TECHNICAL BRIEF

Designing Industrial HPC Solutions for Advanced Metrology Applications

Introduction

Semiconductor manufacturing involves 400 to 600 process steps carried out over one to three months to produce completed wafers ready for testing and packaging. A critical part of this flow is metrology, which provides the measurements and feedback loops needed to adjust and optimize process parameters that determine yield and process control. Metrology is embedded throughout wafer fabrication to verify alignment, critical dimensions, and defect detection. The accuracy of these measurements directly affects yield, as errors left unchecked early in the sequence can compromise weeks of downstream work.

To optimize yield and maintain control at advanced nodes, metrology methods have evolved. Optical inspection provided fast coverage but limited resolution as feature sizes shrank. Today, advanced e-beam metrology systems extend this role by combining critical dimension measurement with high-resolution defect detection to monitor production and validate process models. With pixel sizes on the order of 1 nm, defect sensitivity below 5 nm, and measurement precision tighter than 0.1 nm, these platforms capture extremely dense imaging data across fields exceeding 12,000 × 12,000 pixels. High-throughput operation means this data is generated continuously, often in parallel across multiple inspection modes.

The result is an unprecedented volume of data that must be processed in real time. Traditional computational methods are no longer sufficient at this scale, leading to a shift toward AI-driven defect recognition. Supporting these capabilities requires dedicated compute resources positioned in the sub-fab. The analysis pipelines draw from raw imaging, design databases, and computational models to classify defects and verify process performance without delay. This demands tightly integrated systems with high-bandwidth interconnects, large memory footprints, and sustained compute density engineered for continuous operation.

Constraints in Sub-fab Compute

Beneath the process floor of a fab lies the sub-fab, the support level that houses the essential infrastructure required to keep production tools running. It is here that vacuum pumps, abatement systems, power distribution, and increasingly, dedicated compute appliances are located. Placing compute in the sub-fab minimizes latency between the tool and the processing system, allowing metrology data to be analyzed in real time and fed back into the process without delay.

Unlike a controlled data center, the sub-fab is a challenging environment. Equipment is densely packed, access is limited, and strict rules govern noise, airflow, seismic requirements and safety. Every system installed in this space must be engineered with these conditions in mind. However, compute appliances that support metrology cannot simply be scaled-down versions of data center racks, they must be specifically designed from the outset for continuous operation in a space that was never meant to host high-performance computing.

Compliance with Global Standards

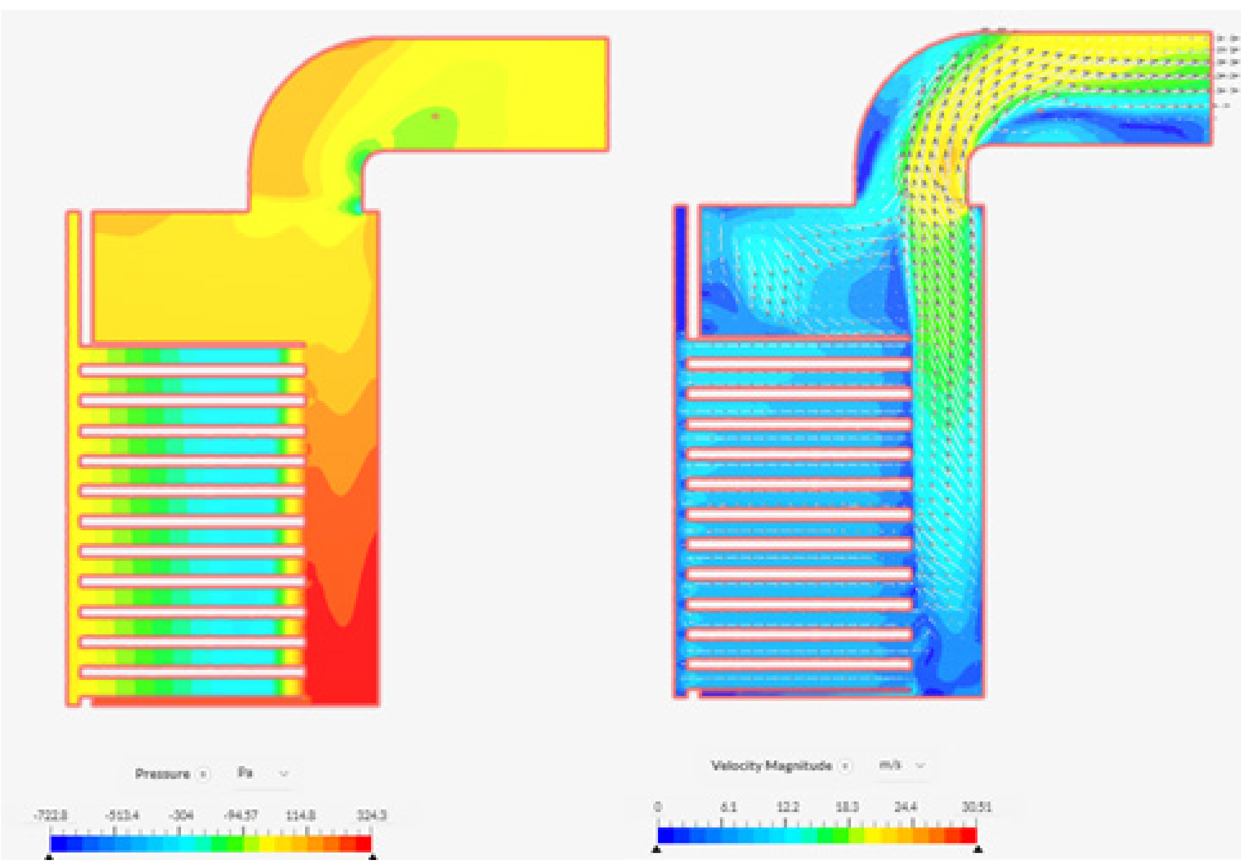
Meeting industry and regional compliance standards is central to every deployment. Appliances are designed for SEMI S2 and S8 safety and ergonomics, SEMI F47 voltage sag immunity, NFPA 79 and IEC/EN 60204 electrical safety, SIL-3 functional safety levels, EMC testing to the EN 61000 series and FCC Part 15, and seismic evaluations per tool-provider specifications. Certification processes typically involve independent evaluations by accredited bodies such as TUV and Nemko, with cabinet-level testing conducted in specialized labs. This ensures each system arrives production-ready with complete documentation and certification reports.

Power Quality and Safety

Electrical safety is a non-negotiable requirement for sub-fab compute appliances. Designs must account for emergency-off mechanisms tied into facility safety systems, voltage sag immunity, and clean power distribution. All critical components, from PDUs to power modules and safety relays are validated through UL or NRTL certification. Integration with company electrical codes and safety protocols is addressed early in the design phase to prevent delays in compliance testing and deployment.

Thermal and Airflow Management

Compute appliances in the sub-fab must operate at full load under tightly controlled thermal conditions. Simulations and physical validation are required to ensure stable operation across all nodes, even under degraded scenarios such as a fan module failure. Exhaust assist systems and specialized ducting are used to prevent recirculation and to maintain acceptable temperature deltas across the rack. Heat cannot be released into the sub-fab, so every bit of it must be carried away through ducting.



Computational fluid dynamics simulation.

Seismic and Structural Integrity

Sub-fab installations are subject to seismic design requirements, particularly in regions with elevated risk profiles. Cabinets must withstand defined peak ground acceleration values without compromising system stability or safety. Reinforced frames, anchoring systems, and sway control mechanisms are integrated to meet these standards.

Noise Control

Noise is another critical constraint. Appliances must remain below defined acoustic thresholds to comply with worker safety regulations and to prevent interference with measurement tools.

Reinforced seismic cabinet design.

AMAX Customization Capabilities

Rack and Layout Design

Every sub-fab environment comes with its own spatial and operational constraints. AMAX engineers racks that are dimensioned to fit available footprints while maintaining service accessibility and cable management discipline. Modular designs allow for hot-swappable compute nodes and front-serviceable storage, reducing mean time to repair and supporting long operational lifecycles.

Cooling Architectures

Thermal management is engineered to the application, with both advanced air-cooled and liquid-cooled solutions available. Air-cooled racks include chimney exhausts, high-static pressure fans, and rear-door heat exchangers. For higher loads, multi-stage liquid cooling systems are deployed with direct cold plate designs, leak detection rails, containment trays, and emergency-off integration. Hybrid architectures combining cold plates with rear-door heat exchangers are used where heat neutral operations are required. Each configuration is validated through simulation and hardware testing to confirm 100 percent heat removal capacity under sustained operation.

Acoustic and Vibration Engineering

AMAX designs with noise compliance in mind from the start. Component selection, duct geometry, and fan curve optimization are tailored to hold operation below defined thresholds, even at full system load. Acoustic testing is performed during final acceptance to verify compliance with facility safety limits and equipment compatibility requirements.

Safety and Compliance Integration

Compliance is built into the design process, not treated as an afterthought. AMAX integrates safety relays, SCCR rated panels, PDUs, and power modules that are already UL or NRTL certified, minimizing risk during evaluations. System-level safety features such as emergency-off buttons, leak detection trays, and thermal monitoring are engineered into the appliance to align with SEMI and NFPA standards. Our familiarity with certification processes and test bodies ensures that racks pass audits with minimal rework and are delivered with complete compliance documentation.

CASE STUDY

Liquid-Cooled HPC Appliance for Leading Semiconductor Equipment Manufacturer

Problem

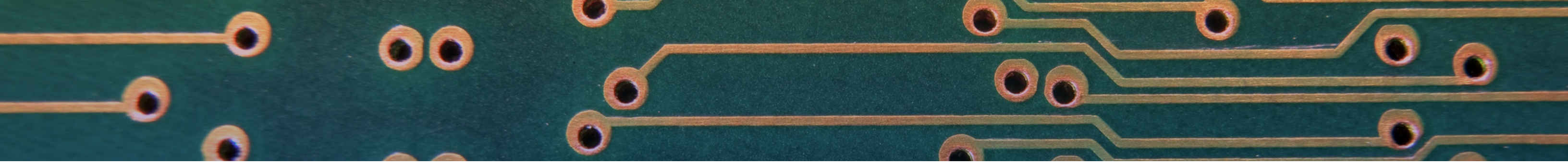
A semiconductor equipment provider required a compute platform to support advanced metrology and inspection tools. The system needed to process high-throughput image analysis and defect classification while operating within strict sub-fab constraints. The challenge was not the compute nodes themselves but the supporting cabinet and infrastructure design. The customer's requirements included:

- Thermal management in a confined footprint with continuous high load
- Acoustic operation below 75 dB to meet worker safety limits
- Seismic stability in a high-risk region, including structural anchoring and sway control
- Compliance to SEMI, NFPA, IEC, EMC, and regional safety standards
- Serviceability requirements such as modular replacements and clear labeling
- Physical integration constraints, including cabinet height, depth, and mobility within
  existing sub-fab layouts

Solution

AMAX engineered a **custom liquid-cooled HPC appliance** with a cabinet designed specifically for this environment. Beyond the compute servers, the engineering focus was on developing a fully customized cabinet with specialized modules and features:

- **Safety Systems:** Dual front and rear Emergency Off (EMO) buttons, integrated smoke sensors, and water leak detection sensors.
- **Cabinet Design:** Specific height and depth to fit the sub-fab environment, reinforced with seismic bracing and anchors. The cabinet included a pallet truck interface and wheels for safe movement in and out of tight sub-fab layouts.
- **Networking & Cabling:** Custom holders and routing channels to secure networking components and maintain airflow while simplifying maintenance.
- **Power & Grounding:** Custom-designed power distribution with grounding measures, NRTL-certified modules, and connectors labeled for operator clarity.
- **Liquid Cooling Integration:** Custom connection points engineered to tie directly into the customer's facility cooling system, including quick-disconnect couplings and redundancy in pump design.
- **Packaging & Deployment:** Specialized packaging and shock absorption for safe global shipment, ensuring the system arrived deployment-ready with no structural rework required.



Compliance and Certification

Compliance is a non-negotiable requirement for sub-fab compute systems.
AMAX designs every appliance to meet global safety, electrical, and environmental standards, ensuring they are ready for deployment in regulated semiconductor environments.

Our experience spans:

- **SEMI Standards:** S2, S8, and F47
- **Electrical Safety:** NFPA 79, IEC/EN 60204
- **EMC:** EN 61000 series, FCC Part 15
- **Functional Safety:** SIL-3 evaluations
- **Seismic: Evaluations aligned to semiconductor tool provider requirements**

Certification is performed in partnership with accredited bodies including **TUV** for rack-level evaluations, **Nemko** for PDU certifications, and UL/NRTL labs such as TUV, Nemko, and Intertek for critical component validation.

This structured approach ensures that AMAX systems arrive fully certified and compliant for global deployment.

Result

The deployment delivered a significant improvement in inspection throughput compared to the customer's previous compute infrastructure, accelerating analysis cycles and tightening feedback loops to the manufacturing process.
By engineering the cabinet and modules to meet precise sub-fab requirements, AMAX eliminated the risk of integration issues, reduced installation time, and ensured reliable long-term operation.

The appliance was validated for thermal, acoustic, seismic, and compliance performance, and shipped with complete certification documentation. This allowed the customer to move directly into production deployment across global fabs, supported by a system that was not only high-performance but also engineered for the realities of the sub-fab environment.

Why AMAX

As metrology workloads expand in scope and precision, sub-fab compute systems become increasingly critical. These appliances must deliver high-density performance while meeting strict thermal, acoustic, seismic, and compliance requirements. AMAX has proven its ability in these environments, from pioneering the first liquid-cooled industrial HPC solution for semiconductor applications to delivering certified systems worldwide.

Our approach is rooted in engineering expertise, customization, and validation to ensure continuous operation. For next generation industrial compute deployments, AMAX supports the full design path from early simulation to compliance planning and certification.

Contact our team to discuss a custom solution engineered for your environment.