Atomic Layer Engineering: Hardware Considerations for ALD System Design and Process Development

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As the portfolio of ALD processes chemistries continues to broaden, there is an increasing need for hardware customization to ensure process compatibility. Furthermore, the manufacturing demands for ALD continue to push for higher throughput, without sacrificing film quality or process reliability. In particular, as the form factor of ALD substrates begins to deviate from planar wafers to 3-D architectures, coupled thermal, mass transport, and chemical kinetics play an increasingly important role in ensuring optimal ALD deposition.

This tutorial will describe several critical, and often under-discussed, aspects of ALD reactor hardware design and process control. The discussion will begin with a primer on vacuum system design in general – materials compatibility, fittings, o-rings/gaskets, valves, flow controllers, pumps, and metrology tools. Next, precursor delivery to the substrate will be discussed, with consideration of special challenges for solid precursors and low-vapor pressure precursor delivery. Various chamber geometries will be compared, and the coupled thermal/fluid transport behavior during vapor transport and reactivity will be described. Incorporation of *in situ* process metrology will be described. Finally, vacuum exhaust line design will be discussed, with an emphasis on maintaining a safe, and reproducible system.