Run-to-Run Mixed Product Overlay Process Control: Using Tool Based Disturbance Estimator (TBDE) Approach

An-Chen Lee, Tzu-Wei Kuo, and Shang-Wei Chiang

***Abstract*—Advanced process control (APC) has been recognized as a proper tool for maximizing profitability of semiconductor manufacturing facilities by improving efficiency and product quality. Run-to-run (RtR) process control with good quality and reliable performance for APC applications are most applicable. This paper proposes a new RtR control scheme, tool based disturbance estimator (TBDE) control scheme, which is adaptive to the mixed product overlay processes. The TBDE control scheme which employs threaded double exponential weighted moving average (d-EWMA) with the drift compensation scheme to deal with the disturbance caused by tool-induced drift and product-induced shift. The method is applied to the estimation of overlay parameters in mixed product lithography overlay process. The experimental results revealed that application of the TBDE is proven to significantly improvement in the mixed product overlay process.**

***Index Terms*—Advanced process control, run-to-run, overlay, mixed product, TBDE control scheme.**

I. Introduction

In the last decade, the run-to-run (RtR) control has been used or proposed for common and critical semiconductor manufacturing processes such as chemical-mechanical planarization (CMP) and lithography line width control [1]. The EWMA and d-EWMA controllers are commonly used by engineers in semiconductor manufacturing, and the control performance and the stability of these two controllers have been studied widely by several authors [2]-[4].

The RtR overlay lithography process control issue also has been investigated by some authors. Lin *et al.* [5] utilized multiple linear regression method to analyze the overlay accuracy model and study the feasibility of using linear methods to solve parameters of nonlinear overlay equations. Martinez *et al.* [6] combined EWMA controller and recursive least squares (RLS) method to estimate the overlay tool bias in overlay process. The simulation results show that their controller reduced the rework rate with 30% in average. Bode et al. [7] and Middlebrooks *et al.* [8] utilized model predictive control (MPC) to deal with the disturbance caused by overlay processes. Based on the tool-product-layer specifically combination, the MPC had well ability to eliminate the disturbance caused by overlay processes. Recently, Lee et al. [9] presented a unified framework called the output disturbance observer (ODOB) structure for the EWMA controller, the d-EWMA controller and the predictor corrector controller (PCC) controller. The work enhances insight into the well-known established algorithms, and contributes to better understanding of how these algorithms operate and why they can be used successfully in practical application. Other methods in RtR controllers have also been proposed and applied in semiconductor manufacturing [10]-[12]. However, those papers did not consider the processes in mixed product situation. Only a few studies have addressed the RtR control of a mixed product process plant, such as: Just-in-time Adaptive Disturbance Estimation (JADE) [13], tool-based and product-based EWMA control [14], threaded PCC [15] and CF-EWMA [16] controller.

In this paper, one proposes a tool based disturbance estimator (TBDE) control scheme, which combines threaded d-EWMA and the drift compensation scheme, to deal with the drift and shift disturbances caused by tool and products, respectively. Moreover, one utilizes online experiment in mixed product overlay process to verify the control performance of TBDE. The experiment results also revealed that the TBDE improves the Cpk significantly in mixed product overlay process.

II. Problem Description

Consider historical data of the mixed product overlay process as shown in Fig. 1, where the X-axis represents lot number (run) and the Y-axis represents the disturbance of the product and layer's combination. The historical data contains one tool, two products and two layers, and there are four manufacturing threads in this production situation. Fig. 1 presents that the characteristic drift in the overlay disturbance is caused by tool over the long term, and each manufacturing thread has its individual initial intercept.

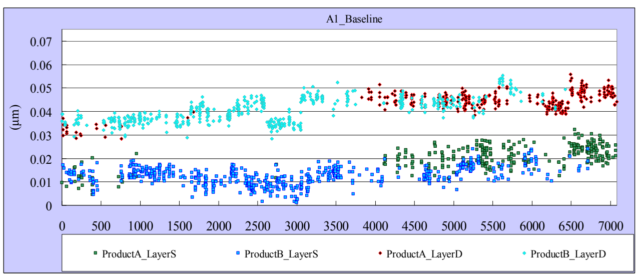

Fig. 1. Historical data of specify products and layers

According to characteristic of overlay processes as mention above, this paper proposes a tool based disturbance

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estimator (TBDE) control with break-product compensation for the drift disturbance caused by the tool. Considering the one tool and multi-products processes, the process model can be presented as:

$$y_{i,k} = \alpha_i + \beta_i u_{i,k} + \delta_{i,k} \tag{1}$$

where $y_{i,k}$ denotes process output, α_i denotes the initial intercept of product *i*, $u_{i,k}$ denotes the control recipe of product *i*, β_i denotes actual process gain for product *i*, $\delta_{i,k}$ denotes process disturbance, *k* denotes the run numbers. The following cases demonstrate the TBDE updating procedure:

Case 1. For the first run of product *i*

$$\hat{d}_{i,k} = \lambda_{1,i}\left(y_{i,k} - b_i u_{i,k}\right) + \left(1-\lambda_{1,i}\right)\left(\hat{d}_{i,0} + \hat{p}_{k-1}\right) \tag{2}$$

$$\hat{p}_k = \lambda_2\left(y_{i,k} - b_i u_{i,k} - \hat{d}_{i,0}\right) + \left(1-\lambda_2\right)\hat{p}_{k-1} \tag{3}$$

Case 2. For product *i* keeping on processing

$$\hat{d}_{i,k} = \lambda_{1,i}\left(y_{i,k} - b_i u_{i,k}\right) + \left(1-\lambda_{1,i}\right)\left(\hat{d}_{i,k-1} + \hat{p}_{k-1}\right) \tag{4}$$

$$\hat{p}_k = \lambda_2\left(y_{i,k} - b_i u_{i,k} - \hat{d}_{i,k-1}\right) + \left(1-\lambda_2\right)\hat{p}_{k-1} \tag{5}$$

Case 3. For break-product (product *j*)

$$\begin{aligned} \hat{d}_{j,k} &= \hat{d}_{j,k-1} + \hat{p}_{k-1} \\ &= \hat{d}_{j,k-2} + \hat{p}_{k-2} + \hat{p}_{k-1} \\ &\vdots \\ &= \hat{d}_{j,k-n} + \sum_{m=1}^{n} \hat{p}_{k-m} \end{aligned} \tag{6}$$

Case 4. For product change (product *i* changes into product *j*)

$$\begin{aligned} \hat{d}_{j,k} &= \lambda_{1,j}\left(y_{j,k} - b_j u_{j,k}\right) + \left(1-\lambda_{1,j}\right)\left(\hat{d}_{j,k-1} + \hat{p}_{k-1}\right) \\ &= \lambda_{1,j}\left(y_{j,k} - b_j u_{j,k}\right) + \left(1-\lambda_{1,j}\right)\left(\hat{d}_{j,k-n} + \sum_{m=1}^{n} \hat{p}_{k-m}\right) \end{aligned} \tag{7}$$

$$\begin{aligned} \hat{p}_k &= \lambda_2\left(y_{j,k} - b_j u_{j,k} - \hat{d}_{j,k-1}\right) + \left(1-\lambda_2\right)\hat{p}_{k-1} \\ &= \lambda_2\left(y_{j,k} - b_j u_{j,k} - \hat{d}_{j,k-n} - \sum_{m=1}^{n-1} \hat{p}_{k-m}\right) + \left(1-\lambda_2\right)\hat{p}_{k-1} \end{aligned} \tag{8}$$

Case 1 shows the update procedure at the first run of product *i* ($i = 1, 2, 3...$), where $\hat{d}_{i,0}$ and $\hat{p}_{k-1}$ denote the initial intercept estimation for product *i* and the drift estimate for tool at run *k*-1, respectively. The b_i denotes the model gain, $\lambda_{1,i}$ and λ_2 denote the weights of TBDE control scheme. When product *i* keeps on processing (Case 2), the intercept and drift estimations are updated by (4)-(5), where $\hat{d}_{i,k}$ is the intercept estimation of product *i* on run *k*, $\hat{p}_k$ is the drift estimation. Meanwhile, the intercept estimations of break product *j*, $\hat{d}_{j,k}$, is updated by the drift estimation, $\hat{p}_{k-1}$, of product *i* on run *k*-1 (Case 3). In other words, product *i* and product *j* share the drift estimation because the drift disturbance is caused by the tool. In the Case 4, the first run of product *j* will utilize the previous estimations on run *k-n* by assuming product *i* has been processed for *n*-1 runs (6) and current measured data to update the intercept and drift estimations. The next run (*k*+1) control input of product *i* can be calculated by:

$$u_{i,k+1} = \frac{T_i - \left(\hat{d}_{i,k} + \hat{p}_k\right)}{b_i} \tag{9}$$

where T_i is process target of product *i*.

III. Experiment

In this section, experiments are conducted to verify the control performance of the TBDE control scheme. The experiment includes one tool and two products, and the tool, Canon AFP 6000 ES6 scanner, was provided by Powerchip Technology Corporation (PSC). The overlay process model can be represented as:

$$\mathbf{y}_{i,k} = \boldsymbol{\alpha}_i + \boldsymbol{\beta}_i \mathbf{u}_{i,k} + \boldsymbol{\delta}_{i,k} \quad i = 1, 2 \tag{10}$$

where $\mathbf{y}$ denotes output parameters, $\mathbf{y} =$ [A1, A2, A3, A4, A5, B5, X7, X8, Y7, Y8]^T, $\mathbf{u}$ denotes recipe, $\mathbf{u} =$ [A1, A2, A3, A4, A5, B5, X7, X8, Y7, Y8]^T, $\boldsymbol{\beta}$ denotes process gain, $\boldsymbol{\beta} = diag$ [1, 1, 1, 1, 1, 1, 1, 1, 1, 1], $\boldsymbol{\alpha}_i$ denotes intercept of product *i*, and $\boldsymbol{\delta}_i$ denotes process disturbance of product *i*. The initial values of the TBDE control scheme are obtained from historical data where the tool and products are same as used in the experiment. Tables 1-2 list the initial values and weights of the TBDE control scheme. The weights of the TBDE control scheme are acquired by sweep method which minimizes RMSE of the historical output data.

TABLE I: Initial Values of TBDE Control Scheme

Parameters	A1	A2	A3	A4	A5
$\hat{d}_{1,0}$	-0.038	0.013	-0.04	0.02	-0.02
$\hat{d}_{2,0}$	-0.051	-0.032	-0.07	0.01	-0.03
$\hat{p}_{1,0}$	6.09E-06	2.58E-05	-2.06E-06	1.57E-05	1.37E-05
Parameters	B5	X7	X8	Y7	Y8
$\hat{d}_{1,0}$	0.03	-1.18	0.54	-0.22	-0.25
$\hat{d}_{2,0}$	-0.01	-1.51	1.05	-0.1	-0.14
$\hat{p}_{1,0}$	-1.71E-05	0.001526	-0.00036	0.000877	-0.00079

TABLE II: Optimal Weight Setting in Experiment

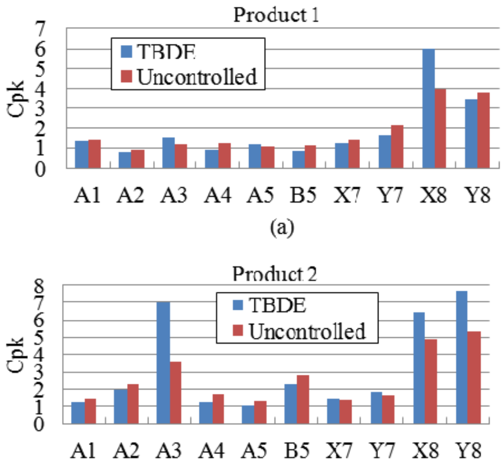
		A1	A2	A3	A4	A5	B5	X7	X8	Y7	Y8
λ_1	Product 1	0.4	0.3	0.3	0.2	0.2	0.2	0.4	0.2	0.4	0.3
	Product 2	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.3	0.3
λ_2	Product 1					0.00001					
	Product 2										

The process capability, Cpk, is used as a performance index in this experiment as follow:

$$Cpk = \min\left[\frac{\left(USL - \bar{y}\right)}{3\sigma}, \frac{\left(\bar{y} - LSL\right)}{3\sigma}\right] \tag{11}$$

where USL and LSL denote the upper specification limit and lower specification limit of output, respectively, $\bar{y}$ denotes the mean of output, σ denotes the standard deviation of output. The specifications of overlay parameters are $\pm 0.012\ \mu m$ for A1 and A2, $\pm 0.1\ ppm$ for A3 and A4, $\pm 0.1\ \mu rad$ for A5 and B5, $\pm 1\ ppm$ for X7 and Y7,

$\pm 1\ \mu rad$ for X8 and Y8, respectively. Fig. 2 shows output performance index of TBDE control scheme and the uncontrolled overlay process.



(a)

(b)

Fig. 2. Performance index Cpk of (a) Product 1 (b) Product 2

Fig. 2 indicates that the application of TBDE reveals a significant improvement on A3 (linear magnification parameters of wafer term in the X-axis) and X8 (the rotation angle of the exposure field image in the X-axis) parameters for product 1, and A3, X8 and Y8 (the rotation angle of the exposure field image in the Y-axis) for product 2. Since the test experiments are costly, the only twenty experiment runs (ten for product 1 and ten for product 2) are available, which leads to inconsistent result for the other parameters where Cpk's are smaller. The better control capacity of TBDE control scheme is expected if more experiment runs are permitted.

IV. Conclusion

This paper proposes a new RtR control method, the tool based disturbance estimator (TBDE) control scheme for mixed product overlay process. The TBDE control scheme combines threaded d-EWMA and the compensation scheme to eliminate the disturbance caused by tool drifting and product shifting. The experiment results show that the TBDE control scheme improves the A3 and X8 of overlay process in Cpk with 31.91% and 50.93% improvement over uncontrolled product 1, respectively. For product 2, the TBDE improves A3, X8 and Y8 in Cpk with 95.87%, 30.73 and 44.24%, respectively.

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