

Advanced Process Control System for CVD Equipment Using Big Data Analytics and Optimization Algorithms

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Abstract

In semiconductor manufacturing, Chemical Vapor Deposition (CVD) is a crucial process for wafer production, which requires extensive machine qualification testing before production. Traditionally, engineers must fine-tune five adjustable process parameters to meet three critical output specifications—film thickness, boron concentration, and phosphorus concentration—within strict tolerance limits for quality control after a CVD equipment has undergone preventive maintenance (PM). This qualification process will rely on engineer experience and trial-and-error adjustments, resulting in low success rates, repeated testing cycles, and reduced utilization efficiency. This study proposes an integrated advanced process control (APC) system that combines predictive modeling with multi-objective optimization to overcome these challenges. In the prediction phase, we developed a novel Siamese-LGBM model, which merges the shared-weight architecture of Siamese Networks with LightGBM predictors. This design addresses the limitations of historical data, mitigates overfitting in small-sample scenarios, and reduces computation time by 20% compared to traditional Siamese Network architectures. In the optimization phase, we implemented a NSGA-II-based algorithm that employs a comprehensive feasible-solution scoring mechanism that integrates five weighted evaluation metrics to assess the quality of feasible solutions. Besides, a fast-convergence mechanism shortens computation time from over 20 minutes to approximately 1 minute by employing early-termination strategies once high-quality solutions are detected. Additionally, a fixed-parameter search mode allows flexible operational constraints according to the engineer's requirements. Implementation results demonstrate substantial improvement in qualification success rates and a marked reduction in testing iterations and equipment downtime.

Keywords

Semiconductor Manufacturing, Advanced Process Control, Siamese Neural Network, NSGA-II Algorithm, Multi-objective Optimization

Biographies

Yu-Wei Shih is currently a Master's student in the Department of Industrial Engineering and Engineering Management at National Tsing Hua University, Taiwan. He received his B.S. degree in Industrial Management from National Taiwan University of Science and Technology in 2024. His research interests include big data analytics, multi-objective optimization, and advanced process control. Previously, he served as an intern engineer in the Big Data Engineering Department at Powerchip Semiconductor Manufacturing Corporation (PSMC).

Kuo-Hao Chang is a Professor in the Department of Industrial Engineering and Engineering Management at National Tsing Hua University, Taiwan, and the Deputy Director of the National Science and Technology Center for Disaster Reduction (NCDR). He received his Ph.D. degree in Industrial Engineering from Purdue University in 2008. He is the recipient of several prestigious international awards, including the 2012 Bonder Scholar Research Award from INFORMS, the 2015 IIE Transactions Best Application Paper Award, the 2015 K.D. Tocher Medal from The OR

Society, and the 2017 IEEE Transactions on Semiconductor Manufacturing Best Paper Award. Domestically, he has received the 2015 Ta-You Wu Memorial Award and the 2019 Outstanding Research Award from the Ministry of Science and Technology (MOST), as well as the 2016 Academia Sinica Junior Research Investigators Award. He has led his team to successfully complete various industrial projects with leading companies, including TSMC, UMC, LiteOn, VisEra, and ITRI. Currently, he serves as an Associate Editor for IEEE Transactions on Automation Science and Engineering and the Asia-Pacific Journal of Operational Research. He is a member of INFORMS and IISE, and a Senior Member of IEEE. His research interests include big data analytics, simulation optimization, and applied probability and statistics.