Abstract Number: 008-0213

Shop-Floor Control Model in Batch Processes of Wafer Fabrication with Time Constraints

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POMS 19th Annual Conference

La Jolla, California, U.S.A.

May 9 to May 12, 2008

Abstract. Time constraint is a queue time boundary set between particular operations to ensure final product yield. Due to the dilemma of increasing machine efficiency or decreasing the queue time of WIP, the issues of time constraint become more complex in batch processing.

This work proposed a shop floor control policy in serial-batch-serial processes with time constraints. The concept of safety stock ([S,s] policy) is introduced to control the WIP level for avoiding machines idle and wafers exceeding time constraints simultaneously. Length of time constraints, MTTR of machines and service rate of workstations are adopted to determine the batch size and boundaries of WIP level. The job hold/release policy is addressed to control the situations of excessively high WIP level. Furthermore, the performance of proposed model is compared with DJAH and MBSX rules. The results indicated that the proposed model could control the batch processing with time constraints more effectively.

Keywords: time constraints, wafer fabrications, batch processing, shop floor control, batch size

1. Introduction

A time constraint (TC) is a time window set between two specific operations to prevent undesirable copper film oxidation or fluorine precipitation on wafer surfaces (Robinson and Giglio 1999, Tu and Liou 2006). Wafers will be reworked or scrapped if they exceeded TC, which will increase cycle time and decrease productivity. To control workstations with TCs effectively is an essential task for semiconductor industry. However, as the result of high production volume, expensive equipment, and time consuming processes, machines in wafer fabrication are usually required to operate at a high utilization level. Extremely high utilization of workstations will cause the difficulty in resolving issues of TC.

The most familiar TC issue is set between wet etch and furnace operations, which wafers will be reworked at wet etch operation while they exceeded TC. In this stage, batch processing and long processing time will cause the dilemma of the management. Machine efficiency and require time for forming batches become a trade-off issue while determining batch size. Low machine efficiency or long batching forming time will both increase the waiting time and also increase the rate of exceeding TC (Rulken et al. 1998). To determine the batch size more effectively will be crucial for conquering the issues of TC in this stage.

There were many studies related to batch size determination in wafer fabrications (Fowler et al. 1992, Glassry and Weng 1991, Weng and Leachmen 1993). These studies have attempted to optimize the performance of batch-processing workstation, for instance, maximize throughput and minimize cycle time. However, the succeeding operation of furnace workstation is still with TC. To optimize the output of furnace workstation will increase the loading as well as the rate of wafers exceeding TC in succeeding operation. Hence, the shop-floor control model in batch process with TC issue should involve a rule to take succeeding operation into consideration.

Accordingly, the purpose of this work is to develop a shop floor control policy to resolve the TC issues between furnace workstation and its preceding and succeeding operations. The proposed model determines the batch size of furnace operation dynamically by considering TC interval and WIP level. Furthermore, the proposed model could also control the WIP at a safe level by adopting safety stock ([S,s]) policy. Finally, the performance comparison among the proposed model, MBS and DJAH was performed.

2. Literatures Review

Previous studies related to batch size determination and shop-floor control rule in batch processes of wafer fabrications are reviewed in this section. The common methodology for determining batch size can be classified into two categories, Minimum Batch Size rule (MBS) and Look-ahead strategy. MBS also called threshold policy, which determines the batch size based on mean arrival rate and service rate of workstation but without future customers arrival information (Neuts, 1967, Deb and Serfozo 1973, Rulken et al. 1998). With MBS rule, machines start operation while batch size is greater than the threshold, on the other hand, they will keep waiting. Weng and Leachmen (1993) introduced multi-product into MBS and proposed MBSX rule. In this policy, the customer with longest waiting time will have the highest priority in the queue.

The look-ahead strategy was first addressed by Glassey and Weng (1991). They proposed the Dynamic Batch Heuristic (DBH) model with time horizon and take future arrival information into consideration to determine batch size dynamically. In this study, they proved that DBH can perform better performance than MBS. Fowler et al. (1992) introduced the concept of rolling horizon into DBH and proposed Next Arrival Control Heuristic (NACH) policy. NACH emphasize that the start of operation should be decided at every customers arriving and leaving. Van Der Zee et al. (1997) introduced multi-product and multi-server into NACH and proposed Dynamic Job Assignment Heuristic (DJAH). This study indicated that the cost considered should be unit time per item of batch. MBSX and DJAH are both methodologies common used in batch size determination in wafer fabrications. However, these methods are without considering TC issues.

There were some studies related to shop floor control policies with TC. Lee and Jung (2003) proposed distributed shop floor scheduling to decrease the rate of wafers exceeding TC. They found the optimal schedule to meet all the timing and other constraints. Wolfgang and Joerg (2000) developed a Kanban dispatching rule to reduce the influence of TC issues. They considered both machine breakdown and difference of arrival rate between each product to reduce the WIP level. However, these studies did not consider the determination of batch size.

3. Dynamic Batch Job Control with Time Constraints (DBCTC)

In this section, a Dynamic Batch Job Control with Time Constraints (DBCTC) is proposed. The system described in this model involves three workstations, three queues, and two TCs. The configuration of the system is presented as figure 1.

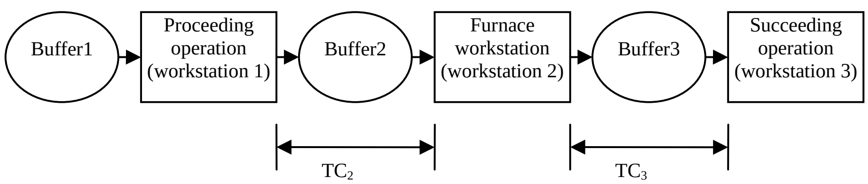

Figure 1. The furnace operations with TC

3.1 Notations

The following terms were required for the DBCTC.

m_i	Number of machines of workstation *i*
μ_i	Service rate of workstation *i*
B_i	Current time buffer of workstation *i*

TR_{ij}	Mean time to be repaired of machine *j* at workstation *i*
C_i	Maximum batch size of workstation *i*
TC_i	Time length of TC in buffer *i*
PT	Processing time of current batch at furnace workstation
q_{ix}	The number of WIP in the queue of product *x* at workstation *i*
W_{x1}	The weight of product x which has not exceeded TC
W_{x2}	The weight of product x which has exceeded TC

3.2 Safety WIP level [S_i,s_i] of workstations

Setting of maximum WIP (S_i) in front of workstation with TC is to prevent wafers exceeding TC. Therefore, S_i should be maximum number of customers that workstation *i* can service within TC interval. The upstream operation should suspend processing if WIP level of workstation *i* is greater than S_i. Moreover, to prevent machine idle, the WIP level should keep at a sufficient quantity to handle machine breakdown at upstream operation. The equations are given below:

$$S_i = (TC_i \times m_i - \sum_{j=1}^{m_i} TR_{ij}) \times \mu_i \qquad (1)$$

$$s_i = S_2 - C_i \qquad (2)$$

3.3 Minimum batch size of furnace workstation

The minimum batch size (*MB*) is set to ensure that WIP can be processed within TC interval. Therefore, minimum batch size should be WIP level divided by the maximum batches that furnace can serve. The equation can be presented as follows.

$$MB = \frac{B_2}{(TC_2 / PT_2) \times m_2} \tag{3}$$

3.4 Tolerance of succeeding operation

The tolerance of succeeding operation (*Tol*) is defined as maximum number that the WIP level of succeeding operation can be increased. The *Tol* is the extra WIP quantity except already in the queue that can be processed within TC interval on succeeding operation. The formula is represented as:

$$Tol = (TC_3 \times \mu_3 \times m_3 - B_3) - (\mu_2 \times m_2 - \mu_3 \times m_3) \times PT \tag{4}$$

3.5 Emergency index of product

The emergency index (I_x) is a weight of product selection for processing at furnace workstation. The I_x is the sum of reciprocals of remaining time to exceed TC and of time length that has exceeded TC. Furthermore, there is a negative-correlation between waiting time and product yield. The weight of WIP which already exceeded TC is negative-correlated with their waiting time.

$$I_x = W_{x1} \times \sum_{l=1, i \in s_1}^{N_{S1}} \left(\frac{1}{TC_2 - T_{xl}}\right) + W_{x2} \times \sum_{k=1, k \in S2}^{N_{S2}} \left(\frac{1}{T_{xk} - TC_2}\right), \qquad x = 1, \ldots, p \tag{5}$$

Where,

Tx_l is the waiting of the lth lot remaining under TC

Tx_k is the waiting of the kth lot over TC

N_{s1} is the numbers of lot of product x under TC in the queue

N_{s1} is the numbers of lot of product x over TC in the queue

3.6 Shop-floor control rule

I. ***Decision points.*** The decisions should be made at the time of lots arrival or departure from furnace workstation or succeeding operation.

II. ***Decisions of suspending and reinstating proceeding operation***

i. The proceeding operation should be suspended when B_2 is greater than S_2 or MB is greater than Tol.

ii. When B_2 is smaller than S_2, the proceeding operation should be reinstated.

III. ***Control rules for furnace workstation***

i. ***Selection of product.*** The product with largest emergency index should be selected into workstation.

ii. ***Determination of batch size***. The batch size (Q) should be determined by following rule:

$$Q = \begin{cases} 0, & Tol < 0 \\ Min(C, Tol, q_{2,x}) & Tol \geq 0 \end{cases} \quad (6)$$

4. Simulation Experiments

In this section, simulation experiments were performed to compare the performance performed by proposed model, MBS and DJAH. The simulation model was designed to explore the characteristics of finance workstation and its preceding and succeeding operations. In simulation model, the TCs were set in front and back of furnace workstation. Wafers exceeded the TC set in front of furnace operation will be reworked, but will be marked and continue their processes if they exceed the TC set in back of furnace operation. In the simulation model, there were four products in the system. The monthly demand rate of each product were 960, 1920, 2880 3840 lots (with reentry wafers). Table 1 shows the detailed data of each workstation.

	Number of machines	***TC (hr)***	***MTTR (hr)***	***Availability***	***Maximum batch size***
Preceding operation	3	-	2	95%	1
Furnace workstation	8	9	4	95%	5

Succeeding operation	7	4	2	95%	1

Table 1. Detailed data of workstations

The simulation program used in this research was eM-Plant version 7.0. The running horizon for each simulation was set at 360 days, 24 hours a day. The first 30 days comprised a warm-up period; therefore, the results are for the remaining 330 days. Each treatment was run 30 times to obtain average results.

4.1 Results comparison

In this section, the defective output (output wafers with ever exceeding TC) and average time length of exceeding TC of DBCTC, MBSX and DJAH were compared. Figure 2, 3 and 4 present the results of comparison.

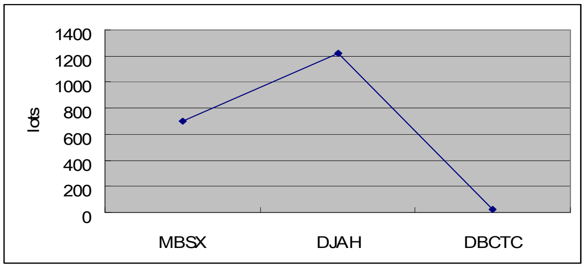

Figure 2. Quantity of wafers exceeded TC set in front of furnace workstation (lots)

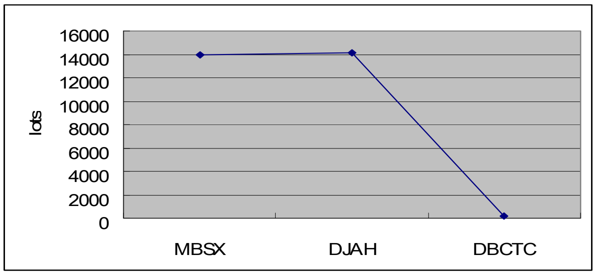

Figure 3. Quantity of wafers exceeded TC set in back of furnace workstation (lots)

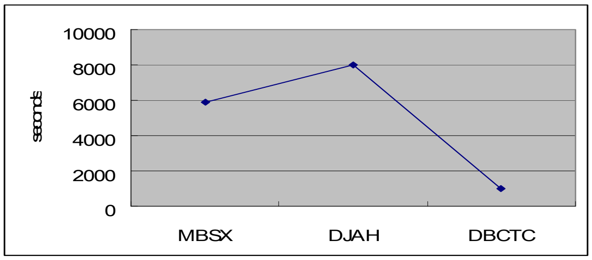

Figure 4. Average time length of exceeding TC

These figures supported that the proposed model could perform better performance in issues of TC with batch processing. Moreover, the results indicated that we should consider the succeeding operation with TC in resolving TC issues at furnace workstation. To maximizing output of furnace workstation will also increasing the loading of succeeding operation. The objective of MBSX and DJAH are both only optimizing the furnace operation, therefore, the performance performed at succeeding operation became undesirable. The proposed model considered furnace workstation and succeeding operation simultaneously, hence, could control the rate of wafers exceeding TC effectively.

5. Conclusions

In this work, a dynamic shop-floor control policy for batch process with TC was proposed. With considering furnace workstation and succeeding operation simultaneously, the rate of wafers exceeding TC could be controlled effectively. Moreover, by adopting concept of [S,s] policy, managers can suspend operation or decreasing batch size dynamically to controlled the WIP level. The simulation experiments support that DBCTC could perform better performance than MBSX and DJAH in TC issues.

The setup time is another critical factor for batch size determination. The required time for machine setting up will affect the result significantly. For instance, long setup time will result in larger batch size to reduce setup times. Future studies should address setup time into the model.

Acknowledgement

The authors would like to thank the National Science Council of the Republic of China for financially supporting this research under Contract No. NSC 95-2221-E-216-038.

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