The Lithography Research Cluster Tool: An Automated Platform for AI-enabled Process Development.

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Acceleration of developing lithographic processes requires laboratory systems that bring together robotic substrate handling, modular processing units, and a fully digital control environment in one integrated setup. In this work, we present a conceptual architecture for a lithography research cluster that transfers principles from automated fabrication into a platform that can be adapted for scientific needs. The design focuses on a robotic handling system with flexible recipe execution, allowing serial and parallel process routes under controlled atmospheric conditions.

The idea follows the concept of automated research clusters that combine preparation, deposition, and in-situ or in-line characterization (Materials Acceleration Platform) in order to speed up experiments and reduce work force requirements.

A central innovation of the concept is the strict combination of process orchestration with the data infrastructure. A central scheduler manages the experimental steps, enables parallel workflows, and offers a simulation layer to test and optimize process paths before real execution. Standardized communication protocols make sure that different modules can work together and that the platform stays open for future extensions.

The integrated Instrument Data Lake is the heart of the digital architecture. It automatically collects raw measurements, process parameters, and machine logs with relevant meta data, and organizes them in layered data domains that keep the raw information but also allow the creation of clean, analysis-ready datasets. This setup supports FAIR data principles and provides a direct interface to analytical workflows and AI tools for guiding experiments.

To show how the concept can be used, we describe an example setup in which optical lithography, solution-based processing, and real-time metrology are connected through the robotic framework. The processing sequence forms a closed feedback loop between patterning, material deposition, and quantitative evaluation. Based on known studies of automated cluster-tool architectures, the example illustrates how synchronized data collection, comprehensive orchestration, and full robotic integration can expand the possible lithography options, improve reproducibility, and significantly shorten experimental iteration times.

By bringing robotics, modular process design, unified orchestration, layered data handling, and AI-supported decision making together in one conceptual framework, this work outlines a technological basis for autonomous and data-driven lithographic research. The approach offers a way toward laboratory infrastructures that can systematically accelerate discovery while still ensuring scientific rigor and transparency.