

Energy Storage



Optoelectronics



Additive Manufacturing



Life Sciences



Performance Materials



WE'VE GOT IT COVERED

At **ALD Nano**, we create cost-effective, precision coatings for advanced materials that are transforming industries. We're the world leader in atomic and molecular layer deposition (ALD) technologies on particles and other materials, with a broad IP portfolio.

GLOBAL LEADER IN ALD ON PARTICLES

We collaborate with world-leading companies that leverage our material designs and reactor systems to innovate products that benefit consumers globally.

ALD-ENABLED ADVANCED MATERIAL SOLUTIONS

For more than a decade, we have commercialized ALD technologies developed internally by our world-class team of scientists and engineers and externally by our partner research institutions.



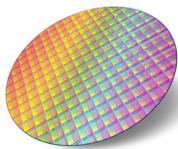
ALD FOR PARTICLE MATERIAL SOLUTIONS

Atomic and molecular layer deposition (ALD) can be economically scaled to coat tons of powder, kilometers of polymers and many thousands of specialty objects a day. ALD first reached commercial scale for coating various chemistries onto silicon wafers in the semiconductor industry in the 1990s, which today is a multi-billion dollar market. ALD is now becoming the method of choice for coating ultrathin, precisely controlled films onto particles and other new material substrates.

ALD Nano helps customers solve particle material challenges by perfecting the necessary ALD coating chemistries, process conditions and manufacturing equipment systems. Our global leadership position is ALD on powders, also known as particles or particle ALD. Many Fortune 500 companies are among our customers and supply channel partners. ALD on particles has many benefits including:

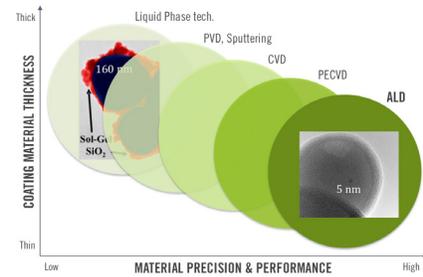
- Superior precision and cost-effectiveness compared with chemical vapor deposition (CVD) and other techniques enable new or better applications for known substrates with improved end-device performance, lifetime, cost and safety.
- Novel atomic-scale material designs can be created with significant value to materials supply chain customers and end-device partners.
- Substrate functionality improvements occur by changing physical characteristics of particles including enhanced (or reduced) chemical stability, flowability, corrosion, oxidation, conductivity, hydrophilicity, optical properties, material compatibility, dispersion, sintering control, barriers, and reduced mass.
- Particle agglomeration does not happen with proper ALD process conditions, regardless of particle size, shape and morphology.

Relative to ALD on silicon wafers for the semiconductor industry, particle ALD presents unique challenges and opportunities for deposition of coatings requiring new precursors, processes, chemistries and manufacturing equipment systems.



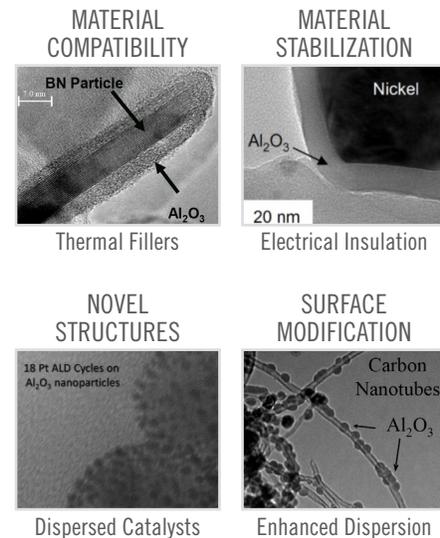
Uniform size of wafer	Particle size distributions
No interaction between wafers	Particle-particle interactions
Particle-free environment	Particles are the environment
Minimal precursor usage	1000 x more precursor
Narrow process windows	Wider process windows
Low surface area	High surface areas
Wafer oriented equipment	New equipment & material production
Few chemistries deployed	Broad spectrum of chemistries

COMPARISON OF DEPOSITION TECHNOLOGIES



Comparison Characteristics	ALD	Other tech. (PVD, CVD, PECVD)
Does not require line of sight	Yes	No
Chemically bonded film to substrate surface	Yes	No
Avoids residue and granular films	Yes	No
Nanometer Control of Thickness	Yes	No

PARTICLE ALD BENEFITS & EXAMPLE SUBSTRATE COATINGS



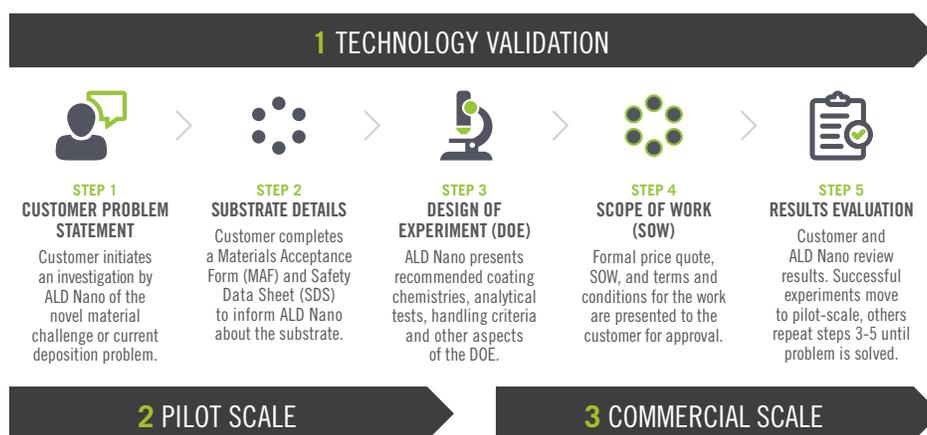
Contact ALD Nano for journal citations for the above images.

HOW ALD NANO CAN HELP YOU

ALD Nano specializes in providing ALD-enabled material solutions for its customers by addressing the ALD chemistry, process conditions and manufacturing equipment systems. Our in-house engineering team designs these systems, also known as ALD reactors, for in-house use and for our ALD material solutions customers. We also partner with leading chemical precursor developers and suppliers to ensure the best ALD coating chemistries in the world.

The ALD Nano product development team works with our customers in a three phase gated process to move from concept to commercial deployment of ALD-enabled materials. In the technology validation phase, we define and solve the material problem. The substrate conditions, material performance requirements, and other metrics used to define success form the basis of each work plan between ALD Nano and its customers. This phase is intended to produce proof-of-concept samples of the desired materials and ALD chemistry and process recipes.

After a successful sample is produced at bench scale, the next phase of ALD Nano's work focuses on developing the material solution at pilot scale through a joint development agreement. At the final phase, commercial production, we bring the ALD chemistry and process recipe plus the proprietary reactor system design into our customer's materials manufacturing facilities for launch of their ALD-enabled material. Alternatively, we toll-coat the ALD-enabled material at our facility for our customers.



Over the three phases, production volumes increase, while costs of finished products decrease. A bench-scale process might produce a few tens or hundreds of grams of coated powder, while a commercial scale reactor can produce up to tons per day. ALD Nano has the capabilities and experience to span this whole range.

ALD COATING EXPERIENCE

Each material coating application is different. Since 2001, ALD Nano has developed broad and deep experience by solving material coating challenges with ALD for over 100 commercial customers. We have handled many types of particle substrate materials and created novel ALD coating chemistries and processes (as shown in the table to the right).

For some of our work, a substrate and coating might have been well-known from CVD applications, and the goal was to develop a better or less expensive ALD process. In other cases, all traditional deposition methods such as CVD may have faced intractable limitations, and an ALD innovation was required.

PARTICLES COATED

METALS: Nickel, iron, tungsten, various alloys
CARBONS: CNTs (MW, DW & SW), graphene, carbon blacks, diamond
METAL OXIDES: Zirconium oxide, titanium oxide, zinc oxide, lithium mixed metal oxides, yttrium stabilized zirconia, various mixed metal oxides
METAL NITRIDES: Boron nitride, aluminum nitride
OTHERS: Zinc sulfide, various polymers
Sizes from 20 nm – 1 mm

COATING CHEMISTRIES

METAL OXIDES: Aluminum oxide, titanium oxide, zinc oxide, zirconium oxide, silicon oxide, tungsten oxide, ruthenium oxide
METAL FLUORIDES: Aluminum fluoride
METALS: Platinum, ruthenium
MIXED METAL OXIDES: Aluminum zinc oxide, various others
ALKOXIDE POLYMER FILMS: Alucones, titanicones, various other molecular layer deposition (MLD) films

ALD-Enabled Materials Created for Our Customers are a Bundle of Products and Services

CHEMISTRY & PROCESS RECIPES • REACTOR SYSTEMS • IP LICENSING • TOLLING OPERATIONS

ALD REACTOR SYSTEMS & PROCESS CONTROL

Processing particles with ALD requires robust and new engineering solutions and reactor designs. For ALD Nano to create material coating solutions, it has designed a suite of the best particle ALD reactor systems. Our facility houses many systems that deliver proof-of-concept sample materials for customers during the technology validation phase of our work. We also have pilot and commercial scale production systems that are proving-out and producing materials for customers in compliance with stringent QA/QC requirements including ISO. And, the entire facility operation includes leading edge safety programs.

ALD Nano's particle reactor systems are flexible in terms of size, operating conditions and throughput capacity. The table to the right presents specifications for these ALD reactors in use at our facility and available as part of our bundle of products and services that we deliver to customers for production of our ALD-enabled material solutions at their locations. We have a broad range of capabilities for managing various substrates and coating chemistries.

ALD REACTOR SYSTEMS	Fluidized Bed Reactors (FBR)	Rotary Reactors (Rotary)	Continuous Vibrating Reactors (CVR)
Substrate Volume	75mL to 10L per batch	10ml to 40L	15L/hr to 150L/hr
Substrate Mass (Density Dependent)	75g - 12.5kg per batch	10g - 50kg per batch	15kg/hr to 150kg/hr
Vapor Draw Sources	2 standard, up to 8	2 standard, up to 8	2 standard, up to 8
Regulatory Compliance	CE, GMP and ISO compliance upon request		
Weight	300 lbs - 1,000 lbs (150kg - 500kg)	300lbs - 4,000lb (150kg - 2000kg)	500lbs - 8,000lb (250kg - 4000kg)
Venting Emissions and Abatement	Equipment can be designed to comply with local jurisdiction codes and regulations		
Electrical Requirements	Project-specific and customized. Further details can be supplied upon request		
Demonstrated Particle Diameters	10 nm - 500micron	10 nm - 200micron	5-50micron
Potential Particle Diameters	2 nm - 1mm	2 nm - 10cm	10nm - 1 cm
Other Features	Highest Precursor Efficiency	Plasma ALD Compatible	Atmospheric Pressure Operation

IP PORTFOLIO AND ALD ON POLYMERS & SPECIALTY OBJECTS

ALD Nano's IP portfolio includes more than 50 provisional, filed and issued patents in the US, Europe, Japan and elsewhere as well as extensive know-how. Much of this IP was developed by our primary research partner, the University of Colorado Boulder (CU). CU houses the world's leading particle ALD research programs, which began over 20 years ago.

Our expertise in solving ALD coating challenges for particles has resulted in a companion effort to develop IP and material solutions for coating polymers and specialty objects, often in related market applications.

We exclusively license the CU IP under a master agreement and continue to add in-house developed IP to our portfolio each year. Various elements of this IP portfolio are licensed to our ALD-enabled advanced materials customers to help them transform industries.

ALD nanosolutions™

Contact us for ALD-enabled advanced materials solutions.

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