Atomic Layer Processing

MKS provides a wide range of solutions to create complex thin films and 3D features for advanced memory and logic technology nodes

Introduction

Smartphones and other mobile consumer electronic devices continue to get thinner and more compact while simultaneously increasing their ability to process, consume and store large amounts of data without negatively impacting overall device battery life and end-user experience. These trends drive the need for denser transistor structures and 3D architectures for logic and memory ICs. Traditional manufacturing processes like Physical Vapor Deposition (PVD), Chemical Vapor Deposition (CVD), and Reactive Ion Etch (RIE) cannot easily produce the extremely thin films and smaller features used in advanced logic and memory technology nodes. Newer technologies like Atomic Layer Deposition (ALD) and Atomic Layer Etch (ALE) create thin films and complex 3D architectures one monolayer or atom at a time using tailored, self-limiting, cyclical chemical reactions at low temperature. The activation method is either thermal or plasma. In both ALD and ALE, a precursor adsorbs on the thin film surface forming a chemically bound monolayer. A reactant is introduced, chemically reacting with the previously modified monolayer surface, resulting in either growth or removal of a thin film layer. Byproducts from the reaction are purged and the process repeats for as many cycles as needed.

MKS products solve key Atomic Layer Processing challenges including precursor reactivity, film uniformity, contamination control, and selective and precise material removal with high-performance solutions in:

- Ozone
- Remote Plasma
- Pressure Measurement
- Pressure Control
- Thermal Management
- Process Traps
- RF Power
- Vacuum Valves

Atomic Layer Processing creates extremely thin films, selectively and precisely etching complex features, enabling today's and the next generation advanced memory and logic technology nodes.

Atomic Layer Deposition

Challenges

ALD creates very thin, highly tuned, conformal dielectric and metal films, barrier layers and spacers several Angstroms thick. A wide variety of precursors are used to create smooth thin films free of pinholes ensuring good electron mobility and IC functionality. These films help maximize performance characteristics of smaller features and stacked 3D architectures.

Challenges specific to ALD include:

- Precursor reactivity
- Film uniformity
- Achieving contamination-free layers

Atomic Layer Processing

Atomic Layer Deposition (cont.)

MKS Solutions

ALD produces the thin films needed for small, dense, and high aspect ratio (HAR) features used in complex 3D architectures. ALD, either thermal or plasma activated, uses pure metals, metal oxides, and nitrides to create highly tunable thin films for high-k/metal gates, liners in dual damascene metallization, spacers for double patterning, and dielectric and metal layers.

In thermal processing, the reaction occurs in a heated chamber, not exceeding 400°C, and is driven by wafer surface temperature and precursor concentration. O_2 is the traditional precursor created by the chemical breakdown of water. Increased use of oxide compounds to create thin films requires a higher purity O_2 source to reduce film contamination. **MKS Ozone Generators** provide high flow concentrated ozone that is ultra-pure, eliminating hydrogen and hydroxyl contamination that occurs with water. Carbon contamination is reduced by the ozone's highly oxidizing nature. This results in very pure thin films that are very electrically efficient due to low leakage current.

Plasma-activated atomic-level processing is an alternative when the materials being used can't withstand the higher temperature requirements of thermal ALD. A remote plasma source or RF generator and match network create free radicals enabling the reaction between the precursor and wafer surface at lower temperature. Radicals improve chemical reactivity with the wafer surface resulting in shorter processing times and thinner films. **MKS Remote Plasma Sources** support H_2 and other process chemistries. Using an enhanced plasma block for improved hydrogen radical output, and with hydrogen flow up to 5 slm, the MKS solution provides stoichiometry control enabling tailored thin film composition.

MKS RF Plasma Generators produce the widest range of radicals including elemental metals such as Ta, Ti and Pt, and nitrides and carbides. The addition of a bias to the RF generator provides directionality to the radicals, enabling better thin film deposition of features like high aspect ratio fins and finer adjustment of film properties. This high degree of film tailoring improves future atomic layer etch results. MKS's RF Generators have advanced pulsing capabilities that support quick switching of precursors, shortening thin film processing time and increasing throughput.

Atomic Layer Etch

Challenges

ALE creates trenches and gaps, trims vertical structures like fins, and removes thin films like interfacial oxide layers at the atomic or monolayer level. Precise control over feature architecture reduces variation die-to-die and wafer-to-wafer resulting in higher yields without causing damage to the surrounding structures or the wafer.

Challenges specific to ALE include:

- Selective material removal
- Precise etching
- Wide range of materials
- Low damage to surrounding features

MKS Solutions

ALE provides a flat etch surface, eliminating micro-trenching that occurs with a continuous etch process. **MKS RF Plasma Generators**, with advanced pulsing capability, provide a level of control over plasma chemistry, separating neutrals from ions allowing saturation during the pulse off stage. The bias provides directionality to the ions further enabling anisotropic etching. These combined features enable selective, precise material removal for deep trenches and HAR features. The generated species are highly reactive and gentle, shortening processing time and reducing damage to the wafer and surrounding structures. The end results are highly repeatable critical dimensions and better IC performance. MKS RF Plasma Generators etch at low power, making them the right choice for delicate films.

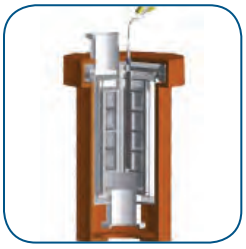
To better enhance film stoichiometry in specific applications, microwave plasma sources are gaining traction. **MKS's Microwave Subsystems** provide multiple power delivery frequencies that can be mixed in a process recipe to increase film stoichiometry. This results in a more reliable and efficient IC.

MKS Solutions in Atomic Layer Processing

The ALD process requires high vacuum and precise pressure measurement and control to ensure the resulting monolayer film has the correct composition and uniformity. The pressure measurement device is in situ and during deposition, residual reactants can potentially cause unwanted pressure measurement drift. The unique patented technology of **MKS Baratron® Capacitance Manometers** minimizes residual deposition and ensures low pressure measurement drift, resulting in highly reproducible thin films. To avoid condensation build-up, the capacitance manometer is heated making it thermally compatible and, using the EtherCAT® protocol, it communicates rapidly with the overall system, improving speed of response.

Controlling gas volume improves process efficiency and reduces the cost of expensive precursors. **MKS Pressure Controllers**, positioned at the inlet of the chamber, provide precise precursor delivery control by sending a highly concentrated volume of gas to the chamber and stopping gas flow quickly once volume is achieved. **MKS High Speed Throttle Valves**, located at the outlet, build pressure quickly inside the chamber using a unique, soft-sealing technology and rapidly modulate pressure caused by the influx of gas with fast opening and closing valve operation. Precise control of gas flow and chamber pressure reduces the amount of wasted gas and ensures optimum chemical reactivity resulting in good thin film deposition.

Temperature differences between feed lines and the process chamber can lead to condensation of precursor gas causing variation in delivered gas volume. This leads to insufficient precursor gas for the chemical reaction resulting in incomplete deposition or etch. The **MKS Thermal Management System** consists of advanced heater jackets made with highly energy-efficient materials, a controller with customized temperature operation, and an intuitive user interface that allows accurate and precise temperature control. This guarantees a self-saturating, self-limiting reaction resulting in high quality, uniform film deposition and precise etching of complex structures. Similarly, the MKS Thermal Management System can be utilized for effective pumpline temperature management.



Byproducts from Atomic Layer Processing and residual precursors can cause hardened deposits in the process chamber and in downstream lines and components. **MKS Heated Trap** solutions use an advanced control system and a heating element capable of reaching 550°C to dissociate organometallic and other metallic precursors and byproducts, separating the gaseous metal from the attaching molecules. Collecting residual byproducts in one trap makes service of the system easier, reduces the amount of maintenance needed, and protects downstream components from damage, resulting in longer uptime and increased throughput.

Atomic Layer Processing creates different residual byproducts requiring an alternate set of species to remove chamber deposits. **MKS Remote Plasma Sources** produce a high concentration of radicals, from O_2 and N_2, reducing chamber clean time and increasing manufacturing equipment productivity.

MKS is a leading global provider of solutions for Atomic Layer Processing *to quickly and accurately create and deliver a wide range of precursor gases, measure and control chamber pressure, heat fore lines, shorten purge cycle time, and manage and clean residual deposits from the process chamber protecting downstream subcomponents and lines. MKS solutions enable the creation of thin, highly tuned, conformal coatings and precisely dimensioned 3D structures with excellent electrical characteristics for more advanced architectural structures used in complex logic and memory ICs.*

We are committed to helping our customers solve their most complex problems. For further information visit us on the web at www.mksinst.com or call us at 978-645-5500.

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ALD/ALE - 11/17