Materials Acceleration Platform for Photovoltaics

Concept Study for a Self-Driving Perovskite Cluster-Tool

Advantages at a Glance

- \+ Fully automated preparation & in-line analysis
- \+ Accelerated experimentation & high-throughput workflows
- \+ Consistent results through robotic integration
- \+ Open, modular design with scalable substrate handling from 1'' to panel size
- \+ AI-ready data management platform

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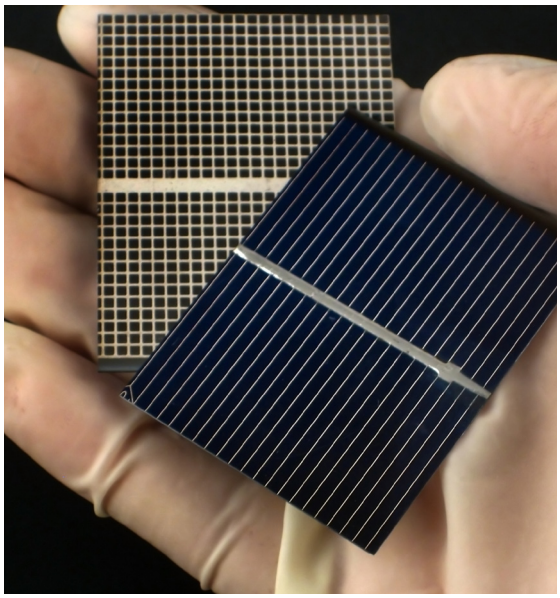
Behind the Concept



From FAB to LAB

At LAB14, we bridge the gap between advanced manufacturing and cutting-edge research. The presented automated research cluster transfers the precision, reliability, processing speed and connectivity demanded by industrial users into the laboratory setting. By integrating excellence in process automation with specialized lab solutions, we ensure that researchers benefit from robust, user-friendly, and service-oriented technologies, enhancing their capabilities and driving innovation forward.

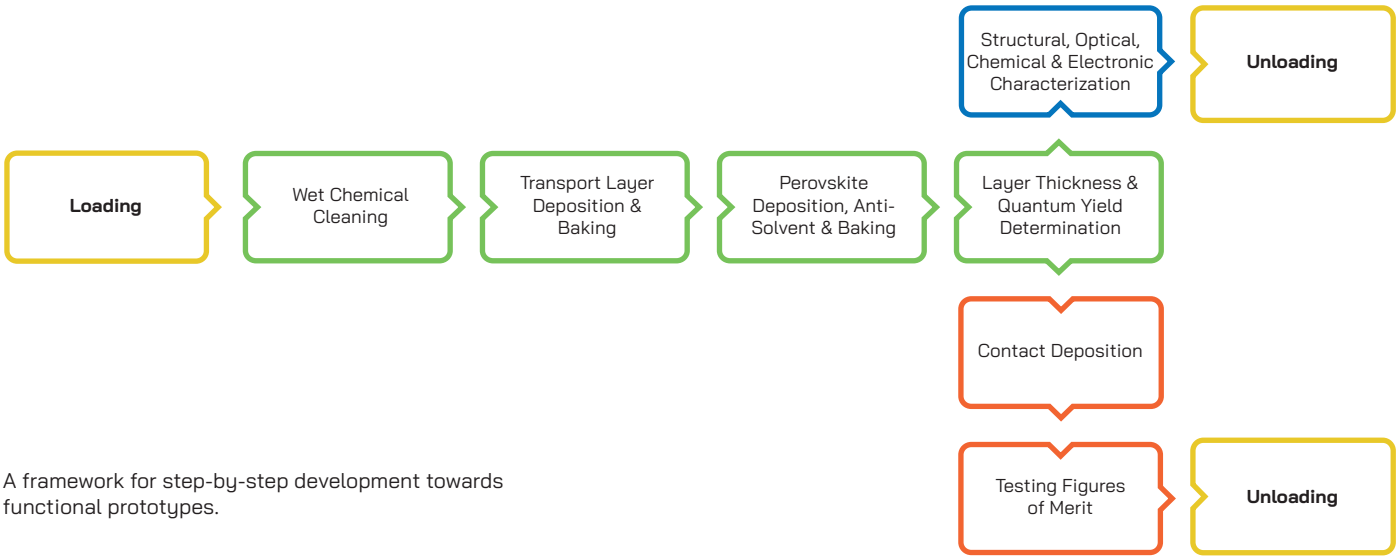
The Future of Automated Laboratories

The automation level in materials research laboratories has steadily increased over the past decades, a trend that is certainly going to continue. The concept of fully autonomous Material Acceleration Platforms (MAP) and Device Acceleration Platforms (DAP) has redefined the vision of automated labs. Achieving automation to such a level requires not only advanced robotics, but also sophisticated software for process control, data analysis, and AI-driven decision-making.
Today, leading universities are building highly automated labs tailored to their particular research focus by themselves, setting new standards in scientific discovery. However, professional automation know-how from decades of experience in semiconductor industries can be leveraged to make automated discovery available to a much broader range of research laboratories. With this concept study of a Materials Acceleration Platform for photovoltaics, we illustrate that highly automated laboratories are not a vision of the future, but already a commercially accessible reality.

Perovskite Solar Cells

Discovered in 2009, perovskite solar cells have already achieved efficiencies of 27%, rivaling the best established PV technologies. Perovskites feature exceptional light absorption in ultra-thin layers, remarkably high defect tolerance and a tunable bandgap, all achievable with very low production costs. Low manufacturing costs originate not only in the comparingly low amount of active material, but also from the possibility to apply low temperature processes and simple solution-based deposition methods like spin-coating, slot-dye coating or printing techniques.
Despite the promising and rapid developments, challenges remain: limited stability under real-world operation, scalability issues and lead content concerns still prevent the use of this material class in commercial products. Their vast range of possible stoichiometries and occasionally surprising material properties make perovskites an ideal showcase for an automated high-throughput laboratory. Our platform enables rapid exploration of countless material combinations and device architectures, unlocking faster innovation in PV materials research. This systematic approach, combined with advanced analytics, deepens the understanding of perovskites and expedites the development of commercially viable solutions.

From Idea to Prototype



A framework for step-by-step development towards functional prototypes.

Model Process of Rapid Prototyping

This concept study aims to accelerate the development of efficient, cost-effective absorber materials and functional layer architectures with high performance. Two key capabilities are essential: rapid screening across a broad parameter space of stoichiometries, layer stacks, and process control parameters on the one hand, and advanced analytics to assess the physical properties of functional layers for targeted parameter searches on the other.

The cluster's configuration is based on a model preparation process as found in many research laboratories, beginning with the introduction of 1" glass substrates, followed by chemical cleaning. Hole transport and absorber layers are deposited by spin-coating, with intermediate thermal annealing and anti-solvent application. This sequence serves only as an example, since the process flow can be freely adjusted and a wide variety of deposition processes, including spray-coating or inkjet printing can be implemented to address specific research needs. Various analytical methods are integrated for characterizing physical parameters: Layer thicknesses are monitored using white-light interferometry. Photoluminescence quantum yield spectroscopy for optical characterization, X-Ray diffraction for crystallinity, atomic force microscopy for roughness and local electrical properties, and X-ray, UV, and inverse photoelectron spectroscopy for chemical composition, electronic properties and band alignment. Before device testing, physical vapor deposition is employed to deposit transport layers and electrical contacts, enabling parallel performance assessments on up to 16 substrates under simulated solar irradiation.

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Our Concept in Detail

1 Robotic Platform

1'' glass substrates can be moved individually through the entire system. For process parallelization in PVD and performance tests, 16 individual substrates are combined on a carrier using a pick & place robot. The System is based Notion System's n.varixx series and operates entirely under protective gas atmosphere or vacuum conditions.

2 I/O Stations

For batch processing, multiple cassettes with 25 substrates of 1'' and additional multi-substrate carriers for 16 substrates each can be loaded, with flexible assignment of input/output location.

3 Wet Chemical Cleaning

An integrated n.chemixx module enables adaptable pre-cleaning of substrates prior to coating, featuring configurable chemical delivery and dispense systems, and substrate heating.

4 Spin Coaters

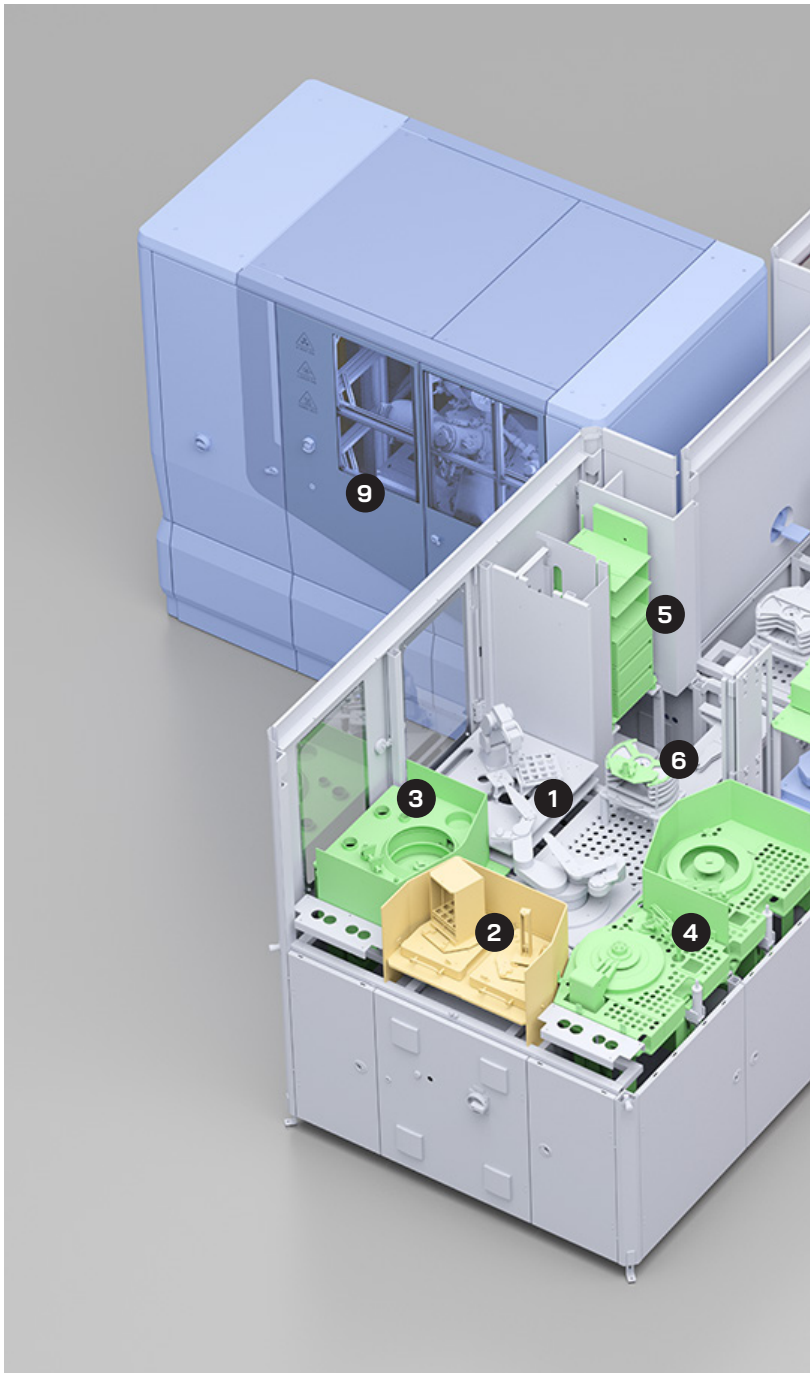
Open bowl or covered chuck spincoaters enable highest process control during layer deposition.

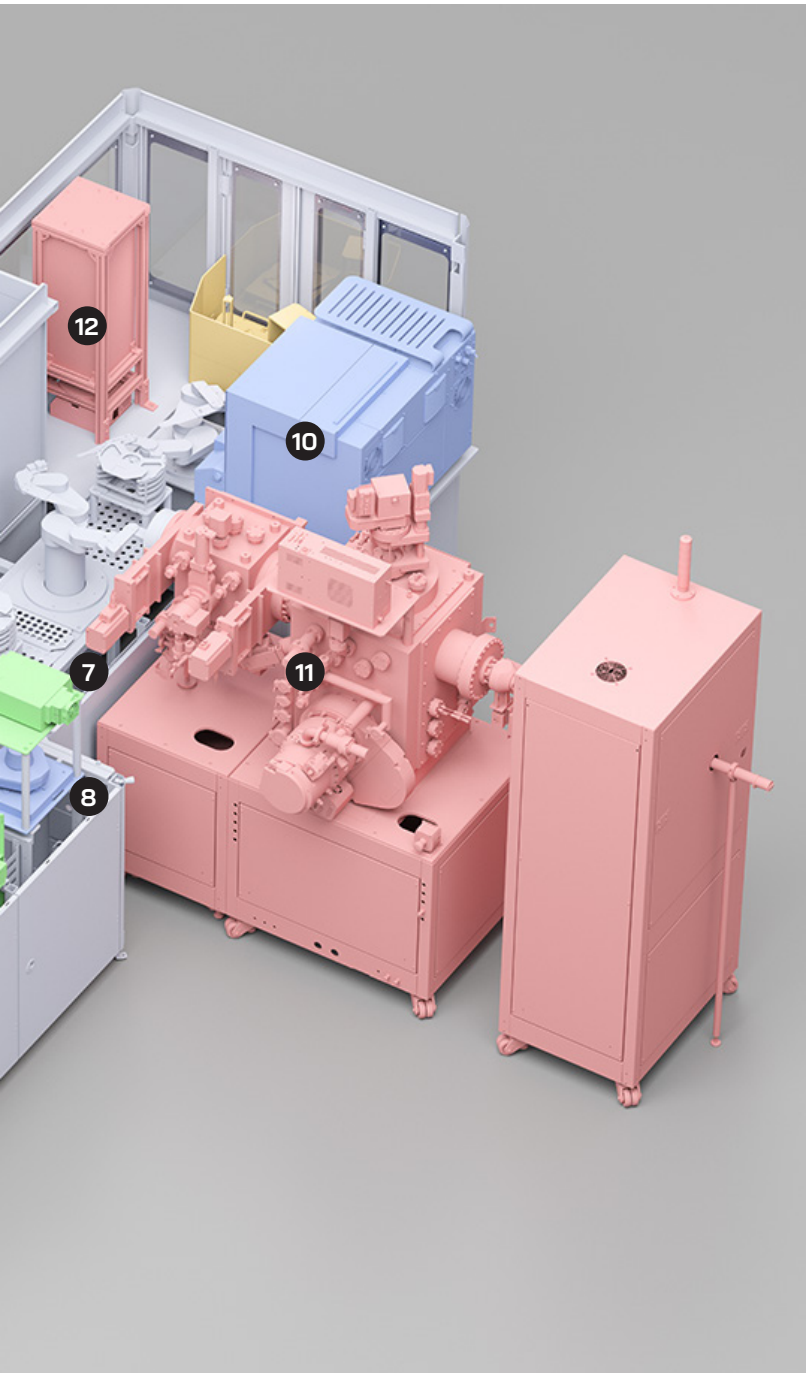
5 Heating Module

For annealing or curing of deposited layers, substrates can be heated up to 220°C with individually set heating times.

6 White-Light Interferometry

Layer thickness and uniformity across multiple deposition stages can be determined.





7 PL & PL Quantum Yield

Quantification of the ratio of emitted to absorbed photons and determination of quasi-fermi level splitting.
(LuQY Pro by Quantum Yield Berlin)

8 Atomic Force Microscopy

Mapping of surface morphology with sub-nanometer resolution and quantification of local electrical properties such as conductivity, work function or charge carrier concentration.
(DriveAFM by Nanosurf)

9 Photoelectron Spectroscopy

Advanced surface analysis during perovskite solar cell fabrication, determining chemical composition, oxidation states, and complete electronic band structures at critical interfaces.
(EnviroMETROS Lab by SPECSGROUP)

10 X-Ray Diffraction

Identification of crystal structures, phase compositions, and lattice parameters of the photoactive and charge transport layers.
(D6 PHASER by Bruker)

11 Physical Vapor Deposition

Versatile vacuum thin-film deposition system for high-quality metallic contacts with optimized work functions and conductivity profiles, functional buffer layers, transparent conductive oxides, or selective transport materials with tailored optoelectronic properties.
(PRO Line PVD 75 by Kurt J. Lesker Company)

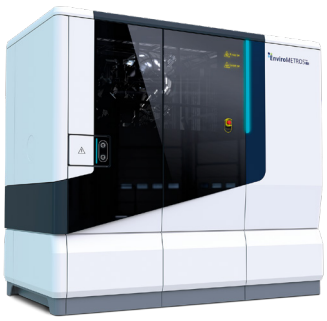
12 Solar Simulator and IV measurement

IV characterization, MPP tracking or light soaking can be performed with simulated sun light on various cells in parallel.
(Sunbrick by G2V Optics with MPP Neo by Automatic Research)

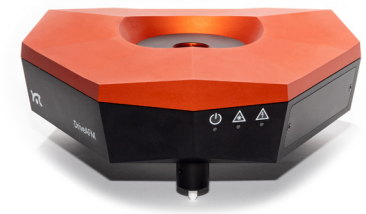
Integration & Data Flow

Connectivity

Software connectivity is crucial for seamless integration and trouble-free operation, it is the basis for data exchange and process automation. Protocols such as LADS/OPC-UA facilitate standardized communication between equipment and ensure interoperability across different platforms. This provides a solid basis for future upgrades and extensions, and the system can adapt to your current research focus.



EnviroMETROS LAB by SPECSGROUP



DriveAFM head by Nanosurf

Data Management

The integrated research data lake provides a centralized and scalable infrastructure for the automated collection and management of large datasets from various sources. Processes, measurement results and machine logs are automatically transferred to a central storage. Unlike traditional databases, this platform stores raw data in its original format and further transforms it into different quality levels up to clean and aggregated application-ready data. This structure facilitates automated data evaluation pipelines, advanced analytics and AI applications. By implementing this platform, LAB14 enhances data availability, improves search capabilities, ensures regulatory compliance, and ultimately supports data-driven research and autonomous experimentation.

Process Control

Central industrial-grade scheduler software serves as the core control system for the cluster. It allows parallel execution of multiple processes, optimizing run-time and enhancing overall throughput. The software features a user-friendly interface for flexible recipe creation. Its multi-tenant capability enables different users and groups to operate independently. The software also provides a simulation mode and real-time monitoring of ongoing operations. The analytical and PVD modules of the cluster can be operated autonomously through their own control software, allowing for standalone use.

n.varixx 806 by Notion Systems

Modules

The LAB14 Modules

Robotic processing platform by Notion System

The system integration and automation concept of this study is based on the modular n.varixx processing platform 806 by Notion Systems. A large variety of modules like spin and spray coating, inkjet-printing, heating, cooling, UV curing, etching, developing, edge bead removal and various inspection methods can be integrated.

Photoelectron Spectroscopy by SPECSGROUP

The EnviroMetros Lab provides a comprehensive range of surface analysis techniques including XPS, HAXPES, UPS, and IPES. This enables precise characterization of chemical composition and electronic band alignment at critical interfaces in multilayered devices. Its environmental control capabilities allow researchers to monitor material degradation pathways and interface evolution under precisely controlled atmospheric conditions with NAP-XPS, providing crucial insights into stability mechanisms.

Atomic Force Microscopy by Nanosurf

The DriveAFM reaches exceptional scanning speeds through its revolutionary WaveMode technology, enabling researchers to capture high-resolution surface morphology and nanomechanical properties at rates up to 20 times faster than conventional AFM systems. Its automation features include motorized laser alignment, cantilever approach, and parameter optimization, dramatically simplifying complex measurement workflows. The system offers an extensive suite of measurement modes including electrical characterization modes (C-AFM, KPFM, PFM, SMM), advanced nanomechanical analysis with viscoelastic mapping.

Our Technology Partners

X-Ray Diffraction by Bruker

The D6 PHASER with autoloader is a benchtop platform for X-ray powder diffraction in reflection and transmission geometry, thin film analysis by grazing incidence diffraction and reflectometry, and bulk sample stress and texture analysis. It features a powerful, Industry-leading 1200 W Xray source and can be use online or in standalone operation, for which is offers comprehensive software solutions for all applications.

PVD by Kurt J. Lesker

Designed for modularity, PRO Line and SPECTROS systems can accommodate a wide range of deposition sources including magnetron sputtering, thermal and electron beam evaporation, and organic material sources. The system is seamlessly integrated with protective gas atmosphere, enabling contamination-free processing of oxygen- and moisture-sensitive thin films.

PL by Quantum Yield Berlin

The LuQY offers absolute Photoluminescence Analysis. It determines the PL Emission Spectrum, Quantum Yield (PLQY), and QuasiFermi Level Splitting (QFLS) within just a few seconds. Thanks to its integrated tunable laser, ideality factors and pseudo-JV curves can also be determined in just a few minutes.

Cell Characterization

The G2V Sunbrick Large Area Class AAA LED Solar Simulator provides precise illumination with wavelength coverage from 350nm up to 1200nm. It features up to 35 LED control channels plus Python API and Labview DLL for the integration into the cluster.
Complementing this, the Automatic Research high throughput measurement unit MPP Neo enables electrical characterization of hundreds of solar cell prototypes in parallel, capturing critical performance parameters including I-V curves, with MPP tracking.

About LAB14

The LAB14 Group is a global leader in cutting-edge nano- and microtechnology solutions, founded on the principle that true innovation arises when expertise, technology, and vision converge. Since 2022, LAB14 – headquartered in Heidelberg, Germany – has united decades of experience from its subsidiaries. The company delivers breakthrough products and services for the most demanding industrial applications. With more than 1,200 employees across 28 locations worldwide, LAB14 offers a comprehensive portfolio of solutions for key future-oriented sectors, including semiconductors, AR/VR, sensors, micro-optics, 3D printing, and MEMS. Through continuous growth and strategic acquisitions, LAB14 has strengthened its position as a technological innovation leader, actively shaping the future of advanced technologies.

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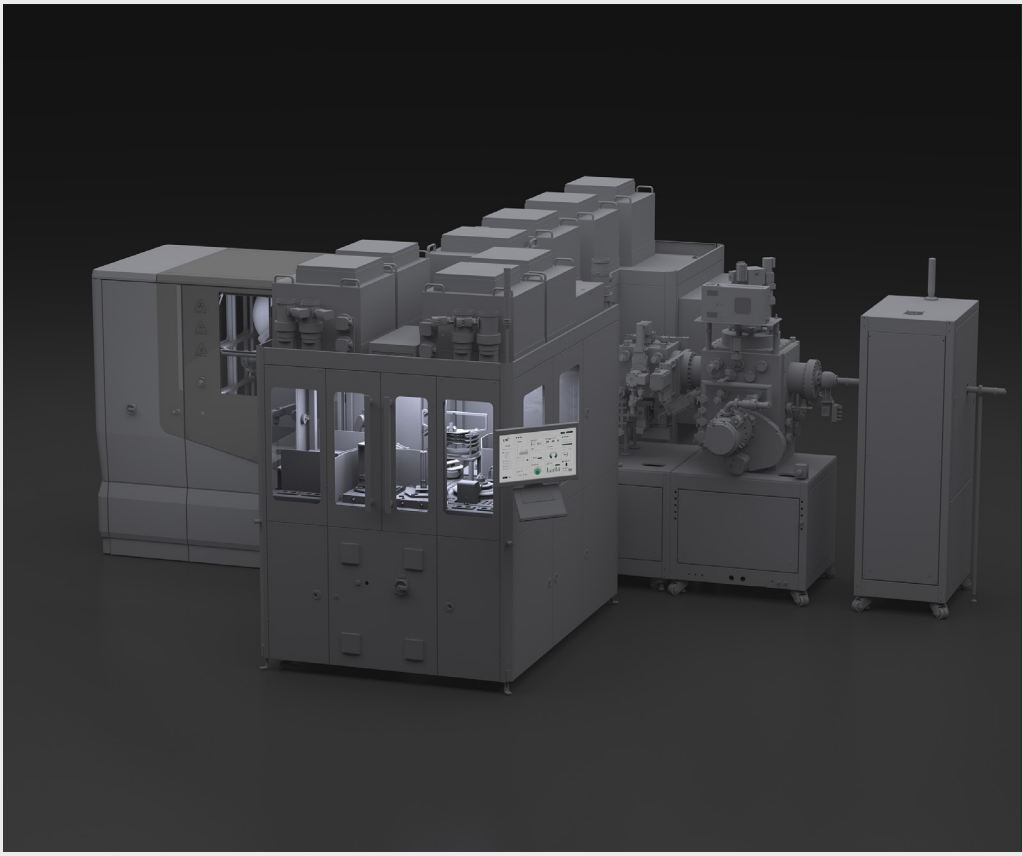

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