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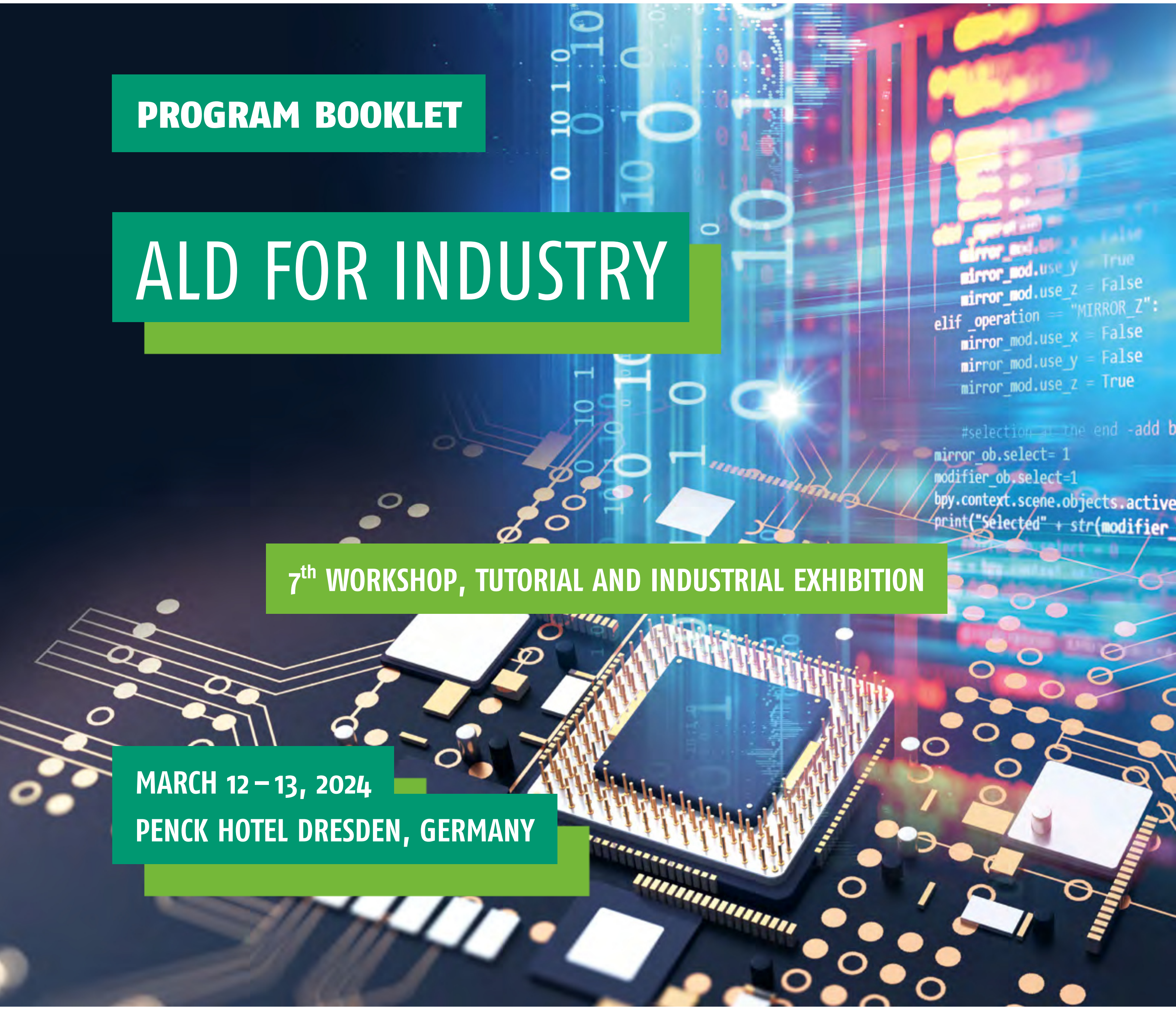

PROGRAM BOOKLET

ALD FOR INDUSTRY

7th WORKSHOP, TUTORIAL AND INDUSTRIAL EXHIBITION

MARCH 12 – 13, 2024
PENCK HOTEL DRESDEN, GERMANY

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PREFACE

A topical workshop with focus on industrialization and commercialization of ALD for current and emerging markets

The 7th International Conference "ALD FOR INDUSTRY" will again bridge the gap between fundamental science, industrialization and commercialization of this technology. Atomic layer deposition (ALD) is a process for depositing a variety of thin film materials from the vapor phase of matter. The growth of this technology is not only based in microelectronics applications, but also in areas of industrial Li–Ion batteries, photovoltaics, optics, light, biomedicine and quantum technology.

This event is already established since 2016 and attracts annually more than 100 participants and numerous exhibitors to visit Dresden. The Conference with Tutorial provides the opportunity to learn more about fundamentals of ALD technology, to get informed about recent progress in the field and to get in contact with industrial and academic partners. Increase your visibility and present your company in our accompanying exhibition.

ALD has a high potential for emerging ALD markets that may grow in the next 5 years:

- Power electronics
- Optics
- Medical
- Particle coating
- Packaging
- Protective coatings
- Energy storage
- Textile
- Fibers
- Decorative coatings

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PROGRAM

Tuesday, March 12, 2024

Tutorial, Workshop & Industrial Exhibition

08:00	Registration & Exhibition Construction
10:00	**Opening of the Tutorial**
10:10	**Tuto1 | ALD fundamentals and process development** Martin Knaut, Technische Universität Dresden, Germany
10:30	**Tuto2 | Analytical methods for ALD Technologies** Dane Walker, HIDEN Analytical Ltd, UK
10:50	Questions
11:00	**Coffee Break & Opening of the Exhibition**
11:30	**Tuto3 | Atomistic simulation for design of atomic level processing chemistries; towards sustainable thin film processing** Michael Nolan, Tyndall National Institute, Cork, Ireland
11:50	**Tuto4 | Paradigm shift for vapor phase delivery of solid precursor** Herve Dulphy, Air Liquide Electronics Systems, France
12:10	**Tuto5 | Precursor development: A Chemist's perspective to develop new ALD processes** Anjana Devi, IFW, TU Dresden, Germany
12:30	Questions
13:00	**Lunch Break**
14:00	**Workshop**
14:00	**WS01 | Green ALD? A guide to a better practice using an LCA approach** Houyem Hafdi, Linköping University, Sweden


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14:20	**WS02 | High performance automation for spatial ALD and general substrate workflow** Aaron Strobel, LSA GmbH, Germany
14:40	**WS03 | ALD: The Swiss Army Knife of Industrial Innovation** Ward Loeffen, Euris GmbH, Germany
15:00	**WS04 | Integrated (PE)ALD solutions for interface engineering in power electronics** Christoph Hossbach, Applied Materials, Germany
15:20	**Coffee Break & Exhibition**
16:00	**WS05 | ALE for GaN in power electronics** Jonas Sundqvist, AlixLabs AB, Sweden
16:20	**WS06 | ALD processes at Infineon** Wolfgang Lehnert, Infineon Technologies AG, Regensburg, Germany
16:40	**WS07 | Modifying the properties and performance of biodegradable polymers with ALD** Gil Menasherov, FNAI-Technion, Israel
17:00	**WS08 | Application of very thin coatings on different grades of particles by ALD** Mario Krug, Fraunhofer IKTS, Germany
17:20	**WS09 | Epitaxial quality Ga_2O_3 and GaN thin films grown by hollow cathode plasma ALD** Ali Kemal Okyay, OkyayTech ALD, USA
17:40	End of first day
19:00	**Get-Together @ Restaurant** Sophienkeller | Taschenberg 3, 01067 Dresden | near to Semperoper, Zwinger and Dresden Castle


© Sophienkeller im Taschenbergpalais

Martin Knaut

Group Leader Atomic Layer Processing |
Technische Universität Dresden, Germany

Studies and doctorate at the Technische Universität Dresden | Senior scientist and group leader at the Institute of Semiconductors and Microsystems, Technische Universität Dresden | Work in the field of atomic layer deposition and thin film metrology since 2004 | Development and optimization of measurement techniques and approaches for ALD processes monitoring since 2007 | Founding member of “ALPIN” (Atomic Layer Processing Innovation Network) | Founder of “ALS Metroglogy UG”

ALD fundamentals and process development

The tutorial presents the fundamentals of ALD and gives insights in ALD process developments. Process development is the key for enabling new ALD processes, materials and applications as well as increasing reproducibility and reliability while decreasing process time and costs. The talk will show how to develop a process by varying process parameters and characterizing its impact on film growth or film properties. Examples will emphasize that ALD processes aren’t always as simple as the idealized ALD principle promises and will highlight the need for a detailed process development. Further, benefits and advantages of process control methods by means of in situ measurement technologies will be illustrated to detect deviations and errors at an early stage.

Dane Walker

Technical Marketing Manager | HIDEN Analytical Ltd, United Kingdom

Holds undergraduate & postgraduate engineering qualifications & a PhD in SurfaceScience from Loughborough Univ., UK. Began in aerospace & defence with nickel superalloy forgings. Over a decade at Hiden Analytical, starting as test & installation engineer for plasma/surface science. Advanced to technical sales, specializing in plasma & SIMS. Now serves as Technical Marketing Manager for Hiden Analytical.

Analytical methods for ALD Technologies

In Atomic Layer Deposition (ALD), accurate process characterisation is essential. Mass spectrometry enables precise real-time process monitoring, crucial for optimal ALD control. The addition of techniques for variable pressure mass spectrometry allow process characterisation at both base and process pressures. For Plasma-Enhanced ALD (PE-ALD), ion mass and energy analysis provide vital insights into ion and radical behaviours, ensuring real time process control and understanding of plasma interactions. These analytical methods collectively enhance ALD process optimization, reflecting significant advancements in efficiency and precision within materials science.

Michael Nolan

Head of Group | Tyndall National Institute, Ireland

Dr. Michael Nolan is the Head of Group – Materials Modelling for Devices at Tyndall National Insitute, Ireland. Dr. Nolan is also interim Chief Scientist, Chair of the Science Council of the Irish Centre for High End Computing and Associate Editor of Beilstein Journal of Nanotechnology. Dr. Nolan leads a team of 5 PhD students and 6 postdocs in the first principles simulation of new atomic level processing chemistries, which is carried out together with leading groups in Europe.

Atomistic simulation for design of atomic level processing chemistries; towards sustainable thin film processing

ALD chemistry takes place at surfaces, driving its self-limiting characteristics and other advantages. However, the other side to device processing is the heavy environmental impact and non-sustainable nature of current processing chemistries, including high process temperatures, the complex precursor discovery, use environmentally unfriendly chemicals, and the large number of laboratory experiments needed to develop a new process chemistry. I will show how we can use first principles and atomistic simulations to gain a deep understanding of a series of process chemistries and how this knowledge can be leveraged to make discovery and use of atomic level processing chemistries more sustainable, highlighting the power of atomistic simulations.

Hervé Dulphy

Chief Technology Officer | Air Liquide, France

Hervé holds a PhD degree in Organic Chemistry. After few years working for oil industry, he joined Air Liquide in 1996 through an entity (Air Liquide Electronics Systems) dedicated to equipment manufacturing. Core products are high tech fluid delivery systems. After diverse project management and start-up experiences, Hervé set a development team which since then has developed numerous products representing nowadays 10+M€/year of sales. Within this team Hervé has co-authored more than 40 patents.

Paradigm shift for vapor phase delivery of solid precursor

Expected ALD film performances are more and more often calling for solid precursor usage. Additionally, using larger precursor containers is necessary to reduce molecule cost (€/g) and process TCO.

The production of these layers requires accurate flow control and quality consistency over the big container depletion. Beside the intrinsic precursor mandatory properties like thermal stability, the main concerns to operate a reliable vapor phase delivery system fed with solid precursors are all about heat transfer and heat control. A proper heating management is required in order to 1/ avoid production shutdown resulting from clogging, 2/ get stable precursor vapor pressure over on/off flow conditions and over varying remaining material quantity inside the container, 3/ get rid of contamination coming from the piping material

Yes, using solid precursors is more complex than gaseous or liquid ones but it is already in production, at HVM scale thanks to Air Liquide patented delivery system.

Anjana Devi

Director of Institute for Materials Chemistry, IFW Dresden | IFW Dresden, Technical University Dresden, Fraunhofer IMS Duisburg, Germany

Anjana Devi is the director of Institute for Materials Chemistry at the Leibniz Institute for Solid State and Materials Research (IFW) in Dresden and Chair of Materials Chemistry at TU Dresden. She is also heading the research group Nanostructured Sensor Materials at Fraunhofer IMS in Duisburg. Her main competencies involve developing novel precursor chemistries and applying them for the synthesis of a broad range of advanced functional materials via CVD, ALD and MLD.

A chemist's perspective to develop new precursors and ALD processes for targeted applications

The success of atomic layer processing of functional materials depends largely on the precursors employed. Its specific chemistry in interplay with substrate surfaces and co-reactants dictates the nature of the layers formed as well as the quality of the material. From a materials chemist's perspective, the strategy is not to synthesize one or more arbitrary precursors with a combination of ligand systems, rather rationally tune the ligand systems as well as identify suitable co-reactants. This approach provides knowledge on the relationship between the molecular structure of the precursors, their thermal characteristics and reactivity, which in turn has a direct impact on film deposition and resulting material properties. Representative cases of precursors and their application for targeted applications will be discussed in this presentation.

Houyem Hafdi

Postdoc | Linköping University, Sweden

I am a Postdoc researcher at Linköping University, experienced in Chemical Process Technology and environmental assessment. Now focusing on developping green approaches to CVD and ALD.

Experienced in analytical chemistry, developed multimetal-doped materials (thin films, powders, membranes) for industrial wastewater treatment via adsorption/desorption and heterogeneous catalysis.

Green ALD? A guide to a better practice using an LCA approach

The ALD process is energy-intensive because of its excessive use of precursor molecules to maintain the self-limiting surface chemistry over the substrate area. As little as 10 % of the supplied precursors are used in film deposition. ALD operates under low pressure; the pump runs on a full load and the reactor must also be heated.

Hence, assessing the environmental implications of ALD and determining resource consumption is critical. One technique that allows this is Life cycle assessment (LCA). It is a tool that substantiates life cycle thinking using a structured methodology to assess the potential environmental impacts of a product or a process.

This talk will use ALD of GaN as a model system for LCA. The collected data concerning the specific ALD equipment, precursor gases, energy flow in the form of electricity, and cooling water are quantified and modeled for assessment The environmental impact and strategies for ways to minimize environmental impacts of ALD will be discussed.

Aaron Strobel

Business unit manager | LSA GmbH, Germany

As physician with pleasure for theoretical physics, programming and experiments at the cutting edge of knowledge I joined LSA directly after my Master thesis at TU Chemnitz 2016. LSA is a high-tech and very innovative medium sized company, a special machine inventor and builder. After several research programs with renominated partners, I am in charge as business unit manager of motion automation for cleanroom and vacuum for PVD, CVD, ALD and (R)IBE. We have 20 years experience in this field.

High performance automation for spatial ALD and general substrate workflow

ALD has higher homogenity than all other deposition techniques, but a much lower deposition rate as in each cycle only one atomic layer is added. Also the ratio of used to exhausted precurser material is relatively low.

Spatial ALD can fill this gap, where the cycles are not temporarly seperated but spatial. As the gap between gas source and substrate has to be very controlled in the precision of 1/100 mm one needs precise motion axes, that offer robustness and vacuum compatibility.

We present a new approach of linear motion for spatial ALD under vacuum conditions that is also capable for Plasma enhancement and can reduce the cycle time dramatical. We present how our approach is adapted also to 3D parts with high aspect ratio or rotary motion.

The precise motion under vacuum condition enables combinations with PVD, CVD or (R)IBE stages in one tool for complex multilayer deposition. We are open to integrate our motion approach into existing chambers, new or used.

Ward Loeffen

Head of Sales | Euris Semiconductor, Germany

- > 20 years of experience in semiconductor, plastics and oil & gas.
- International experience in with multicultural teams throughout Europe, the Middle East & Northern Africa, Northern America and the Far East.
- Focuses on trust and long-term customer relations to offer creative solutions, so he can combine his passion for sales with his love for semiconductors.
- His colleagues and business partners appreciate his pro-active, hands-on mentality and good sense of humor.

ALD: The Swiss Army Knife of Industrial Innovation

Atomic Layer Deposition (ALD) systems are essential for precise thin film deposition. Benchtop GEMStar ALD systems, which offer enhanced thermal and plasma ALD capabilities, excel in a compact, configurable platform, providing atomic-level control over particle sizes, composition, and film thickness. These capabilities are crucial in emerging technologies such as 2D materials, Perovskite solar cells, medical devices, and semiconductors. As these technologies advance, benchtop ALD systems play a pivotal role in driving innovation, facilitating breakthroughs, and opening up new horizons for research and development, ultimately contributing to the evolution of cutting-edge applications across various industries.

Christoph Hossbach

General Manager | Picosun, an Applied Materials company, Germany

Christoph Hossbach obtained the Dr.-Ing. in Electrical Engineering in 2013. Since 2017 he is in European Sales of Picosun, an Applied Materials company. Earlier he worked as a Senior Scientist at TU Dresden, IHM. His fields of expertise include Atomic and Molecular Layer Deposition, Chemical Vapor Deposition, metrology, as well as tool and component design. Dr. Hossbach is co-founder of ALPIN network and was involved in teaching and consulting.

Integrated (PE)ALD solutions for interface engineering in Power Electronics

Fabien Piallat, David Britz, Christoph Hossbach

Challenges typically associated in the most advanced nodes of leading-edge applications, where interfaces drive the majority of the device properties, are increasing being seen in specialty devices, such as Power Electronics. From 2DEG control in GaN HEMT devices to mobility enhancement in SiC devices, integration of multiple steps in a system capable of, for example, pre-clean, PEALD, preferably with a remote plasma source, and ALD. While ALD is the best-in-class solution for high density and conformal layers, addition of pre-clean and/or PEALD deposition without vacuum break in-between the steps allows new surface and interface engineering capabilities, resulting in a dramatic increase in the ALD adoption.

Jonas Sundqvist

CEO / Senior Technology Analyst | AlixLabs AB / TECHCET LLC CA, Sweden

Jonas Sundqvist, PhD in inorganic chemistry from Uppsala University, has extensive experience in ALD and CVD process development. He worked at Infineon, Qimonda, and Fraunhofer CNT, focusing on materials for DRAM and semiconductor technologies. He founded ALD Lab Dresden and BALD Engineering, co-founded AlixLabs, and has been involved in academia and industry, holding 10 patents and co-authoring 40+ publications. Currently, he is CEO of AlixLabs, Senior Technology Analyst at TECHCET CA LLC.

ALE for GaN in power electronics

Atomic Layer Etching (ALE) is key in GaN device fabrication for power electronics, offering enhanced device efficiency. AlixLabs' ALE Pitch Splitting (APS) technology stands out for its low-damage etch process, achieving atomic-level surface smoothness on Silicon, GaP and GaN substrates, crucial for device reliability. Collaboration between AlixLabs, academia, and industry leaders has proven APS's scalability for commercial use, leading to a potential adoption in GaN manufacturing. APS significantly reduces surface defects, boosting electrical performance. This abstract presents AlixLabs' recent ALE advancements for GaN, highlighting the importance of industry-academia collaboration in advancing power electronics.

Wolfgang Lehnert

Process Engineer | Infineon, Germany

Study of Electrotechnics/Technology of Silicon Devices at Friedrich Alexander University, Erlangen | Working 4 years at Fraunhofer IIS-B in Erlangen (equipment engineering furnace, spectroscopic ellipsometrie, in situ process control, fuzzy control) | Since 1999 at Infineon Regensburg, process module furnace LPCVD | Process development LPCVD/ALD (ASM, TEL, BTI) | Processes: amorphous and polycrystalline silicon, in situ doped silicon, silicon nitride, TEOS, Al_2O_3-ALD, SiO_2-ALD, …

ALD processes at Infineon

The “ALD history” at Infineon is an over 20 years lasting successful story. It started with first activities in the former development line in Munich (Perlach) at a single wafer tool (“Pulsar”). But from beginning there was the demand of ALD film thicknesses of several 10nm, therefore batch ALD processes were preferred and together with ASM the first batch ALD processes in a vertical furnace were developed. Al_2O_3 was the first ALD material which was qualified in automotive technologies. In following years the focus was on high k dielectric layers and compatible electrode materials. Most of these high k materials suffer from low break down voltages, high leakage current and low stability. By the use of plasma enhanced deposition methods significant improvements are possible. This encouraged in addition the development and test of thermal PE assisted batch ALD processes for several materials. Meanwhile thermal Batch-ALD is part of the standard process portfolio of every Infineon site.

Gil Menasherov

MSc student, MBA student | FNAI – Technion, Israel

Oct 2017 – Aug 2022: BSc in chemical engineering. | Jan 2021 – Sep 2022: RAFAEL-ADVANCED DEFENSE SYSTEMS LTD, A student position – research and development | Sep 2021 – Aug 2022: Final research project in the FNAI lab, led by associate professor Tamar Segal-Peretz | Aug 2022: SRF Alumni Association Entrepreneurship Program | Oct 2022 – Jan 2023: Czech Israel Partnership Accelerator (CIPA) | Oct 2022 – present: MSc student in the FNAI lab. | Oct 2023: Starting MBA studies in order to integrate ALD-based processes in industry.

Modifying the properties and performance of biodegradable polymers with atomic layer deposition

Using plastic from non-degradable sources leads to long-lasting environmental pollution, posing significant threats to ecosystems and human health.

It is possible to reduce the environmental footprint of plastics by using degradable polymers, but their properties and performance must be improved before their use can be widely adopted.

Here we explored modification of degradable polymers using ALD and SIS to create hybrid materials with enhanced properties.

We investigated the growth of AlOx ontop and within PLA and PHA thin films. We explored the precursor-polymer interactions using in-situ quartz crystal microbalance (QCM) microgravimetric measurements and scanning electron microscopy. This fundamental understanding was further applied in finding the favorable conditions for ALD and SIS processes on 3D printed models of PLA and PHA.

The hybrid AlOx-polymer models showed improved properties such as resistance to organic solvent vapors.

Mario Krug

Senior Scientist | Fraunhofer IKTS, Germany

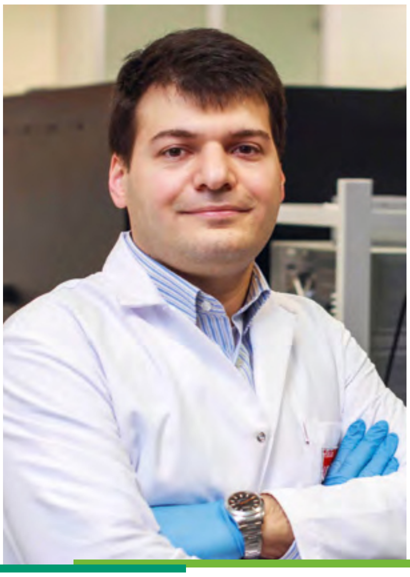
Mario Krug Sr. Scientist at Fraunhofer IKTS Thin Film Group and covers thin film deposition processes by vacuum technologies like PVD, ALD and CVD. Within his experiences of more than 20 years in thin film technologies he dealt with plasma activated high rate deposition and application of PVD technologies. Since 2010 he works in the topics of application driven ALD- and CVD-processes for different applications like semiconductors, protective coatings for fibers and powder/particle materials.

Application of very thin coatings on different grades of particles by ALD

Powder functionalization is becoming increasingly important, not only for battery applications. Thereby, powders are very demanding substrates for processing, considering the extreme three-dimensional character with enormous aspect ratios for a powder spillage of grains of µm-size or even below. ALD is the most promising technology to functionalize such substrates, but the powder grains have to be "moved" to enable a homogeneous coating at reasonable processing times. Rotating drums are one approach for coating powders by ALD. Due to the rotation, the powder material rolls continuously on the inner wall of the drum during the coating process to guarantee powder circulation, preventing or reducing the formation of agglomerates and bring the powder evenly into contact with the gases. Various examples of thin ALD coatings on particles and the process requirements will be presented.

Ali Kemal Okyay

CEO | Okyay Tech, USA



Dr. Ali K. Okyay received his Ph.D. degree in Electrical Engineering from Stanford University, CA, in 2007. He led a research team of 30 at Bilkent University during his appointment as a faculty member until 2016. He published more than 300 scientific papers on device physics and applications of nano-materials by atomic layer deposition (ALD) and he presented over 30 invited lectures, invited seminars, and invited conference talks around the world. He is currently the CEO ok Okyay Tech ALD.

Epitaxial quality Ga_2O_3 and GaN thin films grown by hollow cathode plasma ALD

Wide and ultrawide bandgap (WBG/UWBG) semiconductors make the backbone of high-power high-frequency electronics, used in electric vehicles, 5G and beyond wireless communication systems, and smart power grids. However, the relatively complex growth reactors and typical growth temperatures around 1000 °C lead to increased production costs and limited application space. Gallium oxide (Ga_2O_3) is an emerging UWBG semiconductor showing superior material properties particularly ideal for harsh environments (high temperature, high-energy radiation, corrosion) applications. Reducing the growth and doping process temperatures for Ga_2O_3 would potentially enable a wider integration platform towards post-CMOS integration and flexible electronics.

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PROGRAM

Wednesday, March 13, 2024

Workshop & Industrial Exhibition

09:00	**Opening of DAY 2**
09:10	**WS10 | Scaling ALD for optical coatings using DC plasma and a novel method for precursor separation** Eric Dickey, Lotus Applied Technology, USA
09:30	**WS11 | Application of plasma enhanced rotary atomic layer deposition for optical coatings** Gerd-Albert Hoffmann, Laser Zentrum Hannover e.V., Germany
09:50	**WS12 | Modeling and simulation of ALD in a level set framework** Lado Filipovic, Technische Universität Wien, Austria
10:10	**WS13 | Hybrid Monte Carlo and reactive molecular dynmaics simulation of ALD** Xiao Hu, Center for Microtechnologies, Germany
10:30	**Coffee Break & Exhibition**
11:00	**WS14 | Mechanical model materials with ALD. MLD and PVD** Ivo Utke, EMPA, Switzerland
11:20	**WS15 | Strong chemical reducing agents for metal ALD** Daniel Löffler, BASF SE, Germany
11:40	**WS16 | Presentation of Pegasus Chemicals** Paul Wiliams, Pegasus Chemicals, United Kingdom
11:50	**WS17 | Progress in products, services and strategic vision** Thilo Hepp, Dock Chemicals, Germany

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12:00	**Lunch Break**
13:00	**WS18 | Modulus and yield strength measrurements of ultra-thin ALD coatings in a thickness range between 5 nm and 100 nm** Thomas Chudoba, ASMEC GmbH, Germany
13:20	**WS19 | An infrared optical sensor for quantitative inline inspection of nanocoatings on plastic products** Benedikt Hauer, Fraunhofer IPM, Germany
13:40	**WS20 | In-situ gas monitoring of ALD processes using remote optical emission spectroscopy** Erik Cox, Gencoa, United Kingdom
14:00	**WS21 | Ultra fast industry-compatible FEOL ALD film analysis** Thomas Werner, Chipmetrics Oy, Germany
14:20	**Coffee Break & Exhibition**
15:00	**WS22 | Electrical results of integrated ALE and PEALD process first results of 300mm FALP tool with plasway ESC** Stephan Wege, plasway-Technologies GmbH, Germany
15:20	**WS23 | From Nano to Micro: When ALD meets with PVD to enhance coating performance** Carlos Guerra, Swiss Cluster, Switzerland
15:40	**WS24 | Fast remote plasma ALD and its applications** Harm Knoops, Oxford Instruments and Eindhoven University, Netherlands
16:00	ALPIN – AN ALD Network
16:10	PANEL DISCUSSION
16:40	**final remarks**
17:00	**End of the Workshop**

Eric Dickey

President | Lotus Applied Technology, USA

Eric Dickey is President of Lotus Applied Technology, a company specializing in thin film process research and development, with a particular focus on Atomic Layer Deposition. Eric has over 30 years of experience in ALD technology, including processes for dielectrics, conductors, TCO's, inorganic phosphors, optical coatings, and diffusion barriers. He is currently focused on the development and scaling of high speed low cost Spatial PEALD technologies.

Scaling ALD for optical coatings using DC plasma and a novel method for precursor separation

Spatial ALD offers a path to major increases in deposition speed without sacrificing the unique properties of conventional ALD coatings, while also enabling unique processes not suitable for temporal ALD. For example, a simple DC plasma may be used instead of an RF or ICP source for PEALD. A rotary batch reactor using this process has produced high quality optical coatings while showing excellent conformality, with deposition speeds up to 6 Å per second. In this work, we show a method to achieve separation of the metal-containing precursor and the radical reactant through neutralization of the active radical species, using a compact shield around the plasma source and directed flow of the plasma gas. This technique allows scaling spatial PEALD to multi-meter substrates in a sheet-to-sheet platform, while allowing deposition speeds in excess of 10 Å per second in rotary batch processing.

Gerd-Albert Hoffmann

Head of Optics Integration Group | Laser Zentrum Hannover e. V., Germany

PhD in mechanical engineering in printing of polymer optical waveguides at Leibniz University of Hannover | Since 2021 Head of Optics Integration Group at Laser Zentrum Hannover e. V. | Focus of Work: Research on optical coatings by means of rotary Atomic Layer Deposition; Manufacturing of miniaturized optical components and its hybrid integration into photonic systems

Application of plasma enhanced rotary atomic layer deposition for optical coatings

Our research explores the innovative application of Plasma Enhanced Rotary Aomic Layer Deposition (PERALD) for precision optical coatings, enhanced by real-time spectral in-situ broad band monitoring. This approach offers unmatched precision and adaptability to many applications. Our recent research is exemplified through the application of high uniformity in antireflective coatings on highly curved aspheric lenses and the coating and filling of diffraction gratings tailored for the application in laser systems. With respect to the optical properties of the deposited coatings, planar substrates are characterized. Laser calorimetric measurements according to ISO11551:2019 at 1064 nm show a low absorbance of 3.1 ppm and an extinction coefficient of 1.66*10-6 for SiO_2 and 6.0 ppm and 4.8*10-7, respectively, for Ta_2O_5 including the substrate and thus proofs the qualification of ALD for commercial optical applications.

Lado Filipovic

Associate Professor | CDL for ProMod, TU Wien, Austria

Lado Filipovic is an Associate Professor at TU Wien, working on Process Simulation and Integrated Semiconductor Sensors. He obtained his venia docendi (habilitation) in Semiconductor Based Integrated Sensors and his doctoral degree (Dr. techn.) in Microelectronics from TU Wien in 2020 and 2012, respectively. His group has developed the academic process simulation tool ViennaPS (github.com/ViennaTools/ViennaPS) which has been applied to model semiconductor fabrication steps including ALD and ALE.

Modeling and simulation of ALD in a level set framework

The level set method combined with Monte Carlo ray tracing is often applied to simulate semiconductor fabrication steps. To move the surface, the time-discretized level set equation is solved. Using our in-house level-set based framework ViennaPS, we have applied this method to track the coverage of all surface-adsorbed species during ALD, allowing to accurately track the surface growth for a few cycles. However, when hundreds of cycles need to be simulated in order to ascertain the impact of incomplete conformality during ALD of high aspect ratio structures, this method proves to be too slow. To tackle this, we have developed a model for surface coverage during ALD in the presence of desorption, while discretizing time as it relates to growth-per-cycle and not in seconds. The model, which we apply to model the fabrication of 3D NAND memory stacks, combines Knudsen diffusion with Langmuir kinetics and includes the Bosanquet formula for gas-phase diffusivity and reaction reversibility.

Xiao Hu

Scientific employee | Center for Microtechnologies,
Technische Universität Chemnitz, Germany

Dr. Xiao Hu studied microelectronics at Technische Universität Chemnitz, where he obtained a Ph.D. degree in 2017. His dissertation was devoted to the multiscale simulation of copper ALD. Since 2017 he has been a scientific employee at Center for Microtechnologies, Technische Universität Chemnitz. His research concentrates on the surface chemistry of thin film deposition and etching processes. He is also working on the development and application of atomic and molecular simulation methods.

Hybrid Monte Carlo and reactive molecular dynamics simulation of ALD

Reaction molecular dynamics (RMD) offers valuable insights into the ALD process at the atomic level. However, the inherent time-scale limitations of RMD simulations restrict their capacity to focusing mainly on initial surface reactions. To address this, a hybrid Monte Carlo (MC) and RMD simulation approach has been introduced. The MC methodology adeptly bypasses the time-scale limitations by efficiently sampling the energy landscape of the system. Reactions with minor activation energies are effectively tackled via short-time RMD simulations. Concurrently, the chemical potentials of gaseous species are aligned to realistic experimental conditions. As a demonstration, we will visualize the initial nucleation during copper growth – from the onset of dimers and trimers to the assembly of small clusters, and finally the formation of a continuous film. Furthermore, our hybrid approach also predicts macroscopic outcomes, such as the growth rate and the distribution of species.

Ivo Utke

Senior Scientist | Empa, Swiss Laboratories for
Materials Science and Technology, Switzerland

Ivo Utke received his PhD in 1995 at Humboldt University, Berlin. After 9 years at the École Polytechnique Fédérale de Lausanne, he joined Empa, the Swiss Federal Laboratories for Materials Science and Technology, in 2004. He heads the group “Low Dimensional Materials” employing ALD, MLD, PVD, and focused electron/ion beam assisted CVD for novel film materials and 3D architectures. He has >130 publications and cofounded the start-up SwissCluster commercializing ALD and ALD/PVD hybrid reactors.

Mechanical model materials with ALD, MLD, and PVD

This talk covers our activities to synthesize thin films with tailored mechanical properties, such as fracture toughness, crack onset strain, adhesion, and yield stress as well as related mechanical characterization methods. Combining atomic layer deposition, molecular layer deposition, and physical vapor deposition was the key to achieve high performance materials: Hybrid organic-inorganic MLD/ALD films of alucones grown with trimethyl-aluminum and precursors containing six and ten carbons in the backbone chain gave an increase in crack onset strains by an order of magnitude in tensile tests. The combination of physical vapor & atomic layer deposition is enabling us to synthesize ultrafine grain aluminum with a narrow grain size and shape distribution by periodically introducing extremely thin and conformal aluminum oxide layers by ALD during PVD growth of the metal film. SEM integrated pillar compression tests showed about 20 % higher yield stress than the oxygen-free reference.

Daniel Löffler

Principal Scientist | BASF SE, Germany

Since 2019 Team Leader Research/Principal Scientist, Inorganic Thin Films, BASF SE | 2016 – 2019 Project Manager, Development Cleaning & Etching, BASF SE | 2011 – 2016 Lab Leader, Inorganic materials and synthesis, BASF SE | 2009 – 2011 Scientific employee Fritz-Haber-Institute, Chemical Physics, Berlin | 2005 – 2008 PhD at University of Karlsruhe, Physical Chemistry | 2000 – 2005 Chemistry Studies Universität Karlsruhe (TH)

Strong chemical reducing agents for metal ALD

The introduction of new complex devices structures (e. g., Fin-FET transistors or 3D NAND memory), the ongoing feature down-sizing and the implementation of new materials in today's semiconductor chip manufacturing drives the need for new metallization processes which require the controllable film uniformity of ALD.

Especially ALD deposition processes of electropositive metals are challenging since the for noble metals well-established combustion route or the use of weaker chemical reducing agents, like hydrogen, is not feasible.

A new class of strong, thermally stable, and volatile aluminum hydride compounds as chemical reducing agents for metal ALD was introduced by C. Winter. These reducing agents offer promising opportunities for facilitating the ALD growth of electropositive metals with the desired film uniformity and purity.

In this talk the progress of aluminum hydride based reducing agents towards industrial implementation will be presented.

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2022 – 2024: Post Doc at Materials Sciences Center at the Philipps-Universität Marburg, Germany | 2021: PhD on MOVPE growth of highly mismatched alloys | 2017: Msc in Materials Science on low temperature MOVPE | growth of III/V semiconductors | 2011 – 2017: Physics studies at the Philipps-Universität Marburg, Germany

Progress in products, services, and strategic vision

Our presentation will provide a comprehensive update on our offerings within the semiconductor industry. We will cover key developments in our product line, service enhancements, and the facility expansion.

This session aims to offer a detailed overview of our product range specifically tailored for semiconductor applications. Additionally, we will discuss the enhancements made to our service portfolio to better serve our customers.

Moreover, we will share insights into our strategic site expansion initiatives, illustrating our commitment to scalability and operational efficiency. Improving service offerings and expanding our operational capabilities with analytical methods for the semiconductor market.

Thomas Chudoba

Managing Director | ASMEC GmbH, Germany

Career start in microelectronics for development of lithographic masks | PhD in Physics in the field of ion implantation and contact mechanics | 1997 – 2002 Post Doc at TU Chemnitz, afterwards visiting scientist at BAM, EMPA and CSIRO | 2004 founding the own company ASMEC GmbH with the aim to develop and sell nanomechanical testers | at present as convenor of working group 4 within ISO TC164 SC3 responsible for the revision of the indentation standard ISO 14577

Modulus and yield strength measurements of ultra-thin ALD coatings in a thickness range between 5 nm and 100 nm

The interest in industrial solutions for Atomic Layer Deposition is increasing and the global ALD equipment market is growing every year. The mechanical properties of ALD coatings are often not known due to the low thickness of the layers. Conventional nanoindentation is not able to resolve the properties of layers <100 nm in thickness.

Here we use a technique for the measurement of the Young's modulus of ultra-thin films that is based on fully elastic indentations with a spherical indenter and the fit of the load-displacement curve with a contact model that is considering the substrate influence. The method is applied to Al_2O_3 coatings on Si substrates with thicknesses between 3 nm and 100 nm.

Further, the yield strength of coatings thicker than 20 nm is derived from high resolution scratch tests in combination with a von Mises stress calculation based on the measured moduli. Modulus and yield strength can be used to optimize the coatings according to the requirements of the application.

Benedikt Hauer

Project leader / scientist | Fraunhofer Institute for Physical Measurement Techniques IPM, Germany

Scientist and project leader at Fraunhofer IPM since 2015 with focus on the analysis of technical surfaces and coatings for use in production control. Contrast mechanisms involve primarily infrared vibrational bands or fluorescence.

Diploma in physics (TU Munich) and a doctor in science at RWTH Aachen University (near-field microscopic infrared spectroscopy).

An infrared optical sensor for quantitative inline inspection of nanocoatings on plastic products

Thin inorganic films of materials like AlOx or SiOx drastically improve properties of modern plastic products regarding oxygen diffusion, wettability, etc. Applied via ALD or other plasma-enhanced processes, these materials are on the rise in volume markets, especially in the packaging industry. The decisive factor for the function of the final product is the quality of a coating with a thickness of only few nanometers upwards. Therefore, process control and inline inspection are often mandatory.

The coating materials can be optically addressed via their specific infrared absorption bands. We developed a fast sensor with a small footprint to quantify the film thickness of SiOx or AlOx on non-flat polymer substrates at production speed. Its underlying physical principle is comparable to infrared reflection absorption spectroscopy (IRRAS) at selected fixed wavelengths. Our presented data were measured on actual food containers. They are in good agreement with theoretical predictions.

Erik Cox

New Business Development Manager | Gencoa Ltd, United Kingdom

Erik has a PhD in Physics and over 10 years experience as a research scientist, including research in nanotechnology, atomically precise manufacturing; Integrated calibration standards for scanning probe microscopy. He joined Gencoa in 2021 where his role has been to identify new industry sectors for the company's product portfolio.

In-situ gas monitoring of ALD processes using remote optical emission spectroscopy.

Effective and robust monitoring of individual gas concentrations during the ALD processes offer a unique insight into the process behaviour. Conventional quadrupole RGAs have difficulty monitoring due to the high process pressures and the presence of contaminating hydrocarbons contained within ALD precursors. An alternative gas sensing technique operating directly at pressures above 10 – 4 mbar has been built around remote plasma emission monitoring. Species that are present within the vacuum become excited in the sensor's plasma, emitting a spectrum of light, which is used to identify and monitor the emitting species. The sensor relies on a novel method of generating the plasma which prevents contamination of the sensor’s electrodes and improves the detection sensitivity of precursors and their reaction by-products without disturbing the ALD process itself. Practical examples are presented: detection of contaminants, optimising purge cycle length, monitoring the reaction dynamics.

Thomas Werner

Head of Metrology Wafer Business | Chipmetrics Oy, Germany

Thomas Werner graduated from Chemnitz University in 1996. He joined AMD as Integration Engineer in 1996 and worked in AMD´s Sunnyvale and Austin fabs. In 1998 he transferred to Dresden for the startup of AMD's Fab30. After the spinoff of Globalfoundries, Thomas worked as Manager for Technology and Integration in the field of BEOL. In 2015 he joined Fraunhofer IZM-ASSID as R&D coordinator in the field of Advanced Packaging. Since 2023 he works as Head of Metrology Wafer business for Chipmetrics.

Ultra fast industry-compatible FEOL ALD film analysis

Chipmetrics' PillarHall® technology was introduced in 2019 and has been widely adapted by academic and R&D institutions for conformality characterization of thin film processes. The use in manufacturing environments has been limited due to concerns regarding the compatibility with the requirements of state-of-the-art wafer fabs. In this work we present contamination test results achieved on 300 mm pocket wafers in which PillarHall chips were bonded using a cleanroom compatible adhesive. Furthermore, practical ALD film analysis results (thickness, penetration depth, film composition) gained from different locations of a 300 mm wafer will be presented.

Stephan Wege

CEO | Plasway-Technologies GmbH, Germany

Diploma in Physics | 2016 CEO Plasway-Technologies GmbH | 09/2009 Consultant in Semi-, Solar- and MEMS Industry | 2004 – 07/2009 Qimonda Management | Unit Process Pre-Development | 1998 – 2004 Infineon /Fab Cluster Organi. | Coordinating of World Wide Dry Etch Activities (US, Taiwan, Germany), Planning and Organization of First 300 mm Production Fab(s) | 2001 Principle Dry Etch | 1994 – 1998 Siemens Micro. | Transfer + Start 200 mm Line, Lead Eng. Process 200 mm | Process Eng. Gate Etch in France (J. V. IBM)

Electrical results of integrated ALE and PEALD process first results of 300 mm FALP tool with plasway ESC

Very good results if integrated ALE and PEALD integrated processes on different substrate materials will be presented. On TEM Analyses we can show excellent interfaces. The dielectric performance of the PEALD film is even without any anneal even better compared to a standard ALD film with anneal.

On our 430 mm FALP Tool we achieved further good results on 430 mm substrates for optical applications. Especial the refractive Index value showed an extremely low variation.

We achieved first results from our special 300 mm FALP Beta Tool with ESC. The bipolar ESC is an Plasway-Technologies simulated and developed chuck. We will present first results for PEALD and ALE with much better <1 °C surface temperature control.

With our 10 ms parameter monitoring strategy (of all relevant tool parameters), even with integrated OES Plasma data, we will show the path to the next generation preventive maintenance and quality concept.

Carlos Guerra

CEO | Swiss Cluster, Switzerland

Carlos is the co-founder and CEO of Swiss Cluster, a spinoff company developing innovative coating equipment for R&D and industrial production. He received his MSc. in Materials Science at TU Delft in 2013 and a PhD from ETH Zurich/Empa in 2018. Since then, he has been working actively with ALD and other deposition techniques. He has published over 30 publications and three patents filed for the innovation of a cluster system combining ALD with PVD and scalable ALD vacuum chambers.

From Nano to Micro: When ALD meets with PVD to enhance coating performance

Atomic layer deposition (ALD) and Physical Vapour Deposition (PVD) have shaped and progressed a significant number of industrial technologies.

These techniques have been mostly growing in their own field of application, but when combined, they become an unparalleled materials factory. This combination offers endless variations of coatings with superior properties.

We will present the incorporation of both techniques in a new way leading to the development of the first system combining ALD and PVD in a compact equipment. The SC-1 can fabricate complex coatings with hundreds of nanolayers from the ALD and PVD materials library. The properties of such multinanolayered coatings are strongly influenced by their interfaces. Carefully engineered coatings translate to lighter and cheaper materials with improved mechanical and thermal properties. We will show examples of multinanolayered coatings, such as a 200 nanolayered metal-ceramic coating with improved hardness and yield strength.

Harm Knoops

Atomic Scale Segment Specialist | Oxford Instruments
Plasma Technology, Netherlands

Dr. Harm Knoops is the Atomic Scale Segment Specialist at Oxford Instruments Plasma Technology and holds a part-time assistant professorship position at the Eindhoven University of Technology. His work covers the fields of (plasma-based) synthesis of thin films, advanced diagnostics and understanding and developing plasma ALD, plasma ALE and growth of 2D materials. His main goals are to improve and advance atomic scale processes and applications for Oxford Instruments and its customers.

Fast remote plasma ALD and its applications

To provide high-quality material, the use of plasma in ALD has high interest. To limit damage the energies and fluxes of species to the surface has to be controlled. Remote plasma can improve control of plasma species while maintaining high plasma density. Inductively coupled plasmas have demonstrated excellent device results, but industry desires faster processing. The novel remote plasma source on the Atomfab is optimized for ALD on power electronics devices for substrates up to 200 mm in diameter and allows for Al_2O_3 cycles of less than one second. This application showcases the low damage nature of this remote plasma system. Many other applications could benefit from fast remote plasma ALD which will be discussed. To facilitate process development, a new fast research system has also been developed, which uses the same plasma source. In this new ALD system the ion energy can also be enhanced by substrate biasing which further enhances the parameter space and possible applications.

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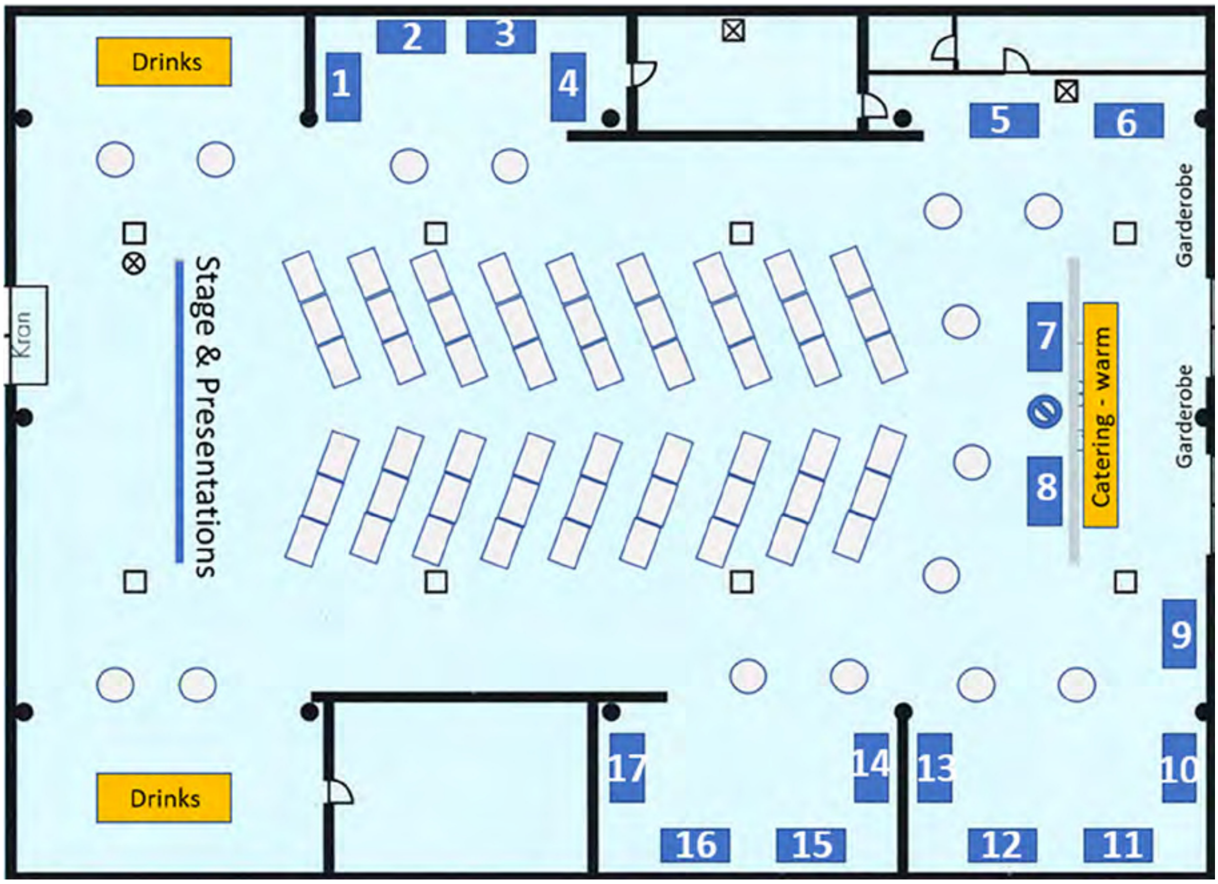

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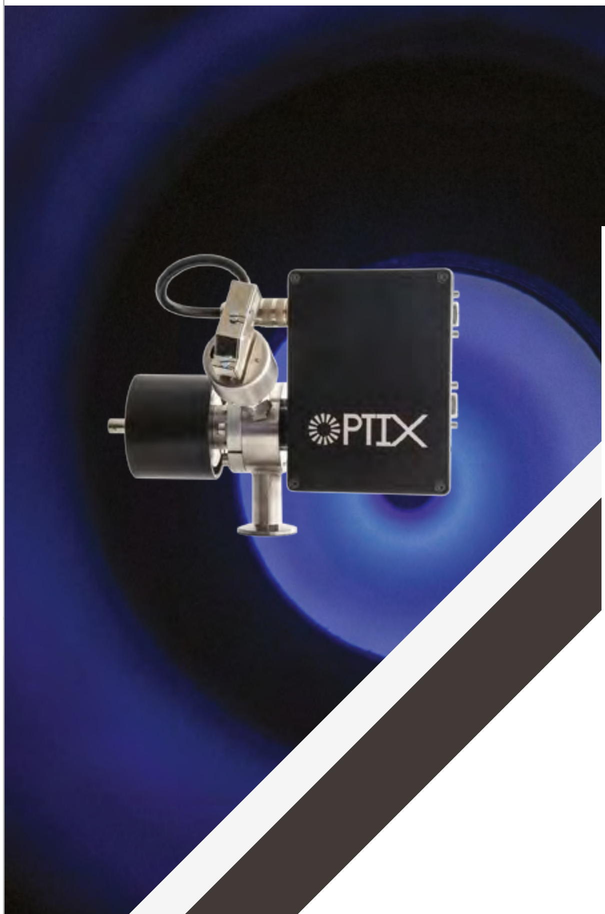

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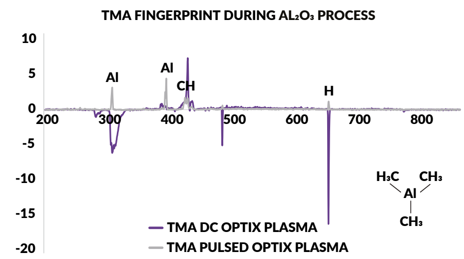

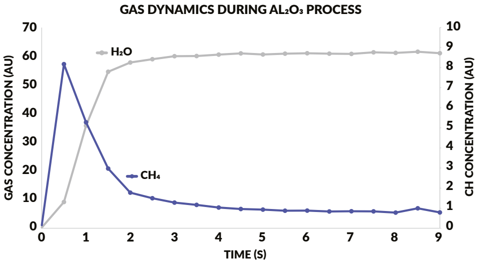

FURTHER INFORMATION
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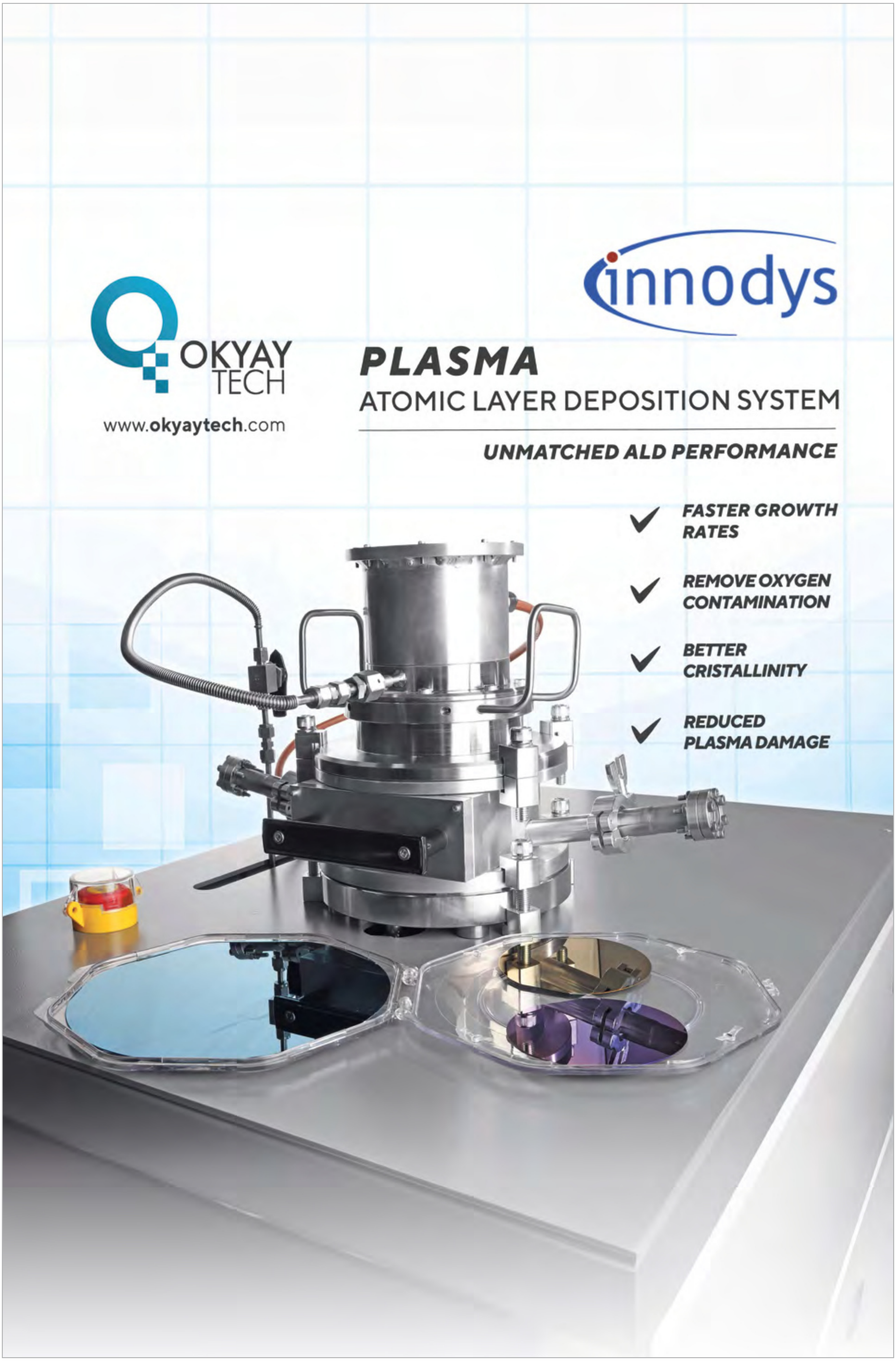

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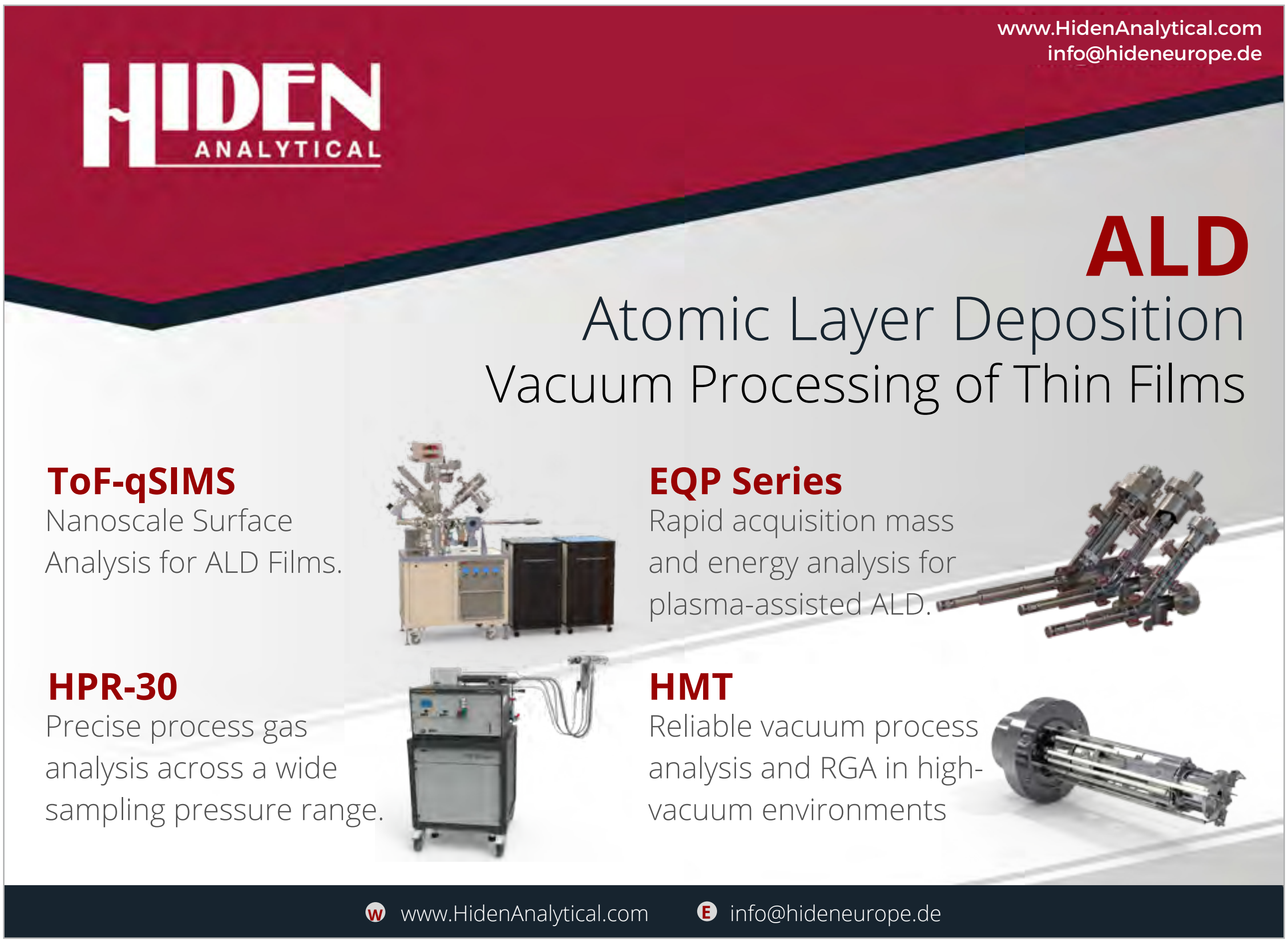

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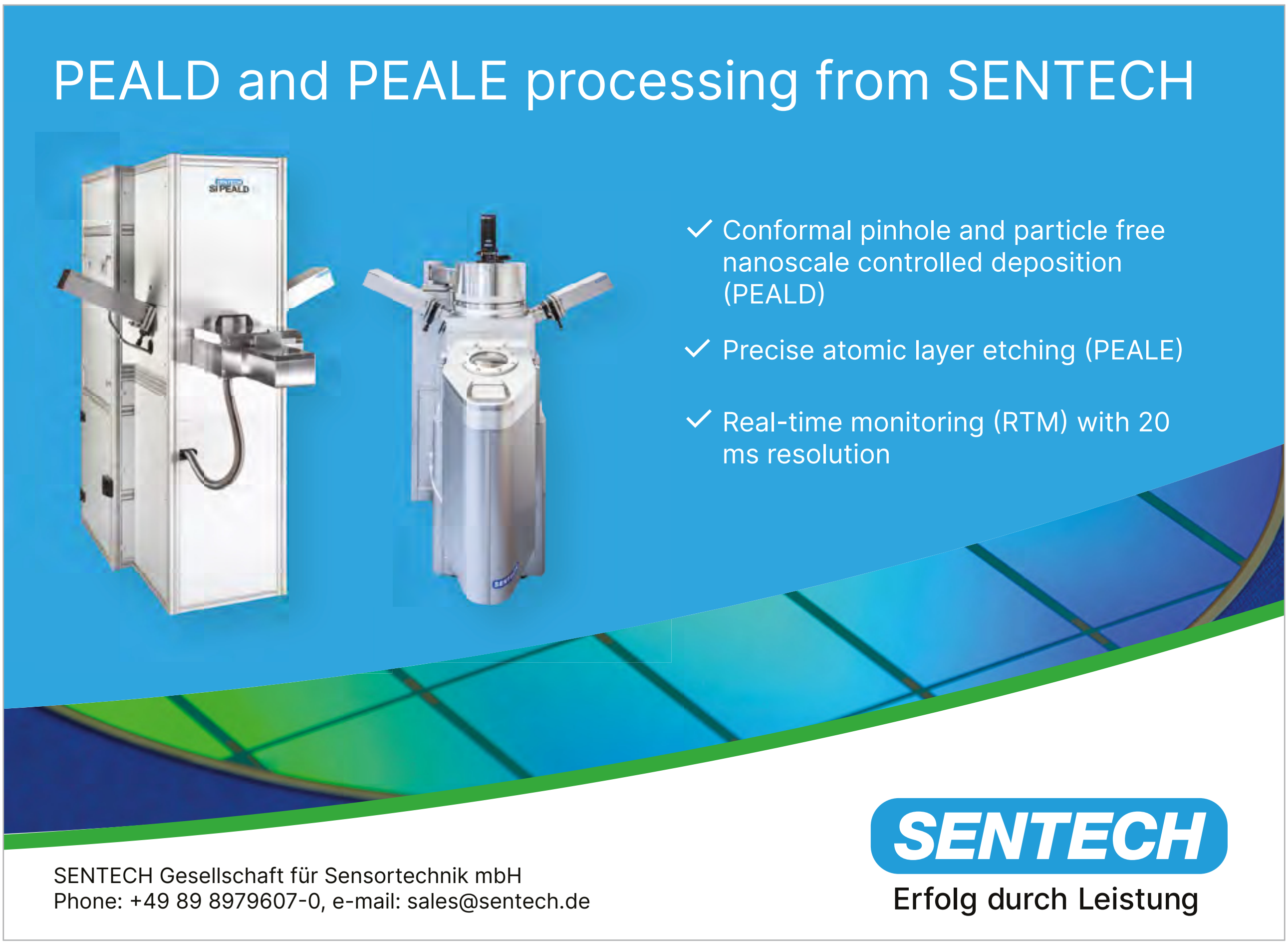

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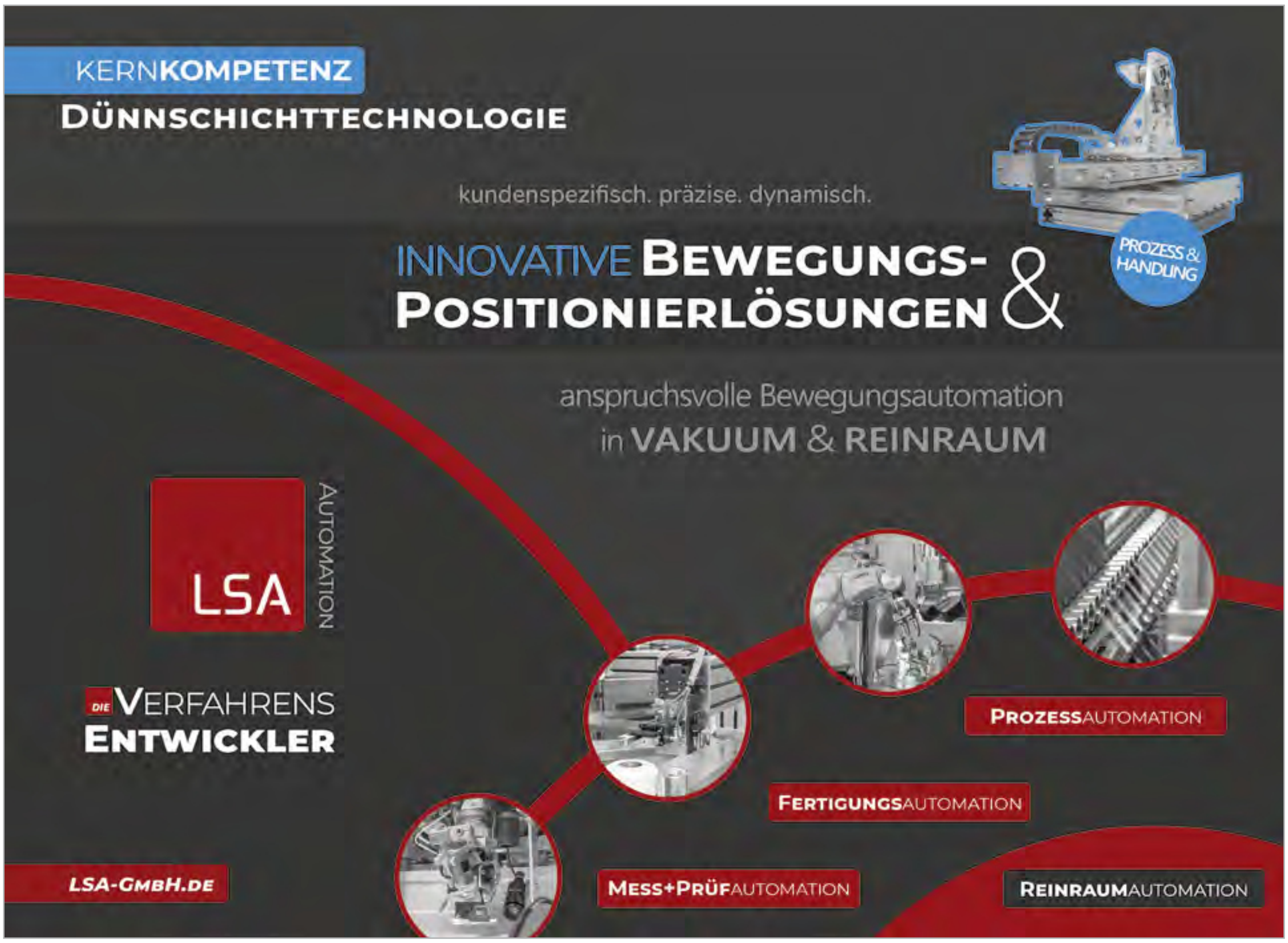

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21./22. März 2023 | Dresden, Germany

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March 21, 2024 | Fraunhofer ENAS, Chemnitz, Germany

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