IMAPS-Silicon Valley Chapter

Physical AI for Autonomous Manufacturing: Real-Time Sensing, Data, Models, Control, and Advanced Packaging

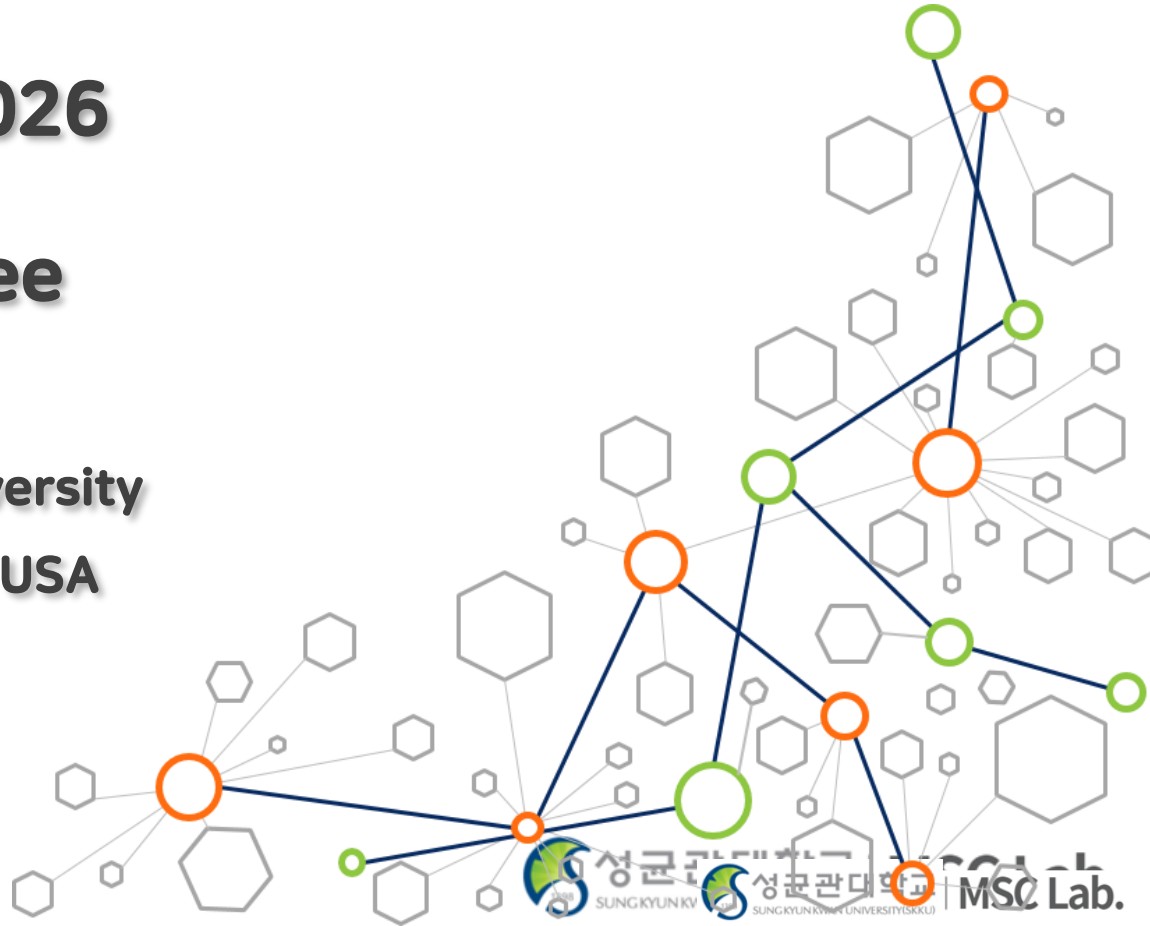
Aug. 11th, 2026

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1. Introduction to SKK R&D Cluster

2. Concept of Physical AI-inspired Autonomous Manufacturing

3. Real industrial Example of Physical AI Manufacturing

4. Packaging Development for Physical AI Manufacturing Implementation

5. Conclusion

■ SKK R&D Cluster

PI Members

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Associate Professor, SKKU (2020.01 – Current)
Director, SKK R&D cluster (2026.03 – Current)
Adjunct Faculty, San José State University (2026.05 – Current)

World Top2% Scientist, Elsevier (2025)
IEEE ECTC the Best Paper Award (2026)


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Taeje Cho

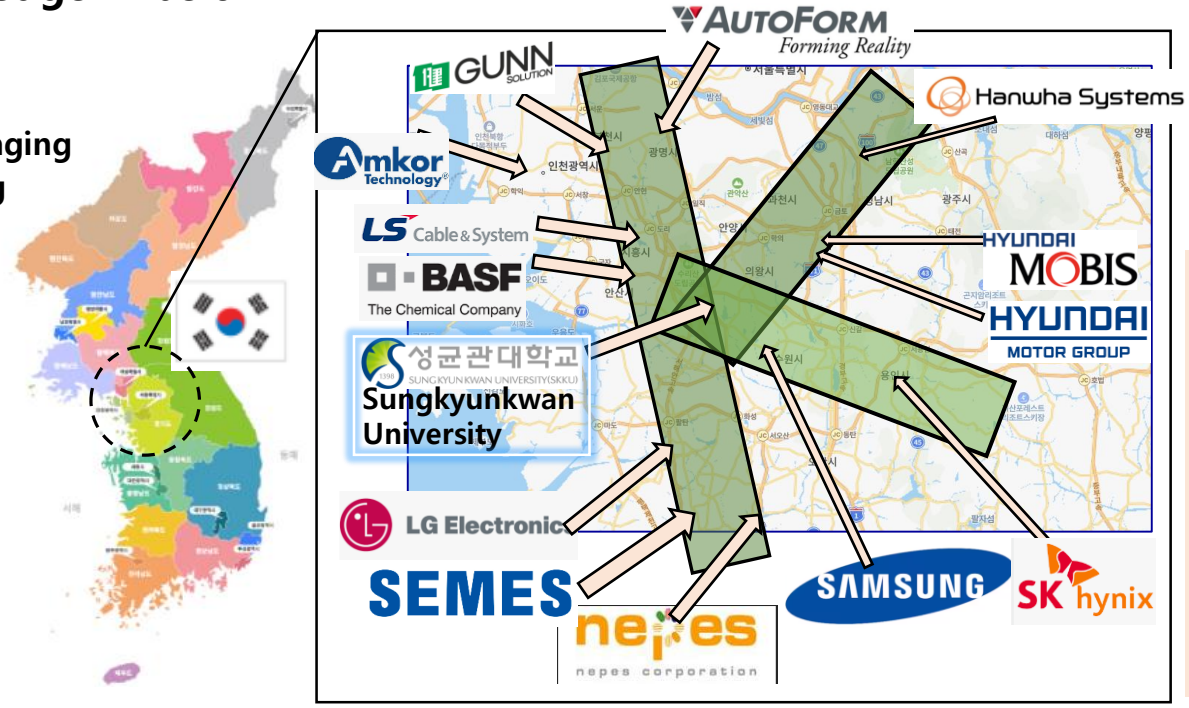

Jungwan Cho


Joonmyung Choi

***SKK: Silicon/Smart Knowledge K-belt**

SKK R&D Cluster

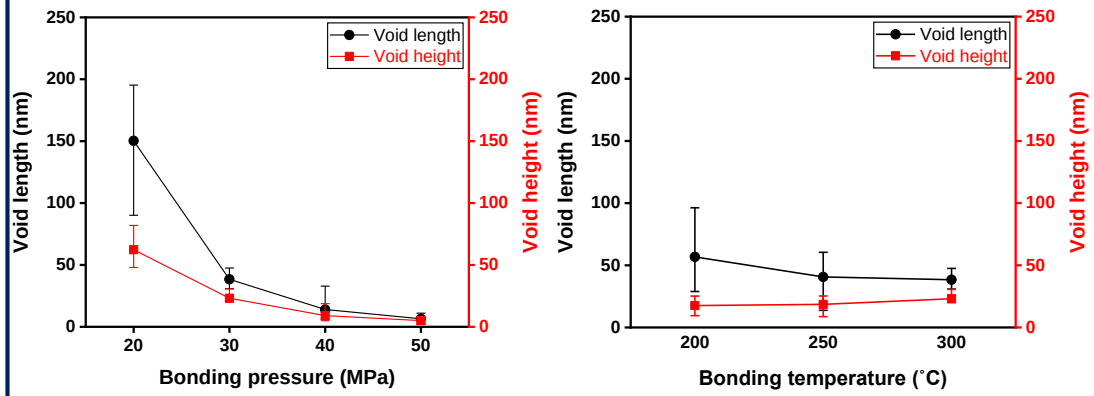
- Advanced Semiconductor Packaging
- Quantum Computing Packaging
- Physical AI-based autonomous manufacturing

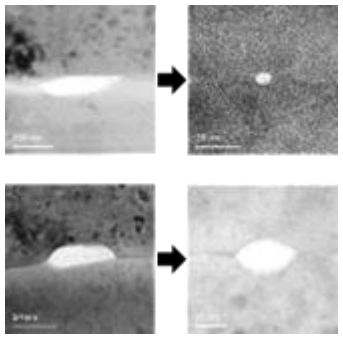


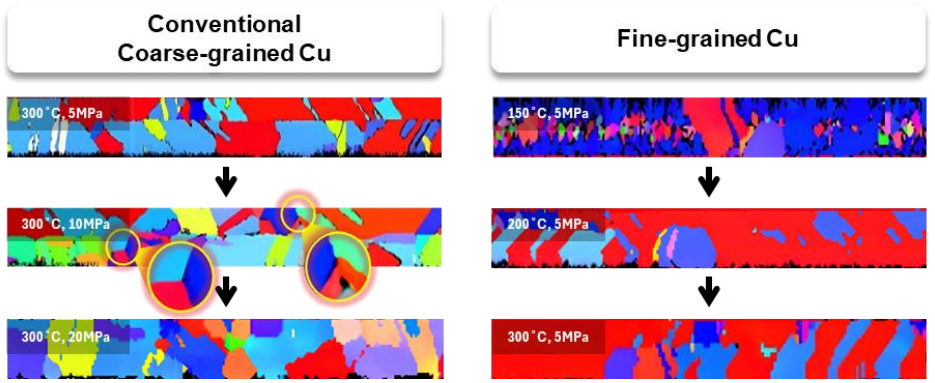
1.Gyeonggi-do's K-Belt brings together Korea's leading companies and offers one of the world's largest industrial process-data environments for Physical AI applications.
2.Located at the center of the K-Belt, Sungkyunkwan University has launched the SKK R&D Cluster with strong support from industry and government.
3.We are actively collaborating with U.S. partners, including GM and Hyundai Motor America.

Hybrid bonding Material: SKK HI R&D Cluster equipment

Study on Void Analysis of Cu-Cu Bonding Interfaces and Fine-Grain Bonding Behavior





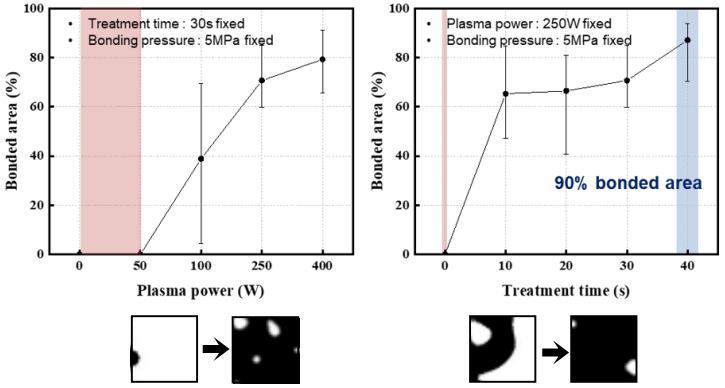


- pressure and temperature effect
- bonding pressure and temperature on the formation

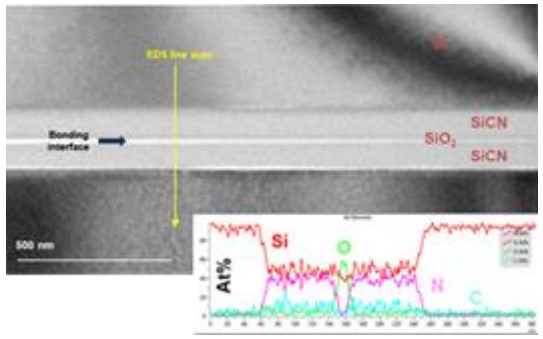
- Micro structure effect on the bonding interface
- Microstructure for low temperature bonding

Dielectric Surface Treatment

< 공정 조건에 따른 SiCN-SiCN bonded area 변화 >

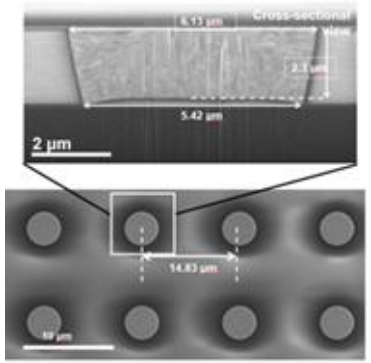


< SiCN-SiCN bonding interface line EDS scan 결과 >

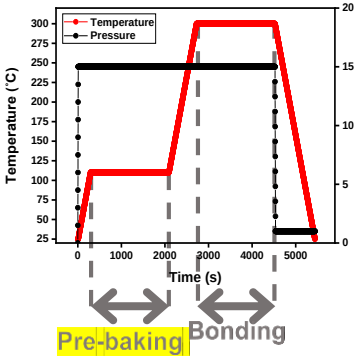


- Plasma activation and SiCN-SiCN bonded area

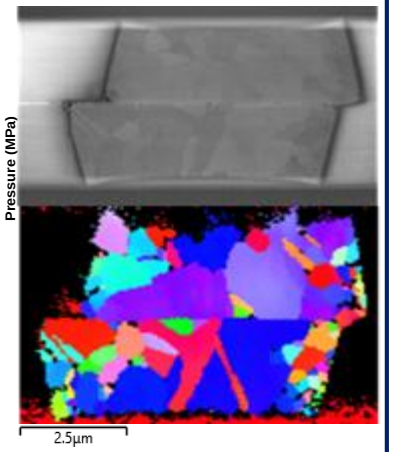
Bonding optimization



-Pad: ~6μm
-Dishing: ~4nm



Bonding condition

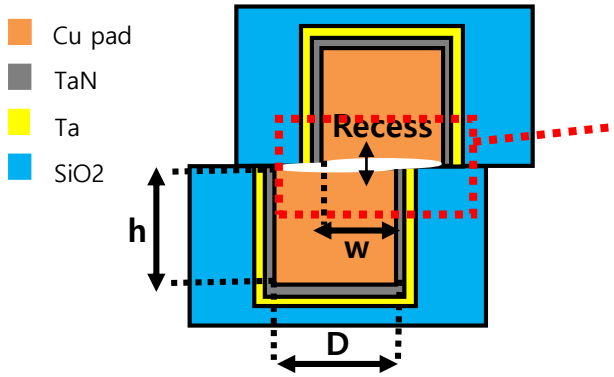


- Hybrid bonding specimen

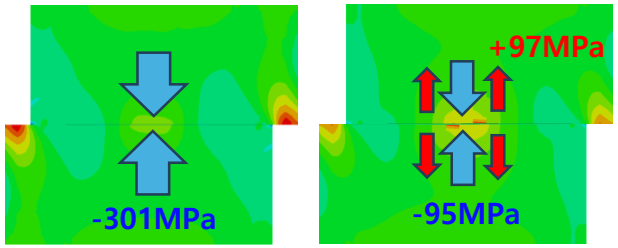
Hybrid bonding Simulation: SKK HI R&D Cluster equipment

Misalignment effect

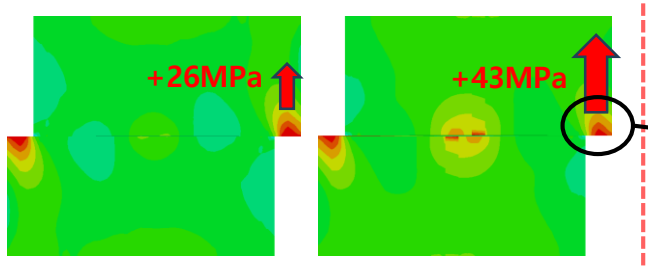
[Cu-Cu hybrid bonding model]



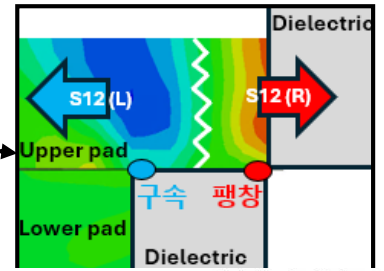
[**Center** of S22 @10% misalignment (left) Case **1** (right) Case **2**]



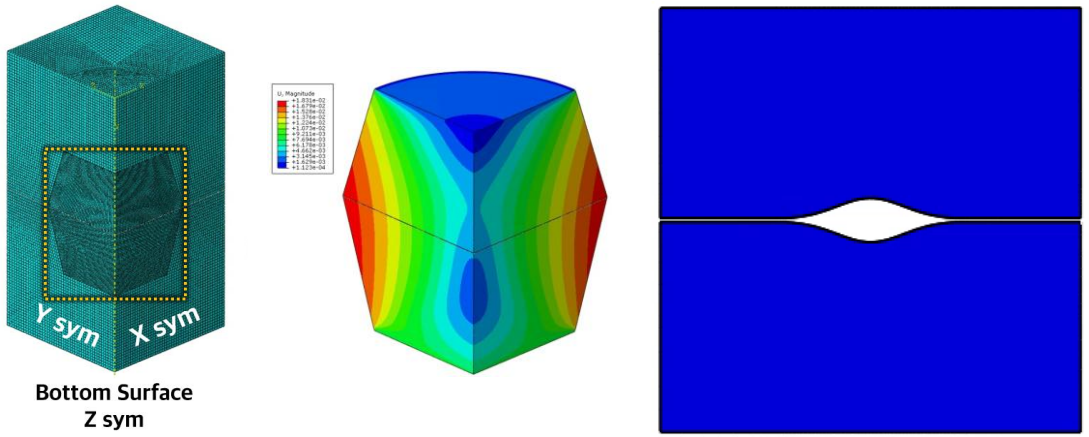
[**Edge** of S22 @10% misalignment (left) Case **1** (right) Case **2**]



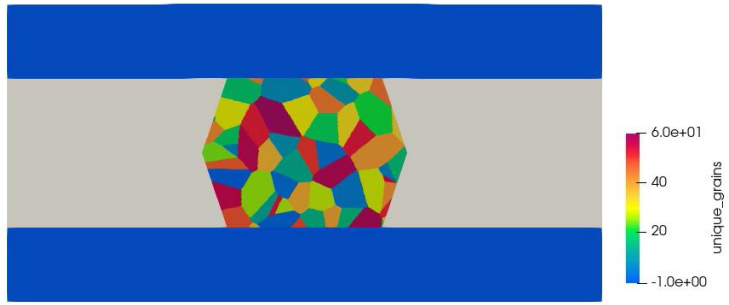
[**Edge** of S12, Shear Stress]

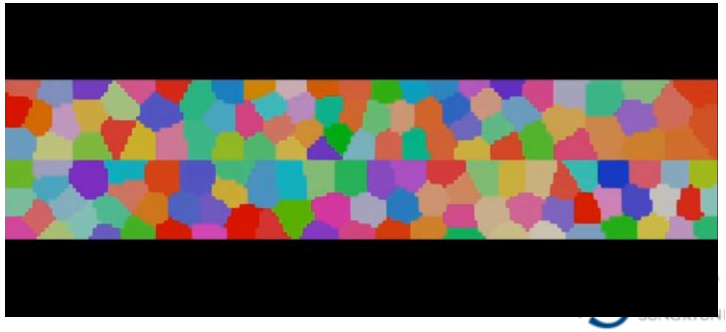


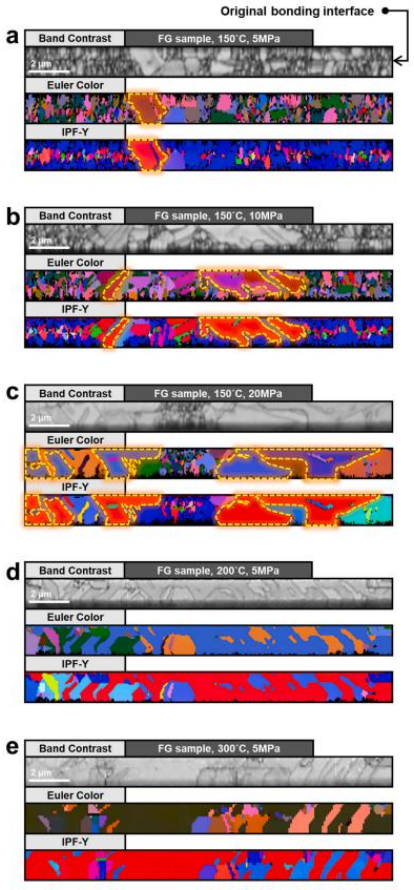
Void closing



Annealing



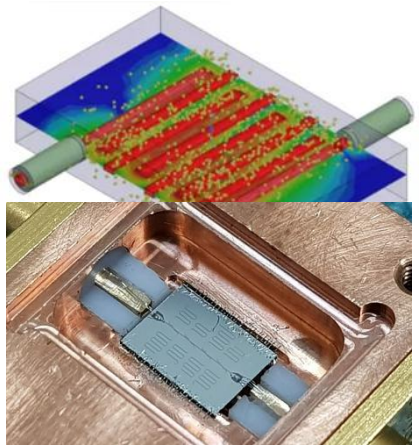




Quantum computing packaging: SKK HI R&D Cluster equipment

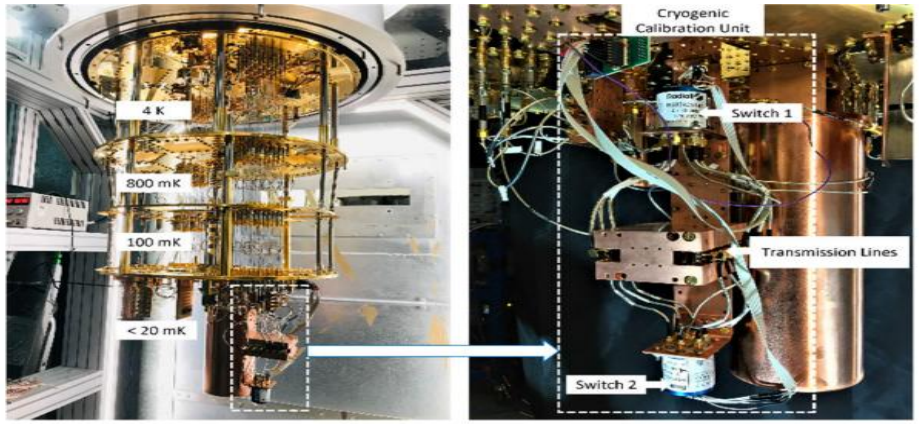
Cryogenic Packaging and Hardware for Solder Characterization

Design of Measurement Jigs for Cryogenic Environments

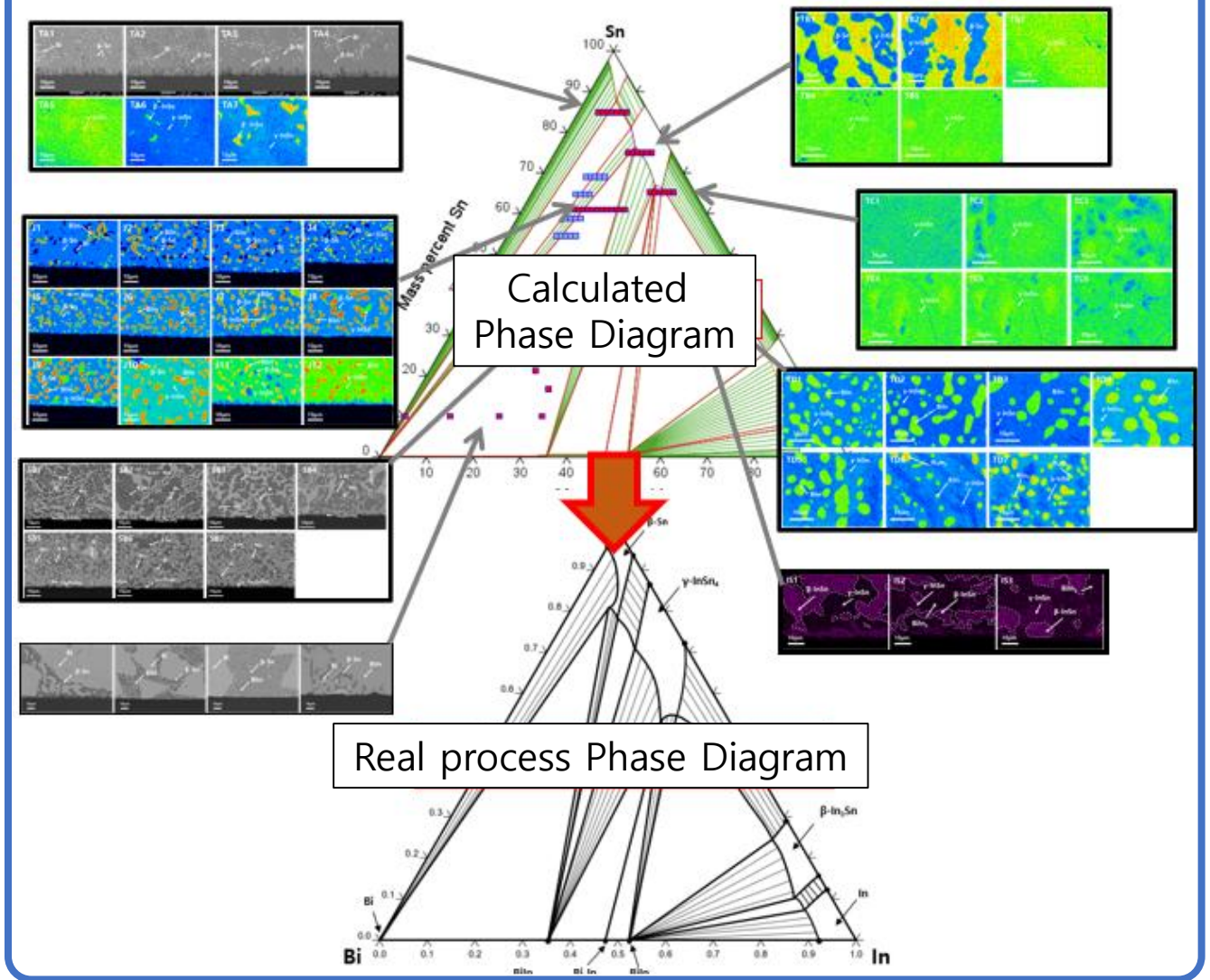


- System Design of OFHC Cu Jigs, Non-Magnetic PCBs, and Superconducting Wire Land/Launch Structures

Advanced Infrastructure for Precise Cryogenic Solder Evaluation



Alloying design for superconducting solder



What is Physical AI?



Perceive (Sensing) → Understand and Learn (Inference & Learning) → Act and Control in the Real World

1 Sensing

Camera, sensors, microphone



2 Inference & Learning

Situation understanding, decision-making, model learning



Physical AI

3 Action & Control

Robot arm, vehicle, drone control



4 Feedback

Check results, correct errors, improve performance



SIMPLY PUT

Physical AI enables digital AI to **make decisions and act in the physical world**, including **real machines, robots, factories, and automobiles**.



Autonomous Driving



Humanoid



Autonomous Manufacturing



Drone

Factory Automation (Automated Factory) vs. Smart Factory vs. AI-Autonomous Manufacturing

Category	Automated Factory	Smart Factory	AI-Driven Autonomous Manufacturing Factory
Core Concept	**A factory that automatically performs predefined tasks**	**A factory that connects equipment, sensors, data, and IT to visualize and optimize processes**	**A factory where AI autonomously makes decisions, predicts, controls, and optimizes based on data**
Primary Goal	Reduce labor requirements, improve productivity, and automate repetitive tasks	Improve quality, optimize processes, and enhance operational efficiency	Respond to uncertainty, enable autonomous decision-making, and minimize human intervention
Operating Approach	Based on predefined logic and fixed sequences	Optimization based on connectivity, monitoring, and analytics	Real-time learning, prediction, decision-making, and closed-loop control
Level of Data Utilization	Limited; primarily PLC and equipment signals	Collection, integration, and visualization of process data	Multimodal data fusion + AI inference + feedback control
Control Characteristics	**Rule-based; focused on fixed conditions**	**Condition-based control + operator decision support**	**AI-based adaptive control and self-optimization**
Human Role	**Equipment setup, monitoring, and intervention when problems occur**	**Data interpretation, decision-making, and improvement activities**	**Focused on goal setting and supervision; AI performs detailed control**
Response to Problems	Stop and manually adjust after an anomaly occurs	Anomaly detection, alerts, and root-cause analysis support	Anomaly prediction, proactive response, and risk-aware control
Key Technologies	**PLCs, robots, CNC, automated material handling, sensors**	**MES, ERP, IoT, CPS, digital twins, cloud**	**AI, reinforcement learning, generative AI, autonomous control, uncertainty quantification (UQ), agentic AI, physical AI**
Flexibility	Low; major reconfiguration required when products change	Medium; can handle multiple product variants	High; adapts in real time to variability and uncertainty
Typical Production Environment	**Mass production**	**High-mix, low-volume production; connected production**	**High-variability, high-complexity production; customized production; toward unmanned operation**
Limitations	**Weak adaptability to change; limited use of data**	**Despite abundant data, final decisions still depend on humans**	**Must ensure reliability, explainability, safety, and data quality**

Physical AI for Autonomous Manufacturing

Closed-loop sensing, intelligence, control, and feedback for smart manufacturing

1 Sensing & Data Acquisition

- Cameras (Vision)
- Force Sensors
- Temperature Sensors
- Vibration Sensors
- Microphones (Acoustic)
- Machine Data (PLC, SCADA, Historian, IoT)



2 State Estimation & Understanding

- AI-powered state estimation
- Digital Twin & Process Modeling
- Analytics & Visualization
- Feature Extraction & Pattern Recognition



3 Prediction & Decision-Making

- Quality Prediction
- Defect Prediction
- Process Optimization
- Scheduling Decisions



4 Autonomous Control

- Robot & Machine Control
- CNC & Process Control
- Conveyor & AGV Control
- Process Parameter Adjustment (Temp, Speed, Force, Pressure, etc.)



5 Manufacturing Execution

- Smart Production Line
- Semiconductor Packaging
- EV Motor / Hairpin Manufacturing
- Precision Assembly



6 Inspection & Feedback

- AOI / Vision Inspection
- Quality Analytics & KPIs
- Pass / Fail / Rework
- Continuous Learning & Model Update



Physical AI

KEY CAPABILITIES

- Real-time monitoring
- Defect prediction
- Adaptive process control
- Human-robot collaboration
- Continuous learning

Autonomous Manufacturing
Higher Quality. Greater Efficiency. Lower Cost. Greater Flexibility.

APPLICATIONS

Smart Factory



Connected machines, real-time data, intelligent decisions across the plant.

Semiconductor Packaging



High-precision packaging, yield improvement, and process optimization.

EV Motor Manufacturing



Hairpin insertion, welding, and assembly with closed-loop quality control.

Autonomous Inspection



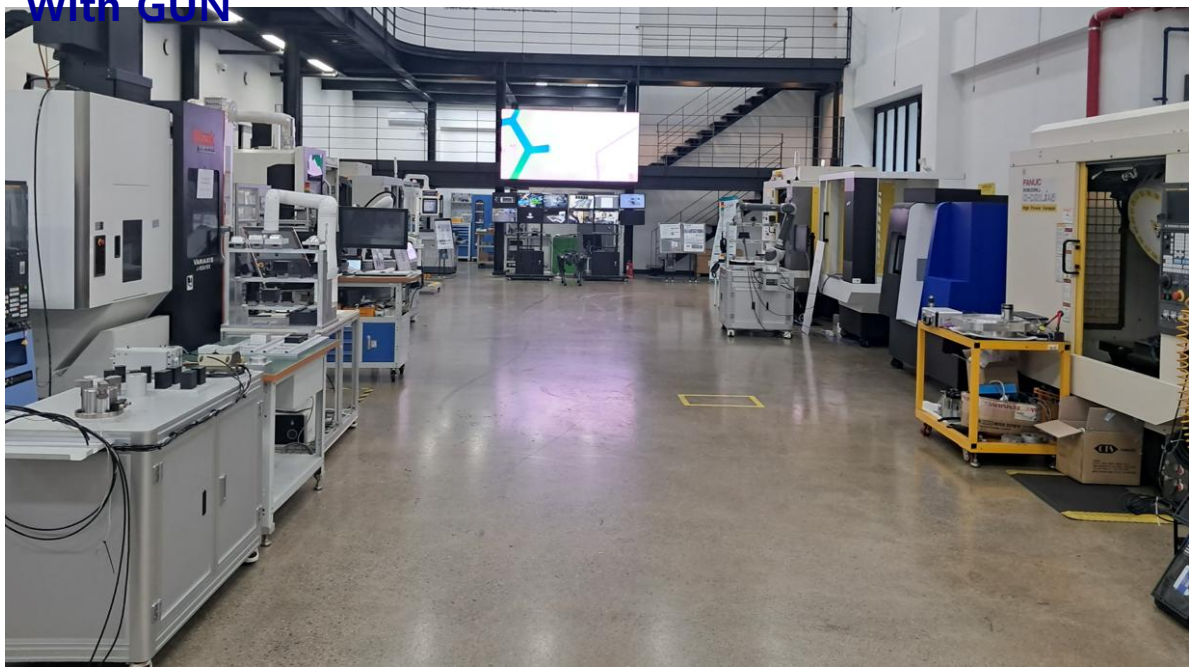
AOI and AI vision for 100% inspection and traceable quality.

Physical AI-Inspired Manufacturing R&D: SKKU R&D Cluster

EV motor manufacturing



With GUN



Machining

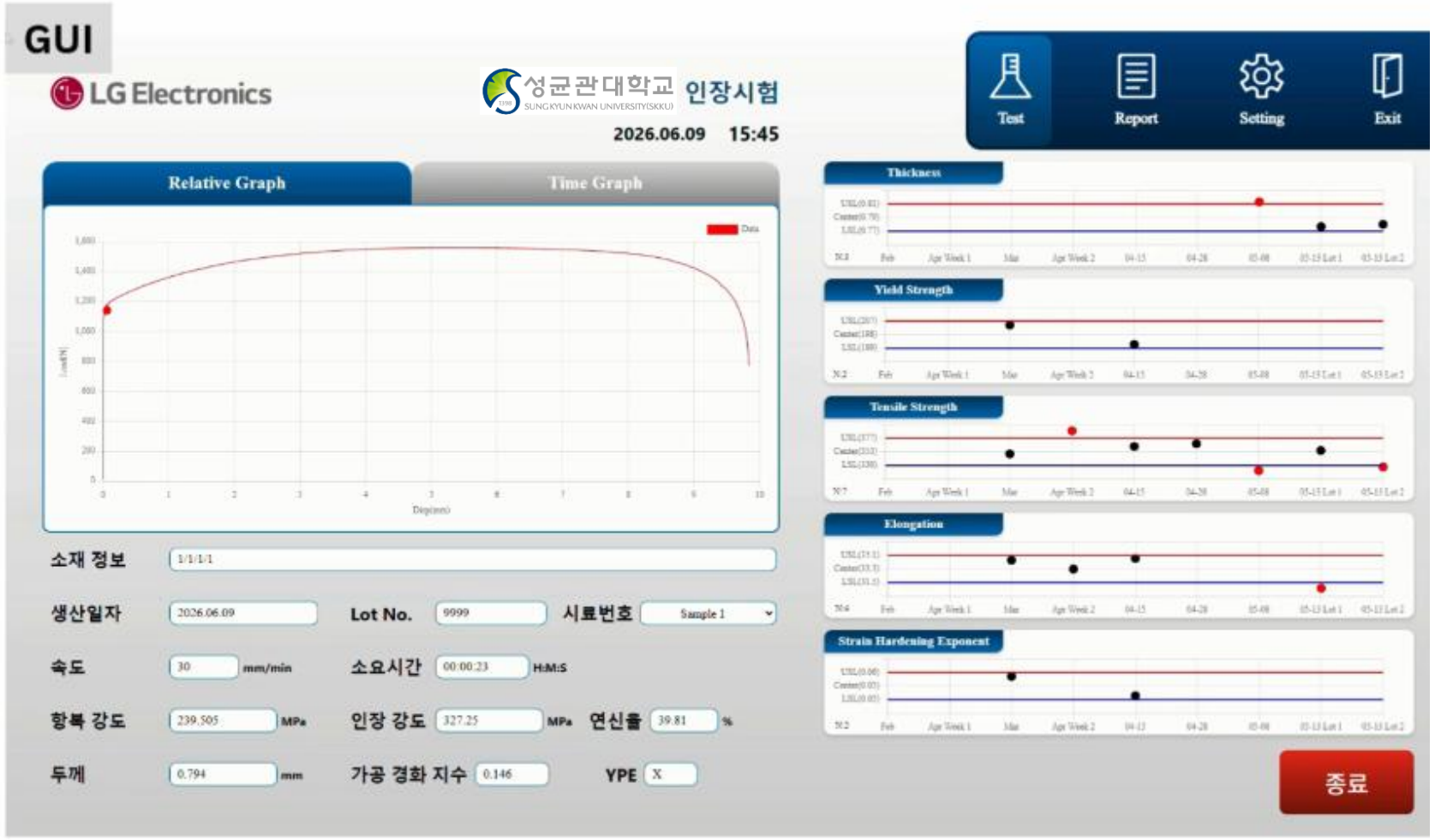


Collaborative Robot



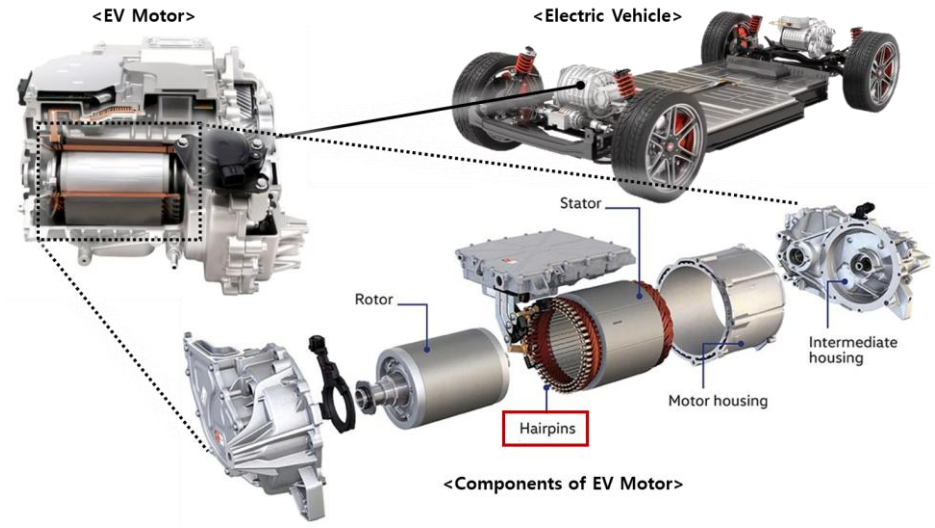
Physical AI-inspired Home Appliance Manufacturing by SKK R&D cluster with LG Electronics

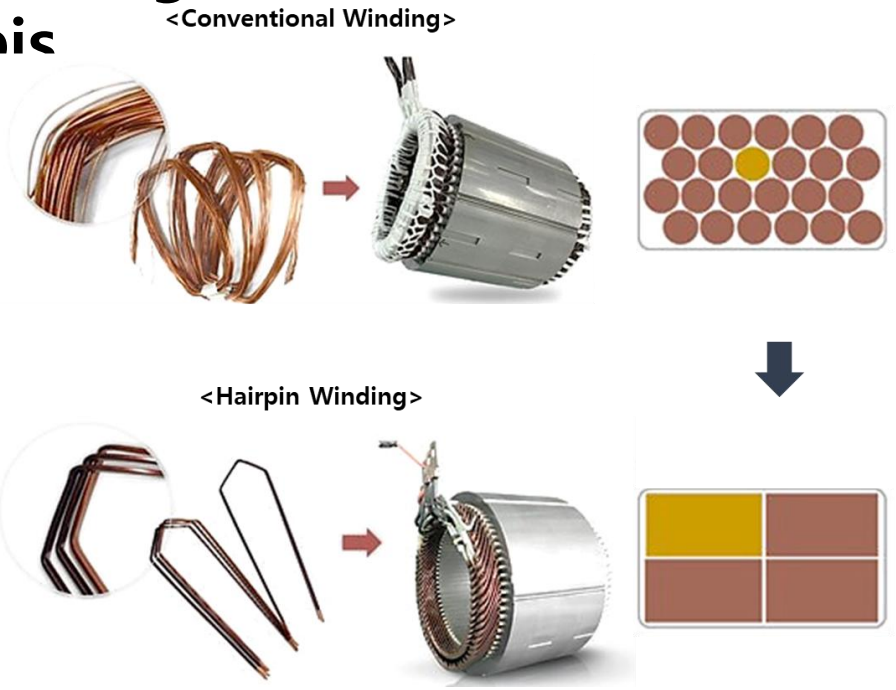




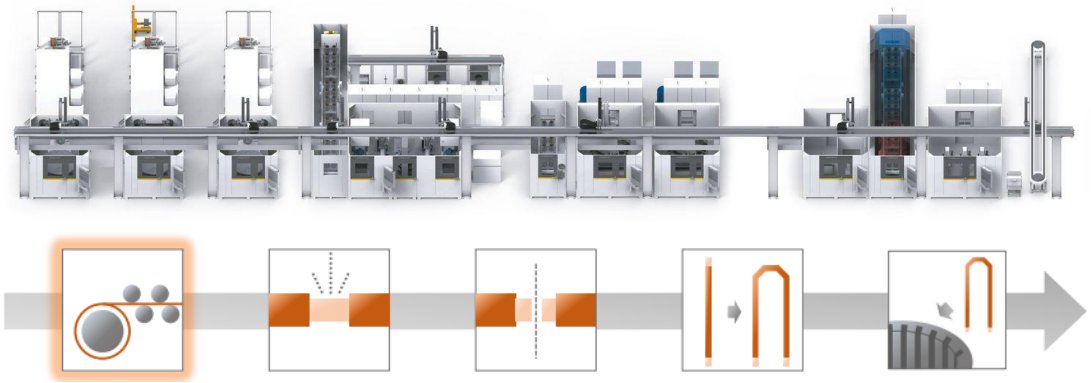
Physical AI-inspired EV motor Manufacturing by SKK R&D cluster with Hyundai Mobis

Introduction of Hairpin Winding Motor

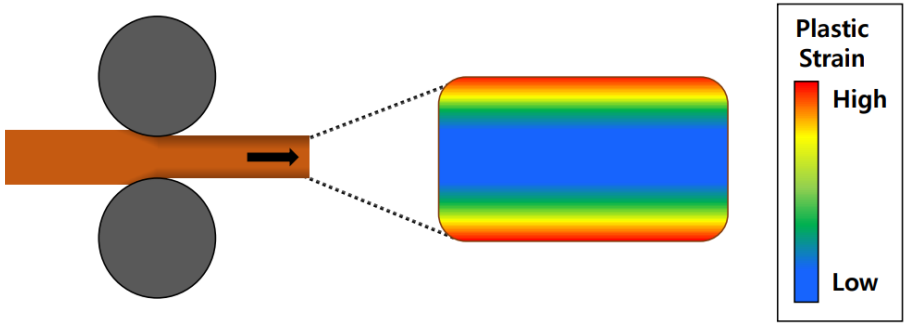




<Manufacturing Process>

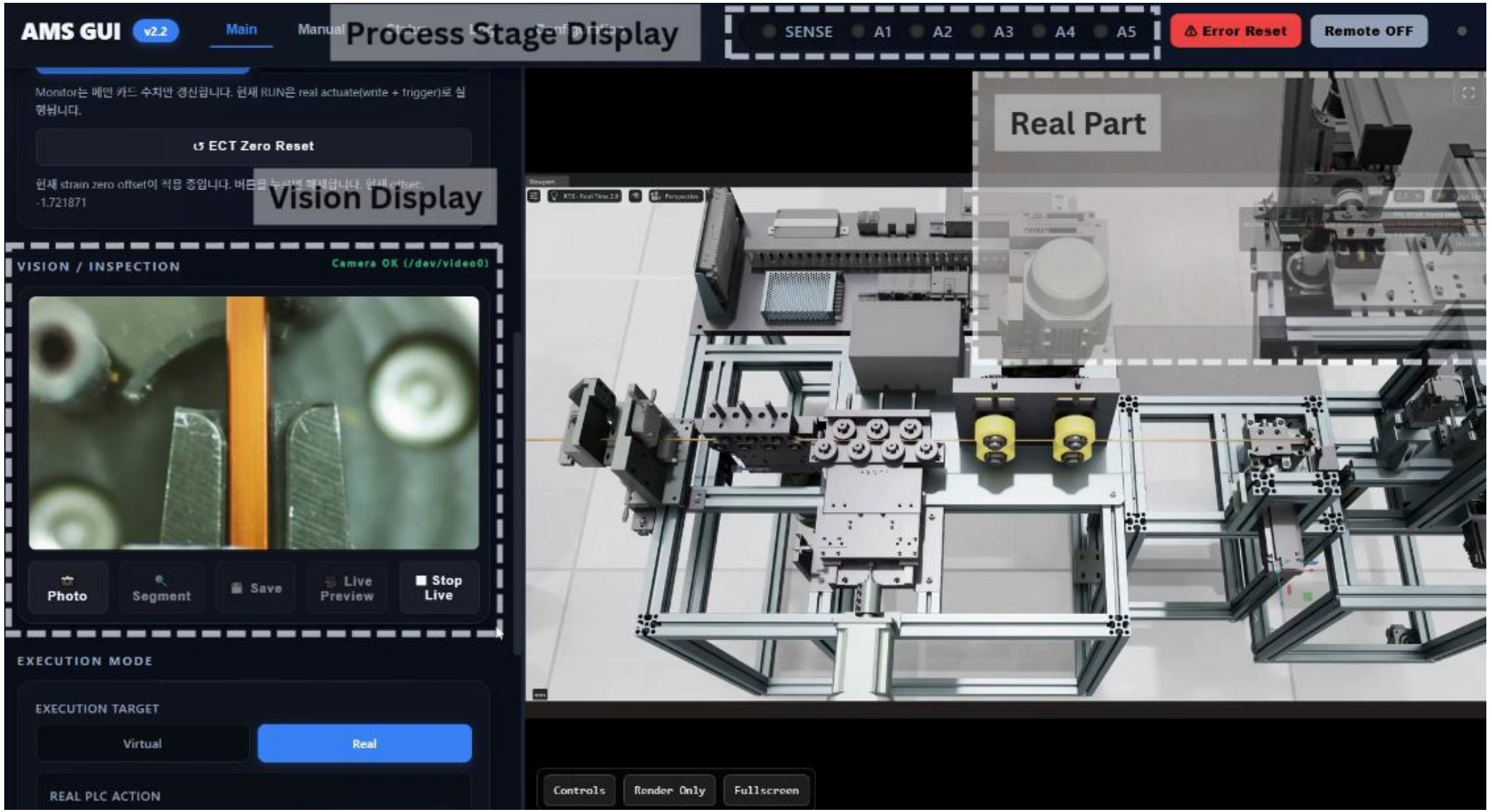


<Plastic Deformation by Straightening>



The hairpin winding motor manufacturing induces **large plastic deformation in the coil.**
Since excessive plastic deformation impact product quality, **we need intelligent manufacturing.**

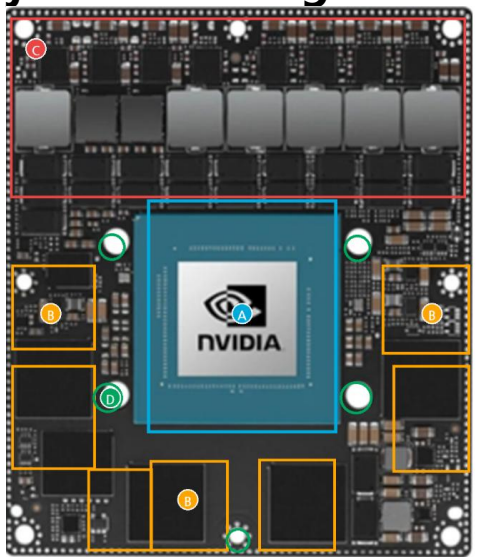
Physical AI-inspired EV motor Manufacturing by SKK R&D cluster with Hyundai Mobis

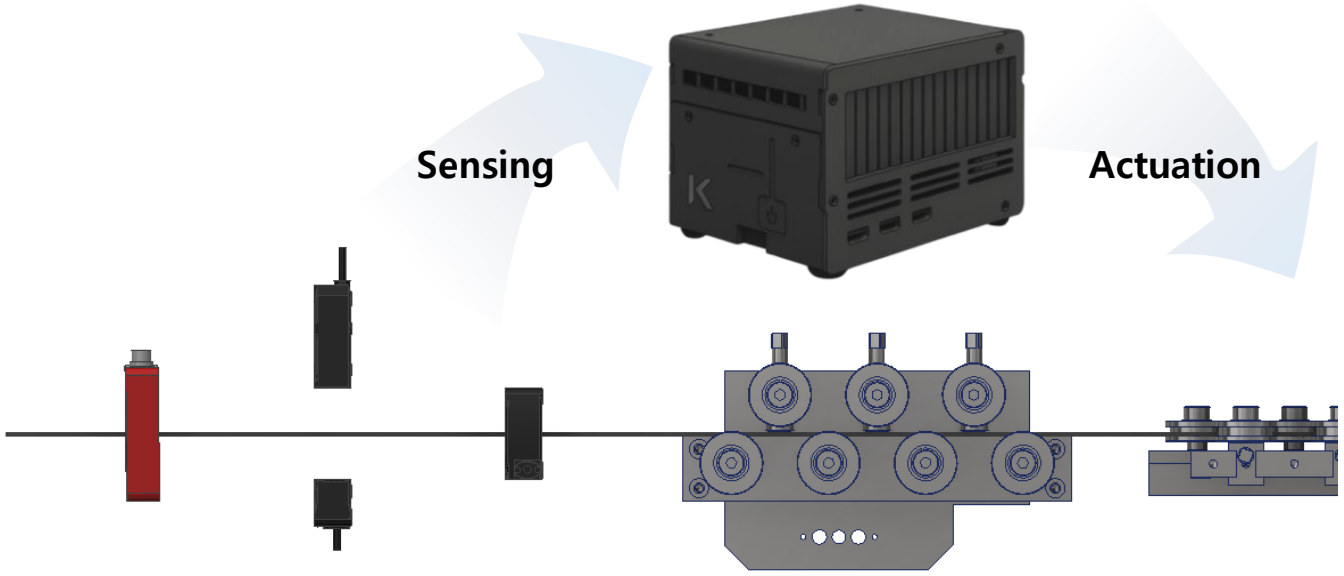


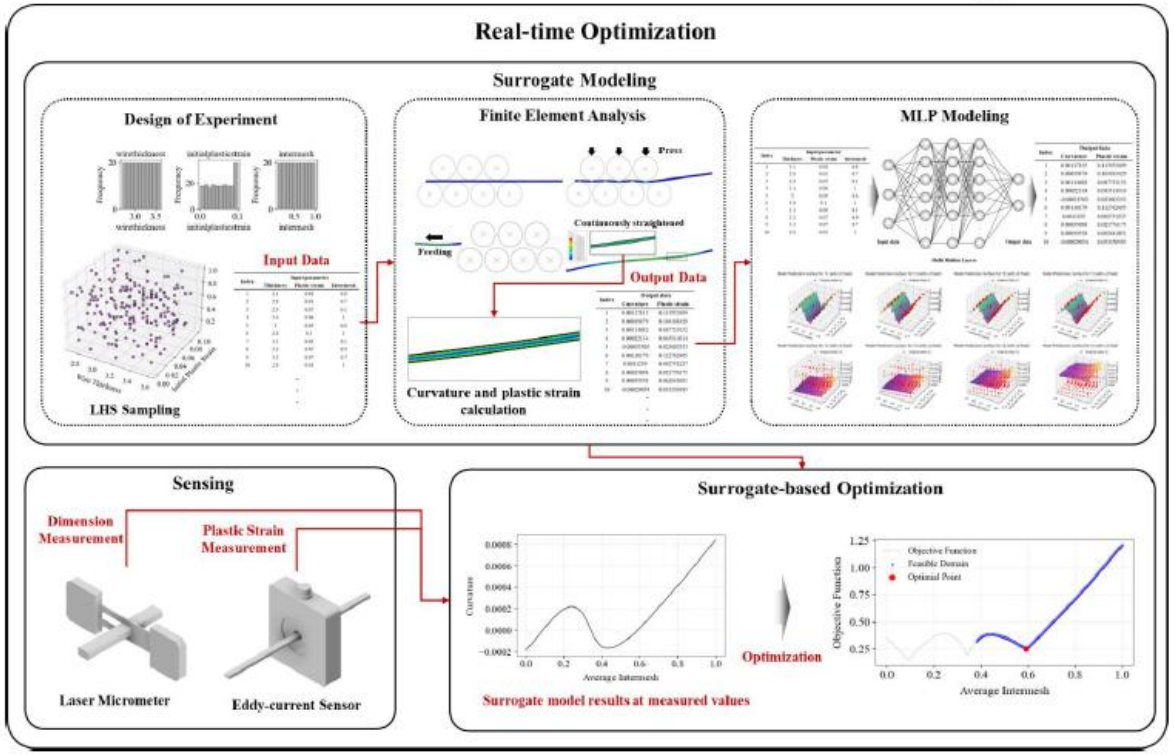
Edge Computation

- Edge PC for real-time embedded AI inference
- Receives dimensions & material properties from sensor module
- Runs MLP-based surrogate model for real-time optimization
- Sends control signals to servo straightener via PLC
- **Edge PC layer이지만 60W로 기존 legacy 장비에서는 없었을 발열 추가 (대량의 장비수)**

jetson orin agx







Real-time process control using edge AI inferen

Five Layers of a Physical AI Autonomous Manufacturing System and the Organic Integration Factory Concept

Prof. Eun-Ho Lee (SKK R&D Cluster)

L5. AI Factory / Cloud / Enterprise

- Enterprise / multi-factory-level learning, knowledge management, and global optimization
- Foundation models, large-scale AI training, and data governance
- Supports model deployment across factories and strategic decision-making

L4. Factory Server / Digital Twin

- Factory-level digital twin, simulation, and process optimization
- Collects line/equipment data and performs AI model training and retraining
- Optimizes productivity, energy, quality, and maintenance strategy

L3. Cell / Line Orchestration

- Line-level scheduling, equipment coordination, and AMR/robot routing adjustment
- Integrates workflow with MES / SCADA / PLC
- Manages process status, quality history, and production KPIs

L2. Edge AI Controller

- Vision inference, anomaly detection, quality judgment, and real-time control
- Executes AI model control that is latency-sensitive at the equipment level
- Handles motion control, sensor fusion, and safety response

L1. Equipment · Sensors · Actuators

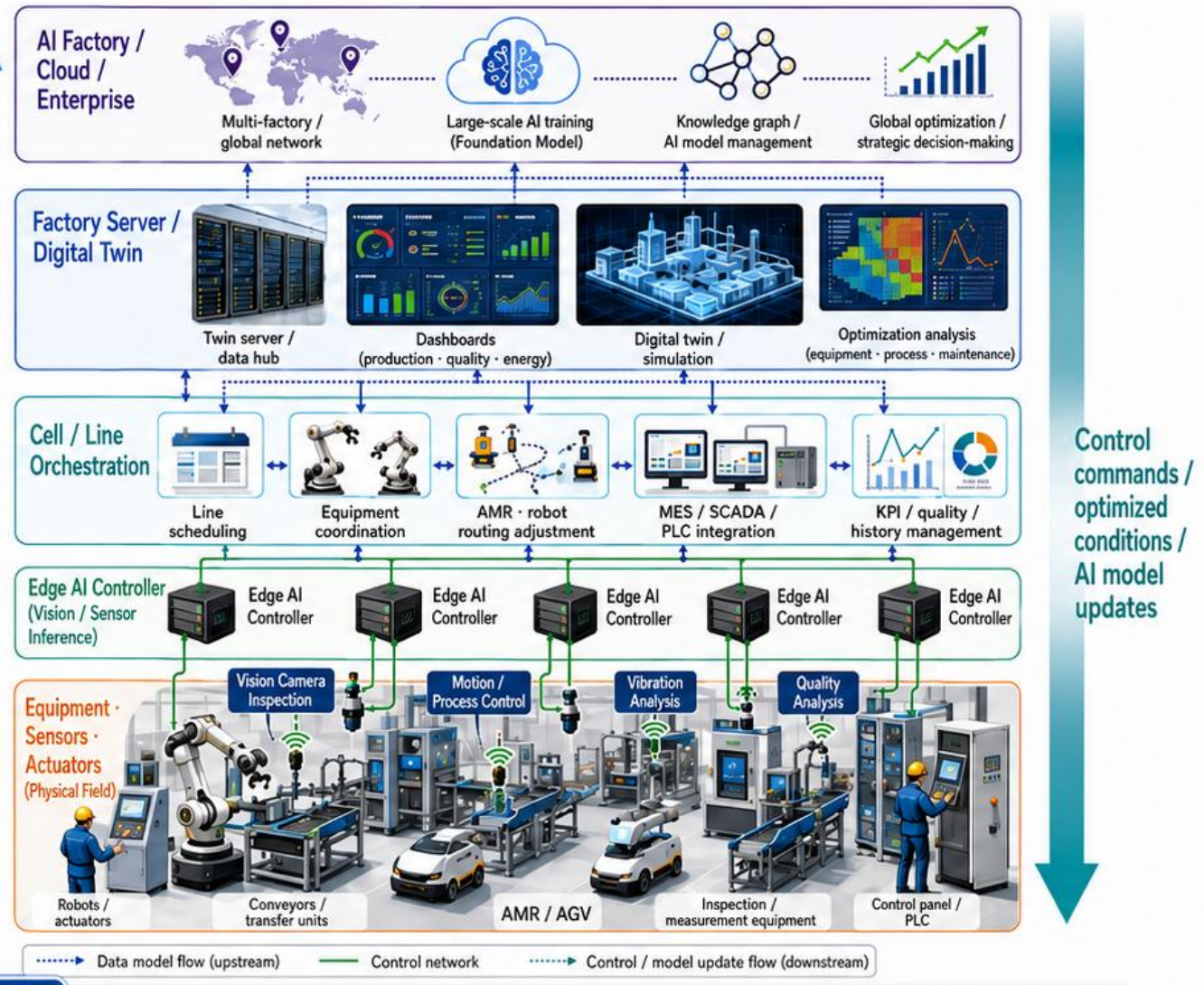
- Robots, equipment, and sensors collect physical data in real time
- Real-time data acquisition and state sensing
- Directly executes process control for motors, power modules, and drive systems

Learning / Optimization Loop (min–days)

Real-time Control Loop (ms–s)

Sensor Data / Process Data / Quality Data

Control commands / optimized conditions / AI model updates



Work by Layer

- **L1–L2:** Real-time execution layer that senses and controls the physical world
- **L3:** Collaboration and operations integration layer at the line level
- **L4–L5:** Learning, simulation, and optimization layer at the factory and enterprise level

AI Autonomous Manufacturing Factory vs. Traditional (Legacy) Factory: Layer Structure Comparison

AI Autonomous Manufacturing Factory (Physical AI Factory)

L5 — AI Factory / Cloud / Enterprise
- Multi-factory data learning, foundation models
- Knowledge management, AI / model-based global optimization
- Model deployment, data governance, security







↕ Model / knowledge deployment · feedback

L4 — Factory Server / Digital Twin
- Digital twin, process simulation
- Production / quality / energy data integration
- Real-time analysis, prediction, and decision support







↕ Analysis / optimization results · scheduling / instructions

L3 — Cell / Line Orchestration
- Line scheduling, work allocation
- Equipment coordination, AMR / robot path optimization
- Integrated control linked with MES / SCADA / PLC







↕ Real-time control commands · status / data

L2 — Edge AI Controller
- Real-time AI inference, anomaly detection, quality judgment
- Process optimization control, local data processing
- Edge SoC + LPDDR, compact module



↕ Low-latency control · sensor / status data

L1 — Equipment · Sensors · Actuators (Field)
- Sensors / measurement, motors / drives, robots / AGV
- Power modules, I/O, safety / protection devices
- Executes the physical process



Features
- AI-based autonomous judgment
- Real-time optimal control (closed loop)
- Multi-factory learning / sharing
- Continuous performance improvement

Traditional (Legacy) Factory

L5 — ERP / Headquarters (Enterprise)
- Production planning, demand forecasting
- Management analysis, KPI management
- Human-centered decision-making



↕ Planning / instructions (day / week unit)

L4 — MES / SCADA / Historian
- Process monitoring, history storage
- Alarms, reports, traceability
- Provides information to operators



↕ Commands / settings (equipment / line unit)

L3 — Line manager / Engineer
- Schedule adjustment, work instructions
- Problem identification, root-cause analysis
- Parameter change / equipment adjustment



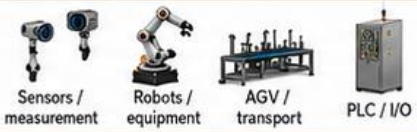
↕ Setting changes / manual control

L2 — PLC / Controller / IPC
- Logic control, sequence execution
- Sensor signal collection, device control
- Limited computing, rule-based control



↕ Control signals (fixed logic)

L1 — Equipment · Sensors · Actuators (Field)
- Sensors / measurement, motors / drives, robots
- Power modules, I/O, safety devices
- Executes the physical process



Features
- Fixed logic control
- Human intervention required
- Post-analysis focused
- Slow response to change

Key Differences

AI Autonomous Manufacturing: AI / ML-based multi-factory learning and model deployment
Legacy: Human-centered planning / analysis / decision-making

AI Autonomous Manufacturing: Digital twin, real-time analysis / prediction
Legacy: Monitoring, historical post-analysis centered

AI Autonomous Manufacturing: Line orchestration and automated collaboration
Legacy: Human-centered field management and manual scheduling

AI Autonomous Manufacturing: Edge AI-based real-time inference and adaptive control
Legacy: PLC fixed-logic control with limited computing

Common: Similar composition of *physical equipment and* sensors

Category	Data Flow	Decision Maker	Control Characteristics	Response Speed	Learning / Improvement	Scalability
AI Autonomous Manufacturing Factory	Field → Edge → Cloud → Field (real-time closed loop)	AI + system (autonomous judgment)	Adaptive / predictive control	Real time to second-level	Continuous learning / deployment updates	Easy multi-factory / global scaling
Traditional (Legacy) Factory	Field → MES / ERP → Human → Field (batch / manual)	Human (experience / rules)	Fixed-logic control	Minute to hour-level	Manual improvement (periodic)	Limited to line / factory level

Prof. Eun-Ho Lee (SKK R&D Cluster)

Advanced Packaging Roadmap and Thermal-Mechanical Design Challenges for Physical AI-Based Autonomous Manufacturing Systems

Linking the 5-layer autonomous manufacturing architecture with layer-specific packaging structures, functions, and thermal-management integration

Data & Learning Flow
Data collection
Analysis
Learning
Knowledge accumulation

		Representative Packaging Structures (Examples)	Key Functions / Roles	Thermal · Electrical · Mechanical Design Points
L5	AI Factory / Cloud / Enterprise Enterprise optimization · knowledge management · global collaboration	Rack-scale AI Package • GPU/AI accelerator module • Advanced package • CPO/Optical I/O • Liquid cooling	• Enterprise-wide optimization, predictive analytics • Global expansion, knowledge sharing • Data lake / governance	• Rack-unit fixed cooling • Liquid cooling (rear-door / CDU) • CPO thermal coupling, power-density increase
L4	Factory Server / Digital Twin Real-time simulation · process optimization · virtual/physical integration	2.5D / 3D Chiplet + HBM Package • HBM Stack • Silicon Interposer • 2.5D / 3D Integration • High-speed I/O	• Digital twin, process simulation • Production / quality / energy optimization • AI model training / deployment	• High-performance server thermal management • HBM / chiplet hotspot control • Interconnect and signal-integrity design
L3	Cell / Line Orchestration Line scheduling · equipment coordination · MES/SCADA integration · KPI management	COM-HPC / Industrial Board • High-performance CPU / SoC • Industrial Ethernet • Industrial I/O • Ruggedized Design	• Line integrated control, scheduling • MES/SCADA integration • KPI / quality management	• Cabinet-level thermal management • Power stability / distribution • EMI/EMC and mechanical durability
L2	Edge AI Controller Real-time inference · anomaly detection · equipment-level control · safety response	SoC + Memory Module / Fan-out SiP • SoC (NPU/CPU) • LPDDR / LPDDR5 • Fan-out / SiP • Compact, Low Power	• Real-time inference / analysis • Equipment control, safety logic • Anomaly detection and alarms	• Fanless / small-form thermal design • Low-power optimization • Vibration and shock durability
L1	Equipment · Sensors · Actuators Physical data collection · drive/control · real-time state sensing	MEMS / Sensor Package · Power Module • MEMS / Sensor Package • Power Module (SiC/Si) • Actuator Driver IC • Overmold / Rugged	• Physical data collection • Motor, valve, robot actuation • Real-time state detection	• Environmentel durability • Temperature / humidity / vibration / contamination resistance • Waterproof / dustproof / coating / sealing

Control & Optimization Flow
Model deployment
Control commands
Parameter updates
Performance optimization

Cross-layer Linkage (Data · Power · Thermal Management)

- **Data Flow**: Sensors → Analysis → Decision-making → Control
- **Power Supply Path**: Power / sensors → board → module → equipment
- **Heat Dissipation Path**: Chip / module → board / system → cabinet / rack → facility cooling

Because each layer requires different functions and packaging structures, a hierarchical thermal-management architecture is essential.

Thanks for listening



Thanks God for meeting good colleagues