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Wafer Fab Operational Cost Monitoring and Controlling with Cost per Equivalent Wafer Out

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***Abstract*—**This paper presents Cost per Equivalent Wafer Out, which we find useful in wafer fab operational cost monitoring and controlling. It removes the loading and product mix effect in the cost variance analysis. The operation heads, therefore, could immediately focus on identifying areas for cost improvement. Without this, they would have to measure the impact of the loading variance and product mix variance between actual and budgeted prior to make any decision on cost improvement. Cost per Equivalent Wafer Out, thereby, increases efficiency in wafer fab operational cost monitoring and controlling.

***Keywords*—**Cost Control, Cost Variance, Operational Expenditure, Semiconductor.

I. Introduction

MONITORING and controlling of wafer fab operational cost is typically done by comparing actual cost with budget cost. But wafer fabs, which generally operate with insignificant backlog, often have difficulty to produce accurate budgeted annual sales volume. Actual loading and product mix, therefore, often derailed from the budgeted. This resulted in higher or lower activities (e.g., wafer moves) than the planned. Ultimately, this caused variance between actual and budget cost. Other issues (e.g., direct material issues and equipment issues) widen the gap between actual and budget cost further.

Realising this, many operation heads equip themselves with Cost per Wafer Out (Cost per WO). It is derived by dividing the operational cost with the WO quantity. Operational cost is monitored and controlled by measuring Actual Cost per WO against Budget Cost per WO. Although the operational cost normally has direct proportional relationship with the sales volume (WO), the cost variance analysis with Cost per WO could be misleading as the WO quantity does not correlate with the fab activities (e.g., wafer moves) sometimes. Additionally, the difference between actual and budgeted product mix could also causes cost variance, as more complex products generally requires more processing steps and perhaps more expensive raw wafer than simpler products.

One of the tools in operation heads' cost control toolbox is Cost per Wafer Move (Cost per WM). The operational cost is most likely to increase if the WM increases and decrease if the WM decreases. But Cost per WM method has two major weaknesses. First, it assumes that the non-process type steps (e.g., measurement, test and miscellaneous/other) are as resourceful and as cheap or expensive as the process type steps. Process type steps are major semiconductor processing steps; e.g., etch, diffusion and implant, and photolithography steps. Second, variance analysis with Cost per WM assumes the actual and budgeted product mix would result in equal number of WM.

Another good alternative is Cost per Mask Layer (Cost per ML). Mask patterning steps are processed at photolithography steppers and scanners. Mask patterning step, therefore, is also called as photo step. A wafer typically will go through the photolithographic cycle 20 to 30 times [1], meaning, 30 ML. A more complex product typically has higher number of ML than a simpler product, thus it cost higher. Cost variance analysis with Cost per ML has one major weakness that is it assumes the actual and budgeted product mix would result in equal number of ML.

Therefore, the aim of this paper is to introduce another wafer fab operational cost control measurement, the Cost per Equivalent Wafer Out (Cost per EWO). Cost per EWO considers the loading and product mix variances, and avoids the processing type issue. It has been used in our fab for the past years and was mentioned in our previous technical paper [2].

II. Calculating Cost per EWO

A. Derivation of EWO

The equivalent wafer out (EWO) measures the WO unit for each product that has Purchase Order (PO) p in term of the total monthly ML processed $M_m(p)$ as compared with the number of photo steps in the process flow $S(p)$. The equation for EWO is shown at (2). ML are processed at photolithography scanner and stepper toolgroups m.

The original equation for $M_m(p)$ is taken from the work of Chih-Yuan Yu and Han-Pang Huang [3].

$$M_m(p) = \sum_{x \in \tilde{L}(p)}^{N} N_L(x) \qquad (1)$$

where N is the number of m tools in $\tilde{L}(p)$; $N_L(x)$ is the quantity of $L(x)$; $\tilde{L}(p)$ is the set of p lots which are processed with the m; and L is the set of all lots. Note that

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$\tilde{L}(p)$ is a subset of L.

Consequently, the equation for actual EWO for month t is as the following.

$$EWO_{actual}(t) = \sum_{p \in \tilde{P}(t)}^{K} \frac{M_m(p)}{S(p)} \quad (2)$$

where K is the number of products in $\tilde{P}(t)$; $\tilde{P}(t)$ is the set of products that has PO which were processed in the fab; and P is the set of all products. Note that $\tilde{P}(t)$ is a subset of P.

For example, if the photolithography scanners and steppers processed 100 wafers of product A and 200 wafers of product B, and if product A's process flow has 20 photo steps and product B's has 16 photo steps, then the EWO from product A is 5 wafers, the EWO from product B is 12.5 wafers and, therefore, the EWO is 17.5 wafers.

The budget EWO takes a simpler approach since it is nearly impossible to forecast the budgeted WM accurately, especially if the wafer fabs are running with insignificant backlog. It is set equal to the budgeted WO.

$$EWO_{budget}(t) = WO_{budget}(t) \quad (3)$$

B. Definition of Operational Cost

Operational cost $OPEX$ is defined as sum of costs that Operation had budgeted and held responsible to (as in their KPI). Hence other costs in the management accounting like depreciation costs, insurance premiums for the equipments and salaries-related are excluded. This could be varied between fabs.

$$OPEX(t) = \sum_{z \in \tilde{C}(t)}^{R} R_C(z) \quad (4)$$

where R is the number of costs in $\tilde{C}(t)$; $R_C(z)$ is the cost of $C(z)$; $\tilde{C}(t)$ is the set of costs in month t that Operation had budgeted and held responsible to; and C is the set of all monthly costs. Note that $\tilde{C}(t)$ is a subset of C.

C. Equation of Cost per EWO

Cost per EWO is derived by dividing the operational cost with the EWO.

$$Cost\ per\ EWO(t) = \frac{OPEX(t)}{EWO(t)} \quad (4)$$

D. Cost per EWO by Cost Centre and Cost Element

It is also possible and beneficial to measure the Cost per EWO of specific cost centres (and sub cost centres) and cost elements (and cost element groups) by filtering the OPEX. This facilitates top-bottom cost drilling analysis, which helps operation heads to identify areas for cost improvement.

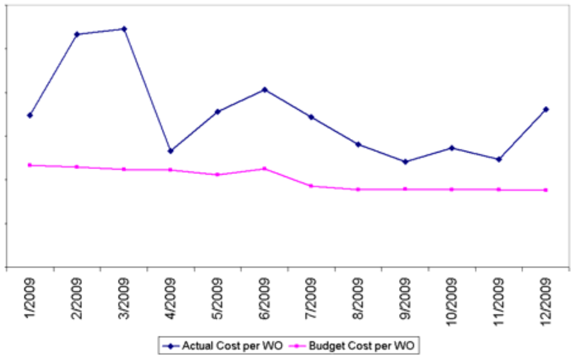

Fig. 1(a). Actual and Budget Cost per WO.

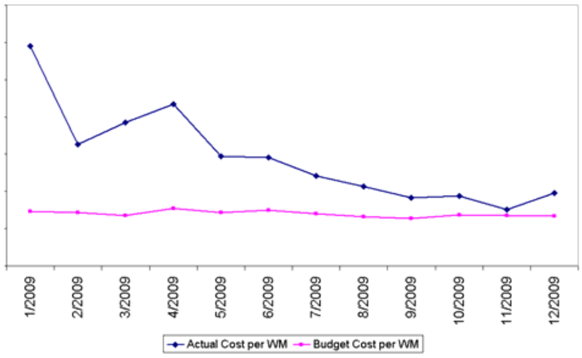

Fig. 1(b). Actual and Budget Cost per WM.

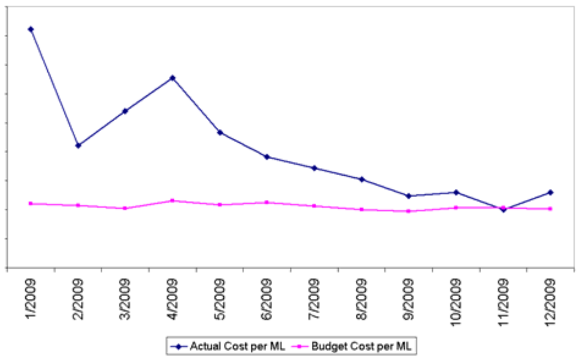

Fig. 1(c). Actual and Budget Cost per ML.

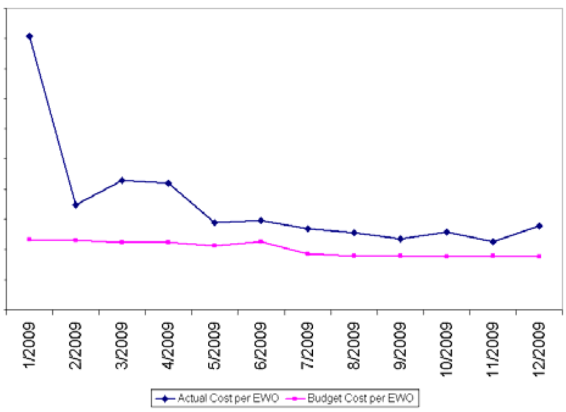

Fig. 1(d). Actual and Budget Cost per EWO.

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$$OPEX(t,CC,CE) = \sum_{z \in \tilde{C}(t,CC,CE)}^{R} R_C(z) \quad (5)$$

where R is the number of costs in $\tilde{C}(t,CC,CE)$; $R_C(z)$ is the cost of $C(z)$; $\tilde{C}(t,CC,CE)$ is the set of costs in month t, cost centre CC and cost element CE that Operation had budgeted and held responsible to; and C is the set of all monthly costs. Note that $\tilde{C}(t,CC,CE)$ is a subset of C.

$$Cost\ per\ EWO(t,CC,CE) = \frac{OPEX(t,CC,CE)}{EWO(t)} \quad (6)$$

III. Measuring Operational Cost per EWO Variance

Actual cost per EWO is measured against Budget Cost per EWO.

$$Cost\ per\ EWO_{Variance}(t) = Cost\ per\ EWO_{Budget}(t) - Cost\ per\ EWO_{Actual}(t) \quad (7)$$

Another method of cost control measurement with EWO is Accumulated Actual Cost per EWO vs. Accumulated Budget Cost per EWO. There are several times when the expenditures or cost items are brought forward or delayed than the planned. And there are few times when the Finance has to do cost adjustment for the wrongly charged last month's cost items to fix it (i.e. wrongly charged amount, cost centre and/or cost element). Accumulated data suppressed the timing issue of the cost items.

$$Accum.Cost\ per\ EWO(t_0 \to t) = \frac{\sum_{T=t_0}^{t} OPEX(T)}{\sum_{T=t_0}^{t} EWO(T)} \quad (8)$$

where t_0 is the starting month of the accumulation.

Consequently,

$$Accum.Cost\ per\ EWO_{Variance}(t_0 \to t) = Accum.Cost\ per\ EWO_{Budget}(t_0 \to t) - Accum.Cost\ per\ EWO_{Actual}(t_0 \to t) \quad (9)$$

IV. Pushing for Lower Operational Cost

A. Cost Monitoring and Controlling

Cost per EWO variance complements the typical Actual vs.

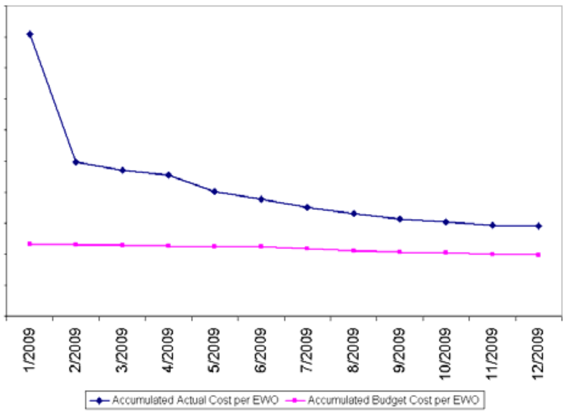

Fig. 2. Accumulated Actual and Budget Cost per EWO.

Budget Cost variance in the periodic operation reports, e.g., operation monthly report and operation annual report. The Cost per EWO effectively removes the loading and product mix effect so that the operation heads could focus on identifying areas for cost improvement. This saves them from having to measure the impact of the loading variance and product mix variance.

B. Budgeting

When applied in budgeting exercise, Cost per EWO helps operation heads to indicate whether the requested operation expenditure budget is reasonable or not. They could approve the budget or push for lower budget of certain cost centres and cost elements after comparing the Cost per EWO of the requested budget against the previous years' Actual Cost per EWO, and considering other factors, e.g., material price increase or decrease, cost reduction, etc. By doing this, the operation heads are able to balance the company needs to make money and to increase profitability; and the operational needs to keep the fab running smoothly such as spare part replacement, maintenance and technical training.

V. Strengths

A. Removes Loading Effect

Operational cost is typically directly proportional to the number of wafers produced. The Actual Cost, therefore, normally increases and is higher than the Budget Cost if the fab produces more wafers than the budgeted.

Cost per EWO cost control method considers the variance between actual and budget loading. In this method, the Actual Cost is divided by Actual EWO and compared with the Budget Cost, which is divided by the Budget EWO. The loading effect to the cost variance, therefore, is greatly reduced.

B. Removes Product Mix Effect

A more complex product generally has higher number of ML quantity and number of processing steps than the less complex product. The Actual Cost, therefore, tends to be higher than the Budget Cost if the fab produces more complex products more than the budgeted.

Cost per EWO variance considers differences between actual and budgeted product mix. As shown in (2), the Actual EWO equation utilises the number of ML processed and the number of photo steps in the process flow. Although the Budget EWO is assumed equals to Budget WO, as it is impossible to budget accurately and any effort to use actual EWO equation to the budget would be futile, the Cost per EWO variance does give good picture of operational cost to operation heads.

C. Cost of Wafer Lots in Various Stages of Completion

Each PO is processed when there is available, suitable slot in the production planning schedule. Fab normally processes large PO in several batches to avoid bottleneck issue. And it would take several weeks to process one wafer to its completion. Therefore, at any given time, all lots in the fab are at various stages of completion. That is why the WO quantity does not correlate with the number of WM (and the number ML processed) sometimes.

Cost per EWO avoids this issue that the Cost per WO carries. As shown in (1), instead of counting the number of WO, the EWO method counts all p lot wafer movements during month t at photolithography stepper and scanner toolgroups m, regardless of at which stages of completion they are during that time.

D. Avoids Processing Type Issue

Measurement, test and miscellaneous (other) type steps are generally cheaper to process than the process-type steps primarily because they require no or less resources, e.g., material, and loading and processing time dependent consumable spare part replacements.

Cost per EWO does not carry the processing type issue that the Cost per WM carries.

E. Focuses on the Controllable Operational Costs

The operational cost is defined as sum of costs which Operation had budgeted (e.g., material, spare parts, maintenance, transportation and technical training) and held responsible to (e.g., raw material write-off, semi-finished write-off and finished goods write off). These are the costs which Operation can control.

By removing the loading and product mix impact in the cost control analysis, the operation heads can focus on identifying areas for further cost improvements.

F. Gives Cost in 'per Wafer' Equivalent

Fab managements like to measure Cost per Wafer as they could relate it to average selling price and average profit margin. Thus they are quite reluctant to accept Cost per WM and Cost per ML. They generally accept Cost per WO. But Cost per WO carries many weaknesses, which could mislead their decisions.

Cost per EWO offers 'per Wafer' equivalent measurement.

VI. Future Works

Our works on Cost per EWO could trigger studies and works in other potential areas, e.g., WM based Cost per EWO and wafer size equivalent Cost per EWO.

A. WM based Cost per EWO

The Cost per EWO that is presented here is ML based. We apply ML into the equation because it is sufficed for us. But there is a possibility of WM based Cost per EWO. Minor modifications in (1) and (2) are needed to derive this. Instead of minimising m to just photolithography scanner and stepper toolgroups, m could be made to cover all tools. If so, then instead of minimising $S(p)$ to just photo steps, $S(p)$ should be made to cover all processing steps. Nevertheless, further study is required to come with the equation and to fully understand its behaviours and its implications to the cost control decision making before we could implement this idea.

B. Wafer Size Equivalent Cost per EWO

There is a possibility to infuse the wafer size (e.g., 200mm, 300mm and 450mm) into EWO equation. But further study is required to come with the equation, and to fully understand its behaviours and its implications to the cost control decision making prior to embracing this idea. The equation must consider the difference in wafer surface area size and the difference in production cost, e.g., the prices of raw 300 mm wafers are 3.3 to 10 times the price of 200 mm wafers [4]. This could be beneficial to the multi-fab companies, which process wafers of various sizes. And it could be useful in fab benchmarking too.

C. Weekly Cost per EWO

One of the possibilities which we haven't venture into is weekly Cost per EWO. Based on our experience, we think that its implementation would require better, more efficient system than monthly Cost per EWO's as the operational cost data and the EWO data would have to be refreshed and computed more rapidly. If this obstacle is overcome, weekly Cost per EWO would certainly improve operational cost control effectiveness.

VII. Conclusion

Cost per EWO measurement has been a great addition to our production cost control application, which was presented in [2]. The cost-drilling analysis is made more efficient by integrating it into interactive production cost control application. The actual and budget cost of individual cost centre and individual cost element are measured in term of 'per EWO', helping operation heads to know where to push for cost reduction to lower the operational cost and ultimately, the product cost.

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