## ALD for Manufacturing
## Room Tampa Bay Salons 5-9 - Session AM-MoP
## ALD for Manufacturing Poster Session

**AM-MoP-1 Implementing Statistical Process Control for Atomic Layer Deposition Tools in an Academic Facility to Meet Industrial Expectations***, Ronald Reger,* Birck Nanotechnology Center, Purdue University*; **Anh Ho,*** Birck Nanotechnology Center, Purdue University.*; Rich Hosler,* Birck Nanotechnology Center, Purdue University

As academic nanofabrication facilities expand their role in advanced research and prototype development, the demand for industrial-level process stability and repeatability in Atomic Layer Deposition (ALD) has become essential. At the Birck Nanotechnology Center, we have implemented a comprehensive Statistical Process Control (SPC) framework applied to multiple Fiji ALD systems to enhance process reliability. The key metrics, including film thickness, uniformity, growth-rate, refractive index, surface roughness, precursor delivery stability, and overall tool-health indicators, were continuously tracked using control charts, capability analyses, and automated data-logging integrated into routine operations. Over several years, SPC-driven maintenance strategies, precursor delivery stability, and recipe standardization have enabled improvements in within-wafer and wafer-to-wafer uniformity, reduced run-to-run variability, and enhanced long-term reproducibility. Several dielectric ALD processes now demonstrate statistically stable performance with sustained operation within established control limits. This work not only demonstrates the value and practicality of applying formal SPC methodologies within an academic cleanroom, effectively bridging research-grade flexibility with industry-grade reliability, but also contributes significantly to building the data foundation for a digital twin model for educational purposes. The results offer a model for academic facilities aiming to improve tool performance, build user confidence, and meet industry-aligned research expectations.

**AM-MoP-2 Anti-Deposition ALD–$Al_2O_3$ Coatings against Silicon Chloride Byproduct for Capacitance Manometers***, **Hidenobu Tochigi,** Keigo Iwamoto, Takuya Ishihara,* Azbil corporation, Japan

In semiconductor manufacturing processes such as dry etching and thin–film deposition, including chemical vapor deposition (CVD) and atomic layer deposition (ALD), capacitance manometers are widely used as essential vacuum pressure sensors to monitor and control the pressures of process gases. Conventionally, diaphragm materials such as nickel-based alloys and polycrystalline aluminum oxide ($Al_2O_3$) are employed to ensure durability under chemically harsh environments. Sapphire, a single crystal of $Al_2O_3$, is known for its excellent chemical stability, and we have developed MEMS-based pressure sensor chips entirely fabricated from sapphire [1]. In actual application, long-term drift and zero-point shift of the sensors have been observed during semiconductor manufacturing processes, which are presumed to be caused by byproduct deposition on the sensor surfaces.

In particular, processes using silicon-chloride precursors are known to generate chlorine–containing reactive intermediates and byproducts that can potentially deposit on the sensor surfaces. Previous studies on ALD processes have reported that a self–limiting surface reaction mechanism, in which SiCl–containing precursors selectively react with reactive surface functional groups such as –OH and –NH, and further adsorption is suppressed once these reactive sites are consumed [2-5]. Based on this concept, we hypothesized that similar self–limiting reactions could occur on –OH–terminated $Al_2O_3$ surfaces deposited by ALD and could consequently suppress the continuous formation of SiCl–related deposits on the sensor surfaces. If effective, this mechanism could be applied as a byproduct deposition mitigation strategy for capacitance manometers used in similar processes.

To verify this hypothesis, $Al_2O_3$ coatings were deposited by ALD using trimethylaluminum and $H_2O$ over the entire internal surfaces of capacitance manometers, and their behavior under SiCl–based process environments was evaluated. As a result, the ALD–coated manometers showed no such degradation, whereas uncoated manometers exhibited zero–point shifts of approximately 40% of full scale and pronounced pressure hysteresis, which exhibited excellent an anti-deposition effect. In addition, the deposited $Al_2O_3$ film quality was examined in detail by X–ray photoelectron spectroscopy (XPS) and transmission electron microscopy (TEM).

References

[1] H.Tochigi, et al., 45th Dry Process Symposium, P-13 (2024)

[2] O. Sneh, M. L. Wise, et al. Surface Science, 334, 135(1995)

[3] J. K. Kang, C. B. Musgrave, Journal of Applied Physics, 91, 3408(2002)

[4] L. L. Yusup, J.-M. Park, et al. Applied Surface Science, 432, 127(2018)

[5] R. A. Ovanesyan, E. A. Filatova, et al. J. Vac. Sci. Technol. A 37, 060904 (2019)

**AM-MoP-5 Design and Flow Optimization of Additively Manufactured Manifolds for Process/Purge Valves in Atomic Layer Deposition***, **Frank Horvat**, Ben Olechnowicz, Masroor Malik,* Swagelok Company

Valve manifolds used in Atomic Layer Deposition (ALD) for precursor delivery and system purging are typically fabricated using standard subtractive machining techniques, which impose strict and highly limiting constraints on internal fluid flow-path geometry. As a result, internal flow fields tend to develop recirculating vortical structures, jet impingement at junctions, high pressure losses, and stagnant volumes, adversely affecting precursor uniformity and delivery in the viscous and transitional flow regimes relevant to ALD. In contrast, additive manufacturing enables the development of manifolds with optimized internal geometries, continuous cross-sectional transitions, and reduced junction complexity while keeping the semi standard for surface roughness. Theseoptimized, additive created geometrieseither suppress or reduce flow separation, lower pressure drop, and minimize stagnant regions leading to improved flow conductance, more uniform precursor transport, and enhanced temporal control of precursor dosing in ALD systems.

This poster will show a comparative analysis of conventionally machined versus additively manufactured ALD valve manifold flow-path geometries using computational fluid dynamics (CFD). The results highlight how geometry-enabled flow control reduces pressure loss, suppresses recirculation and stagnation, and improves precursor transport uniformity and temporal response under viscous and transitional flow conditions relevant to ALD processes.

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**AM-MoP-6 Redefining Precursor Delivery: A Novel ALD Valve Architecture for Enhanced Stability and Reliability in ALD/ALE Processes***, **Philipp Maydannik**,* VAT Group AG, Switzerland

With the industry's move towards **atomic-scale device architectures and complex 3D structures**, the operational accuracy of Atomic Layer Deposition (ALD) and Atomic Layer Etching (ALE) is heavily dictated by the performance of the delivery system. The ALD inlet valve stands as a critical gatekeeper in this ecosystem, directly influencing precursor dosing accuracy, film uniformity, and process repeatability. As requirements shift toward higher throughput and more aggressive chemistries, the limitations of traditional valve designs have become a significant bottleneck for next-generation manufacturing.

The diaphragm valve has long been the standard for ALD applications. However, as process windows tighten, several inherent issues have emerged:

1. **Limited Cycle Life:** Constant mechanical flexing leads to diaphragm fatigue and unpredictable failure.
2. **Flow Conductance Restrictions:** The physical geometry of a flexing diaphragm often limits the flow coefficient (Cv ), restricting the speed of precursor delivery.
3. **Thermal Sensitivity:** High-temperature processes can cause inconsistent sealing and fluctuations in flow due to thermal expansion.
4. **Particle Generation:** Mechanical stress at the diaphragm's edge and seal interface acts as a consistent source of metallic or elastomeric contamination.

To overcome these challenges, **VAT** has departed from traditional diaphragm-based designs to develop a valve with a novel architecture specifically engineered to satisfy tough requirements of ALD/ALE. By rethinking the internal actuation and sealing geometry, this design achieves a level of performance that exceeds current benchmarks.

This presentation will **detail the mechanical innovations** behind the VAT ALD inlet valve. We will present comprehensive test data, including:

1. **Flow Stability:** Comparative data showing Cv consistency over extended cycling and wide temperature range.

2. **Timing Precision:** Data demonstrating stable open/close transitions over extended cycling tests.
3. **Reliability Metrics:** Results from life testing and particle contamination benchmarks.

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