Machine Learning Based Virtual Metrology for Effective Process Control in High Product Mix Manufacturing – Hyung Joo Lee

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Introduction

The semiconductor foundry industry has changed, with high product mix manufacturing becoming more prevalent. Custom-designed products from diverse customers require increased manufacturing flexibility. However, managing multiple products in one facility is highly challenging. Coordinating numerous chambers and process steps with different designs and technology nodes is complex as shown in Figure 1. The challenges of high product mix manufacturing lead to reduced yields and increased costs. Addressing this issue and developing effective strategies are critically needed.

CVD process is crucial in semiconductor manufacturing but faces challenges with high product mix. Deposition thickness variations arise from device layout design and CVD process chamber condition drift. Figure 2(a) shows a schematic demonstrating the difference in film thickness between single and double pitches. Figure 2(b) presents TEM images illustrating discrepancies in silicon nitride film thickness between wide and narrow patterns. Apart from line pattern spacing, other design features impact film thickness variation. Lack of control across different layouts and resulting film variability significantly affects transistor parameters, leading to yield loss.

Figure 3 depicts the drift in CVD film growth rate during PM and chamber-to-chamber variations. Film growth variation arises from diminishing surface area and reactive gas consumption on the inner wall of the CVD chamber due to accumulated thickness. Managing chamber-by-chamber variation is crucial in high-volume manufacturing. Insufficient solutions for PM cycle variation and achieving chamber matching hinder fab line management, causing throughput loss.

The variation in CVD film thickness comes from design features and chamber characteristics in high volume manufacturing fabs. Controlling it with traditional methods is challenging. High product mix production requires frequent NPI, affecting efficiency without optimization. This paper proposes a ML based VM approach for effective process control in high product mix manufacturing, demonstrated through simulation.

Modeling

To achieve precise CVD process control, suitable metrology systems are necessary. However, increased reliance on metrology activities and investment lead to longer processing times and higher costs. To address this trade-off, VM has been developed, utilizing FDC data from the process chamber to predict metrology results, integrating them into real-time process control, especially in R2R. Design features are extracted and used for prediction across layouts and technologies, benefiting new layout introductions and production stages. Siemens' Calibre® software is used to extract design features from diverse layouts and incorporate them into chamber-level FDC data using ML methodologies to construct the VM model. The dataset includes three technology nodes, 70 products, and 15 CVD chambers. Results highlight the impact of design features and FDC data in VM modeling as shown in Figure 4. The VM model with both design features and FDC outperforms others, particularly for high product mix manufacturing. Segmented comparisons by product and chamber further demonstrate the VM model's superior performance as shown in Figure 5 and 6.

Result

Our proposed APC system, shown in Figure 7, uses the VM model for R2R control in the CVD process. The VM model incorporates design features, FDC, and incoming measurements to achieve the desired thickness target. The APC system calculates the prediction error during the post-measurement stage and triggers an update to the VM model if predefined rules are exceeded. Figure 8 demonstrates the improved process capability (Cpk) of the APC system, effectively reducing variations in deposition film thickness. The integration of the APC system with the VM model and specific design features improves thickness control for each product and chamber. Figures 9 and 10 show the thickness variation improvement achieved through control simulation, highlighting the effectiveness of the APC system in reducing variations in a high-mix product foundry fab.

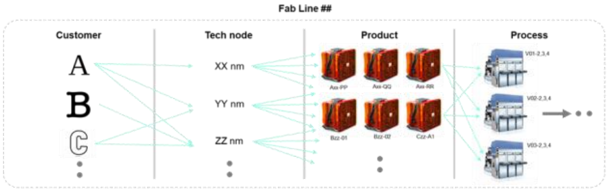
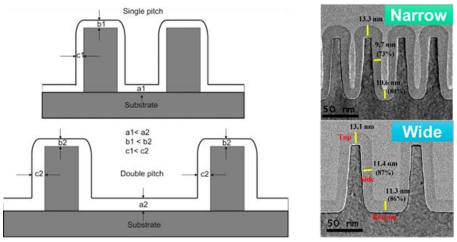


Figure 1. High product mix manufacturing in semiconductor foundry



(a) (b)

Figure 2. (a) schematic of the difference in film thickness for a single and double pitch (b) TEM images of silicon nitride film thickness differences between a wide and a narrow pattern

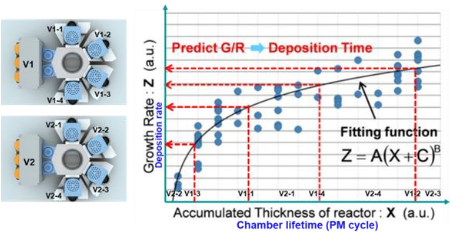


Figure 3. PM cycle and chamber-to-chamber film growth rate variations

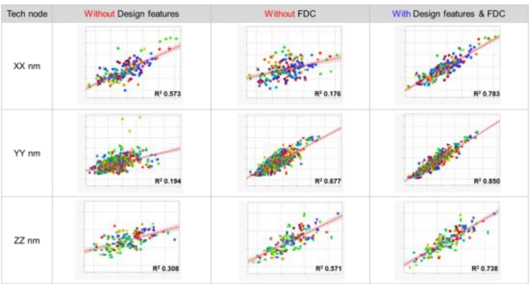


Figure 4. VM modeling with and without incorporating design features and FDC data

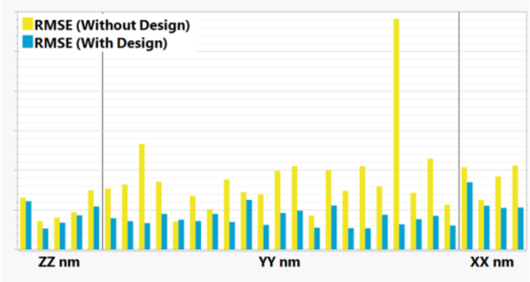


Figure 5. Segmented comparison of the VM model with and without design features by product

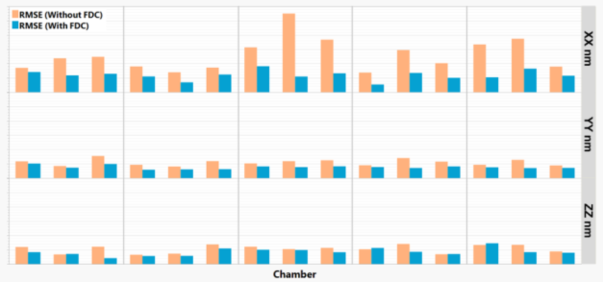


Figure 6. Segmented comparison of the VM model with and without FDC by chamber

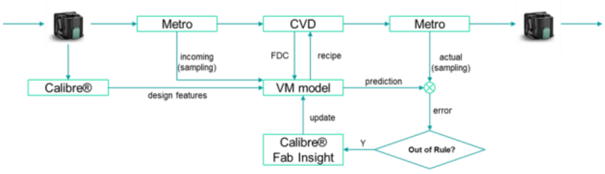


Figure 7. Schematic diagram of APC system

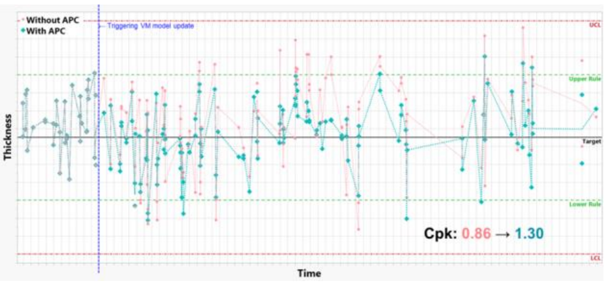


Figure 8. Control simulation result of APC system

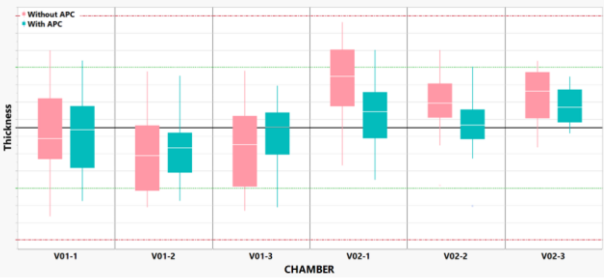


Figure 9. Control simulation result of APC system by chamber

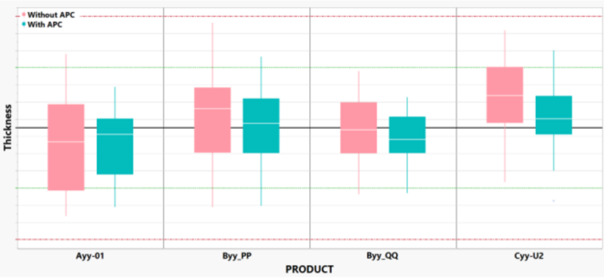


Figure 10. Control simulation result of APC system by product