Picosun ALD Solutions


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Managing director, Picosun Oy
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Picosun in brief
Picosun mission

PICOSUN OFFERS AGILE ALD™ SOLUTIONS FOR COMPANIES DRIVEN BY INNOVATION

AGILE ALD™ is

- Fast and Efficient
  - High throughput and yield with low CoO, constant development in collaboration with customers
- Reliable
  - Production-proven processes, operational excellence programs, ISO-certified company
- Adaptable
  - We provide ALD solutions both to the world’s leading IC manufacturers as well as to the academia. Innovation is our passion. We work together with our customers to create novel, ALD-based solutions to shape the future industries!
A people first business driven by success

- Our company values reflect who we are. They define how we act towards our customers, colleagues, and stakeholders every day.
- We are driven by success. Success to us means working with our customers to create cutting edge innovation and enduring reliability.
- As a people first business, we are both dedicated to diversity and committed to our social responsibility.
Picosun history

PIONEERING THE FIELD OF ALD SINCE ITS INVENTION

- ALD was invented and patented in Finland 1974 by Picosun Board Member Dr. Tuomo Suntola
- Picosun is the only company solely dedicated to ALD
- Established in 1997, in ALD business since 2004
- Picosun core team consists of Doctors in ALD science, with decades of experience in the field

Left: Mr. Sven Lindfors, "the world’s most experienced ALD reactor designer" and a former Picosun Board Member designed state-of-the-art ALD systems since 1975.
Middle: The first industrial application of ALD, thin film EL display, from the early 1980’s.
Right: Dr. Tuomo Suntola receives the European SEMI award 2004 from SEMI President and CEO Stanley T. Myers.
Picosun today

"PICOSUN DANCES WITH GIANTS" – *Talouselämä* magazine, Finland, May 2017

- Profitable for 8 consecutive years
- 26 M€ in sales
- 100+ full-time own employees
- HQ in Finland, 100% Finnish ownership
- Rapid expansion, worldwide presence
  - Subsidiaries in Europe, USA, Singapore, China, Taiwan, India and Japan
  - Sales and support network in over 30 countries
- The ALD technology provider for global industry leaders
  - IBM, Bosch, and other IC giants
  - TOP10 companies in Nasdaq
  - Largest foundries, MEMS, LED, and microelectronics manufacturers
  - Prominent Mints, luxury product manufacturers, and medical technology companies
Picosun in Russia and CIS countries

- The official representative on the territory of Russia and CIS countries – company «Eurointech», Moscow:

  - www.europointech.ru
  - The head of sales department of microelectronics equipment, Mr. Oleg Simonov: sov@eurointech.ru, phone +7 495 925-77-10.
  - The technical support on the territory of Russia and CIS countries is accomplished by the certified engineers of «Eurointech», and directly from the Picosun headquarters in Finland.
  - Leader in research and industrial ALD market
The basics of ALD
The principle of ALD

THIN FILM GROWTH BY CONSECUTIVE ATOMIC LAYERS

• The most advanced thin film coating method of today
• Precise control of the film thickness and structure down to nanometer level
• The highest film uniformity and conformality over and inside the smallest nanoscale features
• Dense, pinhole-free and defectless films
• Digitally repeatable process
• Low process temperatures, gentle to sensitive substrates

Key enabling technology in modern IC industry!
ALD growth conditions

SELF-LIMITING, SURFACE CONTROLLED FILM FORMATION

- Deposition pressure is adjusted with inert carrier/purge gas (N₂ or Ar)
- The reaction chamber and substrate are heated to the deposition temperature
- Typical deposition pressure is 1 – 10 hPa (mbar)
- Typical deposition temperature is 200 – 400 °C
- Certain materials, especially nitrides, may require even higher temperatures
- With plasma-enhanced ALD, it is possible to go to lower temperatures – with some oxide materials even close to room temperature
Some typical ALD materials

NOTE: THE LIST IS NON-INCLUSIVE – FOR MORE DETAILED INFORMATION PLEASE CONTACT PICOSUN DIRECTLY!

- Oxides: \( \text{Al}_2\text{O}_3 \), \( \text{HfO}_2 \), \( \text{TiO}_2 \), \( \text{SiO}_2 \), \( \text{Ta}_2\text{O}_5 \), \( \text{Y}_2\text{O}_3 \), \( \text{ZnO} \), \( \text{ZnO}:\text{Al} \), \( \text{ZrO}_2 \), \( \text{Al}_x\text{Ti}_y\text{O}_z \), \( \text{In}_2\text{O}_3 \), \( \text{MgO} \), \( \text{SrTiO}_x \), \( \text{La}_2\text{O}_3 \), \( \text{CeO}_2 \)
- Nitrides: \( \text{AlN} \), \( \text{TiAlCN} \), \( \text{TiN} \), \( \text{TaN}_x \)
- Metals: \( \text{Ir} \), \( \text{Pt} \), \( \text{Ru} \)
The main markets of Picosun
Integrated circuits (IC)

PICOSUN IS THE ALD PARTNER OF CHOICE FOR THE WORLD’S LEADING IC MANUFACTURERS

• IC industry has been the main user of ALD since early 2000’s
• ALD is the key enabling technology in manufacturing IC components on silicon and III-V semiconductors
• Picosun offers SEMI S2 compatible, cutting-edge solutions for power electronics, mixed signal, advanced logic, new types of memories, and hard drives
• PICOSUN™ ALD systems, integrated in fully automated cluster platforms, have the best CoO in single wafer and batch production
• Typical ALD materials for IC applications:
  ▪ Oxides for high-k materials, insulators, patterning, passivation, and moisture barrier layers
  ▪ Nitrides, carbides and pure metals for electrodes, diffusion barriers, interface layers, and capping layers
Microelectromechanical systems (MEMS)

PICOSUN OFFERS THE PROVEN ALD SOLUTIONS FOR HAR STRUCTURES AND OVER HIGH STEPS

• MEMS and sensor industries utilize the electrical and mechanical properties of silicon and other semiconductor materials

• ALD is the ideal method to deposit protective and functional layers on microscale 3D devices with HAR structures and high steps

• Picosun is the market leader in delivering cost-effective, high quality batch ALD solutions for various MEMS applications such as sensors, print heads, microphones, optoelectrical and RF devices

• Typical ALD materials for MEMS:
  ▪ Oxides for insulation, passivation, etch stop and barrier layers
  ▪ Hybrid materials and nanolaminates for hydrophobic and hydrophilic layers, moisture protection, anti-sticking, and optical layers
Solid state lighting (LEDs)

PICOSUN IS THE TECHNOLOGY PROVIDER OF CHOICE FOR THE LED INDUSTRY LEADERS

- LED industry requires ALD to enable products with higher brightness, longer lifetime, and lower consumption of electricity
- Picosun provides a complete range of ALD systems of high efficiency and throughput for 50 – 150 mm LED wafers of
  - GaN on Si
  - GaN
  - Sapphire
- Picosun is working with the LED industry leaders for device passivation, moisture protection, buffer and interface nitride layers, and to create new 3D LEDs and more efficient light-emitting phosphors
- Typical ALD materials for LEDs:
  - Single wafer nitrides
  - Oxides and transparent conductive oxides on wafer batches and on phosphor powders
Minting, watches, and jewelry

MARKET LEADING, AUTOMATED ALD SOLUTIONS FOR LUXURY PRODUCT MANUFACTURERS

• Minting, watchmaking, and luxury product industries utilize ALD for
  ▪ Anti-tarnish coatings
  ▪ Passivation layers
  ▪ Colored coatings
• Picosun is the market leader in providing high throughput and cost-efficient batch ALD production solutions for these applications
• Our selection of ALD equipment ranges from simple air-opening systems with manual substrate loading to fully automated production units with several substrate handling options:
  ▪ Linear inline loader
  ▪ Industrial robot loading
  ▪ Vacuum load lock
• Thousands of substrates can be processed in one single run
Medical technology

CUTTING-EDGE ALD TECHNOLOGY FOR SURGICAL IMPLANTS AND DRUG DELIVERY SYSTEMS

• Medical industries utilize ALD for various applications from protection and passivation to device manufacturing

• Prominent medical technology manufacturers use Picosun's ALD solutions for
  ▪ Biocompatible and bioactive coatings on surgical implants
  ▪ Protective coatings for powders for controlled drug delivery

• Other medical ALD applications include
  ▪ Medical MEMS and LOC devices for sensing, diagnostics, and analysis
  ▪ Hydrophobic/hydrophilic coatings
  ▪ Extremely thin films for stents

• Where the highest conformality is needed, our proprietary Picoflow™ technology enables coating of standard ALD materials in aspect ratios of up to several thousands to one.
PICOSUN™ ALD solutions for R&D
PICOSUN™ R-200 Standard ALD system

THE AFFORDABLE OPTION FOR BASIC R&D ON ALD

• Ideal for R&D institutes, academia, and industries who are at the beginning of their ALD research

• Simple, robust, easy to use, and quick to maintain – without compromising the strictest production-level process quality and purity standards

• Suitable for R&D on dozens of applications such as IC components, MEMS devices, displays, LEDs, lasers, and 3D objects such as lenses, optics, jewelry, coins, and medical implants
PICOSUN™ R-200 Standard ALD system

TECHNICAL FEATURES

Typical substrate size and type
• 50-200 mm single wafers
• 156 mm x 156 mm solar Si wafers
• 3D objects
• Powders and particles
• Mini-batch
• Porous, through-porous, and high aspect ratio (up to 1:2500)

Processing temperature
• 50 – 500°C

Typical processes
• Al₂O₃, TiO₂, SiO₂, Ta₂O₅, HfO₂, ZnO, ZrO₂, TiN, AlN, metals such as Pt or Ir

Substrate loading
• Manual loading with a pneumatic lift
• Load lock with magnetic manipulator arm

Precursors
• Liquid, solid, gas, ozone
• Up to 6 sources with 4 separate inlets

Options
• Picoflow™ diffusion enhancer, RGA, N₂ generator, gas scrubber, customized designs, glove box compatibility for inert loading
PICOSUN™ R-200 Advanced ALD system

THE ULTIMATE SOLUTION FOR ADVANCED R&D ON ALD

• Ideal for R&D institutes, academia, and industries who want a multi-functional ALD facility suitable for top level, cutting-edge ALD research on various topics

• Flexible, versatile, modular, easy to use, and quick to maintain – without compromising the strictest production-level process quality and purity standards

• Suitable for R&D on dozens of applications such as IC components, MEMS devices, displays, LEDs, lasers, and 3D objects such as lenses, optics, jewelry, coins, and medical implants
**PICOSUN™ R-200 Advanced ALD system**

**TECHNICAL FEATURES**

**Typical substrate size and type**
- 50-200 mm single wafers
- 156 mm x 156 mm solar Si wafers
- 3D objects
- Powders and particles
- Mini-batch
- Porous, through-porous, and high aspect ratio (up to 1:2500)

**Processing temperature**
- 50 – 500°C, plasma 450°C (650 °C with heated chuck on request)

**Typical processes**
- Al₂O₃, TiO₂, SiO₂, Ta₂O₅, HfO₂, ZnO, ZrO₂, AlN, TiN, metals such as Pt or Ir

**Substrate loading**
- Manual loading with a pneumatic lift
- Load lock with magnetic manipulator arm
- Semi-automatic loading with handling robot
- Cassette-to-cassette loading with cluster tools

**Precursors**
- Liquid, solid, gas, ozone, plasma
- Up to 12 sources with 6 separate inlets (7 if the plasma option is chosen)

**Options**
- Cluster tools, Picoflow™ diffusion enhancer, roll-to-roll chamber, RGA, UHV compatibility, N₂ generator, gas scrubber, customized designs, glove box integration for inert loading
PICOSUN™ ALD solutions for production
PICOSUN™ P-300B ALD system

AIR OPENING BATCH ALD SYSTEM FOR PRODUCTION

Typical applications:

• Manufacturing of MEMS devices such as print heads, sensors, and microphones

• Protective/decorative/functional coating of various 3D objects such as
  ▪ Mechanical parts
  ▪ Glass or metal sheets
  ▪ Coins
  ▪ Jewelry
  ▪ Medical implants
PICOSUN™ P-300B ALD system

TECHNICAL FEATURES

Typical substrate size and type
• 200 mm wafers in batches of 25 pcs (standard pitch)
• 150 mm wafers in batches of 50 pcs (standard pitch)
• 100 mm wafers in batches of 75 pcs (standard pitch)
• Non-wafer substrates (tailored holders)
• High aspect ratio samples (up to 1:2500)

Processing temperature
• 50 – 500°C

Typical processes
• Batch processes available with cycle times down to single digit seconds
• Al₂O₃, SiO₂, Ta₂O₅, HfO₂, ZnO, TiO₂, ZrO₂, AlN, TiN, and metals
• Down to <1% 1σ non-uniformity in a batch (Al₂O₃, WIW, WTW, B2B, 49 pts, 5mm EE)

Substrate loading
• Manual loading with a pneumatic lift
• Linear semi-automatic loading
• Industrial robot loading

Precursors
• Liquid, solid, gas, ozone
• Level sensors, cleaning and refill service
• Up to 8 sources with 4 separate inlets
PICOSUN™ P-300BV ALD system

AUTOMATED PRODUCTION ALD SYSTEM WITH VACUUM BATCH LOADING

Typical applications:

- Production of LEDs
- Production of discrete devices
- Manufacturing of MEMS devices such as print heads, sensors, and microphones
PICOSUN™ P-300BV ALD system

TECHNICAL FEATURES

Typical substrate size and type
- 200 mm wafers in batches of 25 pcs (standard pitch)
- 150 mm wafers in batches of 50 pcs (standard pitch)
- 100 mm wafers in batches of 75 pcs (standard pitch)
- Non-wafer substrates (tailored holders)
- High aspect ratio samples (up to 1:2500)

Processing temperature
- 50 – 450°C

Typical processes
- Batch processes available with cycle times down to single digit seconds
- Al₂O₃, SiO₂, Ta₂O₅, HfO₂, ZnO, TiO₂, ZrO₂, AlN, TiN, and metals
- Down to <1% 1σ non-uniformity in a batch (Al₂O₃, WIW, WTW, B2B, 49 pts, 5mm EE)

Substrate loading
- Semi-automatic loading with vertical loaders (one or two loaders)
- Optional heating for load lock

Precursors
- Liquid, solid, gas, ozone
- Level sensors, cleaning and refill service
- Up to 8 sources with 4 separate inlets
PICOSUN™ P-300S ALD system

CLUSTER-COMPATIBLE PRODUCTION ALD SYSTEM FOR LARGE SINGLE WAFERS

Typical applications:

• Production of IC components such as microprocessors, memories, and hard drives

• Manufacturing of MEMS devices such as print heads, sensors, and microphones
PICOSUN™ P-300S ALD system

TECHNICAL FEATURES

Typical substrate size and type
- Max. 300 mm single wafers
- High aspect ratio samples (up to 1:2500)

Processing temperature
- 50 – 500°C

Typical processes
- Single wafer processes available with cycle times down to single digit seconds
- Al₂O₃, SiO₂, Ta₂O₅, HfO₂, ZnO, TiO₂, ZrO₂, AlN, TiN, and metals
- Down to <1% 1σ non-uniformity (Al₂O₃, WIW, WTW, B2B, 49 pts, 5mm EE)

Substrate loading
- Load lock with magnetic manipulator arm
- Automatic loading available through Picoplatform™ 200 or Picoplatform™ 300 vacuum cluster system
- Cassette-to-cassette and FOUP loading available with cluster systems
- N₂ cabinet loading

Precursors
- Liquid, solid, gas, ozone, plasma
- Level sensors, cleaning and refill service
- Up to 12 sources with 6 separate inlets

Certifications
- SEMI S2/S8
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PICOSUN™ P-300F ALD system

CLUSTER-COMPATIBLE PRODUCTION ALD SYSTEM FOR WAFER BATCHES

Typical applications:

• Production of IC components such as microprocessors, memories, and hard drives

• Production of power electronics and mixed signal components

• Manufacturing of MEMS devices such as print heads, sensors, and microphones
**PICOSUN™ P-300F ALD system**

**TECHNICAL FEATURES**

**Typical substrate size and type**
- 200 mm wafers in batches up to 50 pcs
- 150 mm wafers in batches up to 50 pcs
- 100 mm wafers in batches up to 50 pcs
- High aspect ratio samples (up to 1:2500)
- Substrate materials: Si, glass, quartz, SiC, GaN, GaAs, LiNbO₃, LiTaO₃, InP

**Processing temperature and capacity**
- 50 – 300°C
- Up to 1000 wafers / 24 hours @ 15 nm Al₂O₃ thickness

**Typical processes**
- Batch processes available with cycle times down to single digit seconds
- Al₂O₃, SiO₂, Ta₂O₅, HfO₂, ZnO, TiO₂, ZrO₂, and metals
- Down to <1% 1σ non-uniformity in a batch (Al₂O₃, WIW, WTW, B2B, 49 pts, 5mm EE)

**Substrate loading**
- Fully automatic loading with vacuum cluster tool combined with vertical flip function
- Cassette to cassette batch loading through Picoplatform™ 200 vacuum cluster system
- Optional SMIF station

**Precursors**
- Liquid, solid, gas, ozone
- Level sensors, cleaning and refill service
- Up to 12 sources with 6 separate inlets

**Certifications**
- SEMI S2/S8
PICOSUN™ P-1000 ALD system

ULTRA-LARGE BATCH PRODUCTION ALD SYSTEM FOR NON-WAFER APPLICATIONS

Typical applications:

- Protective/decorative/functional coating of various 3D objects such as
  - Mechanical parts
  - Glass or metal sheets
  - Coins
  - Jewelry
  - Medical implants
PICOSUN™ P-1000 ALD system

TECHNICAL FEATURES

Typical substrate size and type
• Small and large 3D items such as mechanical parts, glass or metal sheets, coins, jewelry, medical implants

Processing temperature
• 50 – 400°C

Typical processes
• Al₂O₃, ZnO, TiO₂

Substrate loading
• Manual loading with loading accessory such as forklift cart

Precursors
• Liquid, solid, gas, ozone
• Level sensors, cleaning and refill service
• Up to 10 sources with 6 separate inlets
The key design features of PICOSUN™ ALD systems
The key design features of PICOSUN™ ALD systems

UNMATCHED FLEXIBILITY AND MODULARITY FROM R&D TO INDUSTRIAL PRODUCTION

- Dual chamber structure (hot wall reaction chamber inside the cold wall vacuum chamber)
  - Important to prevent influence of ambient air flows or temperature variations, leaks of gases, moisture and particle penetration into the chamber, and corrosion of the vacuum chamber walls
  - Easy to coat different samples in the same reactor: just change the reaction chamber, no need to purchase several different reactors!
  - Safe operation when the outer surface of the reactor stays in room temperature
  - Reaction chamber wall temperature = substrate temperature → no secondary reaction routes, no CVD

- Top-flow (showerhead) design for all the precursors.
  - Always optimal precursor flow against the substrate surface
  - Enables coating with difficult processes and coating of through-porous/high aspect ratio substrates.
The key design features of PICOSUN™ ALD systems

UNMATCHED FLEXIBILITY AND MODULARITY FROM R&D TO INDUSTRIAL PRODUCTION

- Fully separated, heated precursor inlets to the reaction chamber, several individual, heated precursor lines
  - No cross-contamination and premature reactions between different precursors
  - Prevents condensation of precursors along the inlet tubings
  - Helps to keep the chamber clean and particle level down

- No water cooling needed to reach 500 °C reaction chamber temperature
  - Removes the risk of clogging, water leaks and overheating

- Precursor delivery systems for all chemicals: from gases and liquids of high vapor pressure to solids of extremely low vapor pressure
  - Max. temperature of the precursor sources 350 °C
  - Innovative boosting options to enable vaporization of extremely low volatility chemicals
The key design features of PICOSUN™ ALD systems

UNMATCHED FLEXIBILITY AND MODULARITY FROM R&D TO INDUSTRIAL PRODUCTION

- High quality and reliable electronics package with advanced control program
  - Touch screen user interface, software control to max. 12 precursor sources
  - Easy to use PC-based control program with fully programmable pulsing sequences and process parameters
  - Real time display of process status and PC data logging of all key process parameters
  - Possibility to save log files on an USB stick or a flash card memory
  - Individually programmable process parameters including reactor temperature, precursor source temperature, gas flow rates etc
  - Multiple user levels allows customized data security
The key design features of PICOSUN™ ALD systems

UNMATCHED FLEXIBILITY AND MODULARITY FROM R&D TO INDUSTRIAL PRODUCTION

- Complete safety features through both hardware and software interlock systems
  - Complete fail-safe operation with warning/error messages and history records
  - Hardware interlocks for vacuum chamber over pressure, overheating (touch safe at ~60 °C), pneumatic lift crash etc
  - Software interlocks for reactor and vacuum chamber pressure, precursor source lines and ALD valves etc
  - Emergency Off (EMO) buttons
  - Chemical source cabinets for hazardous and pyrophoric chemicals
  - Lock-out, tag-out of reactor cover and source/gas cabinets
  - Normally closed pneumatic valves (all valves closed if the pneumatic line fails)
Some performance values of PICOSUN™ ALD system
# Some performance values of PICOSUN™ ALD systems

**EXCELLENT FILM UNIFORMITY – EXAMPLES OF SOME RECORD VALUES**

<table>
<thead>
<tr>
<th>ALD material</th>
<th>Non-uniformity (1σ, %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al2O3 (batch)</td>
<td>0.13</td>
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<tr>
<td>SiO2 (batch)</td>
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<tr>
<td>TiO2</td>
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<tr>
<td>HfO2</td>
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<tr>
<td>ZnO</td>
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<tr>
<td>Ta2O5</td>
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<tr>
<td>TiN</td>
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<tr>
<td>CeO2</td>
<td>1.52</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PEALD material</th>
<th>Non-uniformity (1σ, %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al2O3</td>
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</tr>
<tr>
<td>AlN</td>
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<tr>
<td>In2O3</td>
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<tr>
<td>SiO2 (low-T)</td>
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<tr>
<td>SiN (low-T)</td>
<td>1.58</td>
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<tr>
<td>TiN</td>
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<tr>
<td>ZnO</td>
<td>2.64</td>
</tr>
<tr>
<td>TiAlN</td>
<td>2.87</td>
</tr>
</tbody>
</table>

Customer data showing examples of film thickness uniformities on 150 mm and 200 mm wafers in PICOSUN™ R-series ALD systems. PEALD = plasma-enhanced ALD.
Some performance values of PICOSUN™ ALD systems

EXCELLENT CONFORMALITY – ”ALD FILM TO GO WHERE NO FILM HAS GONE BEFORE”

Conductive layer deposited in a PICOSUN™ ALD reactor

SEM images credit Fraunhofer IMS
Some performance values of PICOSUN™ ALD systems

RECORD LOW PARTICLE LEVELS

Hot wall reactor: essential for low particle level

- The reaction chamber wall is set at the same temperature as wafer during deposition
- Film deposited on the sidewall is the same as on wafer, no secondary CVD reactions
- Avoid chemical condensation on the sidewall, eliminate particle generation

Picosun’s reaction chamber after process

Cold wall causes chemical condensation...

... and particle generation

Another manufacturer’s reaction chamber after process
PICOSUN™ services
With the Picosupport™ agreements, we aim to minimize your tool downtime, give you support for both equipment and process questions, and we give you access to additional services such as local spares storage, periodical maintenance programs, and chemicals delivery. We also offer prepaid service hours and discount for spare parts.

Services we offer under PicoSupport™ agreements

- Picotraining™ programs
- Periodical maintenance programs
- Precursor delivery service
PicoDevelopment™

ICODEVELOPMENT™ PROGRAMS

• Process library and process development
• Foundry and coating service
• Consulting services
Thank you!