yield-monitoring requirements. This also allows the chipmaker to measure actual inspector throughput on production wafers. Further, this methodology allows a chipmaker to accurately determine the relative throughputs of inspectors at the sensitivity required for a specific subset of process layers. Based on the monitoring requirements of a production environment, some of these process layers may be inspected more frequently than others, affecting the overall inspector capacity. Thus, the downside of this comparison methodology is that it does not take into consideration how these process layers fit into the overall desired production usage of the inspection tool.

A new, more complete evaluation methodology involves the use of a parameter called the weighted average throughput in production (WATIP). WATIP breaks down the expected production utilization of an inspection tool by layer, or by inspection segment. For each layer, the sensitivity requirements determine the optical mode, pixel size, and algorithm utilized. The pixel size determines the inspector's throughput at a given layer. Additionally, the expected average capacity for each layer is used as a weighting factor for each layer's throughput. The overall WATIP of the inspector is the sum of each individual layer's weighted throughput. WATIP takes into account the sensitivity, throughput, and capacity requirements of each layer projected to run on the inspector. Moreover, it recognizes that different tools meet a particular sensitivity requirement at different throughputs, and that evaluating these differences is a critical factor in tool comparisons. The following section presents an overview of how WATIP is calculated.

Calculating Weighted Average Throughput in Production (WATIP)

WATIP is a new decision methodology for comparing the performance of different inspection tools. WATIP provides an accurate assessment of the overall production throughput of an inspector by taking into account sensitivity, throughput, and layer capacity. It determines the production throughput of each tool once a particular sensitivity requirement has been met. WATIP is calculated using the following

$$WATIP_{tool} = \sum_{layer\ i} WATIP_{layer\ i} = \sum_{layer\ i} (AverageCapacity * TPT)_{layer\ i}$$

In this equation, TPT is the measured throughput. Average capacity is a weighting factor comprised of the percentage of inspection capacity used for each layer or inspection segment. Table 1 shows how WATIP is calculated and compared for two different inspectors.

In Table 1, the operating points where the inspector will be used are shown in the green shaded boxes. These can either represent specific process layers or more general layer categories. The inspection points in Table 1 are typical layer categories for production utilization of a high-end brightfield inspector. In section A of the table, the average capacity is entered as a percentage. This can be based on benchmark data or actual production usage of the tool. In section B, the pixel sizes needed to meet the sensitivity requirements of each layer are listed. These pixel sizes are based on benchmark data or evaluation data from the different inspection tools. The throughput for each pixel size is entered in section C of the table. These throughputs can be acquired from the supplier's standard specification sheet for the tool or, for better accuracy and measurement consistency, determined from timing data collected on the different inspectors using the chipmaker's wafers. Finally, the WATIP for each layer or layer category is calculated in section D by multiplying the average capacities given in section A by the throughputs in section C. The overall WATIP for the tool is obtained by summing the WATIP calculation for the individual layers. In this example, Inspector B has a WATIP that is 1.6x higher than Inspector A. This comparison is meaningful because it utilizes throughputs for each inspection segment that meet the sensitivity requirements, and takes into account the capacity utilization for each segment.The higher WATIP provided by Inspector B would translate into improved lot sampling and contribute to a lower inspector cost of ownership.

A	Etch		CMP	Litho	
	Etch: Critical	Etch: Non-Critical	CMP: Line Monitor	Litho: ADI	
Average Capacity (weighting)	24%	24%	10%	42%	100%
B	**Etch**		**CMP**	**Litho**	
Pixel Size Based on Benchmark Data	Etch: Critical	Etch: Non-Critical	CMP: Line Monitor	Litho: ADI	
Inspector A Pixel	0.16µm	0.16µm	0.26µm	0.12µm	
Inspector B Pixel	0.16µm	0.28µm	0.20µm	0.16µm	
C	**Etch**		**CMP**	**Litho**	
Throughput Based on Pixel Size	Etch: Critical	Etch: Non-Critical	CMP: Line Monitor	Litho: ADI	
Inspector A TPT (wph)	2	2	4	1	
Inspector B TPT (wph)	2	5	3	2	
D	**Etch**		**CMP**	**Litho**	
Weighted Average TPT in Production	Etch: Critical	Etch: Non-Critical	CMP: Line Monitor	Litho: ADI	WATIP
Inspector A WATIP (wph)	0.48	0.48	0.40	0.42	1.78
Inspector B WATIP (wph)	0.48	1.20	0.30	0.84	2.82

Table 1: Hypothetical calculation of WATIP for two inspectors. For each inspection segment, the average capacity utilization (A), pixel size needed to meet the sensitivity requirements (B), and throughput (C) are determined, and WATIP (D) is calculated. Individual layer WATIPs are summed to obtain the overall inspector WATIP. The WATIP for Inspector B is 1.6x higher than the WATIP for Inspector A. This higher WATIP translates into increased inspection capacity and contributes to lower inspector cost of ownership.

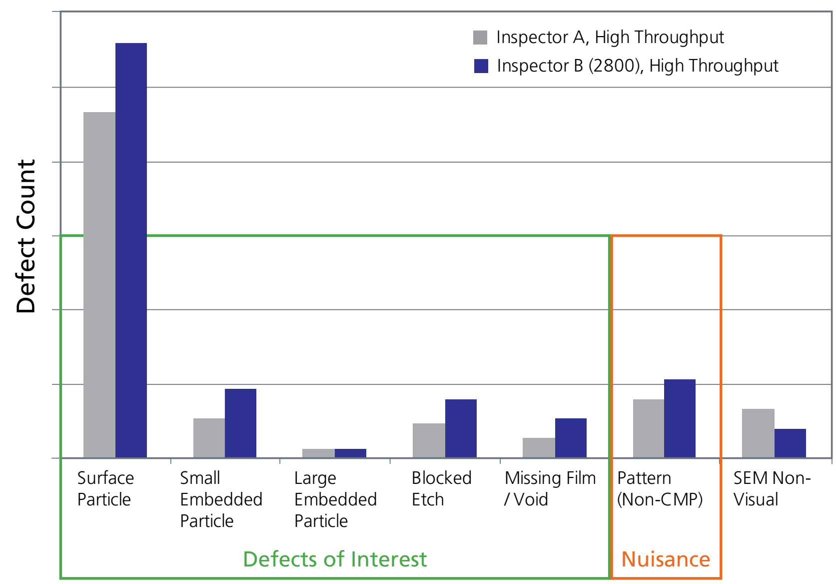

Figure 2: Pareto comparing defect capture on a poly CMP DRAM wafer. Inspector B is KLA-Tencor's 2800 broadband brightfield patterned wafer inspector (2800). The high-throughput recipe of the 2800, with a WATIP of 4wph, provided the highest sensitivity-at-throughput and was therefore the better inspection to use for yield monitoring on this layer.

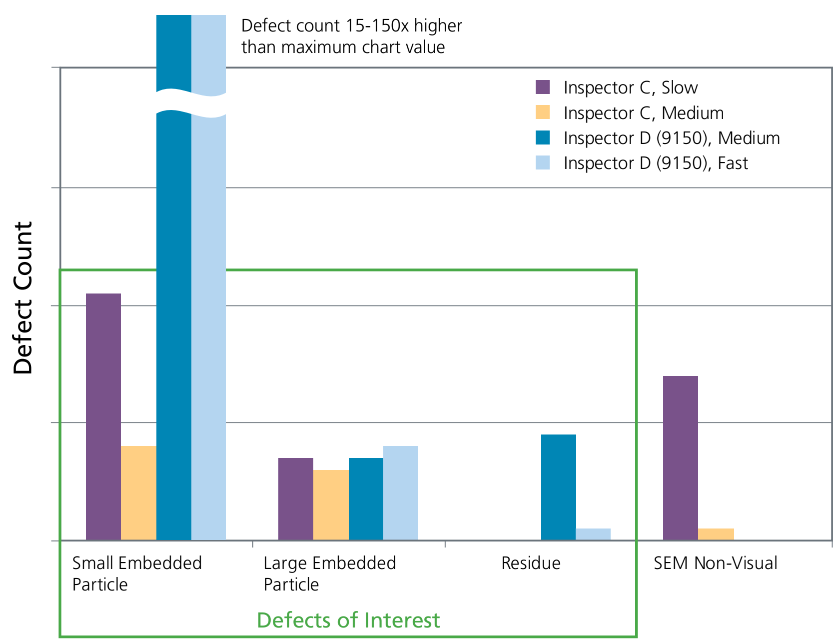

Figure 3: Pareto comparing defect capture on a nitride deposition NAND flash wafer. Inspector D is KLA-Tencor's Puma 9150 darkfield patterned wafer inspector. For each tool, two inspection recipes covering different throughputs were compared. The high-throughput (fast) recipe of the Puma 9150, with a WATIP of 21wph, provided the highest sensitivity-at-throughput and was therefore the better inspection system to use for yield monitoring on this layer.

WATIP: DRAM Use Case

A recent DRAM evaluation focused on two high-end brightfield inspection tools for inline defect monitoring. This evaluation involved assessing the sensitivity-at-throughput of the inspectors on ten process layers. One of these inspectors was KLA-Tencor's 2800 broadband brightfield patterned wafer inspector. For each process layer, one "Production" (high throughput) inspection recipe and one "Engineering" (lower throughput, higher sensitivity) inspection recipe were developed on each tool. The resulting inspections were compared based on sensitivity to critical defects, suppression of SEM Non-Visuals (events detected by the optical inspection system that are not re-detected during SEM review), and throughput. For each process layer, the inspection recipe that best met the sensitivity requirements at the highest throughput was determined for each tool. Then, based on expected capacity utilization of each inspection point, the WATIP for each inspector was calculated. Complete data are presented for one process layer.

Inspector performance was compared for a poly CMP process layer. Initially, two inspection recipes were created for each tool on this layer—a high-sensitivity (lower throughput) recipe and a high-throughput (lower sensitivity) recipe. It was found that the high-throughput recipe provided sufficient sensitivity to the defects of interest, and therefore further analysis was limited to only this throughput mode. Figure 2 shows a defect Pareto comparing the inspection results from the high-throughput recipes of the two different inspectors. Although the SEM Non-Visual rate for Inspector B (4.2%) was lower than that for Inspector A (8.8%), the rate for both tools was below the prescribed limit of 10%. The defect Pareto shows that Inspector B provided higher capture of defects of interest than Inspector A, although both tools met the minimum defect detection requirements for the layer. Based on the expected capacity utilization of this inspection in production, Inspector A had a WATIP of 3wph, while Inspector B had a WATIP of 4wph. Overall, the high-throughput recipe of Inspector B provided better capture of defects of interest at a lower SEM Non-Visual rate and a higher throughput. Thus, for this particular process layer, the best sensitivity-at-throughput was provided by Inspector B.

Using similar analyses on data from ten process layers, it was determined that the overall WATIP for Inspector B was approximately 30% higher than the WATIP for Inspector A. Thus, Inspector B best met the yield-monitoring requirements for this DRAM technology node.

WATIP: NAND Flash Use Case

In addition to brightfield DRAM comparisons, NAND flash devices were used to evaluate two darkfield inspection tools for inline defect monitoring. One of these inspectors was KLA-Tencor's Puma 9150 darkfield patterned wafer inspector. Several different inspection recipes covering different throughputs were developed on each tool for each process layer. The resulting inspections were compared based on detection of critical defects and suppression of SEM Non-Visuals. For each process layer, the inspection that provided the best sensitivity at the highest throughput was determined for each tool. Then, based on expected capacity utilization of each inspection point, the WATIP for each inspector was calculated. Complete data are presented for one process layer.

> WATIP compares the overall production throughput of different inspection tools by evaluating sensitivity, throughput, and layer capacity.

Inspector performance was compared for a nitride film deposition process layer. For each tool, two inspection recipes utilizing different throughputs were developed with the goal of achieving the best possible sensitivity. The recipes for Inspector C covered a slow-throughput mode and a medium-throughput mode. The recipes for Inspector D covered medium- and fast-throughput modes. A defect Pareto comparing the inspection results from the two different darkfield tools is shown in Figure 3. These results show that the slow recipe of Inspector C had a SEM Non-Visual rate of 33%, well above the limit of 10%, and thus was removed from further consideration. The SEM Non-Visual rates for the medium recipe of Inspector C (6.6%) and for both recipes of Inspector D (0%) were below the limit of 10%. These results further show that Inspector D provided much higher capture of defects of interest, including unique capture of residue defects, compared to Inspector C. The inspection recipes that provided the best sensitivity-at-throughput for each tool were the medium recipe of Inspector C and the fast recipe of Inspector D. Based on the expected capacity utilization of this inspection in production, the medium recipe of Inspector C had a WATIP of 13wph and the fast recipe of Inspector D had a WATIP of 21wph. Overall, the fast recipe of Inspector D provided better defect capture at a higher WATIP, and thus was the better tool for yield monitoring on this particular process layer.

Similar data were collected from thirteen different process layers. For each layer, two inspection modes were evaluated—high sensitivity (lower throughput) and high throughput. Based on these analyses, it was determined that the overall WATIP for Inspector D was approximately 4x higher than the WATIP for Inspector C for the high-sensitivity inspections, and approximately 2x higher for the high-throughput inspections. Thus, Inspector D best met the yield-monitoring requirements for this NAND flash technology node.

Conclusion

With today's optical patterned wafer inspectors covering a range of configurations, it is important to utilize a tool selection paradigm that effectively evaluates production performance. Current decision paradigms that rely on a supplier's published specifications based on pixel size can be a poor predicator of real-world sensitivity-at-throughput, as sensitivity depends on multiple tool parameters and throughput can vary depending on measurement methodologies and factors such as area inspected. Furthermore, the utilization of the inspector for each inspection point can significantly affect the measure of an inspection system's overall performance.

This paper introduced a new decision paradigm that utilizes a parameter called the weighted average throughput in production (WATIP). For each inspection point, WATIP takes into account the throughput of an inspector at required sensitivity and the expected capacity utilization of that inspection. The WATIP methodology efficiently and effectively determines which inspector provides better performance with lower capital costs. The details of calculating WATIP and a hypothetical example of how to use WATIP to compare two inspectors were presented. Finally, two use cases involving the comparison of different inspectors for memory defect monitoring were discussed. These use cases demonstrated how a comparison methodology using WATIP can help to effectively determine which tool is best for a fab's particular yield-monitoring requirements.

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